Policy

Planning

LADWP Weather-Based Irrigation Controller Pilot Study

Research

Evaluation

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Preface

This report documents water savings achieved by Los Angeles Department of Water and Power's weather-based irrigation pilot study targeted at large multi-family residential (homeowner associations) and small commercial sites (parks, schools, office buildings). The study was implemented during 2002 and 2003.

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Executive Summary

To date several studies have examined the effectiveness of weather-based irrigation controllers in single-family residential settings, but virtually none to our knowledge have systematically examined how these controllers perform in other types of settings with medium to large landscapes (for example, homeowner associations, schools, parks, and so on). Los Angeles Department of Water and Power (LADWP) undertook this study to fill this knowledge gap. Weather-based controllers attempt to match irrigation to plant evapotranspiration (ET) needs, hence they are also referred to as ET controllers.

Two types of weather-based irrigation scheduling technologies were evaluated under the auspices of LADWP's program; (1) Hydropoint Inc.'s ET controller marketed under the trade name WeatherTrak; and (2) Water2save LLC's weather-based irrigation scheduler. The former replaces the existing controller, while the latter piggybacks on the existing controller. Both technologies rely upon broadcast signals. Budgetary limitations did not allow additional products to be included in the study.

WeatherTrak is an irrigation controller that utilizes paging technology to receive weather-related data signals, which are then processed internally to generate an irrigation schedule. This schedule is followed until new weather data are signaled. Rain interrupts can also be transmitted. Hydropoint collects weather data from a national network of weather-sensing stations, which are then processed to determine reference ET at any given locale. Hydropoint's business model thus requires the purchase of both the controller and a fee-based subscription to the signal service.

The Water2save LLC weather-based irrigation scheduler, an interrupt and control device, is installed between an existing controller and its valve wires. The device is equipped with wireless PCS technology that allows two-way communication between Water2save and the device. Local weather-related data including rain interrupts can be transmitted to the device, and Water2save personnel can also remotely request data about actual water applied. Water2save handles all communication with the device. Since the original controller remains in place, the user does not have to learn the operation of a new piece of hardware. Water2save clients do not purchase the control device. Instead, they share a negotiated portion of savings observed in the customer's water bills. Water2save thus follows a pay-for-performance type of business model. The profitability of this business model depends to a greater extent upon careful site selection, and Water2save generally examines billing histories of potential participants to assess likely savings before retrofitting a site.

It should be noted that in all our study sites, professionals installed the hardware, and set up the baseline schedule.

This study from the beginning was seen as a technology demonstrator. Its goal was primarily to assess the performance of weather-based irrigation technologies, and secondarily customer acceptance of these technologies in predominantly non-single family residential and small commercial settings. In such settings since the site owner is usually divorced from routine landscape maintenance, success requires the cooperation of both the owner and the landscaper. Since demonstration of the technology was a key goal, it was decided early on to include both dedicated irrigation and mixed-use accounts in the study. Dedicated irrigation accounts offer a direct and powerful way of gauging how well irrigation tracks ET.

A total of 25 sites with roughly 83 acres of landscape (35 acres planted with turf, the rest with shrubs) were recruited for this study. Selected sites included homeowner associations, schools, commercial sites, public parks, and so on. Dedicated irrigation meters supplied water to roughly 60 of the total 83 acres. These were retrofitted with weather-based irrigation technologies from the two vendors participating in the study. The retrofits occurred on a first-come first served basis, in a staggered manner over time as sites were recruited and screened for suitability. To avoid implementation delays, the study did not randomize the assignment of sites to the vendors.

Water use was tracked for at least a year after the retrofits, and water savings were determined through statistical models that compared two years of pre-retrofit to one year of post-retrofit consumption accounting for weather.

These analyses were conducted separately for dedicated irrigation and mixed-use accounts. Since no separation of indoor and outdoor consumption is required among the former accounts, it was relatively straightforward to evaluate how well applied irrigation tracked ET before and after the retrofits. We found that both technologies were very successful in changing irrigation patterns to accord with weather, with Water2save’s and Hydropoint’s technologies reducing irrigation by 28.3% and 17.4%, respectively. But, Water2save’s sites also exhibited greater levels of wasteful irrigation prior to the retrofits, and therefore had a higher level of conservation potential to begin with. The percentage of the pre-retrofit conservation potential converted into actual savings was higher in the case of Hydropoint’s dedicated landscapes (95%) than Water2save’s (71%). These percentages being unequal do not necessarily imply that one technology is superior to the other because many factors could account for the inequality, such as distribution uniformity being especially poor, or cooperation from the on-site landscapers being especially poor, in one set of sites compared to the other. What they do imply, however, is that by paying greater attention to these additional factors, water savings perhaps could be improved even more, although such steps would also tend to drive up program costs.

Among the mixed-use accounts, most of the acreage being under Hydropoint's control made it difficult to detect any significant difference in savings achieved by the two different technologies. Combined though, we estimate that weather based irrigation technologies reduced outdoor consumption by 27%, which in turn represents roughly 78% of the total pre-retrofit conservation potential.

Overall, it appears that landscapes supplied by dedicated irrigation meters are saving roughly 56 acre-feet per year, while landscapes supplied by mixed-use meters are saving 26 acre-feet per year, for a total program savings of 82 acre-feet per year. During the evaluation phase, we telephoned several individuals intimately involved with irrigation management at the study sites, to solicit feedback about their experience with the retrofitted controllers. We heard no strong negative comment about either technology.

To facilitate comparison of our results with those of other studies, we also converted estimated savings into inches per turf-equivalent area so as to remove the effect of landscape size and plant composition (turf vs. shrubs). We estimate that across all the test sites included here, weather-based controllers reduced outdoor consumption by roughly 17 inches per year for pure turf landscapes (and by assumption half of this for pure shrub landscapes since shrubs normally need only half as much water as turf). Our savings estimate in inches is very close to what at least two previous studies have found in Irvine, California.

We then used our savings estimate to project dollar benefits likely to accrue to LADWP and its customers under differing assumptions. For example, a customer with a quarter acre of (turf-equivalent) landscape, supplied by a dedicated irrigation meter, can expect to save roughly between $1,124 and $1,527 over a ten year period (assumed device life) depending upon whether a 6% or 0% discount rate is assumed. Were the site connected to a mixed-use meter, dollar benefits to the customer from water savings alone would rise to between $2,062 and $2,801 over a ten-year period because LADWP charges such meters significantly higher water rates. And for mixed-use accounts, were one to also take sewer surcharges into consideration, the above-mentioned dollar benefits would roughly double. Avoided (water) costs to LADWP over a ten-year period would range between $1,153 and $1,566. Obviously, these estimates are highly dependent upon landscape size, rising proportionally with size.

Total avoided costs provide an indication of the maximum subsidy LADWP can provide per customer to promote the dissemination of weather-based controllers. This is not the same as saying that LADWP should automatically offer a rebate equal to its avoided costs. How a program is marketed and how customer perceptions about these new technologies are modified through market transformation strategies can significantly affect the level of financial incentives that are necessary to tip private decisions in favor of weather-based irrigation technologies.

Although savings reported here are quite significant, it should be noted that we expect the cost of promoting weather-based irrigation technologies among non-single family and small commercial customers to also be relatively high. Marketing this pilot study was not easy and took a lot of effort by LADWP staff. Ensuring compliance by the on-site landscapers also required outreach, education, and monitoring, all of which would have to be made part and parcel of any real-world program. Overall program success thus greatly depends upon landscaper participation and support, crucial for maximizing water savings, and upon convincing customers of the dollar benefits likely to accrue to them, a key driver of the adoption rate.

Acknowledgments

Several dedicated individuals from LADWP and the technology vendors contributed to the design and implementation of this pilot study. These include, Tom Gackstetter, Mark Gentili, Robert Estrada, David Olmstead, Michael Marian, and Gary Gelinas. We thank them all for their enthusiasm, hard work, and unstinting support. We would also like to thank LADWP's conservation branch for giving us the opportunity to undertake this evaluation on their behalf.

1. Introduction

Relatively inexpensive weather-based irrigation controllers for application in residential and small commercial sites are a new and exciting development in the water conservation arena. Weather-based controllers attempt to match irrigation to plant evapotranspiration (ET) needs, hence they are also referred to as ET controllers. Although such technologies have been available in the past, their considerable expense and complexity made them suitable only for large landscapes. But innovations in microprocessor and signal transmission technology, and expansion of the California Irrigation Management Information System's (CIMIS) network of weather sensing stations have made weather-based irrigation controllers an option worth considering for even medium to large residential and small commercial landscapes. Heretofore, the predominant strategy for promoting outdoor water use efficiency in these smaller landscapes has been through behavior modification, for example, through education, surveys/audits, conservation rate structures, and ordinances (day-of-week irrigation limits, Model Landscape Ordinance). While behavior modification strategies still remain relevant, these new controllers, independently or in concert with these strategies, offer yet another powerful tool for improving outdoor water use efficiency.

Irrigation accounts for a large proportion of total urban water demand. It also is a key driver of peak demand, and a significant source of urban runoff. Most studies have shown, and green industry professionals also believe, that over-watering is widespread among the region's urban landscapes. All these factors combined suggest that conservation activity in this arena is likely to yield rich dividends on a number of different fronts.

While several studies have examined the effectiveness of these newer weather-based irrigation controllers in single-family residential settings, virtually none to our knowledge have systematically examined how these controllers perform in other types of settings with medium to large landscapes (for example, homeowner associations, schools, parks, and so on.) Los Angeles Department of Water and Power (LADWP) undertook this study to fill this knowledge gap.

Two types of weather-based irrigation scheduling technologies were evaluated under the auspices of LADWP's program; (1) Hydropoint Inc.'s ET controller marketed under the trade name WeatherTrak; and (2) Water2save LLC's weather-based irrigation scheduler. The former replaces the existing controller; the latter piggybacks on it. Both technologies rely upon broadcast signals. Budgetary limitations did not allow additional products to be included in the study.

WeatherTrak is an irrigation controller that utilizes paging technology to receive weather-related data signals, which are then processed internally to generate an irrigation schedule. This schedule is followed until new weather data are signaled. Rain interrupts can also be transmitted. Hydropoint collects weather data from a national network of weather-sensing stations, which are then processed to determine reference ET at any given locale. Hydropoint's business model thus requires the purchase of both the controller and a fee-based subscription to the signal service.

The Water2save weather-based irrigation scheduler, an interrupt and control device, is installed between an existing controller and its valve wires. The device is equipped with wireless PCS technology that allows two-way communication between Water2save and the device. Local weather-related data including rain interrupts can be transmitted to the device, and Water2save personnel can also remotely request data about actual water applied. Water2save handles all communication with the device. Since the original controller remains in place, the user does not have to learn the operation of a new piece of hardware. Water2save clients do not purchase the control device. Instead, they share a negotiated portion of savings observed in the customer's water bills. Water2save thus follows a pay-for-performance type of business model. The profitability of this business model depends to a greater extent upon careful site selection, and Water2save generally examines billing histories of potential participants to assess likely savings before retrofitting a site.

It should be noted that in all our study sites, professionals installed the hardware, and set up the baseline schedule.

Before proceeding further, let us briefly review the range of water savings documented by previous studies.

Previous Studies

Two studies performed in Irvine, California (Hunt et al., 2001; Diamond, 2003), and one in Denver, Colorado (Aquacraft, 2001 and 2002), specifically examine the efficacy of a broadcast-signal type controller (WeatherTrak). A more recent study sponsored by the Metropolitan Water District of Southern California (2004) compares the efficacy of the above controller to two non-broadcast type controllers —a controller that modifies historical ET data using a temperature sensor (AquaConserve), and a controller that imputes ET by measuring solar radiation (WeatherSet). Although these studies do not suggest that all of the above controllers perform equally well, they do suggest that each has the potential of saving substantial amounts of water when programmed with accurate baselines schedules. Additional studies are underway to fully understand the pros and cons of each type of controller technology. Technology vendors also continue to refine their products.

Assuming technical efficacy reaches an acceptable level in the future, water savings will become primarily a function of landscape size and the level of over-watering taking place prior to the ET controller retrofit. Studies that have evaluated water savings have come up with similar results, which is comforting. For example, Hunt et al. (2001) estimated that an ET controller program marketed to the top third (in terms of consumption) single-family homes in Irvine Ranch Water District's (IRWD) service area could be expected to reduce *total* residential consumption by 10-11%, or *outdoor* consumption by approximately 24%. A later evaluation of a follow-on program in IRWD's service area, also targeted at large single-family homes, estimated a 10% reduction in total household consumption (Diamond, 2003). Both of these programs tested the performance of a broadcast-signal ET controller (WeatherTrak). Addink and Rodda (2002) evaluated savings achieved by embedded historical-ET controllers (AquaConserve) in three agencies (Denver, Colorado; Sonoma, California; Valley of the Moon, California) and estimated that *outdoor* consumption in these three agencies declined by 21 percent, 23 percent, and 28 percent, respectively.

A more recent study of WeatherTrak controllers in Santa Barbara (Jordan et al., 2004) found an even greater level of savings, mainly because the program targeted sites with very large landscapes (approximately 1 acre). Although not necessarily representative of the average California water agency, findings from Santa Barbara underscore the strong relationship between landscape size and water savings as commonsense would dictate.

Format of the Report

The balance of the report is structured as follows. Section 2 describes the setting and implementation of this study. Section 3 describes key findings from the water savings analyses, but the technical details are relegated to Appendix A. Section 4 presents qualitative user feedback. Section 5 summarizes the study's conclusions.

2. Study Setting and Implementation

Overall goals

This study from the beginning was seen as a technology demonstrator. Its goal was primarily to assess the performance of weather-based irrigation technologies, and secondarily customer acceptance of these technologies in predominantly non-single family residential and small commercial settings. In such settings since the site owner is usually divorced from routine landscape maintenance, success requires the cooperation of both the owner and the landscaper. Since demonstration of the technology was a key goal, it was decided early on to include both dedicated irrigation and mixed-use accounts in the study. Dedicated irrigation accounts offer a direct and powerful way of gauging how well irrigation tracks ET.

It was not an explicit goal of the study to predict likely savings from a large-scale program marketed to LADWP's customers in general, or marketed to a customer class in particular. Although clearly this study's results can assist in formulating preliminary answers to these sorts of questions, a much larger and more expensive pilot study would have to be undertaken to reliably address these questions.

Geographic Setting and Site Recruitment

Given the above objectives, test sites were selected from only one portion of LADWP's service area (west San Fernando Valley) to reduce travel and retrofit costs. Test sites were also selected on a first-come, first-served basis. LADWP staff identified potential commercial, industrial, institutional (CII) sites with significant landscapes by examining summer-winter usage differentials. They then contacted these sites to inform them about the pilot program, and to solicit participation. It was not an easy sell in spite of participants being insulated from all study expenses, including LADWP's offer to re-install the old controllers if need be. LADWP staff spent countless hours trying to market this pilot project, and in many cases visited potential sites in person to promote participation.

A total of 25 sites with a combined landscape area of roughly 83 acres were retrofitted with the new weather-based irrigation controllers—18 with Hydropoint's and 7 with Water2save's technology. The retrofits occurred in a staggered manner between March and December of 2002, as participants were steadily recruited and screened for suitability. At the time of selection, careful attention was paid to the general condition of the irrigation system. Sites with irrigation systems in significant disrepair, or sites where significant alterations had been made to the landscape in the prior two years, were excluded. The recruited sites included homeowner associations, schools, commercial sites, public parks, and so on.

Implementation

Baseline schedules were set after examining both landscape and irrigation system characteristics, such as, precipitation rates and distribution uniformity. Landscape size, including proportions covered by turf and shrubs, were also physically measured. In many instances, however, further adjustments were required to these baseline schedules, either to circumvent inherent irrigation system deficiencies (poor uniformity), or to correct inadvertent, sometimes deliberate, tinkering of the schedules by the landscaper. LADWP staff maintained a spreadsheet with updated billing histories to identify sites with emerging problems such as leaks, malfunctioning meters, and misuse of the new controllers. Where such problems were detected, they were corrected as soon as possible, and also noted for the purposes of data editing and analysis.

3. Water Savings Analyses

This section provides an overview of the billing history analyses and discusses the key findings. Precise details about billing and weather data processing, model specification, and statistical estimation can be found in Appendix A.

Overview of methodology

Analysis Strategy. Our basic unit of analysis is a clearly delineated landscape, with consumption consolidated across all meters that supply water to it. Water savings were estimated by comparing weather normalized billing histories before and after the retrofit. Two separate models were estimated; one for landscapes supplied by dedicated irrigation meters, the other for landscapes supplied by mixed-use meters because the former exhibit a significantly sharper seasonal pattern. Prior to the retrofit, sites were also screened to ensure that no significant alteration had been made to either indoor end uses or to the landscape in the previous two years to prevent confounding with the program's impact. In general, we used two years of billing histories to capture the pre-retrofit baseline, and one year to capture the post-retrofit experience. In few cases, only one year of clean pre-retrofit histories were available for reasons discussed later. We performed sensitivity analyses to assess whether using three, or two, or one year of pre-retrofit billing histories significantly affected the savings estimates. This turned out not to be the case, suggesting that apart from weather variation other confounding factors were not present to any significant degree. But, overall, using two years of pre-retrofit histories seemed to strike the best balance between having an adequate level of statistical precision, without unduly increasing the risk of introducing unknown confounding factors, a prospect more likely with a longer pre-retrofit baseline.

Weather Normalization. West San Fernando Valley has no CIMIS station, so we averaged weather data from two CIMIS stations that appear to bracket this general geographic area (Piru, Ventura County, in the west, and Glendale, Los Angeles County, in the east). Although the average level of annual ET recorded at these two CIMIS stations is quite different, the patterns of change in daily ET, even rainfall corrected daily ET, are correlated almost 90 percent. Thus, the statistical models are not sensitive to which station's data are used to perform the weather normalization. But to address how closely post-retrofit irrigation matches ET, requires establishing an ET benchmark. Professionals involved with this study, and knowledgeable about the area in question, suggested that a "normal year" reference ET of 51 inches ought to be sufficient for west San Fernando Valley where all the test sites are located. We worked backwards from this recommendation to figure out the relative weight that must be applied to Piru and Glendale to obtain an average annual reference ET of 51 inches, which worked out to be 37 and 63 percent respectively. Based upon these weights, rainfall corrected “normal year” annual ET in West San Fernando Valley works out to 49.4 inches, which serves as the benchmark against which applied irrigation during the post-retrofit phase is assessed.

Data Processing. In principle, our basic unit of analysis is a distinctly identified landscape, with consumption consolidated across all meters that supply water to it. Overall, 29 clearly delineated landscapes (which we label accounts) were identified across the 25 retrofitted sites. As a practical matter then, the meaning of “site” and “account” differs little, barring few exceptions. If all meters supplying the landscape were dedicated irrigation meters, the account was labeled as dedicated. If one or more of the meters were mixed-use, the account was labeled as mixed-use.

Many of the 25 retrofitted sites were supplied by more than one meter. Data from these meters were edited for consistency, and sometimes consolidated prior to analysis. The need to combine data across meters at a site arose for several reasons. For example, if multiple (dedicated or mixed use) meters existed at a site, but portions of the landscape supplied by each meter could not be individually identified, consumption across these meters was consolidated and treated as one account. This sort of data manipulation, although tedious to perform, was conceptually easy since meters at the same site are almost invariably read on the same cycle. In some cases, irrigation sub-meters had been installed relatively recently, but since an adequately long baseline from these meters was unavailable, this pure outdoor consumption was consolidated with indoor consumption and the whole account treated as a mixed-use account. In the case of one large homeowner association, for instance, data from 25 mixed-use meters were consolidated to create a single mixed-use account.

Careful field notes compiled by LADWP staff were extensively consulted during the data processing phase. These notes identified time periods plagued by problems potentially damaging to the study, such as malfunctioning meters, significant leakage, or problems with the controller. After removing data from these affected time periods, we were still able to retain a continuous two-year pre-retrofit billing history except in few cases where only a one-year baseline could be used. On the post-retrofit data front, we were able to construct a continuous full year of consumption history in all but one case. Overall, only 2 of the 29 accounts had to be completely excluded from the analysis because of unsalvageable data. These two accounts represent relatively small landscapes, accounting for roughly 1.6 acres of the total 83 acres found at the 25 retrofitted sites.

Composition of Analysis Sample. Table 1 shows the allocation of distinctly identified landscapes stratified by technology type (Hydropoint vs. Water2save) and account type (dedicated vs. mixed use). As mentioned earlier, separate models were estimated for the dedicated and mixed-use accounts. Since sites were recruited on a first-come, first-served basis, the average acreage, and its breakdown between turf and shrub, look quite different across the four strata defined by technology type and account type. We thus not only have to pay a lot of attention to achieved water savings, but also to how these savings compare to the pre-retrofit savings potential, which need not have been comparable across the various study sites. Also, note that in keeping with the technology demonstration goal, the selected sites are heavily weighted in favor of landscapes connected to dedicated irrigation meters—such sites account for roughly 60 of the 80+ acres affected by the retrofits.

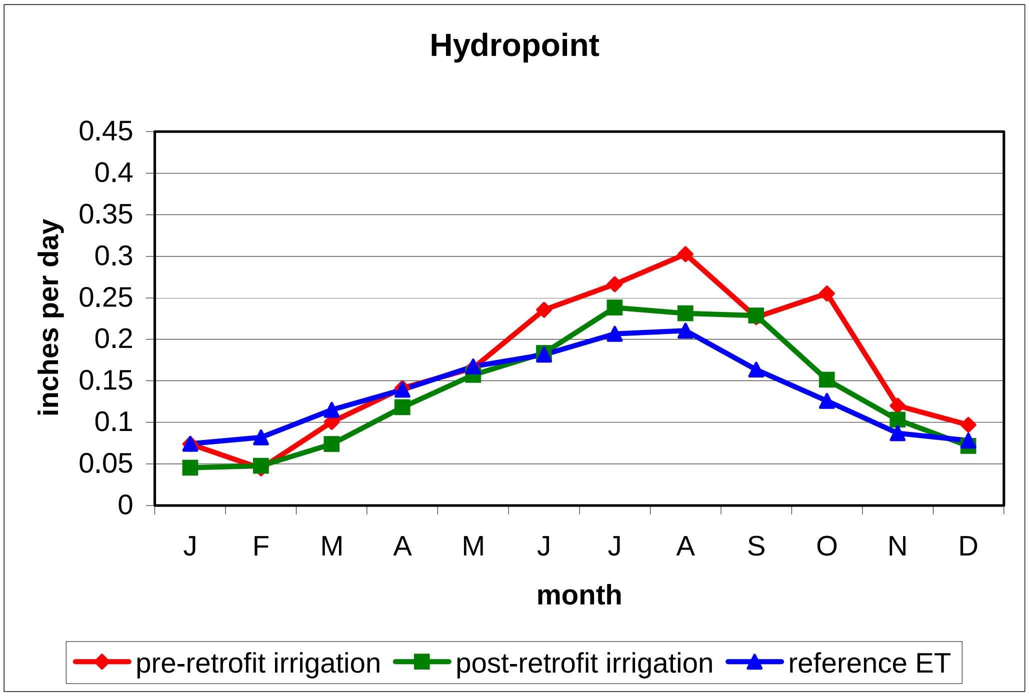
Table 1 Composition of final analysis sample with landscape acreage

Technology	Type of Account	Number of accounts	Average turf area per account (acres)	Average shrub area per account (acres)	Total land-scape across all accounts (acres)
Hydropoint	Dedicated	15	1.15	1.12	34.05
	Mixed use	6	1.44	2.00	20.64
Water2save	Dedicated	4	2.17	4.29	25.84
	Mixed use	2	0.17	0.26	0.86

How well does irrigation track ET?

This question was addressed by examining consumption data from landscapes connected to dedicated irrigation meters (dedicated accounts), which is the most reliable way of addressing this question. Although in principle this question can also be addressed using data from mixed-use accounts, to do so would require a much larger sample than the one available here.

Figure 1 shows the seasonal pattern in applied inches per day before and after the retrofits, relative to rainfall corrected reference ET. While converting billing data into inches per day, shrub-planted area was halved to convert it into turf equivalents. Shrubs on average need only half as much water as turf. This modification was necessary to ensure that applied inches per day are based upon turf equivalent areas so that in turn these estimates can be meaningfully compared to reference ET. The applied irrigation data were then weather normalized using statistical models, so as to represent what they would be in a “normal weather” year,



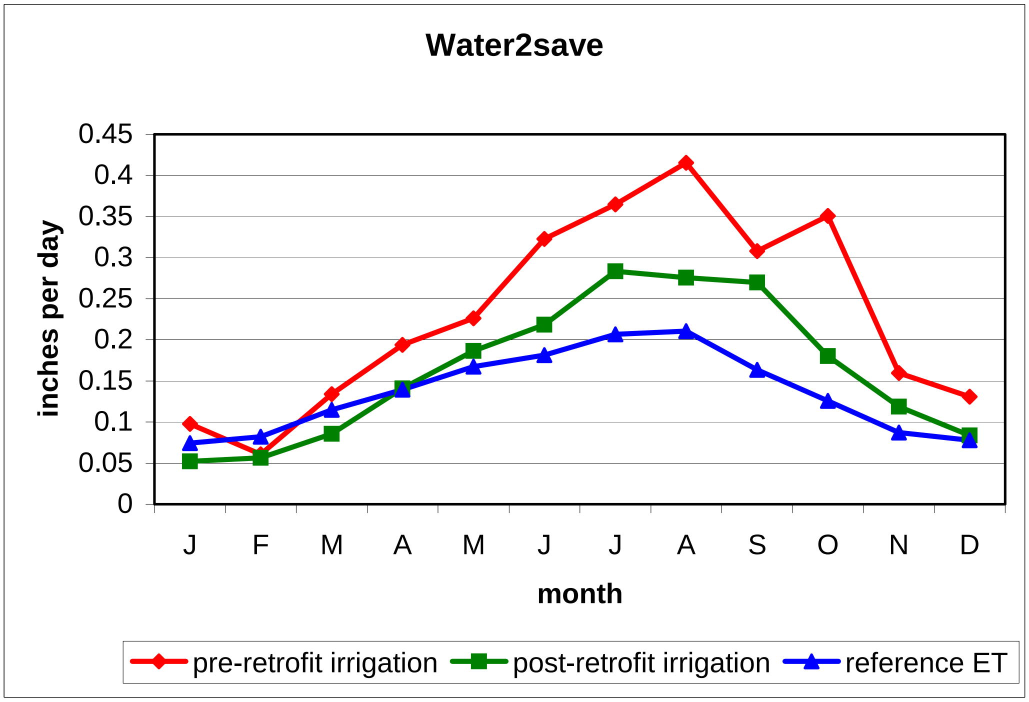


Figure 1 Pre and post-retrofit consumption in the dedicated landscape accounts

to enable an apples-to-apples comparison between the pre- and post-retrofit periods. Rainfall corrected reference ET represents our best estimate of this benchmark in a "normal weather" year in west San Fernando Valley.

In Figure 1, the space between red and green curves indicates achieved water savings, while the space between red and blue curves indicates the pre-retrofit savings potential. Three observations follow from this figure. First, and foremost, weather-based irrigation controllers were successful in modifying irrigation patterns to accord with seasonal weather variation. It should be noted that turf's water requirements don't exactly track reference ET. Because turf's water needs relative to reference ET vary by season (that is, crop coefficient varies across seasons) applied irrigation should be somewhat less than reference ET during the spring season and somewhat higher during the summer season, which is exactly what Figure 1 shows.

Second, Water2save's technology achieved greater savings, but only because these sites exhibited greater pre-retrofit savings potential—in fact, Figure 1 suggests that post-retrofit irrigation could have been reduced some more in Water2save's sites.

Third, this figure once again underscores what previous studies have also found, namely, that over-irrigation is not a year-round, but predominantly a summer and fall season phenomena. To save water it is essential to get the summer baseline schedule right. Simply transferring summer schedules from the existing to the new weather-based controller is unlikely to yield significant savings. This observation in turn implies that careful initial programming of the weather-based controller, perhaps even some ongoing customer and landscaper education must be made part and parcel of any large-scale retrofit program.

Water savings in landscapes supplied by dedicated irrigation meters

Table 2 shows "weather normalized" annual irrigation (of turf equivalent areas) before and after the retrofits expressed in inches. Our best estimate of rainfall corrected reference ET in a "normal weather" year for west San Fernando Valley is also included. The data underlying Figure 1 are the same as Table 2.

These data show that irrigation dropped roughly by 17.4% and 28.3% in (dedicated) landscapes installed with Hydropoint's and Water2save's technology, respectively. As noted earlier, however, the higher savings achieved in the Water2save's accounts are largely a result of the greater pre-retrofit conservation potential. Under the assumption that irrigation could have been reduced all the way down to the level of reference ET (which is a realistic assumption only if one believes that distribution uniformities and the level of customer cooperation were both high, and similar, across sites), one can ask what proportion of the total conservation potential was converted into savings? For Hydropoint and Water2save, these estimates work out to roughly 95% and 71%, respectively.

Table 2 Savings achieved in dedicated landscapes

Technology (# of accounts)	**Annual pre-retrofit irrigation (inches)**	**Annual post-retrofit irrigation (inches)**	**Normal year rainfall corrected reference ET (inches)**	**Percentage reduction in irrigation[‡]**	**Conservation potential converted into savings**
Hydropoint (15)	60.8	50.2	49.6	17.4%	94.8%
Water2save (4)	82.8	59.4	49.6	28.3%	70.5%

[‡] Model derived estimates are statistically significant at 1% level.

As a result of the retrofits, the 19 (dedicated) landscape accounts combined are saving roughly 56 acre-feet of water per year. Derivation of this estimate requires combining information from Tables 1 and 2. Take savings in inches from Table 2 and multiply by corresponding acreage in Table 1, giving only half as much weight to landscape area planted with shrubs as turf. Generally shrubs require only half as much water as turf. Because our methodology for converting billing data into inches embeds this assumption, we have to maintain it to revert back to volume.

Water savings in landscapes supplied by mixed use meters

Table 3 shows savings achieved in the case of landscapes supplied by mixed-use meters. For two reasons, data across the two technologies were pooled together. First, the overwhelming majority of the acreage was under Hydropoint's control (Table 1). Second, sensitivity analyses could not discern any significant difference in the performance of either technology.

The data show average annual "weather normalized" water use at the eight retrofitted sites before and after the retrofit. For mixed-use meters, it is not possible to represent *total* consumption in inches, but later on we represent our best estimate of *outdoor* consumption and savings in inches to permit a comparison with dedicated landscapes. According to these estimates, weather-based irrigation controllers have reduced consumption by 8.8% on average. Using our statistical models, we estimate that outdoor consumption (irrigation) at these sites was on average roughly 33 percent of total consumption prior to the retrofit. Our best estimate of reduction in irrigation then works out to roughly 27% (8.8% ÷ 0.33).

Table 3 Savings achieved in mixed use landscapes

Technology (# of accounts)	Average annual pre-retrofit water use (acre-feet)	Average annual post-retrofit water use (acre-feet)	Percent reduction in annual use‡	Outdoor use as a percent of pre-retrofit total use (best estimate)	Percent reduction in annual outdoor use (best estimate)
Hydropoint (6) & Water2save (2)	36.6	33.3	8.8%	33%	27%

‡ Model derived estimate is statistically significant at 1 percent level

It is also helpful to express these savings in inches, because removing the effect of landscape size facilitates a direct comparison with savings achieved elsewhere, such as, among the dedicated landscape accounts included in this study, or results from other studies. Using data in Tables 1 and 3, we estimate that weather normalized pre-retrofit irrigation (of turf equivalent areas) in these mixed-use accounts was roughly 76 inches per year, which dropped to roughly 55.5 inches per year after the retrofits. Assuming that post-retrofit consumption could have been further reduced to the level of reference ET (49.6 inches per year for the area in question), it appears that 78% of the conservation potential has been converted into achieved savings.

Overall, Table 3's data suggest that these eight landscapes combined are saving roughly 26 acre-feet per year ([36.6-33.3]×8).

Quantifying dollar savings from future programs

Costs incurred during the implementation of this pilot study are difficult to quantify because LADWP staff devoted numerous unrecorded hours to the entire process. Thus, instead of attempting a cost-benefit analysis, we only try to quantify likely benefits under a range of scenarios, against which cost data can be compared, when such data become available.

The savings analyses presented above suggest that across all the 27 landscapes, irrigation (per turf equivalent areas) dropped by roughly 17 inches per year as a result of the weather based irrigation controllers. Assuming that weather-based irrigation controllers have a useful life of ten years, one can quantify water savings, and dollar benefits likely to accrue to both customers and to LADWP.

We classify customers into two groups for the purpose of illustration—those with dedicated irrigation accounts, and those CII accounts with mixed-use meters 2 inches or above. LADWP charges them very different water rates, $0.99 and $1.816 per hundred cubic feet (HCF) respectively. As a point of reference, note LADWP charges multi-family mixed use meters $2.087 per HCF, and CII mixed-use meters under 2 inches $2.157 per HCF. For the purpose of developing Table 4, we have deliberately tried to be conservative by using the lowest water rate applicable to the multi-family and CII sector. We also quantify benefits under two discount-rate scenarios—0% and 6%. The results are presented in Table 4. For example, customers with a quarter acre of turf landscape connected to dedicated irrigation meters can expect to save between $1,527 and $1,124 over a ten-year period, depending upon the discount rate used. Mixed-use CII accounts supplied by meters 2-inches or above can expect to save even more—roughly between $2,062 and $2,801 depending upon the discount rate used. To estimate dollar savings for mixed-use accounts charged a rate higher than $1.816 per HCF, simply multiply Table 4's estimates by the ratio of the two water rates.

Table 4 Likely water savings benefit from future programs

Turf equiv-alent land-scape area	**10 year water savings benefit (discount rate=0%)**			**10 year water savings benefit (discount rate=6%)**		
	To dedicated irrigation accounts[†]	**To mixed-use CII accounts**[*]	**To DWP**[‡]	**To dedicated landscape accounts**[†]	**To mixed-use CII accounts**[*]	**To DWP**[‡]
0.25 acre	$1,527	$2,801	$1,566	$1,124	$2,062	$1,153
0.50 acre	$3,055	$5,604	$3,132	$2,248	$4,124	$2,306
1.00 acre	$6,110	$11,208	$6,264	$4,496	$8,247	$4,611

[†] Dedicated landscape accounts are charged $0.99 per HCF ($431.3/acre-foot) for water.
[*] CII accounts with meters 2" and above are charged $1.816 per HCF ($791.2/acre-foot) for water. Sewer charges are additional as discussed in text.
[‡] LADWP reports its avoided costs to be $442.3/acre-foot.

It is worth noting that since mixed-use meters also accrue sewer surcharges, the total dollar savings experienced by the customer will be significantly greater. According to LADWP's data, mixed-use CII and multi-family accounts are, on average, charged an additional sewer surcharge of $2.115 per HCF of billed water use. Taking these surcharges into account would more than double the mixed-use customer benefit reported in Table 4. For example, dollar savings experienced by customers with a quarter-acre of turf landscape would rise to between $4,463 and $6,063 over a ten-year period depending upon the discount rate used.

Table 4 also quantifies benefits to LADWP in terms of avoided costs, and these estimates indicate the maximum level of program costs that LADWP could help defray on behalf of the customer and still have a cost-effective program. This is not the same as saying that LADWP should automatically offer a rebate of, say, $1,153 to customers with a quarter acre of turf landscape (under the 6% discount rate scenario), only that it would be the maximum justifiable amount. How a program is marketed and how customer perceptions about these new technologies are modified through market transformation strategies can significantly affect the level of financial incentives that are necessary to tip private decisions in favor of weather-based irrigation technologies.

4. User Feedback

During the evaluation phase, we telephoned several individuals intimately involved with irrigation management at the study sites, to solicit feedback about their experience with the retrofitted controllers. Although achieving success with either technology, in principle, requires a partnership between the site owner, the landscaper, and the vendor, notable differences exist between Hydropoint's and Water2save's technology and business models. While we heard no strong negative comment about either technology, we did hear significant differences in emphasis.

With Water2save's technology the user does not have to learn the operation of any new gadgetry, which obviates the need for extensive training. This was reflected in the feedback. No individual at the Water2save test sites had any specific comments to offer about the technology's efficacy, or ease of use, or malfunction rate. None reported any deterioration in the condition of their landscapes, but none had any feel for water savings either. A couple of individuals reported having to work harder, because poor uniformity required them to often supplement irrigation by hand watering or by altering schedules on the existing controller. However, in one key respect, they found the weather-based controller to have reduced their work—this was in connection with rain events where they no longer had to manually shut off the controllers. Education of the site owner was suggested as an important element because reduced watering often necessitates improvements in the irrigation system. Thus an owner's willingness to fund upgrades may be crucial to overall success. At least one individual thought that communication with Water2save's office being limited to English-speaking personnel was a drawback. Overall, our impression is that by and large the individuals we spoke with perceived the Water2save controller more with a sense of mystery than a sense of partnership.

In the case of Hydropoint, the user has to be intimately involved with the operation of the new controller, which of course comes at a price. While all our interviewees sounded highly positive about the WeatherTrak controller, it probably had taken them a while to get to this stage. Most reported having had to tinker with baseline schedules a few times before they were satisfied. One individual reported the need to improve head coverage, and the need to homogenize precipitation rates across heads controlled by a valve, before irrigation could be successfully reduced. All liked the rain interrupt feature. Only a couple reported experiencing technical glitches with the controllers. At least one individual thought WeatherTrak was still not adequately user friendly, and that its user interface needed improvement. This same individual mentioned that these controllers must be made available in larger capacities (24 and 48 stations) before they can be successfully employed in the CII sector. Because of the ultimate user's greater involvement with WeatherTrak, individuals had a definite perception that these controllers were saving significant amounts of water. Many also said the controllers were labor saving, but only after all the initial setup and teething problems had been ironed out.

During our telephone interviews, we also queried what steps LADWP should undertake to promote weather-based irrigation controllers in their service area. Outreach and education of landscapers was at the top of the list, followed by education of site owners who rarely appreciate the full magnitude of dollar savings likely to accrue to them. Aggressive marketing of smart controllers through the print and television media, highlighting their dollar savings and environmental benefits, was also suggested as a way of promoting these new technologies.

Appendix B includes photographs from a few select sites.

5. Findings and Conclusions

This study from the beginning was seen as a technology demonstrator. Its goal was primarily to assess the performance of weather-based irrigation technologies, and secondarily customer acceptance of these technologies in predominantly non-single family residential and small commercial settings. In such settings since the site owner is usually divorced from routine landscape maintenance, success requires the cooperation of both the owner and the landscaper. Since demonstration of the technology was a key goal, it was decided early on to include both dedicated irrigation and mixed-use accounts in the study. Dedicated irrigation accounts offer a direct and powerful way of gauging how well irrigation tracks ET.

A total of 25 sites with roughly 83 acres of landscape (35 acres planted with turf, the rest with shrubs) were recruited for this study. Selected sites included homeowner associations, schools, commercial sites, public parks, and so on. Dedicated irrigation meters supplied water to roughly 60 of the total 83 acres. These were retrofitted with weather-based irrigation technologies from two vendors—Hydropoint, Inc., and Water2save, LLC. The retrofits occurred on a first-come first served basis, in a staggered manner over time as sites were recruited and screened for suitability. To avoid implementation delays, the study did not randomize the assignment of sites to the vendors.

Water use was tracked for at least a year after the retrofits, and water savings were determined through statistical models that compare two years of pre-retrofit to one year of post-retrofit consumption accounting for weather.

These analyses were conducted separately for dedicated irrigation and mixed-use accounts. Since no separation of indoor and outdoor consumption is required among the former accounts, it was relatively straightforward to evaluate how well applied irrigation tracked ET before and after the retrofits. We found that both technologies were very successful in changing irrigation patterns to accord with weather, with Water2save's and Hydropoint's technologies reducing irrigation by 28.3% and 17.4%, respectively. But, Water2save's sites also exhibited greater levels of wasteful irrigation prior to the retrofits, and therefore had a higher level of conservation potential to begin with. The percentage of the pre-retrofit conservation potential converted into actual savings was higher in the case of Hydropoint's dedicated landscapes (95%) than Water2save's (71%). These percentages being unequal do not necessarily imply that one technology is superior to the other because many factors could account for the inequality, such as distribution uniformity being especially poor, or cooperation from the on-site landscapers being especially poor, in one set of sites compared to the other. What they do imply, however, is that by paying greater attention to these additional factors, water savings perhaps could be improved even more, although such steps would also tend to drive up program costs.

Among the mixed-use accounts, on account of the small sample size, we were unable to detect any significant difference in savings achieved by the two different technologies. Combined though, it appears that these weather based irrigation technologies were able to reduce outdoor consumption by roughly 27%.

Overall, it appears that landscapes supplied by dedicated irrigation meters are saving roughly 56 acre-feet per year, while landscapes supplied by mixed-use meters are saving 26 acre-feet per year, for a total program savings of 82 acre-feet per year. During the evaluation phase, we also telephoned several individuals intimately involved with irrigation management at the study sites, to solicit feedback about their experience with the retrofitted controllers. We heard no strong negative comment about either technology.

We also used our savings estimates to project dollar benefits likely to accrue to LADWP and its customers under differing assumptions. For example, a customer with a quarter acre of (turf-equivalent) landscape, supplied by a dedicated irrigation meter, can expect to save roughly between $1,124 and $1,527 over a ten year period (assumed device life) depending upon whether a 6% or 0% discount rate is assumed. Were the site connected to a mixed-use meter, dollar benefits from water savings alone to the customer would rise to between $2,062 and $2,801 over a ten-year period because LADWP charges such meters significantly higher water rates. And for mixed-use accounts, were one to also take sewer surcharges into consideration, the above-mentioned dollar benefits would roughly double. Avoided (water) costs to LADWP over a ten-year period would range between $1,153 and $1,566. Obviously, these estimates are highly dependent upon landscape size, rising proportionally as size increases.

Although savings reported here are quite significant, it should be noted that we expect the cost of promoting weather-based irrigation technologies among non-single family and small commercial customers to also be relatively high. Marketing this pilot study was not easy and took a lot of effort by LADWP staff. Ensuring compliance by the on-site landscapers also required outreach, education, and monitoring, all of which would have to be made part and parcel of any real-world program. Landscaper participation and support is crucial for saving water through improved irrigation scheduling.

Appendix A—Model Specification and Estimation

Conceptual model

A logical way of modeling staggered billing data is to conceive the model at a daily level and then scale it up to the meter-read level. Equation (1) expresses logarithmically transformed daily consumption (U_{it}) for customer (i) at time (t) as a function of the daily weather index (W_t), say, the evapotranspiration rate, customer characteristics (X_i), daily intercept terms (α_t) and random error (ε_{it}). This model is very flexible insofar the intercept terms and weather coefficients are conceptually allowed to vary on a daily basis. Intercept terms are necessary because intervening human factors make consumption's relationship with weather somewhat sticky. Irrigation decisions, to some extent, are based upon experience and "gut feel." A weather index alone is therefore unlikely to fully capture variation in consumption by time of year.

$$Ln(U_{it}) = \alpha_t + \beta_t W_t + \eta X_i + \varepsilon_{it} \qquad (1)$$
$$\text{where} \quad \varepsilon_{it} \sim N(0,\sigma^2)$$

Daily consumption is logarithmically transformed because water consumption is generally distributed with a long right-hand tail. And usually, even after accounting for customer heterogeneity and seasonality, model error does not exhibit a normal distribution. A couple of explanations can be offered for skewed model error. First, the most seasonal component of consumption—irrigation—is a discrete event, even when scheduled according to scientific principles. A landscape is supposed to be irrigated when daily evapotranspiration has depleted the soil water content below a certain threshold (Snyder and Sheradin, 1992). When daily evapotranspiration is low and uncertain, or rainfall is received periodically, average daily consumption may exhibit a rightward skew. Second, landscape professionals often set irrigation schedules by varying a preset baseline schedule in proportion to changes in the evapotranspiration rate. Errors are therefore proportionally magnified or diminished.

Averaging consumption across the (N) days included in a read taken at time (T) yields the meter read-level model (Equation 2). Throughout, summation operators are subscripted backward in time because meter read-dates signal the end of a consumption period. If consumption days (N) vary markedly across reads, averaging insures error homoscedasticity at the meter-read level when daily error is homoscedastic. Of course, in spite of averaging, meter read-level error will be heteroscedastic if daily error itself is heteroscedastic, in which case (2) should be estimated using generalized least squares. Autocorrelation is a different matter, however.

Because of error averaging, autocorrelation at the meter-read level should be low to nonexistent even if daily error is highly autocorrelated. It can be mathematically shown that if daily autocorrelation is as high as 0.9, even then observed autocorrelation will only be 0.092 for 30-day cycle reads, and 0.025 for 61-day cycle reads (Bamezai, 1997).

$$\frac{1}{N}\sum_{t=T}^{T-N} Ln(U_{it}) = \sum_{t=T}^{T-N}\alpha_t \frac{1}{N} + \sum_{t=T}^{T-N}\beta_t \frac{W_t}{N} + \eta X_i + \frac{1}{N}\sum_{t=T}^{T-N}\varepsilon_{it} \qquad (2)$$

$$\text{where } \frac{1}{N}\sum_{t=T}^{T-N}\varepsilon_{it} \sim N(0,\sigma^2)$$

Estimation of (2) as it stands requires the creation of at least 365 daily indicator variables (equal to *1/N* for days included in the read) for capturing the daily intercepts and another 365 interactions of these indicators with the daily weather index to capture the daily weather response. For days not included in a specific meter read the corresponding daily indicators and their interactions take on the value of zero. Such an enormous estimation exercise is unlikely to succeed not only because of the immense computing resources required, but also because of multicollinearity among many of the daily indicator variables. Meter reads must be available for every day in the year to provide the variation necessary for estimating these daily parameters, but read-dates are often clustered by design. Thus, for estimation purposes, it is necessary to impose some simplifying restrictions on these daily parameters.

An option is to assume that the daily intercepts (α_t) and the weather response coefficients (β_t) are equal for all days in a given month. Doing so reduces the estimation problem down to 12 monthly intercepts, 12 weather coefficients, and other customer characteristics included in the model. It is not necessary to place the same restrictions on (α_t) and (β_t). For example, the daily intercept terms (α_t) may be fit with piece-wise linear or cubic splines (Suits et al., 1978; Robb, 1980), while the weather coefficients (β_t) may be assumed constant for either all days in a month or all days in a season. The daily intercepts may also be captured using Fourier harmonics (Bamezai, 1996).

Because monthly restrictions are perhaps the most obvious choice with billing data that follow a 30-day cycle, the implication of these restrictions is developed in greater detail. Equation (3) shows what these restrictions imply for meter reads that span a total of (N) days, with (m) days falling in one month and (n) days in the next.

$$\frac{1}{N}\sum_{t=T}^{T-N} Ln(U_{it}) = \alpha_m \frac{m}{N} + \alpha_n \frac{n}{N} + \beta_m \sum_{t=T}^{T-m}\frac{W_t}{N} + \beta_n \sum_{T-m-1}^{T-m-n}\frac{W_t}{N} + \eta X_i + \frac{1}{N}\sum_{t=T}^{T-N}\varepsilon_{it} \quad (3)$$

To estimate (3) it is necessary to allocate the total number of days covered by a meter read to each month. In other words, 12 monthly variables must be created of which 2 take on the values (*m/N*) and (*n/N*) for any given read, the rest being zero. Similarly, the daily weather index during a read interval must also be split into month-specific aggregates. Once again 12 weather variables are required of which only at most 2 take on a nonzero value for any given read. Meter reads taken bimonthly can be handled just as easily in the above framework, the only difference being that such reads are likely to span 3 instead of 2 months.

Construction of the dependent variable in (3), however, still poses a minor problem. The dependent variable is equal to the sum of logarithmically transformed daily consumption. But billing histories yield only the sum of daily untransformed consumption which after a logarithmic transformation does not equal the desired dependent variable (Equation 4).

$$\frac{1}{N}\sum_{t=T}^{T-N} Ln(U_{it}) \neq Ln(\frac{1}{N}\sum_{t=T}^{T-N} U_{it}) \qquad (4)$$

The above inequality, however, can easily be resolved by leaning on well-known properties of a lognormal distribution.

If $Ln(U_{it}) \sim N(\mu_t, \sigma^2)$

then $$E(\frac{1}{N}\sum_{t=T}^{T-N} Ln(U_{it})) = \frac{1}{N}\sum_{t=T}^{T-N}\mu_t \qquad (5)$$

Similarly

$$Ln(E(\frac{1}{N}\sum_{t=T}^{T-N} U_{it})) = Ln(\frac{1}{N}\sum_{t=T}^{T-N} e^{\mu_t + \frac{\sigma^2}{2}}) = \frac{1}{N}\sum_{t=T}^{T-N}\mu_t + \frac{\sigma^2}{2} + Ln(\frac{1}{N}\sum_{t=T}^{T-N} e^{\varepsilon_t}) \quad (6)$$

where $$\varepsilon_t = \mu_t - \frac{1}{N}\sum_{t=T}^{T-N}\mu_t$$

Under most plausible scenarios of the rate of change in average daily consumption (μ_t) over the course of 30 or 61 days, the last term in (6) converges to zero. In other words, the two quantities cited in (4) differ approximately by a constant (that is, half of the daily variance), hence are readily substitutable.

Approximating nonlinearity and reducing measurement error

If data and model diagnostics indicate that the weather index (say, the evapotranspiration rate) should either be logarithmically transformed, or that higher powers should be included as well, the framework developed in (1) through (6) can easily include such possibilities. One such case is discussed below for illustration.

Assume daily consumption is a quadratic function of weather instead of a linear function (Equation 7).

$$Ln(U_{it}) = \theta_t + \omega_t W_t + \psi_t W_t^2 + \eta X_i + \varepsilon_{it} \qquad (7)$$
$$\text{where} \quad \varepsilon_{it} \sim N(0, \sigma^2)$$

Under the assumption of monthly restrictions, estimation of (7) now requires 12 additional variables to capture the weather index's second power. But by applying a linear approximation to (7) both the computational burden and the impact of measurement error can be minimized. The daily weather index is first reexpressed in terms of deviations from the daily mean, but then higher powers of the deviations are dropped (Equation 8).

$$\begin{aligned} Ln(U_{it}) &= \theta_t + \omega_t(\overline{W_t} + \Delta W_t) + \psi_t(\overline{W_t} + \Delta W_t)^2 + \eta X_i + \varepsilon_{it} \qquad (8) \\ &\Rightarrow Ln(U_{it}) \approx \alpha_t + \beta_t \Delta W_t + \eta X_i + \varepsilon_{it} \\ &\text{where} \quad \alpha_t = \theta_t + \omega_t \overline{W_t} + \psi_t \overline{W_t}^2 \\ &\qquad\qquad \beta_t = \omega_t + 2\psi_t \overline{W_t} \end{aligned}$$

After the linear approximation the essential structure of (8) is identical to (1), except that by working with daily deviations in the weather index, an approximate nonlinear weather specification is implicitly assumed without any increase in the computational burden. Bamezai (1997) demonstrates the validity of this approximation. Two additional benefits also accrue from the above approximation. First, the daily intercepts (or monthly if so constrained) provide a direct measure of average consumption on a particular day (or month) in a normal weather year—the differenced weather index is centered at the mean by construction. Second, a systematic time bias in the weather index's mean caused by lack of information about plant material by customer is likely to influence the deviations significantly less. A differenced weather specification (8) therefore simultaneously minimizes the impact of systematic measurement error while capturing an approximate nonlinear weather response. Even if weather response is linear, a differenced weather index is preferable to an undifferenced index: either index will yield identical results in the absence of measurement error, but the former is likely to be more accurate in the presence of measurement error.

Weather index construction

For the analyses that follow, weather variation is captured through a rainfall adjusted evapotranspiration-rate index (Equation 9). The evapotranspiration rate measures a plant's total water demand. It is necessary to subtract effective rainfall from the evapotranspiration rate to accurately predict net irrigation demand. The daily evapotranspiration and rainfall data are obtained from CIMIS.

$$W_t = \max[0, (ET_t^R K_t^C - P_t u)] \qquad (9)$$

where

W	daily weather index (inches)
ET^R	daily reference evapotranspiration rate (inches)
K^C	crop coefficient
P	daily precipitation (inches)
u	effective proportion of precipitation

CIMIS's ET^R represents the water demand of 4- to 6-inch-tall, cool-season grass transpiring at its maximum rate. In reality, plant height, plant roughness, plant age, ground shading, and other factors, all influence actual evapotranspiration needs of a plant (Snyder, 1993). If plant material is known, (fixed or time-varying) crop coefficients can be incorporated into Equation 9 to correct the reference evapotranspiration rate. For example, Meyer and Gibeault (1987) provide estimates of monthly crop coefficients for cool season turf. Half of daily rainfall is assumed to be effective as per CIMIS's recommendation, but when effective rainfall exceeds total evapotranspiration demand, net evapotranspiration demand is floored at zero. As mentioned earlier, the science underlying irrigation is essentially a stock and flow problem (Snyder and Sheradin, 1992). Soil moisture content (stock) must be maintained within a certain threshold. Evapotranspiration (flow) reduces the stock on a daily basis, effective rainfall adds to it intermittently, with irrigation acting as the balancing lever. A weather index constructed using a stock and flow framework is likely to be a better predictor of irrigation demand—the most weather-sensitive portion of total demand.

Since no CIMIS station exists in west San Fernando Valley where all the test sites are located, data from two stations bracketing this general region

(Piru in the west, Glendale in the east) were averaged to create a weather index. First, each station's daily evapotranspiration data were adjusted for effective rainfall. Then the two series were averaged, with Piru receiving 37% of the weight, and Glendale the remaining 67%. Experts suggested that a "normal year" reference ET of 51 inches ought to be a good estimate for west San Fernando Valley. The abovementioned weights were derived through iteration so as to reproduce this estimate.

Model results

Water reductions achieved through weather-based irrigation controllers were estimated by analyzing pre- and post-retrofit billing histories controlling for weather and other unobserved time-invariant differences (fixed effects) across the various landscape accounts. Some of these accounts were on a monthly, others on a bi-monthly, billing cycle. The model relates the logarithm of average daily consumption to a vector of covariates including monthly time indicators and weather variables. Weather effects were pooled across contiguous months if estimated coefficients were insignificantly different.

Separate models were estimated for landscape accounts supplied by dedicated irrigation meters and mixed-use meters—specification of the former model followed the framework described earlier, but for two reasons specification of the latter model had to be modified somewhat. First, the ratio of annual outdoor use to annual total use varied considerably across the mixed-use accounts (from a low of 5% to 70%), which predictably made data from these accounts exhibit different levels of seasonality. Second, the sample size was very small, which meant that statistical significance could only be obtained with a relatively simple weather specification. In the mixed-use model, then, the effect of weather variation is not allowed to vary by month or season, but is captured as an annual average. The weather variable is also logarithmically transformed to allow a nonlinear response since it does not enter the model in deviation form (model results are not sensitive to this transformation). Furthermore, the effect of weather is allowed to vary across accounts by interacting the weather variable with the proportion of total annual use that is accounted for by outdoor use (Outdoor use was estimated by taking the product of landscape area and reference ET, with shrub-planted area receiving only half the weight as turf-planted area.) The outdoor-use proportion varies across accounts, but not over time, and is simply a way of scoring the relative level of seasonality expected in each of these mixed-use accounts. Both models incorporate a heteroscedasticity correction based upon methods discussed by Carroll and Ruppert (1988).

Table 5 displays the estimated model for dedicated landscapes, which exhibits strong predictive power as indicated by the highly significant time dummies and weather coefficients, as well as a relatively high adjusted-R Square. The time dummies behave as per expectation, indicating minimum usage in the month of February and maximum in the months of July and August. This model shows that after the retrofits average daily consumption declined by 17.4% ($e^{(-0.190-((0.037^{\wedge}2)/2)}$-1) and 28.3% ($e^{(-0.330-((0.058^{\wedge}2)/2)}$-1) in the landscapes retrofitted with Hydropoint's and Water2save's technology, respectively.

Table 5 Estimated model for dedicated landscape accounts

Covariate	Coefficient	Std. Err.	t-statistic
January indicator	-0.392	0.247	-1.59
February indicator	-0.624	0.158	-3.95*
March indicator	0.001	0.168	0.00
April indicator	0.448	0.146	3.06*
May indicator	0.642	0.149	4.32*
June indicator	0.930	0.146	6.39*
July indicator	1.101	0.146	7.54*
August indicator	1.182	0.144	8.22*
September indicator	0.959	0.165	5.83*
October indicator	0.855	0.147	5.80*
November indicator	0.209	0.210	1.00
Dec., Jan., and Feb. weather deviation	23.294	2.873	8.11*
Mar., and Apr. weather deviation	10.334	2.482	4.16*
May, Jun., and Jul. weather deviation	2.326	1.373	1.69
Aug., and Sep. weather deviation	2.103	2.049	1.03
Oct., and Nov. weather deviation	9.577	3.138	3.05*
Post-retrofit indicator × Hydropoint indicator	-0.190	0.037	-5.09*
Post-retrofit indicator × Water2save indicator	-0.330	0.058	-5.65*
Constant	1.363	0.154	8.87*
Adjusted R-square	0.953		

NOTE: *Significant at 5 percent level. Estimated fixed effects not shown, but are included in the model.

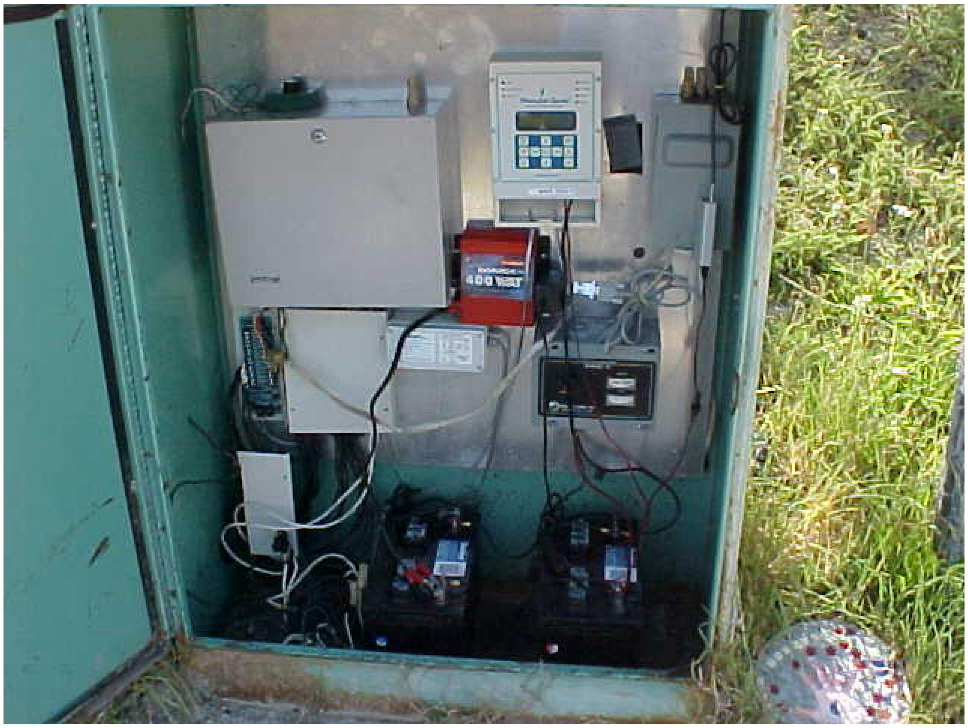
Table 6 shows the estimated model for mixed-use landscapes. Even though this model could not be as richly specified as the previous model, the estimated coefficients appear quite well behaved. For example, all the time indicators are insignificant, as is the main weather variable. The weather variable's interaction with the outdoor use percentage, however, is both positive and highly significant. The estimated model shows that seasonality increases as the proportion of outdoor use increases. Conversely, as outdoor use approaches zero, seasonality disappears completely as one would expect. The coefficient associated with the post-retrofit indicator suggests that annual consumption declined by 8.8% ($e^{(-0.091-((0.034^2)/2)}$-1) after the retrofits.

Table 6 Estimated model for mixed-use landscape accounts

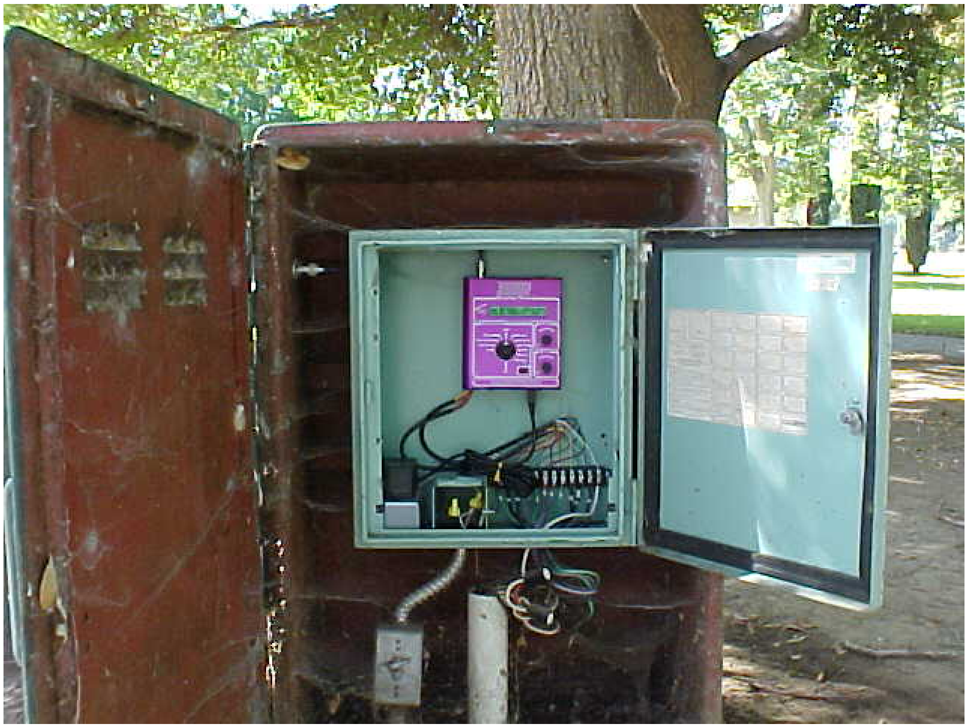
Covariate	**Coefficient**	**Std. Err.**	**t-statistic**
January indicator	-0.232	0.225	-1.03
February indicator	-0.122	0.153	-0.80
March indicator	-0.333	0.184	-1.82
April indicator	0.020	0.191	0.11
May indicator	-0.085	0.207	-0.41
June indicator	-0.025	0.211	-0.12
July indicator	0.026	0.223	0.12
August indicator	-0.064	0.222	-0.29
September indicator	0.039	0.212	0.18
October indicator	0.004	0.163	0.03
November indicator	-0.276	0.231	-1.19
Ln(weather index)	-0.012	0.150	-0.08
Ln(weather index) × outdoor use proportion	1.837	0.259	7.10*
Post-retrofit indicator	-0.091	0.034	-2.66*
Constant	2.707	0.385	7.02*
Adjusted R-square	0.968		

NOTE: *Significant at 5 percent level. Estimated fixed effects not shown, but are included in the model.

Appendix B—Photographs From Select Sites



Example of a Water2save installation



Example of a Hydropoint installation

Post-retrofit landscape appearance at an HOA

Post-retrofit landscape appearance at another HOA

Post-retrofit landscape appearance at a public park

Post-retrofit landscape appearance at a senior citizen center

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