Evaluation of California Weather-Based "SMART" Irrigation Controller Programs

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FOREWARD

Irrigation demand is the single largest end use of water in the urban sector in California. Irrigation demands typically account for 50% or more of the total water used in many California homes and businesses. As water utilities pursue options for new supplies, one option involves capturing savings from water conservation programs. This process also includes continually searching for additional water conservation opportunities through new measures and new technologies. Water agencies, wastewater utilities, the utility customer, and the environment all benefit from improved efficiency.

In support of the goals of water conservation and environmental sustainability, the California Department of Water Resources funded two large-scale regional efforts to improve urban irrigation efficiency and reduce runoff through the installation of smart controllers.

Automatic clock driven in-ground irrigation systems were developed with the goal of delivering water to urban landscapes effectively and efficiently. In well designed, built, maintained, and operated systems this goal is often achieved. In less ideal situations, irrigation systems provide inefficient and excessive water delivery. At the core of the irrigation system is the controller or “clock” where irrigation run days and times are set and where electronic signals that turn on and off irrigation valves are generated. The controller is also the key interface between the irrigation system and person in charge of operating that system – the homeowner, property manager, or landscape contractor.

Smart controllers (commonly referred to as ET controllers, weather-based irrigation controllers, smart sprinkler controllers, and water smart irrigation controllers) are a new generation of irrigation controllers that utilize prevailing weather conditions, current and historic evapotranspiration, soil moisture levels, and other relevant factors to adapt water applications to meet the actual needs of plants.

The irrigation controller is important, but only one piece of the puzzle. Even the best, most water efficient controller cannot make up for poor system design, installation, and maintenance. The focus of this report is on irrigation controllers, but a holistic approach to irrigation systems and landscape design and maintenance is required to achieve the full potential of water savings in the urban irrigation sector.

This report presents an evaluation of the California Weather-Based Irrigation Controller programs. This project presents empirical data on the performance of smart controller products distributed and installed through different methodologies in a wide variety of settings. This report is intended to fulfill a key requirement of the DWR grants and provide information and guidance for future smart controller and landscape conservation programs.

This report reflects the results of an effort that began over four years ago in cooperation with the California Department of Water Resources, the California Urban Water Conservation Council, the Metropolitan Water District of Southern California and their 26 member agencies, and a consortium of six water agencies in northern California led by the East Bay Municipal Utility District. It is hoped that the information presented in this report will be found timely, useful, and objective; will add to the current body of knowledge; and that the appropriate organizations, including water utilities and the California Department of Water Resources, will consider adopting and implementing the study's recommendations.

Innovations in any field involve risk. In the case of this new irrigation technology, weather-based irrigation controllers, people across California have taken the risk of investing their time, money, and expertise to explore the possibility of improving the efficiency of water use in California's urban landscapes. As this report demonstrates, the risks have been justified and the investments are resulting in significant water savings.

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EXECUTIVE SUMMARY

Irrigation demand is the single largest end use of water in the urban sector in California. Irrigation demands typically account for 50% or more of the total water used in many California home and businesses (Mayer et. al. 1999, 2000) (DeOreo 2007). Improving irrigation efficiency is perhaps the single most important goal for water conservation professionals in the coming years. In support of this goal, the California Department of Water Resources (DWR) funded two large-scale regional efforts to affect urban irrigation efficiency and reduce runoff through the installation of smart controllers.

Smart controllers (commonly referred to as ET controllers, weather-based irrigation controllers, smart sprinkler controllers, and water smart irrigation controllers) are a new generation of irrigation controllers that utilize prevailing weather conditions, current and historic evapotranspiration, soil moisture levels, and other relevant factors to adapt water applications to meet the actual needs of plants.

As a relatively new technology, water utilities have had only limited experience with smart controllers. The potential of smart controllers to reduce urban irrigation demands has only been measured through a limited number of studies. The California installation programs represent the largest coordinated effort to implement this technology and as such provide an important opportunity to evaluate the performance of smart controllers in the field and to determine if this is a tool that should be broadly pursued as a conservation measure.

New technology must be proven effective at reducing water demands in laboratory and field settings before it can be responsibly adopted into local, regional, statewide, and national water conservation programs. Research studies over the past 8 years have measured statistically significant water savings and runoff reduction achieved through the implementation of smart irrigation control technology (Bamezai 2004), (DeOreo, et. al. 2003), (IA, 2006, 2007, 2008), (Jakubowski 2008), (Kennedy/Jenks 2008), (Mayer, et. al. 2008), (MWDOC, IRWD 2004), (SCWA 2005), (US DOI 2007, 2008). Over that time nearly 20 smart control product developers and manufacturers have emerged and weather-based irrigation control has become a strategic focus of the irrigation industry.

The controller is important, but only one piece of the irrigation puzzle. Even the best, most water efficient controller cannot make up for poor irrigation system design, installation, and maintenance. The focus of this report in on irrigation controllers, but a holistic approach to irrigation systems and landscape design and maintenance is required to achieve the full potential of water savings in the urban irrigation sector.

Research Approach

The California Proposition 13 Smart Controller programs are the largest scale efforts to date to distribute and evaluate the impacts of weather-based irrigation control technology. This report presents an evaluation of the California weather-based irrigation controller programs in northern and southern California. This project presents empirical data on the performance of and satisfaction with smart controller products distributed and installed through different methodologies in a wide variety of settings.

This executive summary presents key study findings and results summarized concisely and without explanation or reference to the methodologies implemented by the research team. The full body of the report includes detailed explanations of the research approach, all participating agencies and organizations, data sources and analytic and statistical methods employed. Please refer to the Research Methodology chapter and the subsequent results chapters for full details. The Appendices include detailed information about each smart controller technology and brand as well as copies of survey instruments, fully enumerated survey results, and other supporting documentation.

Smart Controller Programs and Installation Summary

Through this program more than 6,342 smart controllers have been installed in southern and northern California. This report presents results of the impact of 3,112 smart controllers (49.1% of the total) installed at 2,294 sites in northern and southern California. These sites met the fundamental data requirements established for inclusion in this study – 1 full year of pre- and post-installation billing data, corresponding climate data, a measurement of the landscape area at the site, and basic information about the site, controller, and installation.

The fundamental unit of analysis for this smart controller evaluation study was on the site level. A site is a property where one or more smart controllers were installed. A single-family residential property with a single smart controller is a site as is a multi-family housing complex with 20 smart controllers installed. Only sites for which sufficient data were provided could be included in the analysis portion of this study. Utility partners were able to provide the necessary data for 2,294 sites encompassing 3,112 smart controllers to be included.

The southern California smart controller programs were made up of a large number of distribution programs developed and implemented by more than 20 water agencies. MWD's member agencies invested significant time and resources to implement and market their smart controller programs, tried various approaches, and made mid-stream adjustments because of lack of participation. Three fundamental smart controller distribution program methodologies were implemented in southern California: rebate and voucher programs, exchange programs, and direct installation. While some agencies tried to target the smart controllers to historically high irrigators, by and large, the southern California program effort was a general distribution program that provided smart control technology to interested and motivated customers.

The northern California Smart Controller programs were made up of rebate, voucher and direct installation programs at five participating agencies under the leadership of the East Bay Municipal Utility District. In an effort to maximize potential water savings, agencies in northern California targeted customers with historically high outdoor water use demands through an analysis of historic billing data.

Table ES.1 presents a summary of the smart controller installations evaluated in this study. A total of 411 controller sites (17.9%) were located in northern California and 1,883 sites (82.1%) were located in southern California. The northern California smart controller sites were located in the San Francisco Bay region including Oakland and the various East Bay cities, Santa Clara County to the south, and Sonoma County to the north. The southern California sites were located in the Los Angeles and San Diego metropolitan area starting from Santa Barbara in the north (outside the MWD service area) and stretching south to San Diego County and the Mexico border.

Table ES.1: Summary of smart controller installations in study

Category	All Sites	Northern Sites	Southern Sites
Total	2,294 (100.0%)	411 (17.9%)	1883 (82.1%)
Customer Category			
Single-Family Residential	1,987 (86.6%)	295 (12.9%)	1,692 (73.8%)
Multi-Family, Commercial, and Other Non-Residential	296 (12.9%)	105 (4.6%)	191 (8.3%)
Irrigation only	11 (0.5%)	11 (0.5%)	
Installation Method			
Self-Installed*	1,374 (59.9%)	182 (7.9%)	1193 (52.0%)
Professional/Utility**	919 (40.1%)	229 (10.0%)	690 (30.1%)
Climate Zone			
Coastal	655 (28.6%)	67 (2.9%)	588 (25.6%)
Intermediate	1,444 (62.9%)	330 (14.4%)	1114 (48.6%)
Inland	195 (8.5%)	14 (0.6%)	181 (7.9%)
Smart Controller Brand			
Acclima	1 (0.0%)	1 (0.0%)	0 (0.0%)
Accurate WeatherSet	342 (14.9%)	3 (0.1%)	339 (14.8%)
Aqua Conserve	288 (12.6%)	52 (2.3%)	236 (10.3%)
Calsense	17 (0.7%)	0 (0.0%)	16 (0.7%)
ET Water	94 (4.1%)	93 (4.1%)	1 (0.0%)
Hunter	44 (1.9%)	44 (1.9%)	0 (0.0%)
HydroEarth	2 (0.1%)	0 (0.0%)	2 (0.1%)
HydroPoint	537 (23.4%)	52 (2.3%)	485 (21.1%)
Irritrol	37 (1.6%)	34 (1.5%)	3 (0.1%)
LawnLogic	1 (0.0%)	1 (0.0%)	0 (0.0%)
Nelson	3 (0.1%)	1 (0.0%)	2 (0.1%)
Rain Master	22 (1.0%)	5 (0.2%)	17 (0.7%)
Toro	68 (3.0%)	42 (1.8%)	26 (1.1%)
Weathermatic	838 (36.5%)	82 (3.6%)	756 (33.0 %)

*Customer was responsible for installing the controller. They could have hired someone else to do it, but this information is not known.

**Controller was installed and/or programmed by an irrigation professional, utility representative, or other party besides the customer

Fourteen different brands of controller were included in the analysis portion of this study. Three brands, HydroPoint, Toro, and Irritrol are the same technology with a different box and face plate, and these were combined into a single category for the impact analysis. Controllers installed at fewer than 15 sites were included in the overall impact analysis, but not in analysis by brand because of the lack of sample size and hence statistical validity. This limitation excluded only 7 controller sites from the brand analysis.

Customers (also referred to as "participants") were responsible for installing about 60% of the smart controllers in this study (referred to simply as "self-installation"). They could have hired someone to perform the installation for them, but that level of detailed information is not known. At about 40% of the sites the controller was installed and/or programmed by an irrigation professional, utility representative, or other party besides the customer (referred to as "professional installation").

In reviewing and comparing the performance of the controllers in this study it is important to keep in mind that water savings is only one evaluation measure. An important evaluation parameter to consider is the post-application ratio (post-AR). A primary goal of smart irrigation technology is to reliably match the actual irrigation application to the theoretical irrigation requirement, (to achieve a post-application ratio of 1.0). Controllers that match actual applications to the theoretical requirement can be considered successful even if they do not reduce (or even increase) water use, because they are performing as designed.

Research Findings

Summary of Key Results.

The evaluation of research described in this report provides strong evidence for the following findings and conclusions:

- Weather-based "smart" irrigation controllers, while a valuable tool, are not a "magic bullet" for achieving perfect irrigation control and water savings.
- On average smart controllers are a moderately effective measure for reducing the amount of water applied by automatic irrigation systems, while maintaining the health, and appearance of landscapes.
- When seeking irrigation water savings, the pre-existing level of excess irrigation at the site is the most important factor to consider.
- The water savings achieved through installation of smart controllers can be maximized by targeting the technology to irrigators with historically high irrigation application rates, not simply customers with high irrigation use.
- The many irrigators who historically apply less than the theoretical irrigation requirement for their landscape are likely to *increase* their irrigation application rate after installing a smart controller.

- Survey results indicate that smart controllers are likely to achieve a high degree of customer acceptance once they more broadly penetrate the consciousness of irrigation contractors and the general public.
- The utility programs implemented through the DWR grant have succeed in raising public awareness of this technology, but survey results suggest most consumers have no knowledge of smart irrigation control.
- Smart controllers can achieve cost effective water savings for utilities and irrigators under some cost and pricing scenarios, however this technology will not be cost effective for all utilities and customers.
- Most of the smart control brands and technologies evaluated in this study reduced irrigation demands on average, but not all of these reductions were statistically significant.

A more detailed summary of the findings from this study are presented below.

Weather-Normalized Change in Irrigation Volume

The total weather-normalized volumetric change in outdoor usage for each study site and region is presented in Table ES.2. This table includes the results from the 2,294 smart controller sites included in the impact analysis. In this study, the smart controllers sites changed water use by -108,418,500 gallons (-144,942 hcf, -330 acre-feet) across California in one year. All but one participating water agency achieved overall water savings. Sites in northern California reduced demand of -152.8 af (46.3% of the total savings), and sites in southern California reduced demand by -177.1 af (53.7% of the total savings).

The average weather-normalized change in water use per smart controller site is presented in Table ES.3. Overall, outdoor water use was reduced by an average of 47.3 kgal per site (-6.1% of average outdoor use) across the 2,294 sites examined in this study as part of the California Weather-Based Irrigation Controller Programs. This reduction was found to be statistically significant at the 95% confidence level. At smart controller sites in northern California the average change in outdoor use was a reduction of 122.2 kgal per site (-6.8% of average outdoor use). This change was not statistically significant at the 95% confidence level, but was significant at the 90% confidence level. At smart controller sites in southern California the average change in outdoor use was a reduction of 30.9 kgal per site (-5.6% of average outdoor use) and this was statistically significant at the 95% confidence level.

Table ES.2: Weather-normalized total change in water use estimated in study (1 year of data)

Site Location	Weather-Normalized Total Change in Water Use		
	kgal	hcf	acre-feet
All Sites	-108,418.5	-144,941.9	-330.0
Northern Sites	-50,215.0	-67,131.2	-152.8
Southern Sites	-58,203.4	-77,810.7	-177.1
Coastal ET Zone	-27,864.8	-37,251.7	-84.8
Intermediate ET Zone	-75,440.9	-100,855.0	-229.6
Inland ET Zone	-5,112.9	-6,835.3	-15.6
Professional Installation	-35,233.0	-47,102.1	-107.2
Self Installation	-73,185.5	-97,839.8	-222.7
Commercial	-67,751.9	-90,575.8	-206.2
Irrigation Only	1,191.2	1,592.5	3.6
Residential	-41,857.8	-55,958.6	-127.4
Alameda County WD	-418.1	-558.9	-1.3
Burbank	-1,442.5	-1,928.5	-4.4
Contra Costa WD	-484.2	-647.3	-1.5
Eastern	-9,625.3	-12,867.9	-29.3
EBMUD	-23,299.0	-31,147.8	-70.9
Foothill	-1,899.5	-2,539.4	-5.8
Glendale	-579.2	-774.4	-1.8
Goleta	-846.6	-1,131.8	-2.6
Inland Empire	-11,463.3	-15,324.9	-34.9
LADWP	-12,100.1	-16176.3	-36.8
Pasadena	-6,010.6	-8,035.5	-18.3
Santa Barbara	-6,584.5	-8,802.6	-20.0
Santa Monica	401.8	537.1	1.2
Santa Clara Valley	-23,627.7	-31,587.2	-71.9
Sonoma County WA	-2,386.1	-3,190.0	-7.3
San Diego County WA	-2,974.9	-3,977.1	-9.1
Western	-5,078.5	-6,789.3	-15.5

Table ES.3: Weather-normalized change in water use volume (kgal)

Site Locations	Weather-Normalized Change in Outdoor Use Descriptive and Validatory Statistics					
	N	**Mean**	**Std. Deviation**	**95% Conf. Boundary**	**Statistically Significant Reduction?**	**% Change**
All Sites	2294	-47.3	669.5	27.4	Yes	-6.1%
Northern Sites	411	-122.2	1305.2	126.2	No	-6.8%
Southern Sites	1883	-30.9	416.5	18.8	Yes	-5.6%
Coastal ET Zone	655	-42.5	399.3	30.6	Yes	-7.6%
Intermediate ET Zone	1444	-52.2	756.7	39.0	Yes	-5.8%
Inland ET Zone	195	-26.2	707.4	99.3	No	-4.5%
Pro. Installation	920	-38.3	599.0	38.7	No	-3.6%
Self Installation	1374	-53.2	712.8	37.7	Yes	-9.0%
Commercial	296	-228.9	1783.8	203.2	Yes	-5.6%
Irrigation	11	108.3	231.1	136.6	No	10.9%
Residential	1987	-21.1	197.0	8.7	Yes	-7.3%
Alameda County WD	5	-83.6	81.2	71.2	Yes	-18.5%
Burbank	76	-19.0	49.1	11.0	Yes	-18.4%
Contra Costa WD	32	-15.1	268.3	93.0	No	-2.1%
Eastern	87	-110.6	284.5	59.8	Yes	-18.7%
EBMUD1	333	-70.0	499.0	53.6	Yes	-5.8%
Foothill	245	-7.8	34.6	4.3	Yes	-10.2%
Glendale	109	-5.3	12.9	2.4	Yes	-18.0%
Goleta	26	-32.6	230.2	88.5	No	-3.3%
Inland Empire	186	-61.6	93.7	13.5	Yes	-41.6%
LADWP	477	-25.4	600.9	53.9	No	-5.5%
Pasadena	17	-353.6	956.2	454.6	No	-8.5%
Santa Barbara	73	-90.2	259.2	59.4	Yes	-14.7%
Santa Monica	71	5.7	41.3	9.6	No	3.9%
Santa Clara Valley	34	-694.9	4254.5	1430.1	No	-8.1%
Sonoma County WA	7	-340.9	753.9	558.5	No	-10.9%
San Diego County WA	401	-7.4	117.7	11.5	No	-4.4%
Western	115	-44.2	1007.4	184.1	No	-1.0%

The overall impact of smart controllers installed in this study was to reduce irrigation demands, but the results suggest that those who historically apply less than the theoretical irrigation requirement for their landscape are likely to increase water use after installing a smart

1 In 2007, EBMUD requested a voluntary 10% cutback in usage from customers in response to drought conditions. Some of the post-installation water use data from EBMUD came from this time frame. It was not possible to determine if this effort impacted water savings in this study.

controller. The Application Ratio is a measure of how closely irrigation applications at a site matched the theoretical irrigation requirement determined from proximal ET weather stations. The level of excess or under irrigation (pre-AR) prior to the installation of the smart controller was the most important factor in determining if a site increased or reduced water use with the smart controller. In this study, a total of 1,300 (56.7%) of the 2,294 study sites had a statistically significant reduction in weather-normalized irrigation application ratio while 959 (41.8%) sites had a statistically significant increase in application ratio. For 35 (1.5%) of sites, there was not a statistically significant change in application. These results are shown in Table ES.4

Table ES.4: Number of smart controller sites and change in application ratio

Statistically significant change in water use?	# of Sites	%
Increase	959	41.8%
No change (+ or – 0.6%)	35	1.5%
Decrease	1300	56.7%

While the overall findings show reductions in outdoor water use through the installation of smart controllers, it should not be ignored that 41.8% of study sites experienced an increase in weather-normalized irrigation application ratio after the installation of a smart controller. Differences between sites that increased and decreased weather-normalized irrigation application ratio were examined and results are presented in Table ES.5.

Sites that increased application after installation of a smart controller had a mean pre-AR of 131% and a median of 95%. The median indicates that more than half of these customers were applying less than the theoretical irrigation requirement prior to the installation of the smart controller. Since smart controllers are designed to adapt irrigation to match the theoretical requirement, it would be expected that installing a smart controller at a site with a history of applying less than the theoretical irrigation requirement will result in increased demand.

Sites that decreased their application ratio after installation of a smart controller had a mean pre-AR of 182% and a median of 137%. The median here indicates that more than 50% of these sites were irrigating in excess of the theoretical requirement prior to installation of the smart controller. The water savings achieved through installation of smart controllers can be maximized by targeting the technology to irrigators with historically high irrigation application rates.2 As shown in Table ES.5, residential sites were more likely to increase irrigation applications after installing a smart controller than non-residential sites.

Table ES.5: Comparison of sites that increased and decreased irrigation application ratio with statistical significance after installation of a smart controller.

Category	Sub-Category	Increased Application	Decreased Application
Customer	Non-Residential Sites	32.9%	67.1%
Category	Residential Sites	43.0%	57.0%

2 Irrigation application rates can be calculated using two pieces of data: (1) Landscape area at the site; and (2) Annual outdoor water use at the site.

Landscape Area (sf)	Mean	22,084	28,505
	Median	6,286	5,698
Pre-Application Ratio (%)	Mean	131%	182%
	Median	95%	137%

Factors that Influenced Water Savings

Multiple regression analysis was used to determine the factors that did and did not influence changes in application ratio. This analysis methodology allowed the researchers to examine the relationship between key site characteristics (such as controller technology) and application ratio after adjusting for factors known to influence savings such as the application ratio prior to installation of the smart controller.

The following factors were examined and determined to have a statistically significant impact on the change in application ratio:

- Pre-smart controller Application Ratio – the application rate relative to the calculated theoretical irrigation requirement
- Installation method (self vs. professional)
- Participating agency (sometimes significant)

Factors that Did Not Influence Water Savings

The following factors were examined and determined not to have a statistically significant impact on the change in application ratio:

- Site classification (residential vs. non-residential)
- Region (northern vs. southern California)
- Climate zone (coastal, intermediate, inland)
- Smart irrigation control methodology (historical ET, on-site readings, remote readings, soil moisture sensor)
- Landscape area

Water Savings by Smart Controller Brand

The data assembled in this project allowed for a comparison of the field performance achieved by each brand of controller installed at the study sites. Controller brands installed at fewer than 15 sites were not included in this analysis (the total number of sites in this category = 7). Controller brand names were made anonymous during the analysis process and were only exposed at the conclusion. This analysis did not attempt to adjust for factors shown to influence water savings such as differences in installation method.

Seven of eight controller brands included in the analysis saved water on average, however the overall variability of the data resulted in broad 95% confidence bounds. When the 95% confidence boundary spans zero (i.e. the upper bound is greater than zero), the water savings associated with brand is not statistically significant. Of the eight manufacturers evaluated here, only two achieved statistically significant water reductions – Accurate WeatherSet and ET Water. Accurate WeatherSet achieved an average weather-normalized per site savings of 50.5 kgal which represented a 33.2% reduction. ET Water achieved an average weather-normalized per site savings of 185.4 kgal which represented a 6.2% reduction.

For five of eight manufacturers, statistically significant reductions in weather-normalized water use were not found. This result means that the water savings measured for these three brands was not statistically different from zero (the confidence boundary crossed zero). Consequently, no statistically “reliable” finding of water savings can be made for these three brands (Hunter, Weathermatic, Calsense, Rain Master, and Aqua Conserve). As additional years of post-installation data become available and/or with an increased sample size it is possible that these technologies could achieve statistically significant water use reductions.

The HydroPoint/Toro/Irritrol controller was the only technology that did not achieve water savings in this analysis, but this technology performed better over time as discussed in the multi-year analysis.

Water savings is only one evaluation measure. An important evaluation parameter to consider for smart controllers is the post-application ratio (post-AR). A primary goal of smart irrigation technology is to reliably match the actual irrigation applications to the theoretical irrigation requirement, (to achieve a post-application ratio of 1.0). Controllers that match actual applications to the theoretical requirement can be considered successful even if they do not reduce (or even increase) water use, because they are performing as designed.

Persistence of Savings – Multi-Year Analysis

The primary results for smart controller sites presented in this study compare a single year of pre-installation data against a single year of post-installation data. While these results are encouraging and show that smart controllers can reduce weather-normalized outdoor use on average, the longer-term performance of smart controllers in the field is of critical importance. Do water savings persist over time after the installation of a smart controller? Do the water savings decay? In the three years of post-installation data examined in this study for 384 study sites, water savings were not found in the first year, but savings were found in year 2 and year 3 and actually increased over time. More than 90% of the controllers in this analysis were HydroPoint/Irritrol/Toro so this analysis largely reflects the performance of this technology over time.

Three years of post-installation data were available for more than 384 smart controller sites. The results show that the controllers in this sample did better over time and in particular in the third year following installation. During post-installation year 1, weather-corrected percent change in water use increased by 6%. In year 2, the weather-corrected percent change water use showed a decrease 7.8% vs. the pre-install year. In year 3 the weather-corrected percent change in water use showed a decrease of 16.4% vs. the pre-install year.

Cost Effectiveness Analysis

Installing smart controllers may or may not be cost-effective for a utility or their customers. The determination of cost-effectiveness depends upon the water savings, the avoided cost for water, local retail water rates, the discount rate factor used, and the expected useful life of the product.

The cost-effectiveness analysis was conducted from two perspectives: (1) the water utility; and (2) the end user or customer. For the water utility perspective, cost-effectiveness analysis was used to determine the incentive levels that could be reasonably justified for a water utility based on the water savings measured in the study. For the customer perspective, cost-effectiveness analysis was used to determine the level of investment that would be reasonable for a customer to make in a smart controller given the anticipated water and cost savings achievable through installation of the device.

A water utility with an annual avoided cost for water of $150/acre-foot that implements a smart controller program aimed at the residential sector and small landscapes (~4,000 sf) would likely achieve cost-effective water savings for a per-site incentive of up to $26. If the same agency implemented a program aimed at large landscapes (~25,000 sf), a $164 incentive would likely result in cost-effective water savings.

Utilities with higher annual avoided costs for water may find smart irrigation control technology to be a cost effective method of reducing demand in new and existing customers. At an annual avoided cost of $1000 per acre-foot a utility could provide nearly a $500 per site incentive for sites averaging 12,000 sf in size. The economics of smart controller incentives will differ between water agencies. But if average water savings as found in this study are achieved, then some utility programs that incent smart control technology will be cost effective.

For a residential customer with a 4,000 square foot landscape who pays $3/hcf for irrigation water who achieves average water savings with a smart controller would be justified in spending up to $229 to purchase, install, and maintain a smart controller over the 10-year expected life of the product. A customer with a 12,000 square foot landscape who pays $2/hcf for irrigation water would be justified in spending $458 on a smart controller. These results indicated that customers who achieve average water reductions can realize cost-effective savings from installing a smart controller.

Each water utility is unique. Each utility normally has its own distinct avoided cost for water and system of water rates and charges, developed over many years through complex processes. In water conservation planning, each utility may place a different value on conserved water. This poses challenges for developing cost-effectiveness analysis for smart controllers that will be broadly applicable across the diverse range of utility agencies that participated in this study and the even larger group that may utilize the results. It is most likely that utilities will use the water savings and percentage decrease estimates from this study and apply them to their own cost-effectiveness models. However, the research team was able to develop an approach to cost-effectiveness analysis that provides information for a broad range of agencies and systems of rates and charges.

Water utilities and customers may wish to promote and install smart irrigation control technology for other reasons besides potential water and cost savings. For water utilities, smart irrigation control offers a number of potential additional benefits including:

- Reduced runoff from urban landscape
- Adaptation of customer demands to calculated water budget allotments

- Potential for peak demand reduction (through coordinated irrigation "brown outs" similar to energy utility peak shaving)
- Improved health and condition of urban landscapes through more proper irrigation applications

For customers and end users, smart controllers offer some of the same potential benefits, but also a few others.

- Convenience – many participants in this study reported appreciating the convenience associated with smart control technology.
- Improved landscape appearance and health. Applying the proper amount of water usually improves landscape quality.
- Better feedback about other problems with the irrigation system. Many smart controllers offer diagnostic tools not available on traditional controllers. Applying the proper amount of water to a zone often reveals distribution uniformity problems or other system deficiencies that may have been masked by excess application in the past.

Conclusions and Recommendations

Process Analysis of Utility Smart Controller Program Design and Implementation

- **Program Design and Efficiency.** The California Prop. 13 Smart Controller Programs set out to test a variety of distribution methods and technologies to determine which approach makes the most sense moving forward. In both northern and southern California a regional approach was attempted, but in many cases each agency chose to follow its own chosen course while cooperating as much as possible with neighboring agencies. These programs benefited from the more efficient unified regional approach adopted for this study and this effort should be expanded. Leveraging common program elements such as design, marketing, and evaluation, stretched funds for program implementation and evaluation funds and increased regional recognition and public awareness.
- **Marketing.** Smart controller programs must be marketed if they are to attract interest. Smart controllers are a relatively new technology and very few people know what they are and what they do. Customers and landscape professionals alike need to be educated about these products and why they are desirable. Marketing materials should explain how the technology works and what benefits it offers. EBMUD found the readily available SWAT marketing materials to effective at explaining the technology and generating interest. Once educated, the public appears quite interested in smart control technology and is willing to give it a try. Customers may need help choosing the smart controller product that best suits their needs. The differences in operation and performance between a signal-based, sensor-based, and historic ET controller are not obvious to the typical customer. Targeted marketing approaches that identify customers with high irrigation demands and focus distribution efforts may be an effective method of placing smart controllers at sites that offer the greatest potential for water savings.

- **Getting Smart Controllers Into the Field.** Public information is critical to success of any utility sponsored smart controller program. Information provided should be clear and concise. A complicated message spanning multiple pages will not be successful. Information provided at the point of sale (e.g. the irrigation supply outlet or retail home and garden center) can be beneficial. Availability of product is essential. It cannot be assumed that smart controllers are easily available. Partnerships with the landscape industry are an excellent way to promote smart controller technology and can be beneficial to customers and landscape professionals alike. Smart controller programs should include a strong education element that focus on proper installation and most importantly programming. Manufacturers and distributors can help educate irrigation contractors and provide incentives for installation of smart controllers. Manufacturers and distributors can also increase marketing efforts in areas where water agencies are offering financial incentives programs that encourage installation of smart controllers. Follow-up inspections can be helpful for assuring maximum benefit, but also increase utility program costs.
- **Market Transformation –** The overall smart controller distribution program design and marketing materials and distribution methodologies developed have the potential to achieve longer lasting impacts on the market. In both southern and northern California, the marketing efforts succeeded in raising public awareness about the technology, although much work remains to be done on this front. Efforts that educate irrigation and landscape contractors can result in increased adoption of the technology, even after the program has ended.
- **Costs.** The type of distribution program a utility chooses to implement impacts program costs tremendously. Direct installation programs are typically the most expensive to implement as professionals are contracted to perform installations and programming. Exchange programs are typically less expensive and place responsibility for installation and programming with the customer. This study found that self-installation resulted in greater water savings compared with professional installation.

  The cost of rebate programs varies depending upon the design. Rebates can be set to match expected utility cost savings/avoided costs. Follow-up visits and inspections can be beneficial, but also add to the overall cost of a program. Agencies with prior experience implementing rebate programs for toilets, clothes washers, and other efficiency measures may have an easier time getting a smart controller rebate program underway. If water savings are the desired outcome, targeting program efforts at customers that historically irrigate in excess of the theoretical irrigation requirement is an essential key to success.

- **Irrigation Systems.** The controller is just one piece of a much larger irrigation system. Performance of the controller is limited by the capabilities of the irrigation system. The most water efficient smart controller cannot operate optimally on an irrigation system with poor head spacing and inadequate distribution uniformity. A systems approach is required to achieve maximum water savings. Some agencies incorporated system repair and upgrades into their smart controller program out of recognition that maximal water savings may not be achieved from poorly designed, maintained or improperly programmed systems.

- **Residential and Commercial Differences.** When implementing a smart controller program it is important to recognize the distinct differences between irrigation sites and to plan accordingly. Small sites such as residential and small commercial properties are distinct from large commercial and institutional sites. At a small site, the financial decision maker and the person in charge of operating and maintaining the landscape and irrigation system are often one and the same. At a large site they are almost always different people who seldom communicate with each other. The smart controller technologies for small and large sites are also different as are the irrigation systems and management arrangements. Smart controller programs targeted at commercial and institutional customers will typically require distinct marketing materials, resources, training, and other program elements. Cost differences and varying potential water savings must be accounted for as well.
- **Program Evaluation.** Effective evaluation of a smart controller program requires fundamental data including: make and model of controller, date of installation, installation method, sufficient water use data (pre- and post-installation), a measurement (or estimate) of the irrigated area, climate data corresponding to the same period as the water billing data, and other data as well. Good program design includes a method for collecting these and other data such as shading as part of the distribution and installation effort.
- **Signaling Fees.** Some controller technologies require the customer to pay an annual fee to receive a signal that adapts irrigation applications to prevailing local conditions. Nearly 48% of the mail survey respondents indicated that they would not continue to pay the signaling fee for their smart controller after the conclusion of the utility program. The failure to pay the signaling fee would transform a signal-based smart controller into a conventional controller. Although this result is only based on a total of 46 survey respondents, the high percentage of customers indicating they will not continue to pay the signaling fee after the program ends is of concern and this should be the subject of follow-up research during the on-going program monitoring effort.

Impact Evaluation of Smart Controller Programs

- **Maximize Water Savings.** Smart controllers can save water. Smart controllers are far more likely to effect savings when they are installed at sites that have historically applied excess irrigation applications. Water providers seeking significant volumetric savings should target smart controllers at these customers in particular. To do this a utility must have three critical pieces of data: (1) Estimated outdoor water use at the site; (2) A measurement (or estimate) of the irrigated landscape area at the site; and (3) The specific (or average) evapotranspiration rate for the locale.

  In this study, 41.8% of the study sites *increased* their irrigation water use after installation of the smart controller. Irrigators who historically apply less than the theoretical irrigation requirement for their landscapes are poor candidates for smart controllers and should be pre-screened from utility distribution programs. Most water utilities have the electronic tools required to calculate which customers are good candidates for smart controllers and which are not. A geographical information system

(GIS) linked to historic water billing data are the perfect system for calculating historic application rates. Not all agencies have such tools readily available.

To maximize water savings, the installation and programming of the smart controller is of critical importance. Landscapes are unique. Experience has shown that the initial or default settings used to program a smart controller will likely need to be fine tuned over the first few weeks or even months of operation to ensure optimal performance. This is not a technology that can simply be installed and forgotten, adjustments are often required during the initial set up to calibrate the controller default settings to the specific conditions of the site. Once the controller is properly adjusted for the site few if any adjustments should be needed. Manufacturers, irrigation contractors, water agencies, and consumers must be made aware of this need for fine tuning. Training and tools should be developed to improve the installation and adjustment process to help ensure that the smart controller performs optimally and does not end up unnecessarily increasing water use.

- **Factors that Influence Water Savings**. This study has identified only a few factors that have a statistically significant influence on water savings. Specifically, the pre-Application Rate at the site, the installation method (self vs. professional), and the participating agency (sometimes a significant factor). Aside from the importance of targeting based on historic application rate (not just volume), these findings offer limited guidance for utility smart controller programs.

    - ***Installation and Programming.*** Remarkably, self-installed smart controllers performed better than professionally installed controllers in this study. It is unclear exactly why this is the case, but a reasonable hypothesis is that customers who installed their own controller were more familiar and comfortable with the technology and hence better able to fine tune the programming to maximize efficiency at their site. Irrigation experts, landscape professionals, and knowledgeable water conservation staff agree that proper installation, programming, and fine tuning are critical to a successful smart controller installation. In northern California utility personnel conducted an inspection of nearly all smart controller sites during which programming adjustments were made. This approach appears to have improved savings for some northern California agencies, but it is unclear if the benefits of these efforts outweigh the additional program costs associated with conducting site inspections. Post-installation inspections are a good idea, but the results from this study show that smart controller programs can achieve significant water savings without conducting site inspections.

    - Customer training programs at distribution and exchange events in southern California proved that a little training goes a long way. Participants were required to bring their old controller to the exchange event or class and were taken through exercises with the new controller to help familiarize them with the technology and to demonstrate the differences from the old controller. The research finding higher water savings from self-installed controllers bears out the efficacy of this training concept. The verbatim customer survey responses indicate that not all self-installations were successful, and in some cases professional assistance was sought. Because of the relatively low cost of implementing an exchange program, other agencies may opt for this distribution method as a reasonable way to promote smart irrigation control technology. An approach that is able to target customers with a history of applying water in excess of ET and then distributing the smart controllers with the low cost and ease of implementation of an exchange event could be an excellent hybrid program solution.

- **SWAT Testing.** Seven of the eight controller brands included in this study[3] have published SWAT test results. Only Accurate WeatherSet has chosen not to participate in the SWAT testing process, but still this technology achieved statistically significant water savings. All of the published SWAT scores were above 95% for adequacy. The results from this study indicate that the SWAT testing protocol may be a predictor of reasonable field performance, but is not a guarantee of water savings. The SWAT testing protocol was not designed as a way to assess water savings, but rather is a method to try and ensure controllers apply the right amount of water based on current ET formulation.

  Testing is essential. If water efficiency is the primary goal of the testing regime, then a conservation-oriented testing criteria perhaps derived from the current SWAT protocol should be considered. Maintaining acceptable landscape appearance and health while minimizing the amount of water used should be the objective of water conservation-oriented smart controller bench testing. Achieving this objective might require an entirely new testing protocol including modifications to the way ET is currently formulated as discussed below.

- **Cost-Effectiveness – Depends on Avoided Costs and Water Rates.** Installing smart controllers may or may not be cost-effective for a utility or their customers. The determination of cost-effectiveness depends upon the water savings, the avoided cost for water, local retail water rates, the discount rate factor used, and the expected useful life of the product. Programs targeted customers who historically irrigate in excess of the theoretical requirement are far more likely to be cost effective under any avoided cost and pricing scenario. Utilities seeking cost-effective demand reductions should focus their efforts on identifying sites that stand the best chance of reducing demands through installation of a smart controller.

  Smart controllers will be cost-effective for many end users, but not all. Utilities could easily provided simple cost-effectiveness calculations for customers to assist them in determining if a smart controller makes sense given their historic outdoor water demands. For some customers, factors besides water and cost savings such as convenience and a desire to enhance landscape health and appearance may convince them to install a smart controller.

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3 Eight smart controller technologies were installed at 15 or more sites in the study, the minimum required for inclusion in the analysis by manufacturer/technology.

- **Long-Term Performance Data Required.** More data on the long-term performance of smart controllers is required. The limited multi-year analysis presented in this report which showed increasing savings over time indicates the potential for long-term water savings from smart controllers is promising, but it is certainly not the final word on this subject. The DWR contract with the participating water agencies in northern and southern California specifies that post-installation water use must be tracked over a five year period. The participating water agencies should take full advantage of this opportunity to continue to monitor the impacts of smart controllers over the coming years and to track the persistence and/or decay of water savings over that time.

- **Long-term landscape health and appearance should also be considered.** Water use data included in this study was from monthly or bi-monthly billing records. Consequently, this study was not able to examine of how the controllers distribute irrigation events through time (i.e. frequency and duration or irrigation run times over a given period of time). With such coarse data it is possible that a controller might apply an amount of water close to the theoretical irrigation requirement over the course of a month or two, but within a given week the irrigation run times might not be distributed properly. While the distribution of irrigation events through time could not be examined in this study, it is potentially significant in the way smart controllers can affect overall plant health over time and should be the subject of further investigation. Some smart controller technologies only adjust run times and not water days which could result in frequent shallow waterings. Data on the long term appearance and health of landscapes irrigated with smart controllers should be collected.

- **CIMIS Data for Urban Irrigation.** Accurate, consistent, and continuous climate, evapotranspiration, and precipitation data will be increasingly important for effective urban water management in the future. The California Irrigation Management Information System (CIMIS) was originally created to provide critical data to agricultural water users in the state. More recently the system has been adapted to provide evapotranspiration data for urban irrigation management. The researchers relied heavily on CIMIS data to develop the analyses presented in this report and the experience of working closely with these data leads to a series of recommendation for improving the CIMIS system to better serve the needs of urban irrigators.

  - ***More CIMIS Stations Needed in Urban Areas.*** California needs more CIMIS ET stations in urban areas. Los Angeles and the surrounding metropolitan area in particular would benefit from additional CIMIS stations. The research team for this study was forced to obtain supplementary climate data for much of the analysis conducted on sites in the Los Angeles area when problems were detected at the few CIMIS stations located in the LA basin.

  - ***Continuous Data are an Important Goal.*** CIMIS stations are regularly removed from service for repairs and maintenance. When this occurs, climate data during the outage is unavailable and those seeking climate that data must use alternative, often less ideal, CIMIS stations. In this study, discontinuous data proved problematic and in many cases a particular CIMIS station could not be used because of discontinuity during the pre- or post-installation year. Repairs and maintenance are essential to assuring the quality and accuracy of CIMIS data, but there might be ways to complete repairs while still recording data from that location. One idea would be to temporarily replace station components with substitutes while others are removed for servicing.

- ***Formulate ET for Acceptable Landscape Appearance and Health Using the Least Amount of Water.*** There is a bright future for the use of evapotranspiration data to help manage urban irrigation. The essential goal of this effort will likely be maximizing water efficiency. Currently, CIMIS evapotranspiration data must be modified with various crop and landscape coefficients to adapt it to urban water requirements. There is general agreement on how this is done, but in the long run, something different is needed.

  The research team believes in thinking big, and our recommendation is that research be conducted to develop a new urban ET factor designed to maximize water efficiency while maintaining landscape health and appearance. Several recent landscape studies, including this one, have found the current ET formulation with a *Kc* value of 0.8 or even 0.7 is simply too high for many urban landscapes which contain a mixture of turf, trees, and plants (Sovocool, et. al. 2006, White, et. al. 2007). The revised urban ET factor should be developed by agronomists, horticulturalists, and landscape experts from around the country with the goal of developing an ET value designed for the efficient irrigation of urban landscapes. A water conservation-oriented ET factor should be based not on maximizing the growth of plants, as many current ET formulations are, but instead should be developed with the goal of *acceptable landscape appearance and health using the least amount of water*. The new factor must be formulated for different parts of the country, different soils, different plant materials appropriate to the setting, and different climates, but with the same goal of acceptable landscape appearance using as little water as possible. Ideally the new water conservation ET factor could be developed in the university environment at different locations across the country. Many universities already have facilities and programs that could be enlisted in this effort which will probably require federal funding to move forward. If urban landscape water conservation is expected to help stretch and support water supplies, this fundamental tool to help manage water use should be developed.

  Once developed, the water conservation ET factor could be incorporated into smart controller scheduling engines4 and algorithms to improve water savings.

4 Scheduling engines are the internal software programs in smart controllers that develop and adjust irrigation run times.