PETER W. MAYER AND WILLIAM B. DEOREO

Improving urban irrigation efficiency by capitalizing on the conservation potential of weather-based "smart" controllers

A MULTIYEAR STUDY OF A CALIFORNIA SMART IRRIGATION CONTROLLER PROGRAM FOUND THAT TARGETING HOUSEHOLDS THAT OVERIRRIGATE COULD DOUBLE POTENTIAL SAVINGS AND REDUCE IMPLEMENTATION COSTS.

In many parts of North America, irrigation demand is the single largest end use of water in the urban sector. Irrigation demands in California typically account for 50% or more of the total water used in many homes and businesses (DeOreo et al, 2008; Mayer et al, 1999). Improving irrigation efficiency may be the single most important goal for water conservation professionals in the coming years. In support of this objective, the California Department of Water Resources (CDWR) funded two large-scale regional efforts to affect urban irrigation efficiency and reduce runoff through the installation of smart controllers.

Smart controllers—also referred to as evapotranspiration (ET) controllers, weather-based irrigation controllers, smart sprinkler controllers, and water smart irrigation controllers—are part of a new generation of irrigation controller products that use prevailing weather conditions, current and historic ET, solar radiation, soil moisture levels, and other relevant factors to adapt water applications to meet the actual needs of plants. Because smart controllers represent a relatively new technology, water utilities have had only limited experience with them. New technology must be proven effective at reducing water demands in laboratory and field settings before it can be responsibly adopted by local, regional, statewide, and national water conservation programs. Research studies over the past eight years have measured statistically significant water savings and runoff reduction achieved through the implementation of smart irrigation control technology (IA, 2008a; 2008b; Jakubowski, 2008; Kennedy/Jenks, 2008; USDOI, 2008; IA, 2007a; 2007b; 2007c; 2007d; USDOI, 2007; IA, 2006a; 2006b; 2006c; 2006d; Bamezai, 2004; MWDOC & IRWD, 2004; DeOreo & Mayer, 2003). During this period, nearly 20 smart control product developers and manufacturers have emerged, and weather-based irrigation control has become a strategic focus of the irrigation industry.

Though important, the controller is only one piece of the irrigation puzzle. Even the most water-efficient controller cannot make up for poor irrigation system design, installation, and maintenance. This article focuses on irrigation controllers, but in reality, 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.

STUDY EVALUATED THE LARGEST-SCALE SMART CONTROLLER EFFORT TO DATE

Programs in northern and southern areas differed. California's smart controller programs, funded through Proposition 13 grants, represent the largest effort to date to distribute and evaluate the effects of weather-based irrigation control technology. The current study reviewed evaluation results from weather-based irrigation controller programs in northern and southern California and offers empirical data on the performance of smart controller products distributed and installed through different methodologies in an array of residential and nonresidential settings.

The southern California smart controller programs were made up of numerous distribution programs developed and implemented by more than 20 member water agencies of the Metropolitan Water District of Southern California (MWDSC) in La Verne. MWDSC member agencies invested significant time and resources to implement and market their smart controller programs, tried various approaches, and made midstream adjustments to solve a lack of participation. Three fundamental smart controller distribution program methodologies were implemented in southern California: rebate and voucher programs, exchange programs, and direct installation. Although some agencies tried to target the smart controllers to historically high irrigators, the southern California program effort was by and large a general distribution program that provided smart control technology to interested and motivated customers regardless of their historic irrigation water demand.

The northern California smart controller programs comprised rebate, voucher, and direct installation programs at five participating agencies under the leadership of the East Bay Municipal Utility District (EBMUD) in Oakland. In an effort to maximize potential water savings, agencies used an analysis of historic billing data to target northern California customers with historically high outdoor water use demands.

Research goals and basic analytical units defined. Two fundamental goals of the evaluation research were to determine the water savings (if any) associated with the installation of smart controllers and identify the factors that influence water savings. Nested within these two goals were numerous data analyses and research questions tasked to the evaluation team. Statistical analysis was conducted on three fundamental levels: local (by agency), regional (by climate zone), statewide (northern and southern programs, and combined). Results were also broken down by manufacturer, product, installation method, and customer class.

The fundamental unit of analysis for the smart controller evaluation study was on the site level. A site was defined as a property where one or more smart controllers were installed. A single-family residential property with one smart controller was considered a single site as was a multifamily housing complex with 20 smart controllers installed. Through the CDWR grant-funding programs, more than 6,342 smart controllers were installed in southern and northern California. This article presents results on the effect 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: one 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.

Table 1 summarizes 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 areas starting from Santa Barbara in the north (outside the MWDSC service area) and stretching south to San Diego County. Fourteen different brands of smart irrigation controller were included in the study.

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). These customers may 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).

The economics of such a large study required compromise in two areas. First, the study group did not include a control group. Although a control group was recommended in the scope of work, it proved impractical to implement for the number of participating water agencies and sites in the sample. A control group could have helped determine how many of the effects on water use were attributable to the simple fact of the site being visited and the controller programming checked versus how many were attributable specifically to the presence of a weather-based controller.

The second area of compromise was in the determination of irrigated areas and landscape coefficients for the study sites. Each participating utility provided a measurement (or estimate) of the landscape area for each site. The overall accuracy of these measurements and estimates is unknown, but it is certain that the landscape area was not always measured by preferred methods such as accurate aerial photos, geographic information system analysis, or physical measurement of the site. Given that landscape area is a key value used in calculating the theoretical irrigation requirement (TIR), errors may have been introduced into the analysis as a result of inaccurate landscape measurements.

Myriad data were collected for the analysis. Each region was responsible for assembling the fundamental data regarding every customer who received a smart controller and then providing this information to the evaluation team. Once the required customer and controller information and historic billing data were provided to the evaluation team, the next item was the challenging task of assembling the varying utility data sets into a single, coherent database that could be used to conduct the impact analysis.

Unless a dedicated irrigation meter was indicated, indoor (nonseasonal) use and outdoor (seasonal) use were disaggregated using a minimum month or average winter consumption technique to estimate annual indoor use. Use of minimum month water consumption as a measure of indoor use works reasonably well in areas with negligible winter irrigation but is less accurate in areas where irrigation is a year 'round activity. In select cases, it was preferable to use a fixed estimate of indoor use developed from water use studies in California (DeOreo et al, 2008; Mayer et al, 1999).

The participating water agencies in northern and southern California provided historic water use data from billing recorders for as many of the smart controller sites as possible. In order for a site to be included in the impact analysis, a minimum of 12 months of water consumption data from the time period before installation of the smart controller and one full year of water consumption data from the time period after installation of the smart controller were required. In some cases, multiple years of pre- and postinstallation data were provided, thus permitting more expanded analysis (discussed later in this article).

Once the appropriate pre- and postinstallation years of data were established, the application rate in inches was calculated by dividing the outdoor water use by the landscape area and applying a standard unit conversion factor. Application rate is a measure of the depth of irrigation water applied across the entire landscape over a year and can be compared with the TIR, which was empirically determined from data provided by the California Irrigation Management Information System (CIMIS), a program in the CDWR Office of Water Use Efficiency.

A detailed survey was sent to each site that received a smart controller through one of myriad utility programs. The survey asked questions about the participants' experiences with the smart controller, including the installation and programming process and ongoing performance. Although referred to in this article, survey results are not presented here because of space constraints. A complete analysis of the survey results can be found in the final report, available for free download from the California Urban Water Conservation Council (www.cuwcc.org) or Aquacraft, Inc. (www.aquacraft.com).

Climate data were essential to the evaluation. The CIMIS manages a network of more than 120 automated weather stations in the state of California. To account for microclimate differences to the extent possible, for each site the daily gross ET_o data and daily precipitation measurements from the nearest weather station in the CIMIS network were carefully aligned with historic billing data; the controller installation data were then used as the dividing marker between the pre- and postinstallation periods. Care was taken to ensure that climate data from the same weather station were used for both the pre- and the postinstallation analysis at every site.

Precipitation is an important factor to consider when evaluating the effect of smart control technology. Ideally, a smart controller should reduce or prevent unnecessary irrigation after sufficient rainfall has occurred. A daily model was used to deduct the amount of effective precipitation for each study site from the daily ET obtained from the local CIMIS station. A maximum of 25% of daily precipitation was considered effective (California Ordinance, 1992).

The TIR served as the fundamental measure of the water requirement for

each smart controller site in the study. The TIR was used to make corrections for changes in climate condition during the pre- and postinstallation periods (as described in the next section) and determine how closely the actual irrigation application matched the needs of each landscape in the study. Eq 1 was used to calculate the TIR in inches for each site.

$$\text{TIR (in.)} = (ET_o \times k_c) - \text{Effective precipitation} \quad (1)$$

in which ET_o is the gross annual ET (in.) from the proximal CIMIS station, effective precipitation is the annual effective precipitation (in.), and k_c (also called k_l) is the ET adjustment factor or crop/landscape coefficient of 0.8, a value taken from the Updated Model Water Efficient Landscape Ordinance (California Ordinance, 2004). In this equation, the effective precipitation is accounted for, a typical value of 0.8 is used to adjust from the reference ET to the landscape ET, and the irrigation efficiency is assumed to be 100%. The effect of these assumptions was that the TIRs calculated were designed to estimate the depth of irrigation water required for landscape health and growth at each site without including an extra allowance for irrigation system efficiency at each site (which was a completely unknown quantity). The consequences of these assumptions become significant when considering the number of study sites found to be underirrigating before installation of the smart controller.

Determination of the landscape coefficient (k_c or k_l) is essential to calculating an accurate TIR and assessing whether a site is over- or underirrigating. In this study, a landscape coefficient value of 0.8 was used for all sites, which is considered sufficient for a primarily turf landscape with a mixture of some trees, shrubs, and other plants. Although a reasonable general estimate, this value was almost certainly a source of error at individual sites. The true landscape coefficient for a given site is the product of three factors:

- the crop or species coefficient (k_s), which relates to the amount of water a particular plant material requires as a fraction of the reference crop,
- the density coefficient (k_d), and
- the microclimate coefficient (k_{mc}), which relates to the amount of shade for a given landscape zone.

In determining the TIR, the current study assumed an irrigation efficiency of 100%, an assumption that likely resulted in an underestimate of irrigation requirements. The application ratio (AR) is a measure of how closely irrigation applications at a site matched the TIR determined from proximal ET weather stations. If the research team had used an efficiency of 80% (which in practice would represent an excellent level of efficiency for an automatic irrigation system), the effect would be to increase the calculated TIRs by 25%, which in turn would have reduced all of the ARs and the amount of excess irrigation in the group. This study was designed as an intervention-style, pre- and postintervention analysis in which the actual irrigation application rates during the pre- and post-installation periods were compared against the TIR in each period. Because the TIR was calculated for both the pre- and post-installation periods, key assumptions regarding crop coefficients and irrigation efficiencies were not harmful to the overall analysis of changes in water use. Future studies must decide how best to include irrigation system efficiencies in the evaluation of landscape programs.

RESEARCH FINDINGS SHOWED MIXED RESULTS

Weather-normalized outdoor water use volumes were reduced. The average weather-normalized change in water use per smart controller site is shown in Table 2. Across the 2,294 sites examined in this study, outdoor water use was reduced by an average of 47.3 kgal per site (–6.1% of average outdoor use). 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), a change that was statistically significant at the 95% confidence level.

The outcome of smart controller installation in this study was an overall reduction in irrigation demands, but results suggested that those customers who historically applied less than the TIR for their landscape were most likely to increase their water use after installing a smart controller. In fact, the preinstallation AR (pre-AR), i.e., the level of over- or under-irrigation before the installation of the smart controller, proved to be the most important factor in determining whether a site increased or reduced water use with the smart controller. In this study, 1,300 (56.7%) of the 2,294 study sites showed a statistically significant reduction in the weather-normalized irrigation AR whereas 959 (41.8%) sites had a statistically significant increase in AR. For 35 (1.5%) of sites, no statistically significant change in application was seen. These results are shown in Table 3.

Although the overall findings showed reductions in outdoor water use following the installation of smart controllers, nevertheless 41.8% of study sites experienced an increase in their weather-normalized irrigation AR after the installation of a smart controller. Table 4 shows the differences between sites that increased and those that decreased their weather-normalized irrigation AR.

Sites that increased application after installation of a smart controller had a mean pre-AR of 131% and a median of 95% (Table 4). The median indicates that more than half of these customers were applying less than the TIR before the installation of the smart controller. Because 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 TIR would result in increased demand.

Sites that decreased their AR after installation of a smart controller had a mean pre-AR of 182% and a median of 137% (Table 4). The median here indicates that more than 50% of these sites were irrigating in excess of the theoretical requirement before the 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. Irrigation application rates can be calculated using two pieces of data: the landscape area at the site and annual outdoor water use at the site.

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

Study identified specific factors that affected water savings. Multiple regression analysis was used to determine those factors that did or did not influence changes in AR. This analysis methodology allowed the researchers to examine the relationship between key site characteristics (such as controller technology) and

AR after adjusting for factors known to influence savings (such as the AR before installation of the smart controller).

The following factors were examined and determined to have a statistically significant effect on the change in AR:

- the preinstallation AR (the application rate relative to the calculated TIR),
- the installation method (self versus professional), and
- the participating agency (sometimes a significant factor, likely because of the distinct differences in participant selection methods and program design).

The following factors were examined and determined not to have a statistically significant effect on the change in AR:

- the site classification (residential versus nonresidential),
- the region (northern versus southern California),
- the climate zone (coastal, intermediate, or inland),
- the smart irrigation control methodology (historical ET, onsite readings, remote readings, soil moisture sensor), and
- the landscape area (not a factor in AR change but would be a factor in changes in the volume of water use).

Preinstallation outdoor water use was the most influential factor. The single most significant factor influencing outdoor water savings at a site was the amount of excess irrigation before the smart controller was installed. A site that historically applied twice the TIR had more opportunity to reduce water use through installation of a smart controller than a site that historically applied half of the TIR.

Table 5 compares average water savings results for sites that applied less than 100% of the TIR to sites that applied more than 100% of the TIR before installation of a smart controller. The average preinstallation application rate for the 47% of sites that were underirrigating was only 19.9 in. (55.2% of the TIR). The overall effect of smart controllers on the underirrigators resulted in an average per site water use increase of 1.49 kgal.

The average preinstallation application rate among the 53% of sites that were overirrigating was 85 in. (236.6% of the TIR). Once the weighting of the differing irrigated areas was brought back into the analysis, the overall effect of smart controllers on sites that were overirrigating preinstallation was an average per site water savings of 90.6 kgal. This is nearly twice the water savings for the study group as a whole (shown in Table 2). This finding is important because the program cost is proportional to the number of sites, and benefits are proportional to the water savings. Therefore, if twice the savings can be obtained with only half of the sites, the benefit–cost ratio is improved by a factor of 4.0.

Table 5 shows the effect of excess water use during the preinstallation period on water savings achieved through installation of a smart controller. The smart controllers installed in this study by and large performed as intended. Sites that historically irrigated less than the TIR increased their application to come closer to an application rate of 100%. Sites that historically irrigated more than the TIR decreased their application. The data indicated that even after installation of a smart controller, these historic overirrigators were still applying more water as a group than was probably necessary in the postinstallation period (1,108.3 kgal versus 361.4 kgal for historic underirrigators). Although installation of the smart controller did not decrease water use as much as was expected, savings rates may improve over time as the controllers are fine-tuned to better meet irrigation requirements.

Figure 1 shows the relationship between pre-AR and post-AR. In Figure 1, data for all of the study sites were sorted according to the pre-AR. This formed a smooth line extending from nearly zero to nearly 10 on the graph. The corresponding post-AR was plotted for each site as a blue dot. A polynomial line was then fit to the post-AR so that trends could be observed and compared. Figure 1 shows that despite a tremendous amount of scatter in the post-AR data, there is a definite trend for the sites at either end of the line to be closer to 1.0 than during the preinstallation period. This indicates that the smart controllers achieved some improvement in the AR and for the most part performed as designed. What is perplexing about the results shown in Figure 1 is the amount of scatter in the postinstallation data. Ideally, all of the postinstallation points would lie on a horizontal line where AR = 1.0. Future research should more closely examine the ability of smart controllers to hit target irrigation application rates in field installations over time.

Smart irrigation control provides multiple benefits of. 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 potential additional benefits such as reduced runoff from urban landscape, adaptation of customer demands to calculated water budget allotments, potential for peak demand reduction (through coordinated irrigation "brownouts" similar to energy utility peak shaving), and 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 plus a few others. Many participants in this study reported appreciating the convenience associated with smart control technology. Applying the proper amount of water usually improved the appearance of the landscape and health of plantings. In addition, many smart controllers feature diagnostic tools not available on traditional controllers and can provide better feedback about potential problems with the irrigation system. Furthermore, 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.

RECOMMENDATIONS AND CONCLUSION

Capitalize on specific factors that influence water savings. The current study identified only a few factors that have a statistically significant influence on water savings—specifically, the pre-AR at the site, the installation method (self versus professional), and the participating agency (sometimes a significant factor). The study's most emphatic finding was the significance of preinstallation overirrigation as a factor influencing water savings.

Water savings can be maximized by targeting overirrigators. Smart controllers can save water, but only if they are installed properly at sites that already have some savings potential. Smart controllers are far more likely to achieve savings when they are installed at sites that historically have engaged in excess irrigation applications. Water providers seeking significant volumetric savings must target these customers in particular for smart controller installation. To identify this group, the utility needs three essential pieces of data: the estimated outdoor water use at the site, a reliable measurement of the irrigated landscape area and coefficient at the site, and the specific (or average) ET rate for the locale.

In the current study, 41.8% of study sites increased their irrigation water use after installation of the smart controller. Irrigators who historically apply less than the TIR for their landscapes are poor candidates for smart controllers and should be prescreened from utility distribution programs. The water savings measured at sites that were overirrigating were twice the savings for the study group as a whole.

Proper installation and programming of the smart controller are key to maximizing savings. Every landscape is unique. Experience has shown that the initial or default settings used to program a smart controller likely will need to be fine-tuned over the first few weeks or even months of operation to ensure optimal performance. The smart controller is not a technology that can simply be installed and forgotten; adjustments are often required during the initial setup 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 the 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 ultimately increase water use unnecessarily.

Remarkably, self-installed smart controllers performed better than professionally installed controllers in this study. It is unclear exactly why this was the case, but a reasonable hypothesis is that customers who installed their own controller were more familiar and comfortable with the technology and therefore 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 successful installation of a smart controller.

In northern California, utility personnel conducted inspections 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. Postinstallation inspections are a good idea, but results from the current study indicate that smart controller programs can achieve significant water savings without 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 walked through exercises with the new controller to help familiarize them with the technology and demonstrate the differences from the old controller. Research pointing to higher water savings from self-installed controllers bears out the efficacy of this training concept. The verbatim customer survey responses indicated 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 first targets customers with a history of applying water in excess of the ET and then distributes the smart controllers through a low-cost and easy-to-implement exchange method could be an excellent hybrid program solution.

Cost-effectiveness of smart controllers depends on water savings, avoided costs, and water rates. Installing smart controllers may or may not be cost-effective for a utility or their customers. The extent of cost-effectiveness is determined by 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 that target 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. The data from this study suggest that such an effort could result in fourfold improvement in the benefit–cost ratio.

Smart controllers will be cost-effective for many end users, but not all. Utilities could easily provide simple cost-effectiveness calculations for customers to assist them in determining if a smart controller makes sense for them, based on their historic outdoor water demands. However, some customers may be convinced to install a smart controller by factors other than water use reduction and cost savings such as convenience and a desire to enhance landscape health and appearance.

More data on the long-term performance of smart controllers are required. The limited multiyear analysis presented here—which showed increasing savings over time—indicates the potential for long-term water savings from smart controllers is promising, but these findings are certainly not the final word on this subject. The CDWR contract with the participating water agencies in northern and southern California specifies that postinstallation 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 effects of smart controllers over the coming years and 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 the current study were taken from monthly or bimonthly billing records. Consequently, this study was not able to examine how the controllers distribute irrigation 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 TIR over the course of a month or two, but within a given week, the irrigation run times might not be distributed properly. Although 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 thus warrants further investigation. Some smart controller technologies adjust only 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.

A new ET should be formulated for acceptable landscape appearance and health using the least amount of water. There is a bright future for the use of ET data to help manage urban irrigation. The essential goal of this effort will likely be maximizing water efficiency. Currently, CIMIS ET data must be modified with various crop and landscape coefficients to adapt to urban water requirements. Although there is general agreement on how this is done, in the long run, something different is needed.

The authors recommend the development of a new urban ET factor designed to maximize water efficiency while maintaining landscape health and appearance. Several recent landscape studies, including the one detailed here, have found the current ET formulation with a landscape coefficient k_l 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 in which shading plays a large role (White et al, 2007; Sovocool et al, 2006). The revised urban landscape coefficient should be developed by agronomists, horticulturists, and landscape experts from around the country with the goal of developing an ET value designed for the efficient irrigation of urban landscapes. An ET factor oriented toward water conservation should be based not on maximizing plant growth (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 United States, different soils, different plant materials appropriate to the setting, and different climates, but with the same objective 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 would 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 algorithms and scheduling engines (the internal software programs that develop and adjust irrigation run times) to improve water savings.

Additional work is needed to better quantify the appropriate landscape coefficients on the basis of density, species, and microclimate factors. In addition, a determination should be made on how best to include the irrigation system efficiency factor in TIR determination. State regulatory agencies should take the lead on this task, with support from academic institutions and industry.

Costs are affected by the type of distribution program a utility chooses to implement. Direct installation programs typically are the most expensive to implement because professionals are contracted to perform installations and programming. Exchange programs usually are less expensive and place responsibility for installation and programming with the customer. The current study found that self-installation resulted in greater water savings compared with professional installation.

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

Irrigation system capability affects controller performance. The controller is just one piece of a much larger irrigation system, and controller performance 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 system 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 must be considered. When implementing a smart controller program, utilities and agencies need to recognize the differences between irrigation sites and 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 often are one and the same. At a large site, these responsibilities almost always are assigned to different people who may seldom communicate with each other. Smart controller technologies for small and large sites are also different as are their irrigation systems and management arrangements. Smart controller programs targeted at commercial and institutional customers typically will require distinct marketing materials, resources, training, and other program elements. The cost differences and varying potential water savings must be accounted for as well.

Accurate and sufficient data are key to program evaluation. Effective evaluation of a smart controller program requires accurate data including the make and model of controller, date of installation, installation method, sufficient water use data (pre- and postinstallation), and a correct measurement of the irrigated area, plus landscape coefficients, climate data corresponding to the same period as the water billing data, and other data. Good program design will include methods for collecting these and other data (such as shading) as part of the distribution and installation effort.

A followup study could provide valuable information. The authors recommend that followup research be conducted on a subset of approximately 200 of the sites in the current study. A control site would be selected for each of the sites, which would be visited so that every controller could be reprogrammed to optimize its performance on the basis of whatever control technology it used. Accurate landscape area and landscape coefficient information would be obtained for each site, and the site's water use would be followed for a least three years. The performance of the smart controllers would be evaluated on their ability to achieve an AR of 1.0 based on the best estimate of TIR for each site. Changes in water use—either savings or increases—would be based on a comparison of historic water use versus postintervention water use.

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ABOUT THE AUTHORS

Peter W. Mayer (to whom correspondence should be addressed) is a partner in Aquacraft, Inc., 2709 Pine St., Boulder, CO 80302; e-mail mayer@aquacraft.com. He holds a *bachelor's degree from Oberlin College in Oberlin, Ohio, and a master's degree from the University of Colorado at Boulder. He has 15 years of experience as a water engineer and consultant specializing in water use and efficiency. William B. DeOreo is a partner in Aquacraft.*

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Improving irrigation efficiency may be the single most important goal for water conservation professionals in the coming years.

Even the most water-efficient controller cannot make up for poor irrigation system design, installation, and maintenance.

The study's most emphatic finding was the significance of preinstallation overirrigation as a factor influencing water savings.

The water savings achieved through installation of smart controllers can be maximized by targeting the technology to irrigators with historically high irrigation application rates.

Irrigation experts, landscape professionals, and knowledgeable water conservation staff agree that proper installation, programming, and fine-tuning are critical to successful installation of a smart controller.

TABLE 1 Summary of smart controller installations in study

Category	All Sites—%	Northern Sites—%	Southern Sites—%
Total	2,294 (100.0)	411 (17.9)	1,883 (82.1)
Customer Category			
Single-family residential	1,987 (86.6)	295 (12.9)	1,692 (73.8)
Multifamily, commercial, and other nonresidential	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)	1,193 (52.0)
Professional/utility-installed	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)	1,114 (48.6)
Inland	195 (8.5)	14 (0.6)	181 (7.9)

*Customers in the self-installed category were responsible for installing the controller; they could have hired someone to do it, but this information is not known. The professional/utility-installed category encompasses all controllers installed and/or programmed by an irrigation professional, utility representative, or other party besides the customer.

TABLE 2 Weather-normalized change in outdoor water use

Site Characteristic	Sites *n*	Mean Reduction/ Increase *kgal*	Standard Deviation *kgal*	95% Confidence Boundary *kgal*	Statistically Significant Reduction?	Change *%*
All sites	2,294	–47.3	669.5	27.4	Yes	–6.1
Northern sites	411	–122.2	1,305.2	126.2	No	–6.8
Southern sites	1,883	–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	1,444	–52.2	756.7	39.0	Yes	–5.8
Inland ET zone	195	–26.2	707.4	99.3	No	–4.5
Professional installation	920	–38.3	599.0	38.7	No	–3.6
Self-installation	1,374	–53.2	712.8	37.7	Yes	–9.0
Commercial	296	–228.9	1,783.8	203.2	Yes	–5.6
Irrigation	11	108.3	231.1	136.6	No	10.9
Residential	1,987	–21.1	197.0	8.7	Yes	–7.3

ET—evapotranspiration, *n*—number

TABLE 3 Number of smart controller sites and change in AR

Statistically Significant Change in Water Use	Number of Sites	Percentage
Increase	959	41.8
No change (+ or –0.6%)	35	1.5
Decrease	1,300	56.7

AR—application ratio

TABLE 4 Comparison of sites that increased or decreased irrigation AR with statistical significance after installation of a smart controller

Category	Sites Increasing AR After Controller Installation	Sites Decreasing AR After Controller Installation
Customer category		
Nonresidential sites—%	32.9	67.1
Residential sites—%	43.0	57.0
Landscape area		
Mean—*sq ft*	22,084	28,505
Median—*sq ft*	6,286	5,698
Pre-AR		
Mean—%	131	182
Median—%	95	137

AR—application ratio, pre-AR—preinstallation application ratio

TABLE 5 Comparison of water savings results by pre-AR and excess use analysis

Statistic	Sites With Pre-AR ≤ 100%	Sites With Pre-AR > 100%
Number of sites	1,079	1,215
Percentage of sites	47.0	53.0
Irrigated area—*sq ft*	30,819	26,225
Average preinstallation application rate—*in.*	19.9	85
Average postinstallation application rate—*in.*	24.1	77.6
Average pre-AR—%	55.2	236.6
Average post-AR—%	64.1	201.4
Average change in AR	0.089	–0.353
Average weather-normalized change in outdoor use—*kgal*	1.49	–90.6
Change in weather-normalized outdoor use—%	0.43	–7.8
Average postinstallation outdoor use—*kgal*	361.4	1,108.3
Average postinstallation excess use—*kgal*	–329.8	487.5
Postinstallation use in excess—%	NA	44.0

AR—application ratio, NA—not applicable, post-AR—postinstallation application ratio, pre-AR—preinstallation application ratio

PHOTOS: AQUACRAFT INC.

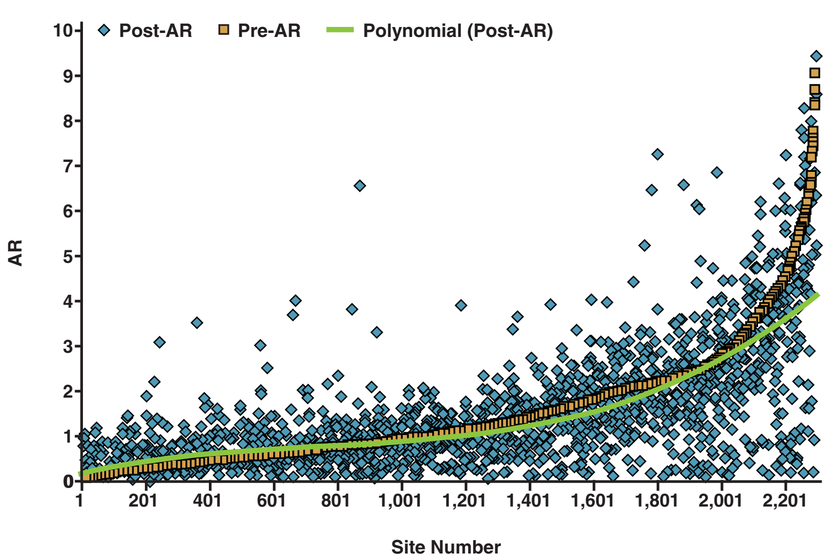
Automated sprinkler systems with smart controllers can help prevent overirrigation and increase water efficiency but only if properly installed, fine-tuned, and maintained.

PHOTOS: ALICE WEBB-COLE OF THE METROPOLITAN WATER DISTRICT

Water utility customers participate in training as part of a smart controller exchange program in southern California.

Customers line up to receive smart irrigation controllers as part of the southern California exchange program.

FIGURE 1 Comparison of pre- and post-ARs for all sites



AR—application ratio, post-AR—postinstallation application ratio, pre-AR-preinstallation application ratio
Site numbers are sorted from lowest to highest by pre-AR.