Estimates of Savings Achievable from Irrigation Controller

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INTRODUCTION

As the atmospheric concentration of anthropogenic greenhouse gases continues to increase and the pace of climate change accelerates, historical patterns of precipitation and water availability are shifting. Freshwater resources are under increasing pressure in many regions, while large volumes of freshwater are used for irrigation in drier areas of the United States. Irrigation in the agricultural and horticultural sectors (including landscape uses such as parks and golf courses) comprised 37 percent of 2005 water withdrawals (Kenny et al. 2009). Although the water used for residential and commercial irrigation is less well quantified, average seasonal outdoor household water use is 58,000 gallons per year (U.S. Environmental Protection Agency [EPA] 2013). Nationwide, almost one third of residential water, or more than 8.5 billion gallons daily, is applied outdoors—representing 60 percent of household water withdrawals in certain climates. The amount of household water used for gardening and lawn care during the growing season can exceed that used for all indoor purposes throughout the year, especially in dry, hot climates. EPA estimates that drinking water utilities will require $334.8 billion to upgrade and replace infrastructure in the next two decades (EPA 2009). Much of this anticipated investment is tied to the volume of water that requires treatment.

Many homeowners water by hand or use conventional irrigation timers, inefficient methods that can waste as much as half the water applied to lawns and gardens. More water-efficient irrigation alternatives are available, among them rain sensors, weather-based irrigation controllers, and soil moisture sensors. (Table 1 describes the various types of sensors.) Improving water efficiency means that water and wastewater utilities will be able to postpone or decrease their investments in new infrastructure while reducing the environmental impacts of runoff, groundwater pollution, and the energy required to pump and treat water and wastewater.

Table 1: Major Types of Irrigation Controllers

Type	Description
Timers	Automatic systems that turn on and off based on a set schedule. These systems, without rain sensors, typically serve as the baseline for experiments.
Rain Sensors (RS)	Devices tied to automatic irrigation systems that prevent watering during or soon after rain.
Weather-Based Irrigation Controllers (WBIC)	Stand-alone controllers or plug-in/add-on devices that schedule irrigation to meet plants' water needs based on current weather data (*e.g.*, solar radiation, humidity, temperature) gathered either via on-site weather sensors or a local weather station. Evapotranspiration principles are used to create or modify irrigation schedules.
Soil Moisture Sensors (SMS)	Devices that gather information about soil moisture content in the active root zone. May bypass scheduled irrigation cycles if soil moisture exceeds a user-defined threshold. Must interface with a controller that accepts a signal from the SMS.

Almost one fifth of single-family detached American homes (13.5 million) have an automatic irrigation system; of those less than one tenth use weather-based controllers (EPA 2011). The potential for reducing water use and its associated costs by increasing the market penetration of advanced irrigation controllers is thus significant. No comprehensive review of studies on the savings achievable by irrigation controllers has been performed to date. While a few reports have collected and summarized various studies, they have not provided meta-analysis on those studies. This paper performs a literature review and meta-analysis of water savings from several types of advanced irrigation controllers: rain sensors (RS), weather-based irrigation controllers (WBIC), and soil moisture sensors (SMS).The purpose of this work is to derive average water savings per controller type, based to the extent possible on all available data. After a preliminary data scrubbing, we utilized a series of analytical filters to develop our best estimate of average savings. We applied filters to remove data that might bias the sample such as data self-reported by manufacturers, data resulting from studies focusing on high-water users, or data presented in a non-comparable format such as based on total household water use instead of outdoor water use. Because the resulting number of studies was too small to be statistically significant when broken down by controller type, this paper represents a survey and synthesis of available data rather than a definitive statement regarding whether the estimated water savings are representative.

Literature Search

To begin collecting controller savings data, researchers at Lawrence Berkeley National Laboratory (LBNL) examined review articles, including reports that Eastern Research Group, Inc. created for EPA in 2007 (regarding WBIC) and 2013 (regarding SMS), as well as documents from the U.S. Bureau of Reclamation (USBR) 2008 and Dukes 2012. Thereafter, LBNL collected primary sources where possible to extract more details that could be useful to the analysis. LBNL collected 39 primary and 8 secondary references that provided information on water savings from irrigation controllers, for a total of 47. Nineteen sources were peer-reviewed journal articles or published conference proceedings, while 28 were reports commissioned by manufacturers, local utilities, counties, or federal agencies such as EPA or USBR. The 47 collected references represent 48 primary citations.

Data Collection and Organization

We compiled data from the collected references into a spreadsheet.[1] Each row of the spreadsheet represents a unique estimation of water savings from a type of irrigation controller. Every primary citation was represented by at least one row. Multiple rows were used if a single citation provided data for multiple types of controllers; multiple baselines, either overall or per site; or multiple sectors (residential/commercial/landscape) for a single controller type. If a single citation included data for other variations of installations (within a single category of WBIC, SMS, or RS), we included all those data on a single line, with a reported or calculated average.

[1] In addition to containing data duplicative of the data from the 39 primary sources that LBNL collected, the 8 secondary sources also contained data from 9 primary sources that LBNL was unable to obtain.

In most cases, where an average was reported, we used that value directly.[2] When an average was not reported, we recorded all the relevant data points with variations based on items such as location, brand, type, season, participant, length of fixed schedule, days per week settings, threshold setting, and type of sprinkler head. We then calculated an average based on those data; in most cases we used a straight average, except when other data, such as number of sites per location, were available to weight the average.

In addition to recording reported water savings values, we collected the following variables when available:

- whether the savings were based on annual or seasonal information,
- whether the data were from a real-world implementation or an experiment,
- whether a baseline or control group provided the comparison,
- whether the baseline was weather adjusted,
- the number of sites tested,
- the year of the study,
- the study location, and
- the sectors covered (residential/commercial/institutional).

Overview of Data Analysis

Because we started with review articles, many data points were duplicated by primary sources (or better secondary sources). These duplicate data points were removed before we performed any analyses. In addition, prior to any analysis, we removed some data points that:

- were updated by other sources [14],
- contained savings only by value and not by percent [3],
- reported only theoretical or potential savings not from actual installations [2], or
- contained only a minimum or maximum savings [1].

After we removed data points that fell into any of the above categories, 84 records remained in the database. We calculated overall average water savings by controller type for all 84 records in the spreadsheet, regardless of exactly what the savings represented. The overall average savings for the meta-analysis was a simple average of the average savings in each row. We then applied our series of filters to the data to screen out data points that might not portray representative or comparable information. We compared calculated water savings after applying each sequential filter.

[2] In a few cases, particularly in reports related to field experiments, the average presented in a report did not seem to represent the true average of all presented data; for example the report might present an average for only a single season rather than across all seasons in the experiment. In such situations, we did not use the reported average, but calculated our own average using the same methodology as we would if no average were presented at all.

ANALYTICAL FILTERS: RESULTS AND DISCUSSION

We applied several filters in sequence to develop more refined estimates of water savings by controller type (WBIC, RS, and SMS). After filtering the data, we also examined the influence of other variables, such as location, sector, and weather-adjustment.

Analytical Filters

Table 2 and Figure 1 show the average savings for the original 84 data points by controller type as well as the savings for a sequence of filters.[3] First we removed five additional data points that were potentially duplicative, resulting in 79 data points.[4] This adjustment made little difference in the results.

Table 2: Estimates of Controller Savings by Sequential Filter

	Original (n=84)		Refined (n=79)		Non-manufacturer reported (n=59)	
Type	Count	Average (%)	Count	Average (%)	Count	Average (%)
WBIC	51	22	46	23	30	17
SMS	23	31	23	31	19	30
RS	7	15	7	15	7	15
Other	3	N/A	3	N/A	3	N/A

	Non-theoretical (n=53)		Non-high water users (n=42)		Non-household use (n=38)		Per-site only (n=37)	
Type	Count	Average (%)	Count	Average (%)	Count	Average (%)	Count	Average (%)
WBIC	29	17	20	15	18	16	17	15
SMS	15	34	13	33	11	38	11	38
RS	6	21	6	21	6	21	6	21
Other	3	N/A	3	N/A.	3	N/A	3	N/A

[3] We did not report average savings for the "other" controller types because there were so few and they were not the same technology.

[4] In one case, it appeared that the data had been updated by another report. We could not verify this occurrence; however we decided to keep only the most recent data. The other four potentially duplicative records were from a report presented data overall; divided into residential, commercial, and irrigation; and as subsets of savings from years 1, 2, and 3. We decided to eliminate the overall data point as well as the three data points from individual years, retaining only the data by sector across all years.

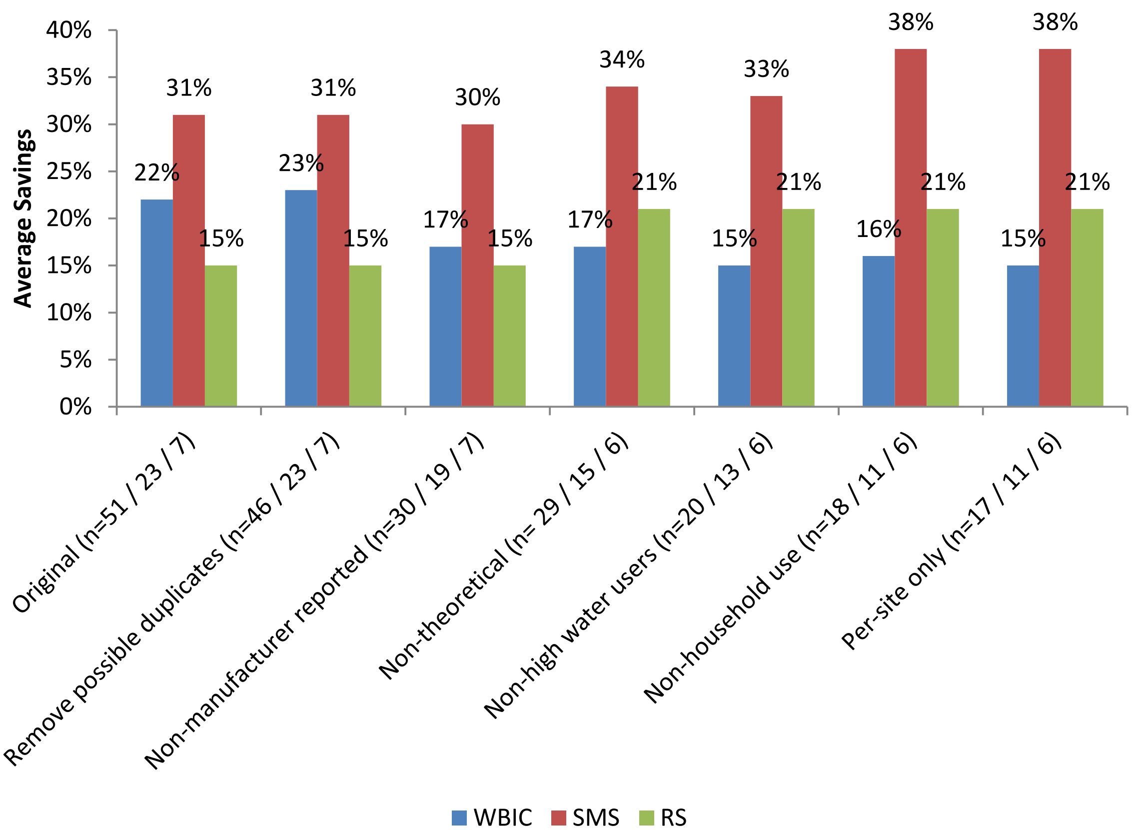

Figure 1: Estimates of Controller Savings by Sequential Filter

Of the 79 remaining data points, 20 were manufacturer-reported data points taken from a USBR (2012) report on controllers. The values typically were reported as a range, from which we had recorded a simple average of the minimum and maximum. We eliminated the manufacturer-reported records because self-reported data can be unreliable and most contained little information on its origin; however, some manufacturer-data were also reported as part of other studies and are therefore included under those citations. After these data were eliminated, mostly in the WBIC category, the estimated savings for WBIC decreased from 23 percent to 17 percent.

We then removed data points in which the water use under a controller scenario was compared to a theoretical value, such as an estimate of irrigation requirements, rather than to a true baseline or control group. This filter removed six items, primarily from SMS. This step resulted in an increased savings estimate for SMS, from 30 percent to 34 percent, perhaps because people often irrigate more than necessary.

Several studies focused on high water users, because entities often implement conservation programs directed at such customers. For this report, we wanted to develop savings estimates that apply across the board, regardless of whether households are high water users. For WBIC only, studies involving some or all high-water users seemed to demonstrate more savings than those without targeted or with unknown samples. This result seems to be intuitive, as high-water users potentially have more opportunity to reduce usage. After removing the studies of high water users from the database, 42 data points remained. This step decreased savings slightly for both WBIC (17 percent to 15 percent) and SMS (34 percent to 33 percent).

Some studies also reported water savings out of total household use rather than compared only to outdoor use. For WBIC only, the studies reporting or likely reporting savings in household use showed lower savings than those reporting unknown or outdoor savings, as would be expected. We removed four studies based on savings being reported in overall household use, resulting in increased average savings for both WBIC (15 percent to 16 percent) and SMS (33 percent to 38 percent).

Finally, some studies report water savings for the entire implementation rather than average savings per house or site. Those overall values are often different from (and larger than) the per-site values. We also removed those values, although only one remained that had not been removed by additional filters.

Other Potential Filters

We also considered filtering out experimental (plot) studies, as we were concerned that they may not capture the influence of human interaction with irrigation controllers. Figure 2 summarizes our estimates of overall savings by controller type, noting differences between experiments and studies of actual installations. However, the differences between the values are small, the sample sizes are not large enough to allow comparison in terms of significance, and the direction of variation is not consistent across irrigation controller types. In addition, for WBIC, the three data points from experiments consist of two with very high savings (32 percent and 43 percent) and one with negative savings (-35 percent); one possible explanation is that decisions made in the set-up and implementation of plot experiments may significantly impact results. For all these reasons, it is difficult to establish whether or not experimental studies reflect savings in real-world implementations; we elected not to filter on this variable.

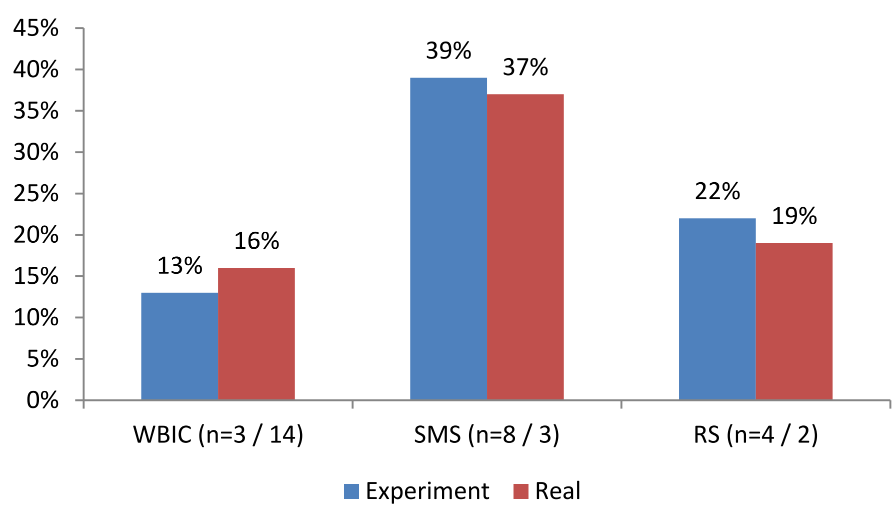

Figure 2: Experimental versus Real-World Savings

We investigated other variables for use as potential filters. For example, we examined the effect of using a weather-adjusted baseline. Such a baseline could bias the results in either direction; if the experiment had rainier weather than the baseline, savings might be higher, whereas in drier conditions requiring more irrigation, savings might be lower. For WBIC only, those we believe did not use a weather-adjusted baseline showed higher savings than those that did (19 percent to 11 percent). The sample sizes, however, are small (five versus nine), and some studies may have weather-adjusted without noting they did so. In addition, two data points that were not weather-adjusted were found to have nearly identical weather or ET data as in the baseline, and those two sites had very high savings (31 percent). For all the above reasons, we did not apply this variable as a filter.

Other variables that potentially could be examined for filters in future work are whether the water savings are based on annual or seasonal usage; how the savings werethe averaged period (cumulative or average daily, weekly, or monthly use); and the period (duration, seasons) of the study.

Overall Savings

Figure 3 shows what we consider to be the most representative savings for each controller type, at the completion of the sequence of filters we implemented.[5] On aggregate, WBIC implementation within the studies examined for this paper resulted in water savings of approximately 15 percent. The other types of controllers show higher savings of 38 percent for SMS and 21 percent for RS. Because of the low sample sizes for each, particularly SMS and RS, it is difficult to determine whether this result would be replicated across a larger range of studies. SMS rely on on-site information, and therefore may be expected to improve savings compared to WBIC. The comparison of RS to WBIC might be more affected by the length and timing of rainfall events. Overall, it appears likely that any of these replacements or additions to a standard timer-based control could save a substantial amount of water on an average basis.

[5] The minimum and maximum shown in Figure 2 and Table 3 represent the minimum and maximum average value of the remaining studies; not minimum and maximum values for individual sites or installations within studies.

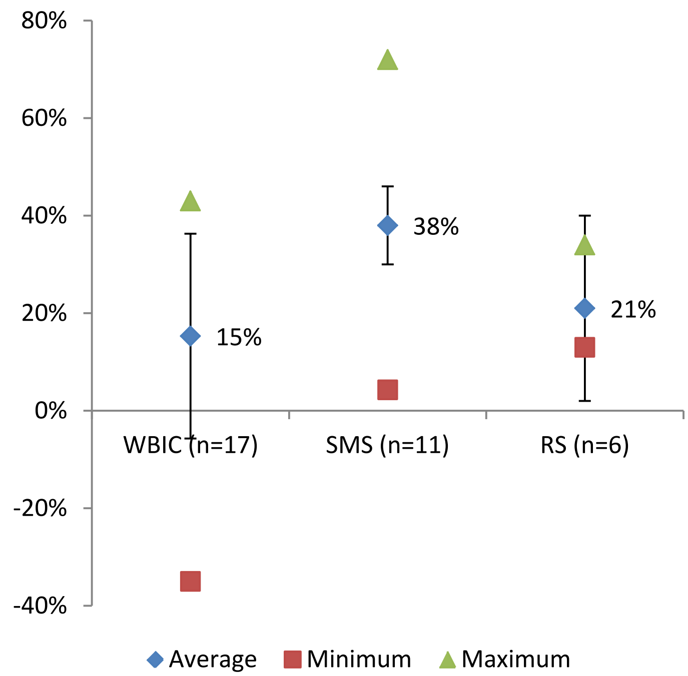

Figure 3: Final Savings by Controller Type

Figure 3 also contains information on minimum, maximum, and standard deviation. Note that for WBIC, the summary minimum average value for water savings is negative, meaning that in some studies, the installation of WBIC on average increases water usage relative to the baseline. This is the case for two of the remaining WBIC data points, one experimental and one real-world. In the experimental case, which was compared to a timer, Grabow et. al (2008) noted that the WBIC was relying on reference evapotranspiration and rainfall information that did not reflect conditions at the site. In the real-world case, which was for purely irrigation installations, Mayer et. al (2009) noted that "those who historically apply less than the theoretical irrigation requirement for their landscape are likely to increase water use after installing a smart controller." Several other studies include individual negative data points, but the averages for those studies remain positive. Although some individual WBIC installations may increase water use, this report indicates that on aggregate, WBIC installations may result in savings of 15 percent.

Results by Installation Type and Location

We also examined WBIC savings separately for residential and for commercial projects (see Figure 4). Commercial projects showed higher savings, but there are few data points in each sector, making it difficult to determine if commercial sites would be likely to obtain higher water savings on a percentage basis than would residential sites.

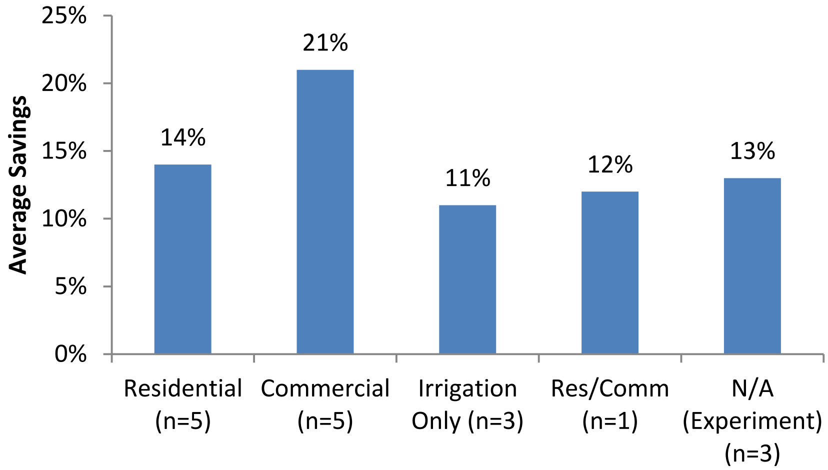

Figure 4: Estimates of WBIC Savings by Sector

We also reviewed savings to determine if they were influenced by location. Ten of the 17 WBIC data points that passed through all the filters are from California, making it difficult to draw any broad conclusions. The average savings of 12 percent for the California studies is less than the overall average of 15 percent. The only other state for which there was more than one filtered data point was Florida, which had two; the two data points, which were derived from experiments, averaged 38 percent.

Collection of additional data that would meet all filters, segmented by sector and by location, would greatly contribute to the review and analysis of impacts from controllers in the future, allowing the determination of savings applicable to specific types of installations.

Final Data Summary

Table 3 summarizes the sources of the individual WBIC savings data that contributed to the average values presented in Figure 3. Table 4 and Table 5 present the data used to estimate water savings for soil moisture (SMS) and rain sensor (RS) controllers, respectively.

Table 3: Final Data Used to Estimate WBIC Savings

Reference	Avg. Water Savings (%)	No. Sites	Real-World or Experiment?	Comparison	State	Sector	Year
Grabow et al. 2008	-35	N/A	Experiment	Control	NC	N/A	2007
Mayer et al. 2009	-11	11	Real-world	Baseline	CA	Irrigation	Unk.
Kennedy/Jenks Consultants 2010	3	209	Real-world	Baseline	CA	Comm	2007
Mayer et al. 2009	6	296	Real-world	Baseline	CA	Comm	Unk.
Mayer et al. 2009	7	1,987	Real-world	Baseline	CA	Res	Unk.
Kennedy/Jenks Consultants 2010	10	899	Real-world	Baseline	CA	Res	2007
Estrada 2003[a]	12	29	Real-world	Unknown	CA	Res/Comm	2003
Quanrud and France 2007[b]	14	<27	Real-world	Baseline	AZ	Res	2006
Devitt et al. 2008	20	16	Real-world	Baseline	NV	Res	2005
Addink and Rodda 2002	21	37	Real-world	Control	CO	Res	2001
MWDOC and IRWD 2004	21	15	Real-world	Baseline(?)	CA	Irrigation	2002
Bamezai 2004	23	<25	Real-world	Baseline	CA	Irrigation	Unk.
Bamezai 2004	27	<25	Real-world	Baseline	CA	Comm	Unk.
MWDOC and A&N Technical Services 2011	28	132	Real-world	Control	CA	Comm	2011
McCready et al. 2009	32	N/A	Experiment	Control	FL	N/A	2007
Griffiths and Olson 2007[b]	41	29	Real-world	Baseline	OR	Comm	2005
Davis et al. 2009	43	N/A	Experiment	Control	FL	N/A	2007

[a] As cited in Pittenger et al. 2004.
[b] As cited in USBR 2008.

Table 4: Final Data Used to Estimate SMS Savings

Reference	Avg. Water Savings (%)	No. Sites	Real World or Experiment?	Comparison	State	Sector	Year
Quanrud and France 2007[a]	4	<27	Real-world	Baseline	AZ	Res	2006
Grabow et al. 2008	11	N/A	Experiment	Control	NC	N/A	2007
Pathan et al. 2003	25	N/A	Experiment	Control	Aus.	N/A	2003
Augustin and Snyder 1984[b]	26	N/A	Experiment	Control	Unk.	N/A	Unk
Cardenas-Lailhacar et al. 2008	33	N/A	Experiment	Control	FL	N/A	2005
McCready et al. 2009	38	N/A	Experiment	Control	FL	N/A	2007
Irrigation of Australia 2004[b]	41	Unk.	Real-world	Control	Aus.	Res	Unk
Cardenas-Lailhacar et al. 2010	48	N/A	Experiment	Control	FL	N/A	2006
Cardenas-Lailhacar et al. 2008	58	N/A	Experiment	Control	FL	N/A	2005
Haley and Dukes 2012	65	<58	Real-world	Control	FL	Res	2008
Cardenas-Lailhacar et al. 2008	72	N/A	Experiment	Control	FL	N/A	2005

[a] As cited in USBR 2008.

[b] As cited in Eastern Research Group, Inc. 2013.

Table 5: Final Data Used to Estimate RS Savings

Reference	Avg. Water Savings (%)	No. Sites	Real Site or Experiment?	Comparison	State	Sector	Year
Cardenas-Lailhacar et al. 2010	13	N/A	Experiment	Control	FL	N/A	2006
Haley and Dukes 2012	14	<58	Real-world	Control	FL	Res	2008
McCready et al. 2009	19	N/A	Experiment	Control	FL	N/A	2007
Davis et al. 2009	22	N/A	Experiment	Control	FL	N/A	2007
Haley and Dukes 2012	24	<58	Real-world	Control	FL	Res	2008
Cardenas-Lailhacar et al. 2008	34	N/A	Experiment	Control	FL	N/A	2005

CONCLUSIONS

One way to boost water efficiency is to promote the use of more technologically advanced controllers so that residential and commercial landscape irrigation moves beyond the currently predominant techniques of manual irrigation or conventional automatic timers. This paper surveyed the literature on water savings associated with the implementation of three types of advanced irrigation controllers: rain sensors (RS), weather-based irrigation controllers (WBIC), and soil moisture sensors (SMS). After examining 47 references, we screened the data to remove points that were duplicative or were secondary sources for which we also had the primary sources. Then we applied a series of filters to refine average water savings by screening out data points having characteristics that, in our view, compromised the integrity of results.

Our meta-analysis demonstrates that advanced irrigation controllers on average can capture substantial water savings—38 percent for soil moisture sensors, 21 percent for rain sensors, and 15 percent for weather-based irrigation controllers. Our conclusions may have limited value from a predictive standpoint given the small sample size, especially when divided into controller type. However, the data support the assertion that although some individual sites may experience an increase in water use, in aggregate, advanced controllers can provide substantial water savings in both residential and commercial applications.

Our findings have implications for water policy. As mentioned previously, manual and timer-based irrigation may lead to over-watering, and the penetration of advanced irrigation devices in the residential and commercial markets is low; meanwhile, water efficiency standards for landscape irrigation are typically voluntary (*e.g.,* EPA's WaterSense program for outdoor watering devices or local utility rebate programs) except in certain extreme drought condtions. Our results suggest wider adoption of advanced irrigation control technologies would result in average water savings that could lessen the strain on aging water treatment infrastructure and on overtaxed freshwater resources.

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*Starred references were not part of the literature review or data analysis, but were used in the introduction and conclusion sections of this paper.