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Managing Water in the West

Final Technical Memorandum No. 86-68210-SCAO-01

Summary of Smart Controller Water Savings Studies

Literature Review of Water Savings Studies for Weather and Soil Moisture Based Landscape Irrigation Control Devices

U.S. Department of the Interior
Bureau of Reclamation

April 2008

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Literature Review of Water Savings Studies for Weather and Soil Moisture Based Landscape Irrigation Control Devices

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Introduction

This document summarizes the findings of a literature review of publicly available reports and articles for water savings studies that evaluated weather and soil moisture based ("smart") landscape irrigation control devices. It serves as a supplemental document to the Bureau of Reclamation (2007) Technical Review Report *Weather and Soil Moisture Based Landscape Irrigation Scheduling Devices.*

The purpose of this document, and the Technical Review Report which it supplements, is to document the overall status of emerging weather and soil moisture based landscape irrigation controller technology with the intent to assist water agencies in their efforts to promote this technology as a means of conserving water and reducing irrigation runoff induced pollution. These reports will be revised periodically in an effort to maintain up-to-date information.

Description of Study Types

Most of the reports and articles reviewed are for weather based controller studies and the rest are for soil moisture based controller studies or for studies that evaluated both types of controllers. Some of the reports and articles reviewed were for field studies and some were for science-based studies.

In field studies, data were collected and analyzed from 'real-world' installations that controlled irrigation at residential and/or commercial sites. In science-based studies, data were collected and analyzed from 'controlled' installations that scheduled actual irrigation of landscape plots in an outdoor laboratory setting or theoretical irrigation of 'virtual' landscapes.

Study Designs and Considerations

The studies associated with the reports and articles reviewed were designed to quantify water savings and/or evaluate irrigation scheduling adequacy that resulted from the use of smart controllers. Some of the studies also addressed other items such as irrigation runoff, controller installation and programming, and participant education and feedback. Study design aspects and related considerations are discussed below.

In most of the field studies reviewed, water savings were calculated based on historical water use. Typically, outdoor water use was calculated from meter data

for periods before and after installation of the controllers. In most cases, the calculated savings were adjusted based on weather conditions during these periods. In addition to weather adjustment, it is significant to consider the type of study participants when historical data are used. In some of the studies, the participants consisted of high water users only and these water savings results are not as representative of an area as those where participants were randomly selected. Similarly, it should be considered that volunteer participants may tend to be more conscientious about water use and studies with high proportions of volunteers may not be representative of an area. Some of the field study reports discuss other factors that may have affected historical water use based savings results.

Other methods used for water savings calculation were based on irrigation quantities applied to control sites, or were based on calculated landscape water demands. Control sites, where irrigation control was by conventional methods, were typically used in the science-based studies. Landscape water demand was calculated in certain reviewed studies by one of two methods: 1) using soil moisture, precipitation and irrigation measurements; or 2) based on net potential evaporation (ET) from weather station data. For both methods, the difference in smart controller irrigation and either landscape water demand or control site irrigation represented savings.

The issue of public acceptance of smart controller technology is of much interest. Several of the field studies reviewed were associated with water purveyor incentive programs and included study components related to public acceptance. Methods of marketing the incentive programs and participant feedback are discussed in several reports. In some cases, cost-benefit analyses were included in the studies to address individual water user and/or water agency cost savings relative to initial investments.

The level of complexity associated with the installation and programming of the various smart controllers on the market varies significantly. In some studies, findings associated with installation/programming issues, including professional versus property owner installation, are presented. On one extreme, some studies included professional installation and follow-up site visits and property owner intervention was minimized. At the other extreme, some studies took a hands-off approach and encouraged property owner installation and adjustments.

A very significant issue regarding the potential for smart controller water savings at a given site is the condition of the irrigation system. Typically, some improvements to an existing system are required to achieve maximum savings when a smart controller is installed. Many of the studies included site inspections, or audits, prior to smart controller installation, and in some cases, system improvements were required as a prerequisite to installation. Post-installation inspections were done in some cases.

Weather Based Controller Study Report Summaries

The following study report and article summaries include brief descriptions of the reported water savings results and study design aspects related to the considerations discussed above. The summaries are presented in chronological order from old to recent.

Residential Weather Based Irrigation Scheduling: Evidence from the Irvine "ET Controller" Study (Hunt et. al., 2001)

This field study evaluated weather based controllers and an irrigation scheduling program conducted at Riverside, California during November 1998 through October 1999. The Irvine Ranch Water District (IRWD), Municipal Water District of Orange County and Metropolitan Water District of Southern California cooperated in conducting this study, with assistance from several private consultants. Study participants included 33 residential customers of IRWD located within the Westpark Village area of IRWD; hence the study is known as the "Westpark Study." High water users were identified and solicited to volunteer for the study.

The study tested a prototype controller/receiver system consisting of a conventional irrigation controller modified to receive a signal broadcasted via satellite. Outdoor water savings were calculated based on 2-years of pre-installation usage and were adjusted for weather conditions. The reported average outdoor savings is 16% and it is also reported this represents 85% of potential savings based on reference ET. Other reported study results include discussions of pre-installation inspections, participant feedback and cost-effectiveness. The report also discusses extrapolation of the water savings to the entire IRWD service area and associated cost savings.

ET Controller Savings Through the Second Post-Retrofit Year (Bamezai, 2001)

This report provides an update to Hunt et. al. (2001) and additional results from the second year of the ET controller study at Irvine, California. The 33-residence average outdoor water savings for the 2-year period are reported to be 18%. The report update also discusses cost savings but does not revisit customer satisfaction.

Residential Landscape Irrigation Study using Aqua ET Controllers (Addink and Rodda, 2002)

This field study was conducted at Denver Water, Denver, Colorado, the City of Sonoma, California, and the Valley of the Moon Water District, California. Water usage data for 74 residences was collected during the 2001 irrigation season. The data were analyzed to determine outdoor water savings resulting from the use of weather based Aqua Conserve controllers provided and installed by the manufacturer. Total savings of 7.64 acre-feet are reported, with average individual residence savings ranging from 7% to 25% for the three study areas. The ranges of individual residence savings are not reported.

Performance Evaluation of WeatherTRAK™ Irrigation in Controllers in Colorado (Aquacraft, 2002)

Report on Performance of ET Based Irrigation Controller (Aquacraft, 2003)

These two reports document the results of a field study conducted at Boulder, Greeley and Longmont, Colorado during 2001 and 2002. The study included evaluations of Hydropoint WeatherTRAK controllers installed at 9 residential sites and one commercial site. Seven of the participants volunteered and 3 were selected based on their high water usage. Post-installation water usage was evaluated relative to historic usage and reference ET. Performance with and without rain sensors and with city imposed watering restrictions was also evaluated. Overall average water savings are reported to be 19% for 2001 and 21% for 2002. The reported average irrigation application percentage of reference ET was 94% for 2001 and 99% for 2002. For 2001, the reported irrigation application percentage of reference ET for controllers with a rain sensor was 84% compared to an average of 104% for controllers without a rain sensor. Individual post–installation water usage increased at 4 sites and it is discussed that these volunteer sites had historically under-irrigated. The reports discuss minor problems with the controllers and resolutions. It is also discussed that overall participant feedback was positive.

Water Efficient Irrigation Study Final Report (The Saving Water Partnership, 2003)

The Saving Water Partnership is a coalition of 24 water purveyors in the Puget Sound Region of the State of Washington. Their study was conducted in 2002 to evaluate water savings and customer satisfaction associated with weather based controllers, rain sensors and an irrigation scheduling service. Study participants were selected based on historical water usage and high peak season users were solicited. The participants included 35 high usage residential sites where Aqua Conserve controllers were installed and 20 of these installations included rain

sensors and the others did not. Water savings were calculated based on historical consumption during 1998 and 2001 and adjustments were made for weather conditions. The reported water savings were 20,735 gallons per year per site for sites with controllers with rain sensors and 10,071 gallons per year per site for sites with controllers only. It is reported most participants were satisfied with the performance of the controllers but many found the devices difficult to operate. The report also includes a discussion of feedback from the consultant that installed and programmed the controllers.

Weather Based Controller Bench Test Report (Metropolitan Water District of Southern California, 2004)

This report presents the findings of a one-year bench test of three weather based controllers. The controllers included in the test were by Aqua Conserve, Hydropoint WeatherTRAK and Accurate WeatherSet. The controllers were tested to evaluate performance under three landscape conditions. Virtual landscapes were used and theoretical irrigation volumes were calculated and evaluated with respect to soil moisture depletion and soil absorption (runoff).

Results varied significantly for the various simulated landscape conditions and from controller-to-controller. Overall, the results indicate relatively good performance by the Aqua Conserve and WeatherTRAK controllers and questionable performance by the Accurate WeatherSet controller. It is reported the results of the test were "very encouraging" but certain deficiencies were discovered with each of the products. Significant problems identified were associated with default precipitation rates for sprinkler types (Hydropoint WeatherTRAK), default crop coefficients (all three controllers), and long run times that would cause excessive runoff (Accurate WeatherSet). The report discusses that all three controllers were modified during and following the test in attempts to correct the problems identified.

The Residential Runoff Reduction Study (Municipal Water District of Orange County and Irvine Ranch Water District, 2004)

This study, known as the R3 Study, evaluated water savings, runoff reductions, runoff water quality and public acceptance associated with ET controller installations combined with education efforts and education efforts only. Hydropoint WeatherTRAK controllers were professionally installed and water usage data were collected from 97 residential sites and 15 commercial sites (irrigation only use at condominiums, HOAs and street corridors) within the Irvine Ranch Water District service area. Residential participants volunteered for the study and there was no effort to target high water users. The controllers were installed and data collection occurred during June 2001 through July 2002. The data were adjusted for weather conditions and compared to pre-installation data from July 1997 through May 2001.

The reported average reduction in residential water usage is 10% of total household water use and the reported commercial water savings is 21%. The report discusses the apparent increase in savings potential for larger landscapes. The reported runoff reduction results include an approximate 50% reduction from limited pre-installation measurements (4-months) and a statistical reduction of approximately 70% relative to control area measurements. Pre- and post-installation concentrations of measured water quality constituents were reportedly unchanged; hence a net reduction in pollutant migration apparently occurred. It is reported that public feedback was generally positive and 72% of the participants liked the controllers. This study benefited from the previous Westpark Study (see Hunt et. al., 2001) and was well designed and implemented, as reflected by the high quality, in-depth report.

Evaluation of Weather-Sensing Landscape Irrigation Controllers (Pittenger et. al., 2004)

This science-based study was conducted at the Center for Landscape and Urban Horticulture, University of California Cooperative Extension in Riverside, California during 2003. It evaluated four weather based controllers using 5 hypothetical landscapes and one actual turf grass landscape. The devices evaluated were weather based controllers by Accurate WeatherSet, Aqua Conserve, Calsense® and Hydropoint WeatherTRAK. The Calsense controller was dropped from the study due to installation problems which Capitanio (personal corr., 2008) reports were due to the researchers' use of improper equipment. Performance was evaluated relative to plant water requirements based on reference ET calculated from measurements at a nearby weather station and hypothetical site conditions.

The reported results show varying accuracy for each controller and for each landscape. Overall, the report shows the Aqua Conserve controller over-irrigated in most cases, the Accurate WeatherSet controller under-irrigated in most cases, and the Hydropoint WeatherTRAK controller over-irrigated in some cases and under-irrigated in others. The report discusses installation and programming, monitoring and follow-up adjustments. The report is critical of the performance and accuracy of all of the devices evaluated and recommends the "manufacturers need to reassess their algorithms." The report also critiques various other reports on smart controller studies and demonstration projects.

Residential Water Savings Associated With Satellite-Based ET Irrigation Controllers (Devitt et. al., undated)

This field study was conducted in the Las Vegas area during an 18-month period that ended in August 2005. The study included 17 residential sites where Hydropoint WeatherTRAK controllers were installed by the study entity and 10

control sites with conventional controllers where participants received irrigation scheduling recommendations. The sites were selected based on landscape and irrigation system conditions, and water usage was not a selection criteria. Water savings were calculated based on historic water use. Landscape, soil moisture and soil salinity conditions were also monitored. The average water savings for all smart controller sites is reported to be approximately 20%, and individual savings ranged from 61.6% to -68.1%. It is discussed that landscape conditions were maintained or improved at all sites and that reference ET values were evaluated in the water savings calculations. Participant survey results and observed relationships between water use and site conditions are also discussed.

Interim Process Evaluation Report on Prop. 13 Smart Controller Programs (Aquacraft and NRC, 2006)

The State of California's Proposition 13 provides funding to the California Department of Water Resources for the development of smart controller incentive programs by water agencies throughout the state. Aquacraft, Inc. and National Research Center, Inc. (NRC) have been contracted to evaluate and document program implementation processes and impacts. The interim report (Aquacraft and NRC, 2006) documents program implementation progress and the final report will document program impact analyses when published in the Fall of 2008. The interim report includes detailed descriptions of the programs that have been implemented by the 24 participating water agencies. The descriptions include the type of program (e.g. rebate, exchange and direct install), the targeted number and type of participants, number of installations to date, products included, installation and participant feedback information, marketing strategies, and implementation costs. The report discusses that more than 2,400 installations had occurred through implementation of programs in Southern California and that the Northern California agencies had conducted market research, planning activities and developed a data base prior to program implementation. The final report's impact analysis will focus on water savings and benefit/cost analyses.

Evaluation and Demonstration of Evapotranspiration-Based Irrigation Controllers (Davis et. al., 2007)

This report presents preliminary results of an ongoing scientific study being conducted at the University of Florida comparing Weathermatic SmartLine®, Toro Intelli-Sense and ETwater controllers relative to theoretical irrigation demand and clock-type controller performance. Rain sensors were connected to all controllers and data were collected during May through November 2006. The study also adhered to local watering restrictions of 2-days per week. The report states: "These initial results show that ET controllers have the potential to reduce water application relative to time-based schedules while maintaining acceptable turf quality." The study results include that all smart controllers irrigated less than the clock-type controller, and that the Weathermatic and Toro products

applied less than the theoretical irrigation requirement and the ETwater product applied more than the theoretical irrigation requirement. All of the controllers did not function for the entire study period for various reasons and apparent problems with certain devices are discussed. Snow (personal comm., 2008) reports that since publication of the preliminary report, ETwater has changed its weather station site and contacted the researchers and identified other potential problems. Dukes (personal comm., 2008) reports the study protocol has been modified accordingly and this will be reflected in the final report upon study completion.

City of Bend WaterWise Program Smart Controller Study (Griffiths and Olson, 2007)

This study was conducted by the City of Bend, Oregon Public Works Water Resources Team. It included installation of weather based controllers at 29 city-owned and study partner-owned commercial sites. The summary document does not indicate the type of controllers used. A water savings analysis was done using post-installation water usage data collected during April to October 2005 compared to pre-installation data from 2004. It is reported that based on a comparison of ET data, weather conditions were similar for these 2 years. Average water savings are reported to be 41%, with a range of savings from 2% to 86% for the individual sites. Associated annual energy savings are reported to be $4,586 and the cost to purchase water rights equivalent to the savings amount is discussed. Various other ancillary benefits are also discussed. The document discusses issues associated with marketing smart controllers to the public and provides various recommendations.

Pilot Implementation of Smart Timers: Water Conservation, Urban Runoff Reduction, and Water Quality (Kennedy/Jenks, 2008)

This field study evaluated water savings and irrigation runoff associated with 1,222 weather based controllers installed at residential and commercial sites throughout Orange County, California. Eight different controller brands were included in the study, but they are not identified. The study evaluated water savings for all participants in controller rebate programs where adequate data were available. Dry weather runoff flow measurements and water samples in two areas of the county were analyzed.

One year of post-installation and historic water use data were collected and adjusted for weather conditions in the water savings analysis. Average water savings are reported to be 18.3 gallons per day for the residential sites and 190 gallons per day for the commercial sites. Higher water savings occurred during summer months and some of the controller brands performed better than others. For both residential and commercial sites, no significant change in water use was found at approximately one-half of the study sites and significant savings occurred at about one-third of the sites. Residential water savings were also

evaluated with regard to whether the controller was installed by the homeowner or a professional, but the results were inconclusive.

Runoff analyses were performed for two areas with relatively high densities of smart controller installations and a control area without smart controller installations. Pre- and post-installation data were collected. The runoff quantity analysis found significant reductions at both areas, however, based on data from the control area and other factors, it appears the installation of the smart controllers is only part of the cause for the reductions. No definite conclusions were drawn from the runoff quality analysis.

Soil Moisture Based Controller Study Report Summaries

The following study report and article summaries include brief descriptions of the reported water savings results and study design aspects related to the considerations discussed earlier in this document. The summaries are presented in chronological order from old to recent.

Moisture Sensor-Controlled Irrigation for Maintaining Bermudagrass Turf (Augustin and Snyder, 1984)

This article discusses a science-based study conducted in southern Florida during December 1979 to June 1983 that evaluated water savings and fertilizer practices associated with soil moisture based irrigation control. Water savings, nitrogen levels and turf quality were evaluated for plots irrigated based on a soil moisture tension[1] threshold of 0.01 mega-pascal relative to plots irrigated daily to replace calculated ET. An Irrometer® Company TGA tensiometer was used in combination with a clock-type Irritrol® controller. Reported monthly water savings range from 42% to 95% and the study total amount of water applied to the soil moisture-controlled plots is reported to be 26% of that of the control plots. The report also discusses effects on nitrogen levels with slow release and water-soluble nitrogen sources and declination of turf quality relative to fertilization and irrigation control.

[1] Soil moisture tension is directly related to soil moisture content and is a measure of the pressure required for a plant to draw soil moisture into its root system. Soil moisture tension (negative pressure) increases as soil moisture content decreases.

Demonstration of Potential for Residential Water Savings using a Soil Moisture Controlled Irrigation Monitor (Allen, 1997)

This study was conducted during 1996 by Utah State University as a water management and conservation activity for the Bureau of Reclamation. The study evaluated water savings from one commercial and 26 residential participants located in the cities of Salt Lake City and Providence, Utah. Soil moisture based systems by Turf Tech, Inc. (no longer in business) were installed and water usage was compared to historic and to 39 control sites. Participant selection criteria and pre-installation inspections/audits are not discussed. The report discusses that post-installation visits did not occur for the majority of the participants and it was attempted to evaluate the systems with no outside professional oversight ("hands-off"). Once the systems were installed and programmed by the study entity, the participants received operations manuals and programming instructions and post-installation visits occurred at 10 sites for various reasons.

It is reported that installation, initial programming and instructing the participants "required on average only 30 minutes." Reported average water savings are 10% relative to the control sites. Each participant's weather-adjusted post-installation water usage was also compared to their 1994-1995 pre-installation usage with an average post-installation savings of 4%. Selected individual participant water savings are presented and conditions that potentially affected water savings are discussed. It is also discussed that overall participant feedback was positive.

Soil Moisture Sensors for Urban Landscape Irrigation: Effectiveness and Reliability (Qualls et. al., 2001)

Soil Moisture Sensors: Are They a Neglected Tool (DeOreo, undated)

Performance of Soil Moisture Sensors During Two Years of Field Operations (undated)

Untitled (undated)

During 1992 to 1997, a series of field studies were conducted by the City of Boulder, Colorado with assistance from Aquacraft, Inc. to evaluate soil moisture sensor based irrigation control systems. The studies included water savings analyses for portions of 107 total Irrometer Company systems installed at 47 sites (23 in 1992 and 24 in 1994). The sites included both residential and commercial landscapes. Study participant selection is not discussed in the cited documents. Some of the systems were installed by landscape professionals and some were installed by study participants. Installation times and programming are discussed. Water savings evaluations were based on historic water usage comparison to control groups and comparison of post-installation water usage to net potential ET

values calculated from local weather measurements. It is reported that 1994 average water usage was 21.7 inches, net potential ET was 29.8 inches, and the reported average 1997 water usage was 73% of net potential ET. Other study findings reported include participant feedback, water cost savings and sensor reliability and longevity.

Soil Moisture Sensor Controller Irrigation for Maintaining Turf (Pathan et. al., 2003)

Evaluation of a Soil Moisture Sensor to Reduce Water and Nutrient Leaching in Turf (Pathan et. al., 2003)

These report and journal article documents present the findings of a science-based study conducted during April 2002 to March 2003 by the School of Plant Biology, Natural and Agricultural Sciences, University of Western Australia. The study was conducted at 2 sites located near the cities of Perth and Stirling, Western Australia. The study included evaluation of water savings and effects on nutrient leaching resulting from the use of WaterSmart soil moisture based irrigation control systems (not available in the U.S.). Irrigation depths and leaching effects from WaterSmart plots were compared to control plots irrigated under best practices, as recommended by the Water Corporation of Western Australia. It is reported the total volume of water applied to the WaterSmart plots was 25% less than that for the control plots and turf quality was maintained. The reported reduction in leaching is 100 liters per square meter.

Sensor-Based Control of Irrigation in Bermuda Grass (Cardenas-Lailhacar et. al., 2005)

This science-based study was conducted at the University of Florida Agricultural and Biological Engineering facility in Gainesville, Florida. The study evaluated water savings associated with the use of soil moisture based controllers and rain sensors. Water usage was monitored on plots of grass with irrigation control by various devices and under different schedules. Soil moisture based systems included in the study were by Acclima®, Irrometer, Rain Bird and Water Watcher. Water savings were calculated with a clock-type controller with rain sensor usage as the baseline. Data were collected during July 20 to December 14, 2004, and the report discusses the relatively high amount of precipitation that occurred during this period. Several base scheduling scenarios were evaluated to address performance under watering restrictions. Reported water savings for 3 of the smart controllers range from 59% to 82%, and the fourth controller only saved water within a 1-day/week irrigation frequency schedule.

Weather and Soil Moisture Based Controller Study Report Summaries

The following study report summaries include brief descriptions of the reported water savings results and study design aspects related to the considerations discussed earlier in this document. The summaries are presented in chronological order from old to recent.

"Smart" Irrigation Controller Study in Tuscon, Arizona (Quanrud and France, 2007)

This field study evaluated water savings resulting from installation of weather and soil moisture based controllers. Data were collected at 27 residential sites in Tucson, Arizona during August 2004 to July 2006. The weather based controllers included in the study were products by Hydropoint WeatherTRAK and WeatherMiser, and the soil moisture system included was the Rainbird MS-100 (no longer available). The devices were installed by a landscape professional with support from manufacturer representatives. The participants consisted of volunteers and high water usage was not a selection criteria. Reported average water savings are 25% for Hydropoint WeatherTRAK, 3.2% for WeatherMiser, and 4.3% for Rainbird. Water savings calculations were based on 2 years of historic water usage and all data were adjusted for weather conditions. Average installation times are reported to be 4, 2 and 0.75 hours for the Rainbird, Hydropoint WeatherTRAK and WeatherMiser systems, respectively. Participant feedback is reported to be positive and the report also includes a cost-benefit analysis discussion.

Evaluation of Evapotranspiration and Soil Moisture Based Irrigation Control On Turfgrass (Shedd et. al., 2007)

This science-based study was conducted during 2006 at the University of Florida, Plant Science Research and Education Unit in Citra, Florida. The study evaluated soil moisture based systems by LawnLogic® (Alpine Automation, Inc.) and Acclima, Inc., weather based systems by Toro (Intelli-Sense) and Rain Bird (ET Manager), and clock-type controllers with and without rain sensors. The soil moisture based systems were tested with low, medium and high soil moisture threshold settings. The systems were tested with actual irrigation systems on plots of turf grass. Reported results include water savings relative to a clock-type control without rain sensor and reference ET-based plant water demand.

Reported soil moisture based water savings range from zero to 63% and reported weather based savings range from 36% to 59%. It is discussed that the highest soil moisture based savings (over 36%) from the low threshold setting systems resulted in unacceptable turf quality degradation. The report states: "The LawnLogic sensors did not bypass irrigation as predictably as the Acclima

sensors." It is also discussed that the Toro Intelli-Sense and Rainbird ET Manager systems applied 70% and 109% of calculated plant water demand, respectively.

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