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Resources for National Water Savings for Outdoor Water Use

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RESOURCES FOR NATIONAL WATER SAVINGS FOR OUTDOOR WATER USE

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RESOURCES FOR NATIONAL WATER SAVINGS FOR OUTDOOR WATER USE

In support of efforts by the U.S. Environmental Agency's (EPA's) WaterSense program to develop a spreadsheet model for calculating the national water and financial savings attributable to WaterSense certification and labeling of weather-based irrigation controllers, Lawrence Berkeley National Laboratory reviewed reports, technical data, and other information related to outdoor water use and irrigation controllers. In this document we categorize and describe the reviewed references, highlighting pertinent data. We relied on these references when developing model parameters and calculating controller savings.

We grouped resources into three major categories: landscapes (section 1); irrigation devices (section 2); and analytical and modeling efforts (section 3). Each category is subdivided further as described in its section. References are listed in order of date of publication, most recent first.

1. LANDSCAPES

This category contains references that pertain to the range of landscapes in the United States and to the range of landscape requirements for water. The category encompasses:

1. evapotranspiration;
2. estimates of landscape water use (national, regional, or per home/business);
3. calculating water use of individual landscapes (e.g., water budgets); and
4. landscaping water use ordinances, programs, or guidelines.

References in each of the four categories are described below.

1.1 Evapotranspiration

This section presents resources related to measuring or calculating evapotranspiration (ET) based on climatic and landscape characteristics or zones.

1.1.1 Estimation of Evapotranspiration across the Conterminous United States Using a Regression with Climate and Land-Cover Data

By W.E. Sanford and D.L. Selnick.
Journal of the American Water Resources Association, Vol. 49, No. 1, 13 pages with maps.
February 2013.
http://onlinelibrary.wiley.com/doi/10.1111/jawr.12010/pdf

This study used a water-balance method and a climate and land-cover regression equation to estimate evapotranspiration (ET) across the conterminous United States. To develop long-term estimates of ET, the authors compiled precipitation (P) and stream flow records from 1971 to 2000 for 838 watersheds. The regression equation relates the ratio ET⁄P to climate and land-cover variables within the watersheds. The authors found that ET can be predicted well at a watershed or county scale based on climate variables alone; land-cover data improve the predictions.

Applying the climate and land-cover data at a scale of 800 m, then averaging to a county scale, the authors created maps showing estimated ET and ET⁄P for the conterminous United States. Maps include mean annual precipitation; mean annual daily and diurnal range in air temperatures; fraction of land classified as agricultural, forest, grassland, or shrubland; estimated percent of precipitation lost to ET during 1971–2000; and estimated mean actual annual evapotranspiration in centimeters for 1971–2000.

1.1.2 Reference Evapotranspiration Zones

By California Department of Water Resources (DWR), California Irrigation Management Information System (CIMIS).
Map prepared by D.W. Jones, 1999, and developed as a cooperative project between the Department of Land, Air and Water Resources, UC Davis, and the Office of Water Use Efficiency, California DWR. 4 pages.
January 2010.
http://wwwcimis.water.ca.gov/cimis/pdf/CimisRefEvapZones.pdf

This publication's map and table shows the reference evapotranspiration zones in California. The zones are numbered according to land type (e.g., zone 1 = coastal plains, heavy fog belt).

1.1.3 Model Water Efficient Landscape Ordinance: Appendix A

California Code of Regulations, Title 23, Waters, Division 2.
DWR, Chapter 2.7, Appendix A. 8 pages.
September 2009.
http://www.water.ca.gov/wateruseefficiency/docs/MWELO09-10-09.pdf

California's statewide ordinance for major landscape installations provides monthly and annual values of ETo for every county and major city in California. ETo is the evapotranspiration rate from a reference surface or reference crop. The reference surface is a hypothetical grass crop having specific characteristics.

1.1.4 Draft Weather-Based Irrigation Controller Technical and Market Research Report

By Eastern Research Group, Inc. (ERG) for the U.S. EPA Municipal Support Division Office of Wastewater Management under Contract No. GS-10F-125P, Work Assignment BPA-05-02/TO 8. 75 pages.
May 2007.

This report summarizes methods for measuring and estimating ET. Because climatic parameters affect ET, no single equation can estimate ET accurately under all conditions. The Penman-Monteith method, which utilizes measurements of solar radiation, wind speed, maximum and minimum temperatures, and relative humidity, predicts reference ET for many types of climates. Unfortunately, specific equipment must be available to gather the required measurements. When detailed climatic data are unavailable, air temperature data, which have proven more readily available than other climatic data, can be used in temperature-based equations for ET.

1.1.5 Standardized Reference Evapotranspiration: A New Procedure for Estimating Reference Evapotranspiration in Arizona

By University of Arizona Cooperative Extension (UACE).
12 pages, including appendix.
November 2005.
http://cals.arizona.edu/pubs/water/az1324.pdf

This publication examines the need to adopt a single standard method for calculating ETo. A Task Committee (TC) of the American Society of Civil Engineers (ASCE) spent years developing recommended procedures for calculating ETo. The UACE report (1) reviews the computational procedure recommended by the ASCE TC; (2) describes the procedure the Arizona Meteorological Network (AZMET) will employ; and (3) compares results of the ASCE's standardized ETo procedure with those of the AZMET procedure. Because crop coefficients (Kcs) are used to convert ETo data into estimates of crop evapotranspiration (ETc), Kcs must be matched to ETo in order to identify ETc. An appendix describes the procedures and equations UACE used to compute the variables in the AZMET version of the ASCE equation.

1.1.6 ASCE Standardized Reference Evapotranspiration Equation

Edited by R.G. Allen, I.A. Walter, R.L. Elliott, T.A. Howell, D. Itenfisu, M.E. Jensen, and R.L. Snyder.
American Society of Civil Engineers Standardization of Reference Evapotranspiration Task Committee .
216 pages.
2005.
For purchase at:
http://www.asce.org/Product.aspx?ID=2147485918&ProductID=5412

The ASCE Task Committee (TC) created standardized equations for calculating reference evapotranspiration (ET) from weather data and developed procedures for controlling and assessing the quality of weather data. The standardized equation for reference ET and the calculation procedures were intended to provide a standard basis for determining or transferring crop coefficients. The equation utilizes the ASCE Penman-Monteith method described in ASCE Manual of Practice 70, Evapotranspiration and Irrigation Water Requirements. Initial recommendations of the ASCE TC were summarized in an 11-page paper presented at the National Irrigation Symposium in Phoenix AZ, in 2000: http://www.kimberly.uidaho.edu/water/asceewri/ASCE_Standardized_Ref_ET_Eqn_Phoenix2000.pdf.

According to the paper, the TC recommended modeling two standardized reference ET surfaces, one for a short crop about 0.12 m tall (similar to grass), and one for a crop about 0.50 m tall (similar to alfalfa).

1.1.7 Basics of Evaporation and Evapotranspiration

By University of Arizona Cooperative Extension.
Turf Irrigation Management Series 1. 4 pages.
December 2000.
http://ag.arizona.edu/pubs/water/az1194.pdf

This report gives an overview of evaporation and evapotranspiration. Reference ET (ETo) provides a baseline for comparing other ET measurements. Reference ET is the ET measurement of a 3- to 6-inch-tall, cool-season grass that completely covers the ground and receives adequate water. Four factors affect ET: soil moisture, plant type, stage of plant development, and weather. Because calculations of ETo involve a standard surface (3- to 6-inch-tall, cool-season grass), three of the four factors that affect ET (crop type, stage of crop development, and soil moisture) do not change. Only the fourth factor—weather—varies in the calculation of ETo. ETo thus can be regarded as a measure of atmospheric (or meteorological) demand for water.

The Penman-Monteith equation, or a variation of it, generally is used to calculate ETo. Because each modified equation differs slightly, each will produce a different ETo value, even given identical weather data. Different weather stations that utilize different equations may produce systematic differences in ETo caused by the equation itself, not local weather conditions. In addition, some irrigation technologies, such as CIMIS, AZMET, Rainbird's ET Manager, and Toro's Intelli-Sense irrigation controller, utilize variations of the Penman-Monteith equation, so that they, too, may produce different ET values given identical weather data.

1.2 Estimates of Landscape Water Use—National and Regional

This section describes resources that examine landscape water use on a broad regional or national basis.

1.2.1 The USGS Water Science School: Irrigation Water Use

By The U.S. Geological Survey (USGS).
Webpage containing 2005 data:
http://ga.water.usgs.gov/edu/wuir.html
Last modified, May 23, 2013.

The USGS reports water withdrawals for the United States. For 2005, total irrigation withdrawals for agriculture were about 128,000 million gallons per day (Mgal/day), or 144,000 thousand acre-feet per year (data from the USGS's Estimated Use of Water in the United States in 2005). Irrigation withdrawals were 37% of total freshwater withdrawals and 62% of total freshwater withdrawals for all categories except thermoelectric power. Surface water accounted for 58% of total irrigation withdrawals.

Withdrawals for irrigation increased by more than 68% from 1950 to 1980 (from 89,000 to 150,000 Mgal/day). Withdrawals declined after 1980, stabilizing at between 134,000 and 137,000 Mgal/day between 1985 and 2000, and falling to 128,000 Mgal/day in 2005.

1.2.2 Status and Trends of Land Change in the Western United States 1973–2000

Edited by B.M. Sleeter, T.S. Wilson, and W. Acevedo.
U.S. Geological Survey Professional Paper 1794–A, 324 pages.
2012.
http://pubs.usgs.gov/pp/1794/a/
Regional summary:
http://pubs.usgs.gov/pp/1794/a/chapters/pp1794a_chapter00_regional_synthesis.pdf.

This report documents changing trends in land use, which affect irrigation use. The report found that as developed land expands, so does the potential for irrigation water use. This study assessed land use and land cover in the Western United States on an ecoregion-by-ecoregion basis. The researchers identified 30 ecoregions for the Western United States, which they divided into six major groups having similar physical and biological characteristics: the Marine West Coast Forests, the Rocky Mountains, the Western Mountain Ranges, the Mediterranean California, the Cold Deserts, and the Warm Deserts.

In the Western United States, 5.8% of the land area changed ecoregion category at least once during the 27-year study period. The largest net change was a decline of 33,197 km^2 of forest land cover. Agriculture and grassland/shrub land experienced net declines of 4,414 km^2 and 1,106 km^2, respectively, whereas developed land increased by an estimated 12,785 km^2. Developed land accounted for 1.0% of the Western United States in 1973 and 1.5% in 2000. The expansion of developed land was common in several ecoregions, especially in the coastal areas.

1.2.3 Analysis of Water Use in New Single Family Homes: Final Report

By Aquacraft, Inc.
Submitted to the Salt Lake City Corporation and the U.S. EPA. 156 pages.
July 2011.
http://www.aquacraft.com/sites/default/files/pub/Analysis-of-Water-Use-in-New-Single-Family-Homes.pdf

This project, performed in conjunction with nine participating utilities, was designed to measure baseline water use in "standard" new homes built after January 2001 and in "high efficiency homes" (based on the WaterSense New Home specifications). The study analyzed indoor and outdoor water use. The authors used data on irrigated area, local weather, and ET to establish theoretical irrigation requirements for 235 new homes; measured actual irrigation application; and determined excess or deficit irrigation for each home. The irrigated area at each site was measured using electronic mapping and/or aerial photos. Important variables included the irrigated area and type of landscape compared to a pure turf landscape, as measured by the landscape ratio. The data found that the average over-irrigation among the standard new homes was 6 thousand gallons (kgal) per home. That value represents the average of homes that under- and over-irrigate. The 62% of the homes that did over-irrigate, however, averaged in excess of 27.7 kgal per household. The data indicated that the new homes tended to use more water for outdoor purposes than suggested by a previous study, even when smaller areas were being irrigated.

1.2.4 California Single-Family Water Use Efficiency Study

By W. B. DeOreo et al., Aquacraft, Inc., Water Engineering and Management, Boulder, CO.
Sponsored by the California DWR; managed by the Irvine Ranch Water District. 391 pages.
June 2011.
http://www.aquacraft.com/node/63

This study analyzed indoor and outdoor water use for about 750 single-family homes in 10 major water districts in California. Valid flow trace data were obtained for 734 homes, of which 639, or 87%, appeared to be irrigating. Each site that appeared to be irrigating was analyzed based on plant types and the landscape area estimated from photo analysis. Each plant type was assigned an irrigation efficiency based on whether it usually would be watered by a spray or a drip system. Each site's theoretical irrigation requirement was calculated based on the area for each plant type, ET data, and efficiency allowances. Each site's outdoor water use was estimated by subtracting the estimated annual indoor water use, obtained primarily from logged data, from the annual water use derived from billing data. The average per-site non-seasonal water use within the study group, as determined from billing data, was 75 kgals per year. The average outdoor use for each site, estimated from data logging, was 93.6 kgals per year.

1.2.5 California Embedded Energy in Water Studies: Study 3—End-Use Water Demand Profiles

Prepared by Aquacraft, Inc., under contract to the California Public Utilities Commission Energy Division, CALMAC Study ID CPU0052, 216 pages.
April 2011.
ftp://ftp.cpuc.ca.gov/gopher-data/energy%20efficiency/Water%20Studies%203/End%20Use%20Water%20Demand%20Profiles%20Study%203%20FINAL.PDF

In order to develop accurate profiles of California end-user water demand, this study obtained data on hourly water use for commercial, industrial, and public buildings and agricultural sites as well as single- and multi-family residences. The authors performed flow trace analysis to examine where, when, and how much cold water was used in six end-use categories plus urban irrigation. The authors developed disaggregated hourly water demand profiles (indoor, continuous, and outdoor) for public buildings, schools, and hospitals. For industrial sites, water use was separated into continuous, process, and irrigation. If any of the 69 public buildings in the study showed evidence of irrigation, the seasonal variation in water use was estimated based on combined historical billing data and logged data. Flow trace data (26 traces) were collected from 12 industrial facilities. Six other flow trace files from previous studies for 5 industrial sites also were used to create hourly water demand profiles.

1.2.6 East Cherry Creek Valley Water and Sanitation District: Irrigation Demand Study

By Aquacraft, Inc., Water Engineering and Management, Boulder, CO.
25 pages.
August 2001.
http://www.aquacraft.com/sites/default/files/pub/Aquacraft-(2001)-East-Cherry-Creek-Valley-Water-District-Irrigation-Demand-Study.pdf

The East Cherry Creek Water District, near Aurora, CO, conducted a study to estimate how much land could be irrigated given the water rights, storage, and pumping capacity of a planned raw water distribution system. Based on a typical annual per-lot irrigation requirement of 2.5 feet, 1,000 acre-feet of water would supply a maximum of about 400 acres of land. The authors used micro-flow metering to measure peak demand in 29 irrigation systems that the raw water system might serve.

The study used the flow data to build a database of one-minute, hourly, and daily demands on the system and to examine the relationships among irrigated area and peak instantaneous, hourly, and daily demands. Without changing system scheduling, 260 acres was the maximum area that could be served under the observed demand patterns. Increasing scheduling efficiency would increase the reliability of the system and the area it could serve. If the largest schools and parks avoided irrigating on successive days and alternated their water use, the observed demands would allow for serving a maximum of 342 acres. The situation could be improved further by a radio-controlled system that could track ET and curtail individual systems as needed during peak periods.

1.2.7 1999 Residential End Uses of Water Study (REUWS)

By Aquacraft, Inc. (which is updating the REUWS in 2011–2013).
352 pages, including appendixes.
http://www.waterrf.org/PublicReportLibrary/RFR90781_1999_241A.pdf
(among many websites)

The REUWS study aimed to obtain data on the end uses of water in residential settings across North America. The authors derived outdoor use from each site's historical billing data by calculating the average daily indoor consumption from REUWS data-logging results, extrapolating that consumption throughout a year, and subtracting that amount from the historical consumption. The authors performed a regression analysis using net ET and the average annual outdoor use obtained using a leveraged approach. The least-squares fit of a straight line to the data yielded a coefficient of determination of 0.59, an improvement over data based on average winter consumption (a common approach). The authors found a strong relationship between climate and average outdoor water use, as well as a strong positive relationship with home square footage (a parameter that might serve as a proxy for standard of living and thus a greater ability to pay for more discretionary water use).

1.2.8 Urban Water Use in California

By California Department of Water Resources (DWR).
Bulletin 166-4.
August 1994.
http://www.water.ca.gov/historicaldocs/irwm/b166-1994/ch3.html

For this bulletin, the DWR analyzed water data for 1980–87 for 68 cities throughout California. Seasonal use was derived by the minimum-month method of analyzing water use records. The "Seasonal Versus Outdoor Use" section notes that in Southern California, 90% of seasonal outdoor water use in the residential sector and 84% in the non-residential sector were attributable to irrigation. The DWR found that baseline water use for both Los Angeles and Fresno were roughly the same, but that Fresno's seasonal use was greater because of the large landscape irrigation requirement during summer in the Central Valley.

1.2.9 Residential Irrigation Uniformity and Efficiency in Florida

By M.C Baum, M.D. Dukes, and G.L. Miller.
American Society of Agricultural and Biological Engineers (ASABE).
Paper number FL03-100, 2003 Special Meeting Papers . St. Joseph, Mich.
2003.
http://elibrary.asabe.org/abstract.asp?aid=15703&t=2&redir=&redirType=
**Abstract Only*

This study aimed to document irrigation water use in the Central Florida Ridge region. Using data collected from weather stations, the authors calculated reference ET to determine required irrigation amounts for each site. The study found that over-irrigation often was a result of trying to maintain "acceptable turf quality," socioeconomic level, or a misunderstanding of irrigation run times based on equipment type and seasonal ET rates. Irrigation accounted for more than 70% of the volume of residential water use for the houses in this study.

1.3 Water Needs of Individual Landscapes

The resources described in this section provide tools and evaluate methods for calculating the needs of individual landscapes in specific locations .

1.3.1 Home Water Works website

2012.
www.home-water-works.org

This website provides a water calculator that estimates residential water use based on user responses to questions. The water calculator utilizes per-capita demand curves developed by Aquacraft from various residential end-use studies. Outdoor use is estimated based on local climate zone, irrigated area, landscape type, and irrigation method.

1.3.2 Revised Draft Water-Efficient Single-Family New Home Specification: Water Budget Tool, Version 1.01

By EPA WaterSense.
August 2010.
http://www.epa.gov/watersense/water_budget/

This tool helps determine whether a landscape design meets Option 1 of the EPA's WaterSense Water Budget Approach to meeting the New Home Specification. The user calculates the landscape water allowance (LWA) for a residential landscape based on peak watering month and the landscape water requirement (LWR). The goal is for the LWR to be no more than the LWA.

1.3.3 Residential Benchmarks for Minimal Landscape Water Use

By C.C. Romero and M.D. Dukes, Engineering Dept., Univ. of Florida (UF). Prepared for UF Water Institute in partial fulfillment of the Conserve Florida Water Clearinghouse Research Agenda, DEP Contract No. WM955–amendment 3. 49 pages.
June 2010.
http://waterinstitute.ufl.edu/news/downloads/Romero_Dukes_Residential%20Benchmarks_CFWC_ResearchSynthesis2010.pdf

Much research has been conducted on the irrigation requirements of turfgrass and agricultural crops, but little on landscape plants. This paper reviews ways to estimate plant water use, usually using an equation for soil-water balance. The results can be used to quantify the theoretical irrigation requirements of turfgrass and landscape plants. Given the theoretical requirements, one can establish benchmarks for water use and assess potential water savings. After reviewing the benchmarking literature, the authors concluded that more research is needed to estimate the water needs of ornamental plants in order to evaluate potential water savings. This summary paper also reviews methods of estimating ET using crop coefficients (Kc) and landscape coefficients (KL). The landscape coefficient, created to determine irrigation scheduling for landscapes, is calculated as the ratio of actual evapotranspiration (ETa from turfgrass plus ornamentals) to ETo. KL includes stress, density, microclimate, and vegetation coefficients (coefficients for species, density, and microclimate). A computer program for calculating landscape coefficient, the Landscape Irrigation Management Program (LIMP), was developed by Snyder and Eching in 2005. LIMP provides a quantitative approach to estimating landscape irrigation needs. LIMP calculates the regional daily mean ETo rates by month using the regional mean climate data from CIMIS (the California Irrigation Management Information System).

1.3.4 Water Budget Workbook, Beta Version 1.01 Calculator

By the California DWR, Statewide Integrated Water Management, Water Use and Efficiency Branch.
May 2010.
http://www.water.ca.gov/wateruseefficiency/landscapeordinance/

This tool can be used to calculate maximum applied water allowance and estimate total water use for a landscape. The tool utilizes local values for reference evapotranspiration, which are contained in Appendix A of the California DWR's Model Water Efficiency Landscape Ordinance (reference 1.1.3).

1.3.5 WaterSense Water Budget Approach, Version 1.0

By the U.S. EPA WaterSense program.
December 2009.
http://www.epa.gov/watersense/docs/home_final_waterbudget508.pdf

This document was developed in support of the WaterSense New Home Specification. To meet the landscape design criterion of the specification, a builder must either:

- use the WaterSense Water Budget Tool to develop the landscape design, or
- provide that turfgrass does not exceed 40% of the landscaped area.

The document defines the data required for the first option and gives the equations used for calculating baseline conditions, landscape water allowance, and landscape water requirements. The resource also provides worksheets.

1.3.6 Quantifying Effective Rain in Landscape Irrigation Water Management

By S.E. Moore, Irrisoft, Inc.
19 pages.
October 2009.

http://www.irrisoft.net/news/Quantifying_Effective_Rain_in_Landscape_Irrigation_Water_Management_IA_%20Technical_%20Conference_2009_%20Steven_Moore.pdf

The author maintains that managing landscape irrigation requires quantifying both ETc and effective rainfall. Effective rainfall is the amount of rain a plant can utilize. The moisture-holding capacity of the soil and current moisture content limit the amount of rain that can be utilized. Smart controllers often incorporate a rain shut-off device, which may, however, resume watering sooner than called for. If a smart controller measured both ET and rain, it would not irrigate during rainfall and would sense when irrigation should resume after a rain. The author used four factors to quantify effective rain:

- amount of measured rain,
- percolation versus runoff,
- root zone storage, and
- moisture balance.

1.3.7 Turfgrass Irrigation Requirements Simulation in Florida

By M.D. Dukes, Agricultural and Biological Engineering Dept., Univ. of Florida.
2007.
**Found through search of the Irrigation Association website.*

Because residents of Florida have access to various methods for scheduling turfgrass/landscape irrigation, they often are confused about which method best balances water conservation with plant needs. For this study, irrigation requirements were simulated for a 30-year period, using a daily soil-water balance to compare net irrigation requirement, drainage below the root zone, and the influence of effective rainfall. The authors simulated an optimized irrigation schedule based on refill of the soil profile when the soil water content reached a stipulated depletion. The schedule, which emulated the effects of soil moisture sensors and ET controllers, reduced irrigation requirements by 60% compared to a recommendation of 0.75 inches when turf wilts. Drainage was reduced accordingly.

1.3.8 Landscape Irrigation Scheduling and Water Management: Draft

By the Water Management Committee of the Irrigation Association.
189 pages, including references and glossary.
March 2005; out for peer review, November 2008.
http://www.asla.org/uploadedFiles/PPN/Water%20Conservation/Documents/LISWM%20Draft.pdf

This document reviews approaches to obtaining efficient, water-conserving landscape irrigation. Included are basic irrigation concepts, methods for scheduling and water management, quality ratings for irrigation systems, landscape water allowance, and drought management through deficit irrigation. Topics include ET, landscape coefficient, net plant water requirement, irrigation water budget, precipitation rate, optimum irrigation interval, irrigation run time, and avoiding runoff. The authors describe scheduling (1) based on historical ET, (2) using a rain shut-off device, and (3) using a soil moisture sensor. They provide equations for calculating landscape water allowance and applying deficit irrigation.

1.3.9 A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California: the Landscape Coefficient Method and WUCOLS III

By the University of California Cooperative Extension and California DWR.
150 pages.
August 2000.
http://www.water.ca.gov/pubs/conservation/a_guide_to_estimating_irrigation_water_needs_of_landscape_plantings_in_california__wucols/wucols00.pdf

This guide offers two formulas for estimating water needs of landscape plants: the landscape evapotranspiration formula, and the landscape coefficient formula. The landscape coefficient was developed by modifying the coefficient for crops and turfgrass in order to estimate water needs of landscape plants. A landscape coefficient (KL) replaces the crop coefficient (Kc).

1.3.10 Appendix E in Urban Water Use in California

By the California Department of Water Resources.
Bulletin 166-4.
August 1994.
http://www.water.ca.gov/historicaldocs/irwm/b166-1994/apendx.html

Among other materials, Appendix E, titled “Precipitation and Urban Landscaping,” contains:

- Table E-2, Estimated Values for Species, Density, and Microclimate Factors Used to Determine the Landscape Coefficient (KL) for Selected Vegetation Types;
- Figure E-1, Annual Precipitation and Per Capita Water Use;
- Figure E-2, Average Maximum July Temperatures and Per Capita Water Use; and
- Figure E-3, Normal Monthly Evaporation and Rainfall for Two Precipitation Zones in the Central Valley.

1.3.11 CIMIS GOES Dish and Receiver Installation

California DWR, Water Use Efficiency: CIMIS.
http://wwwcimis.water.ca.gov/cimis/cimiSatModel.jsp

In December 2012, the California Irrigation Management Information System (CIMIS) installed a satellite dish and receiver to obtain data from the National Oceanic and Atmospheric Administration’s Geostationary Operational and Environmental Satellite (GOES). The Spatial CIMIS model would use the satellite data from more than 140 automated weather stations throughout the state to produce daily maps of reference evapotranspiration (ETo) and solar radiation on a 2 km grid of California. The public can access the maps via the CIMIS website and web services. Spatial CIMIS ETo will be calculated by combining GOES data with interpolated weather parameters from individual CIMIS stations.

1.3.12 City of San Diego Landscape Watering Calculator

By City of San Diego Public Utilities, San Diego, CA.
http://apps.sandiego.gov/landcalc/

This calculator develops a weekly schedule for the maximum amount of water plants may need throughout the year in San Diego, CA. The calculator incorporates average numbers for local weather, plants, and soils. The user answers questions about the soil, watering system, and types of plants in as many as six areas of a yard. Based on the inputs, the calculator prepares a watering schedule.

1.3.13 Irrigation Association Tools and Calculators

By the Irrigation Association.
http://www.irrigation.org/Resources/Tools___Calculators.aspx

Among other information, this webpage offers tools and a tutorial on applying the EPA WaterSense water budget. The webpage also presents resources for calculating evapotranspiration and finding local ET data.

1.3.14 Irrigation Tutorials

By Jess Strykr, landscape architect.
http://www.irrigationtutorials.com/

This website shares information on scheduling landscape irrigation and calculating irrigation needs in Los Angeles County. A spreadsheet creates an irrigation schedule and calculates water usage, as required for landscape and irrigation designs submitted to the Los Angeles County Planning Department. The spreadsheet, intended for design professionals, is accompanied by the county's chart of monthly ETo values for various areas. In addition, Mr. Strykr reviews products (sprinklers, valves, and controllers).

1.3.15 Landscape Water Budget Worksheets

By Aquacraft, Inc.
http://www.aquacraft.com/node/81

Two worksheets utilize monthly water budget as well as actual and cumulative use data to compare landscape water budgets and actual use. The Microsoft Excel worksheet has pages in which the user can input site information and monthly local ETo information. There is also a water budget worksheet and a tracking sheet. Graphs and tables enable the user to compare monthly and cumulative water use to the water budget.

1.3.16 The Pacific Northwest Landscape Network

A product of the Saving Water Partnership (Seattle and participating local water utilities) and the Irrigation Water Management Society (IWMS), also a WaterSense Partner.
http://www.iwms.org/

This website provides an interactive map of weather stations in Washington State's Puget Sound area. The map provides details regarding local temperature, wind, relative humidity, rain, and so on. The website offers two calculators for obtaining Seattle-specific watering schedules. The site also offers "to build calculators for your local area" if requested. One calculator gives three levels of scheduling, from the simplest to a complex version for irrigation professionals. The second calculator estimates how much supplemental water a lawn needs to stay green and healthy, based on the size of the irrigated area and yearly weather averages for the Seattle region. There also is a basic calculator for manually adjusted controllers and an intermediate calculator based on users' water bills.

1.3.17 Run Time Scheduler and Irrigation Water Budgets

By Denver Water.
http://saver.denverwater.org/

This website has links to two tools. One, a run-time scheduler, creates a zone-by-zone schedule based on a user's description of the characteristics of each zone in a landscape. The tool utilizes average historical values for the Denver area to determine an efficient watering schedule for a given landscape. The user can also input specific values to fine-tune the schedule. The second link connects to an irrigation water budget, an abbreviated version of a run-time schedule. The user must know, through estimates or measurements, the square footage of each irrigation zone. The user obtains annual water requirements for the landscape and the approximate gallons of water that will be consumed by following the schedule.

1.3.18 Saving Water Partnership

By Seattle and participating local water utilities.
http://www.savingwater.org/

The website for the Saving Water Partnership has a section on irrigation efficiency and outdoor water use: http://www.savingwater.org/outside_watering.htm. The website presents links to scheduling tools, along with many irrigation tips.

1.3.19 Texas ET Network

By Texas A&M AgriLife Extension, Irrigation Technology Program.
http://texaset.tamu.edu/

The TexasET network provides weather information, current and average ET data, and irrigation recommendations. The user may select a weather station either from a drop-down menu or by clicking on a station shown on a map. The website provides data for the previous day's weather and historical averages in Texas, including ETo, rainfall, temperature, and relative humidity.

1.3.20 Watering Index and Calculator

Developed by the Metropolitan Water District of Southern California.
On the bewaterwise website: http://www.bewaterwise.com/index.html

This webpage has links to two tools for scheduling irrigation in Southern California. One link connects to the watering index, which can be used in developing a watering schedule based on changes in the weather. The watering index compares current ET data with the highest average ET value recorded in the past 10 years. The historical high, which occurs in July, equals 100% on the watering index. If the on-site irrigation controller has a water budget adjustment feature, it can be set to the peak watering months of July and August, then adjusted to make the percentage on the controller match the percentage of the watering index. Changing the controller's water budget setting applies the percentage change to the watering times for all valves controlled by that controller.

The second tool is a watering calculator, which customizes the watering schedule for an automatic timer. If the controller lacks a water budget adjustment feature, the watering calculator can provide an initial schedule that can be adjusted over time. After the user provides a postal ZIP code and answers some questions about the landscape and watering system, the program provides a weekly schedule in minutes of watering time per station. The user can start with the recommended schedule, changing the watering times manually as needed.

1.3.21 WATERIGHT website

Developed by the Center for Irrigation Technology at Cal State Fresno, with support from the U.S. Bureau of Reclamation.
http://www.wateright.org/

The WATERIGHT website offers several resources, including a program that helps users develop site-specific, seasonal irrigation schedules. WATERIGHT is connected to CIMIS and the AgriMet system in Washington, Idaho, and Oregon. Both systems' weather stations provide scheduling routines based on reference ET data for a given locality. The user can consult individual sections to obtain scheduling for homes, commercial turf, or agriculture. WATERIGHT also offers advisories and tutorials, historical data from CIMIS and AgriMet weather stations, and references for identifying regions and species factors in the "Water Use Classification of Landscape Species " (WUCOLS; see reference 1.3.9).

1.4 Landscaping Water Use Ordinances, Programs, and Guidelines

This section discusses some of the ordinances and programs, including the EPA WaterSense program, developed to encourage appropriate water use for landscape irrigation.

1.4.1 WaterSense Final Specification for Single-Family New Homes, Version 1.1

By EPA WaterSense.
Effective January 1, 2013.
http://www.epa.gov/watersense/docs/home_finalspec508.pdf

This specification establishes the criteria for water-efficient new homes. The specification applies to newly constructed homes that are single-family homes and townhomes; residential units in multi-family buildings three stories or fewer in size; or residential units in multi-family buildings, including mixed-use buildings, in which heating, cooling, and hot water systems are separate from those of other units. WaterSense makes the following stipulations regarding acceptable irrigation systems.

- Irrigation systems must be designed or installed by a WaterSense irrigation partner. After installation, all irrigation systems must be audited by a WaterSense irrigation partner.
- Irrigation systems must achieve a lower quarter distribution uniformity (DULQ) of 65% or greater. Distribution uniformity is to be measured on the largest spray-irrigated area during the post-installation audit.
- Irrigation systems must include technology (e.g., rain sensors, soil moisture sensors) that inhibits or interrupts system operation during periods of rainfall or sufficient moisture.
- As of June 1, 2013, irrigation systems shall be equipped with WaterSense-labeled weather-based or soil moisture sensor-based irrigation controllers that provide eight capabilities in both smart and standard modes (e.g., "The controller shall be capable of interfacing with a rainfall device," and "The controller shall include a percent adjust [water budget] feature").
- Sprinkler irrigation, other than as a component of a micro-irrigation system, is not to be used to water plantings other than turfgrass.
- Two watering schedules, developed by the WaterSense irrigation partner, will be posted at the controller. One schedule will be designed to provide for the initial growing phase of the landscape, the second to provide for the established landscape. Both schedules shall change based on the seasons.

1.4.2 WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities: Chapter 5, Outdoor Water Use

Developed by EPA WaterSense.
EPA 832-F-12-034. 308 pages, including 2 appendixes.
October 2012.
http://epa.gov/watersense/docs/ws-at-work_bmpcommercialandinstitutional_508.pdf

This document outlines the use of irrigation controllers and sensors in commercial and institutional facilities. Suggestions for obtaining water savings through irrigation system retrofits include the following.

- Replace basic controllers with WaterSense-labeled weather-based irrigation controllers.
- Connect soil moisture sensors to an existing system, enabling irrigation as plants need it.
- Consider installing rain-sensing technology that can prevent irrigation during periods of sufficient moisture.
- Consider installing wind-sensing technology that interrupts irrigation cycles if significant wind is detected.
- Consider installing freeze-sensing technology to prevent irrigation during freeze conditions.
- Consider installing flow rate-monitoring equipment, which interrupts irrigation if excess flow is detected (e.g., from broken pipes, fittings, emitters, or sprinklers).
- For a central system, consider demand-based controls, which can use various means of communication to remotely operate multiple irrigation systems at multiple locations.

1.4.3 Status of Adoption of Water Efficient Landscape Ordinances Pursuant to California AB 1881, Section 65597

By the California Natural Resources Agency, Department of Water Resources.
9 pages.
December 2010.
http://www.water.ca.gov/wateruseefficiency/docs/LandscapOrdinanceReport_to_Leg-4-22-2011.pdf

This DWR report gives the status of water efficient landscape ordinances adopted by local agencies pursuant to the requirements of the statewide Water Conservation in Landscaping Act (2006). After adopting the Updated Model Water Efficient Landscape Ordinance, DWR mailed a notice of compliance to 586 local agencies, receiving 338 responses. The status update notes that whereas past surveys showed that local agencies lacked awareness of the ordinance and often had less stringent requirements in place, local agencies more recently appeared to be more knowledgeable and to be taking greater responsibility for monitoring water use and water waste. The report has links to "Ordinance by City" and "Ordinance by County." The page notes: “Consult your Legal Counsel to determine if your local ordinance is at least as effective in conserving water as the updated model adopted by the DWR.”

1.4.4 LEED for Homes Rating System

By the U.S. Green Building Council (USGBC)
114 pages.
January 2008, with errata and clarifications from January 2009 and new text from January 2010.

http://www.usgbc.org/Docs/Archive/General/Docs3638.pdf

This USGBC document updates previous performance rulings related to the Leadership in Energy & Environmental Design (LEED) for Homes Rating System. The report describes measures for designing and installing a high-efficiency irrigation system (based on overall landscaping plans, including measures adopted at so-termed Sustainable Sites). The following are among irrigation efficiency measures that earn points toward earning LEED certification for a home.

- Install an irrigation system designed by an EPA WaterSense-certified professional.
- Install a timer or controller that activates the valves for each watering zone at the best time of day to minimize evaporative losses while maintaining healthy plants and obeying local regulations and water use guidance.
- Install a moisture sensor controller or rain delay controller. For example, "smart" ET controllers receive radio, pager, or Internet signals to direct the irrigation system to replace only the moisture that the landscape has lost through heat, wind, etc.

1.4.5 Research Report on Turfgrass Allowance

By EPA WaterSense.
12 pages.
December 2009.
http://www.epa.gov/WaterSense/docs/home_turfgrass-report508.pdf

This report presents the rationale behind the WaterSense Single-Family New Homes Specification for landscapes. The report presents data demonstrating that residential landscapes consisting primarily of turfgrass use significantly more water than landscapes that comprise a mixture of other plants. The report highlights studies (some summarized in this bibliography) that demonstrate the high water requirements of turfgrass and the savings associated with limiting the amount of turfgrass cover.

1.4.6 Model Water Efficient Landscape Ordinance

California Code of Regulations, Title 23, Waters, Division 2.
Department of Water Resources, Chapter 2.7, 33 pages.
September 2009; updated October 2009.
http://www.water.ca.gov/wateruseefficiency/docs/MWELO09-10-09.pdf

This California statewide ordinance for new landscape installations became effective on January 1, 2010, after which date the ordinance applied generally to public, private, and developer-installed projects having a landscape area equal to or greater than 2,500 square feet. The ordinance also applies to new-construction landscapes that are homeowner-provided and/or homeowner-hired in single- and multi-family projects having a total project landscape area equal to or greater than 5,000 square feet.

Compliance requires applicants to submit a project documentation package that includes:

- water efficient landscape worksheet;
- hydrozone information table;
- water budget calculations;
- maximum applied water allowance (equation provided);
- estimated total water use;
- soil management report;
- landscape design plan;
- irrigation design plan; and
- grading design plan.

Penalties apply for non-compliance with the ordinance. Appendix A of the ordinance provides a reference ET table by county and major city. The ordinance relies on WUCLOS III (reference 2.3.9) for plant factors.

1.4.7 The California Water Smart Irrigation Controller Project—Results and Perspective on a Large Field Study of an Important Emerging Technology

By P. Mayer et al. of Aquacraft. Presented by A. Webb-Cole, Metropolitan Water District of Southern California; J. Bauer, East Bay Municipal Utility District; R. Eagle, Contra Costa Water District; K. Galvin, Santa Clara Valley Water District; and P. Mayer, Aquacraft.
Slides presented at a WaterSmart Innovations Conference, Las Vegas NV, October 7–9, 2009. 84 slides.
http://www.watersmartinnovations.com/PDFs/Wednesday/Sonoma%20C/1500-%20Peter%20Mayer-%20The%20California%20Water%20Smart%20Irrigation%20Controller%20Project.pdf

This slide presentation summarized various water agency programs aimed at introducing and expanding the adoption of smart irrigation controllers (those that use data from on-site sensors or respond to a broadcast signal). Speakers from water agencies throughout California described their respective program approaches and shared challenges and successes. Consumer adoption and water savings results also were summarized.

1.4.8 Index of Model Water-Efficient Landscape Ordinance Documents

By the California Department of Water Resources.
2009.
http://www.water.ca.gov/serp.cfm?q=Model+Water-efficient+landscape+ordinance&cx=001779225245372747843%3Amxwnbyjgliw&cof=FORID%3A10&ie=UTF8&siteurl=http%3A%2F%2Fwww.water.ca.gov%2F

This webpage lists documents related to California's Landscape Water Ordinance. Items in the list are hyperlinks to background documents and iterations of the ordinance. All are on the site water.ca.gov.

1.4.9 Landscape Sizing in Santa Ana Heights—A Model to Efficiently Size Landscape Area for any Community

By G. Simjian and F. Sanchez.
September 2003.
http://www.allianceforwaterefficiency.org/mainsearch.aspx?searchtext=Santa%20Ana
**Irvine Ranch Water District's report is listed as a resource on the Alliance for Water Efficiency page*

The Irvine Ranch Water District (IRWD) found that applying a tiered-rate billing system, based on a water budget allocation, helped reduce consumer water use. The rate structure was aimed at providing customers with the water they need at the lowest rates in Orange County ($0.75 per hundred cubic feet [CCF] in 2003) while penalizing inefficient use with higher rates, ranging from $1.50 to $6.00 per CCF. After the IRWD billing system was introduced in 1991, water use dropped from an average of 4.4 to 2.2 acre-feet (AF) per acre while turf quality either improved or remained the same. Residential use declined from 0.32 AF per year per customer in 1989–90 to 0.28 AF per year per customer in 2002–03, a 12.5% decrease. IRWD sought to establish a ratio between landscape area and total lot size, then used that ratio to assign water allocations. Given the ratio, the district needed only total lot size to calculate landscape percentages. To allow for variations in residential developments, IRWD based the allocation on lot sizes where the landscape area fell within 1 standard deviation of the average (mean, not median) landscape area.

1.4.10 Water Right—Conserving our Water– Preserving our Environment

By Turf Producers Foundation, part of Turfgrass Producers International (TPI), an industry association.
64 pages.
2001.
http://www.turfgrasssod.org/pages/resources/water-right-publication

TPI terms this book "an educational tool for green industry professionals to use in presenting the realities of our planet's available water supply to water-policy decision makers, businesses, educators, and consumers." Ten case studies cover topics such as golf courses, xeriscapes, water budgets, and irrigation controllers.

1.4.11 BMP Category: Programmatic-Landscape

By J.B Whitcomb, G.F. Kah, and W.C. Willig.

California Urban Water Conservation Council (CUWCC).
As Amended December 10, 2008.
http://www.cuwcc.org/Resources/MemorandumofUnderstanding/Exhibit1BMPDefinitions,Schedules,andRequirements/BMP5Landscape.aspx

This Best Management Practice (BMP) helps California water agencies understand and administer landscape conservation programs in accordance with the BMPs identified in the Memorandum of Understanding (MOU) Regarding Urban Water Conservation in California, as governed by the CUWCC. For agencies that have signed the MOU, this BMP provides guidance on helping irrigators "achieve a higher level of water use efficiency consistent with the actual irrigation needs of the plant materials." The guidance governs implementing, and documenting the implementation of, water efficiency improvements for outdoor irrigation at non-residential sites. A link to Resources provides water agencies with planning tools and models for implementing and documenting the implementation of efficiency programs, as well as a Landscape BMP Implementation Guidebook, which describes the calculations used to develop a water budget, types of monitoring and tracking devices, water use surveys, audits, and financial incentives.

1.4.12 The Pacific Northwest Landscape Network

A product of the Saving Water Partnership (Seattle and participating local water utilities) and the Irrigation Water Management Society (IWMS), also a WaterSense Partner.
http://www.iwms.org/

This website offers homeowners resources for improving their outdoor water use efficiency. Among other things, the site includes homeowner FAQs, tips for getting the most water savings from irrigation controllers, and water management calculators. The Saving Water Partnership also offers controller cards that can simplify use of four water-saving features of an irrigation controller. The user identifies the brand and model of the controller and downloads the matching PDF card (which includes pictures), takes the card to the controller, and follows instructions to adjust the controller for maximum efficiency. Other aspects of the website are described in reference 1.3.16).

2 IRRIGATION DEVICES

This category contains data resources that pertain to the devices (primarily controllers) used to control landscape irrigation, whether commercial/institutional or residential. The topics included in this category are:

1. controllers (general plus WaterSense specifications);
2. satellite technology;
3. controller savings;

4. evaluation and testing protocols;
5. shipments;
6. marketing and market penetration of WaterSense controllers; and
7. lifetime, payback period, and cost-effectiveness.

References that fall within each of the seven categories are described further below.

2.1 Controllers

The following resources describe the types and functions of various smart irrigation controllers, as well as the WaterSense specifications for smart controllers.

2.1.1 WaterSense-Labeled Irrigation Controllers

By EPA WaterSense.
http://www.epa.gov/WaterSense/products/controltech.html

This webpage discusses the practice of "smart watering" and describes weather-based irrigation controllers (WBICs) that have earned the WaterSense label. The page has links to a WBIC fact sheet, a list of WaterSense-labeled controllers, a specifications sheet, and a mini-report on WBICs. The link to the mini-report is:
http://www.epa.gov/WaterSense/docs/irrigation_controller_rpt_minireport_508.pdf
(July 2012).

The mini-report states that WaterSense-labeled controllers are certified to meet plants' water needs without overwatering. The irrigation adequacy of labeled controllers exceeds 80% in each irrigation zone, and the irrigation excess is less than 5% averaged across all zones. WBICs automatically alter the irrigation schedule daily or weekly based on site-specific variables, such as soil type, sprinkler application rate, and local weather changes. The mini-report describes three basic types of WBICs: stand-alone controllers, add-on devices, and plug-in devices. All three types are available in sizes suitable for sites ranging from small residential to large commercial. WBICs generally employ one of two technologies:

- on-site, sensor-based control, or
- signal-based control.

On-site, sensor-based controllers use real-time measurements of local variables (e.g., temperature, humidity, solar radiation) to adjust the irrigation schedule. Signal-based controllers receive a regular data signal of prevailing weather conditions via radio, telephone, cable, cellular, web, or pager technology. A device such as a rainfall interrupt or a tipping-bucket rain gauge senses or measures rainfall and reduces or interrupts irrigation in response. Many states have mandated the use of rainfall devices. The webpage has a link to 125 WaterSense-labeled products: *http://www.epa.gov/watersense/product_search.html?Category=5*.

2.1.2 Soil Moisture Sensor Technical and Market Research Report

By Eastern Research Group, Inc. (ERG), for the U.S. EPA Municipal Support Division Office of Wastewater Management under EPA Contract No.EP-C-09-008, Work Assignment 3-05. 55 pages.
April 2013.

This report projects the water and cost savings potential of soil moisture sensors (SMSs). Appendixes summarize results from field studies of SMSs performed on residential and commercial landscapes and turf plots and describe how ERG calculated potential SMS water savings and cost-effectiveness. Several field tests demonstrated a reduction in water applications using SMS compared to irrigation systems based on a clock timer or operated manually. The field tests also demonstrated that sensor-controlled irrigation closely matches theoretical ET requirements for most landscapes.

2.1.3 Efficient Irrigation: Services & Products

By the Saving Water Partnership.
Updated February 2013.
4 pages.
http://www.savingwater.org/groups/public/@spu/@swp/documents/webcontent/04_009109.pdf

Among other things, this document gives specifications for water-saving rain sensors; ET controllers (they refer the reader to the Irrigation Association's Smart Water Application Technologies [SWAT] site); soil moisture sensors; pressure-regulating master valves; pressure-regulating zone valves; high-uniformity, low-precipitation rate, multi-stream spray head rotor nozzles; pressure-regulating spray heads; and spray and rotor heads having check valves.

2.1.4 Weather- and Soil Moisture-Based Landscape Irrigation Scheduling Devices: Technical Review Report—4th Edition

Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Southern California Area Office, Temecula, CA; and Technical Service Center Water Resources Planning and Operations Support Group, Denver, CO.
141 pages.
July 2012.
http://www.usbr.gov/waterconservation/docs/SmartController.pdf

This report presents descriptions of irrigation controllers (weather-based and soil- moisture-based) by brand and model. The report compares products based on criteria that include operation, installation, price, and warranty. A detailed two-page table summarizes features of all the covered WBIC products. Regarding the water savings attributed to various devices, the report notes that most of the water savings cited are as reported by the device manufacturer.

2.1.5 WaterSense Specification for Weather-Based Irrigation Controllers, Version 1.0

By EPA WaterSense.
12 pages.
November 2011.
http://www.epa.gov/watersense/docs/final_controller_specification_102611_final508.pdf

This specification promulgates the criteria for weather-based irrigation controllers that can be labeled under the WaterSense program. The specification, effective November 3, 2011, applies to controllers used in residential or commercial landscape irrigation. The criteria provide that the controller, when programmed and operated according to the manufacturer's instructions, will provide adequate and efficient irrigation while minimizing runoff. The specification applies to stand-alone, add-on, and plug-in devices that use current weather (ET) data to create or modify irrigation schedules. Among other requirements are the following.

- Irrigation adequacy for each zone must be greater than or equal to 80%.
- Irrigation excess for each zone must be less than or equal to 10%. The average of the irrigation excess for all six zones must be less than or equal to 5%.

Controllers must be tested in accordance with the eighth draft of the Irrigation Association's SWAT test protocol for climatologically based controllers. In addition to the SWAT requirements, WaterSense outlines supplemental capability requirements as well as requirements for packaging and product documentation.

2.1.6 Supplemental Guidance for WaterSense Certification and Labeling of Weather-Based Irrigation Controllers

By EPA WaterSense.
11 pages.
November 2011.
http://epa.gov/watersense/docs/guidance-for-certification-and-labeling_102611_final508.pdf

This supplement to the Watersense Specification for Weather-Based Irrigation Controllers provides manufacturers with clarification and specific directions for having controllers certified and labeled. The supplement includes the SWAT performance test protocol and general requirements for the capabilities of calibration and of testing laboratories.

2.1.7 Draft Weather-Based Irrigation Controller Technical and Market Research Report

By Eastern Research Group, Inc. (ERG), for the U.S. EPA Municipal Support Division Office of Wastewater Management under Contract No. GS-10F-125P, Work Assignment BPA-05-02/TO 8. 75 pages.
May 2007.

This report categorizes WBICs. All WBICs use some type of weather data to either modify a programmed irrigation schedule or direct irrigation to match the landscape's current needs. WBICs fall into four categories depending on the source of the weather data: historical ET data and patterns that are preprogrammed into the device; one or more sensor measurements that update the historical ET curve; ET data obtained from a signal that sends local, real-time weather data to the controller; and on-site weather-sensing technologies that tailor irrigation to the landscape's current needs. Devices in all four categories are available to either replace a controller or be added on to it.

When discussing WBIC performance, the authors note, "Field tests on weather-based irrigation systems in residential landscapes have demonstrated between a 7% and 30% reduction in water use. However, water savings are dependent on the geographic location of the landscape, the type of WBIC used, and the irrigation behavior of the user prior to installation…The systems require ongoing user interaction, which may reduce operational efficiency."

2.2 Satellite Technology

The resources that follow examine the performance and practicality of irrigation controllers that utilize satellite or wireless technology to obtain climatic data and adjust landscape watering schedules.

2.2.1 ET Data Protocol

By Irvine Ranch Water District (IRWD) under Grant 030-2007 from the Innovative Conservation Program of the Metropolitan Water District of Southern California. 17 pages.
December 2009.
http://www.bewaterwise.com/icp/IRWD.pdf

Controller manufacturers currently rely on various sources for the ET data that direct controller operation. The IRWD worked with the California DWR and state water agencies to develop an accessible, standard protocol to be used statewide for transmitting reference ET to irrigation sites. The project was integrated with GOES (now spatial CIMIS), which provides triangulated ET data for the state on a 2 km x 2 km grid. The ET data protocol provides consistency, quality control, reliability, and standardization. The authors stated the ET data protocol "will help foster the market transformation and adoption of the weather-based irrigation technology, potentially on a national scale." They discussed how availability of quality-controlled ET data gradually will facilitate residential WBIC market penetration because of the potential elimination or minimization of monthly service fees.

IRWD recommended that the use of the protocol be promoted within member agencies. Member agencies could use the data to develop water budgets for customers and provide a website link to the spatial CIMIS website, which customers could then use to develop watering schedules. IRWD also encouraged WBIC manufacturers to design products that are compatible with the ET data protocol, as doing so would reduce the cost of controllers and encourage consumer adoption. The authors also noted that expanding the protocol nationwide would benefit all states, particularly those looking to reduce their need for imported water supplies.

2.2.2 Automating Landscape Sprinkler Control Using Weather Data Broadcast to Unlimited Properties

By S.E. Moore, Irrisoft, Inc.
2007.
**Abstract only, obtained through search of Irrigation Association website.*

The author summarized the benefits of wireless technology for operating WBICs. Measured weather conditions currently are used to automate water management for large landscapes, with ET calculated from weather sensor input. The author noted that precision sensors must be sited appropriately and well maintained; however, their cost and complexity inhibit widespread adoption. Wireless technology would enable a single weather station to provide data to an unlimited number of landscape sites. A controller interface would calculate ET from weather data to manage irrigation at the separate sites. The author stated that this technology provides significant water savings and has proven affordable and reliable.

2.2.3 Water Conservation Using Satellite Technology for Irrigation Scheduling

By W.J. Carlos, W.W. Miller, D.A. Devitt, and G.J. Fernandez.
Presented at Globalization and Water Management: the Changing Value of Water, the AWRA/IWLRI-University of Dundee International Specialty Conference. 6 pages.
August 6–8, 2001.
http://s3.amazonaws.com/zanran_storage/www.awra.org/ContentPages/9889715.pdf

This study, conducted in northern Nevada, investigated the usefulness and cost-effectiveness of using satellite technology to conserve water compared to voluntary conservation and conventional irrigation scheduling. The study examined the conservation potential specific to Truckee Meadows. The report notes that “50 to 70 percent of the total water supply is used for outdoor irrigation during the summer months." Their unpublished data suggest that in non-drought years residents "typically apply anywhere from 2 to 10 times more water for landscape irrigation than is actually needed (personal communication, Gary Kah, Aqua Metrics, 1999), most of which occurs during spring and fall when evapotranspiration demands are lower relative to irrigation application rates."

Researchers studied four irrigation methods: intuitive irrigation, manually scheduled ET-based irrigation, manually scheduled ET-based irrigation with management training, and satellite-controlled ET-based irrigation. The satellite technology uses data generated by local weather stations to control the duration and frequency of outdoor irrigation. Each method was tested on residential and commercial landscapes, replicated three times, and examined five response variables: total applied water (per application and seasonally), plant stress index, soil moisture penetration, turf quality, and cost recovery. The authors describe plans to conduct cost-benefit analysis and compare results for each irrigation method.

2.3 Controller Savings

The following resources present analyses of the water or monetary savings associated with smart controllers.

2.3.1 Year 1 of Implementing Smart Irrigation Controllers in Orange County

By S.L. Davis and M.D. Dukes.
Slides presented at the Florida Water Research Conference. 22 slides.
April 29–30, 2013.

This slide presentation described the first year of a study of the effectiveness of two types of smart controllers in reducing the landscape irrigation for high water users in Orange County: the Rain Bird ESP-SMT ET controller, and the Baseline WaterTec S100 soil moisture sensor (SMS). The study identified 7,407 possible participants, of which 843 responded to a study questionnaire and of which 167 ultimately participated. The treatments tested were using the ET controller; using an ET controller plus educational guidance; using a SMS; using a SMS plus educational guidance; and a control group that received no technology. The monitoring period was November 10, 2011, through January 14, 2013.

The authors described future project work to continue data collection and analyses into 2014, develop better benchmarks for over- and under-irrigation, and evaluate commercial properties that recently received controllers.

2.3.2 Validation of Landscape Irrigation Reduction with Soil Moisture Sensor Irrigation Controllers

By M. Haley and M. Dukes.
Journal of Irrigation and Drainage Engineering, Vol.138, No. 2, pages 135–144.
February 2012.
http://ascelibrary.org/doi/abs/10.1061/(ASCE)IR.1943-4774.0000391

This project aimed to determine whether automatic residential irrigation systems using SMS controllers could reduce irrigation while maintaining turfgrass quality as successfully in homes as in plot studies. Research was conducted at 58 homes in southwest Florida. Experimental treatments were (1) automatic timer with bypass SMS control system, (2) automatic timer with rain sensor and educational materials, (3) automatic timer with rain sensor, and (4) automatic timer only (typical for the region). Irrigation application amount and frequency, quarterly turf quality ratings, and weather data were collected throughout 26 months. Homes that had SMS controllers bypassed unneeded irrigation events during both rainy and dry periods, averaging 2 irrigation events per month; all other treatments averaged 4.5 to 6 events per month. SMS control systems resulted in a 65% cumulative reduction in number of irrigation events compared to homes having typical timer controls (72% and 54% in rainy and dry weather conditions, respectively). Irrigation application was influenced significantly by the season of the year; spring had the highest average irrigation demand (56 mm/month) because of relatively high evaporative conditions and low rainfall. Observed on-site savings were comparable to previous plot research, indicating that plot savings could be scaled up as long as SMS control systems are installed properly.

2.3.3 Soil Moisture Sensor Landscape Irrigation Controllers: A Review of Multi-Study Results and Future Implications

By B. Cardenas-Lailhacar and M.D. Dukes.
Presented at the 5th National Decennial Irrigation Conference as Paper No. IRR109600.
Transactions of the American Society of Agricultural and Biological Engineers, Vol. 55, No. 2, pages 581–590.
2012. ISSN 2151-0032.
http://abe.ufl.edu/mdukes/pdf/publications/SW/SW9335_soil-moisture-sensor-review.pdf

This article reviews the results of several research projects performed in Florida to evaluate soil moisture sensor (SMS) systems for residential irrigation control. Experiments were conducted on two University of Florida sites, one comprising 56 plots and the other 36. The researchers also performed residential field tests, in which 58 households participated. All the households had an automated in-ground irrigation system that used potable water. Results demonstrated that programming irrigation systems to run every day and letting the SMS decide when to irrigate could produce higher water savings than day-of-the week water restrictions, given that “homes with SMSs applied 65% less water than the homes with automated irrigation systems without sensor feedback.” The authors concludes that, when properly installed, set, and maintained, SMSs could save significant amounts of irrigation water while maintaining turf quality in Florida.

2.3.4 Final MWDOC Smart Timer Rebate Program Evaluation

By A & N Technical Services, Inc., Encinitas, CA.

Prepared for the Municipal Water District of Orange County (MWDOC). 59 pages.
November 2011.
http://www.mwdoc.com/cms2/ckfinder/files/files/SmartTimerRebateEval_Final.pdf

The MWDOC received a CalFed grant from the U.S. Bureau of Reclamation to initiate a SmarTimer rebate project. The program, implemented between September 2008 and June 2010, attracted 836 participants, 588 from the commercial sector and 248 from the residential. The project evaluated the effectiveness and cost-effectiveness of WBICs (smart timers) as a best management practice for suburban landscapes.

The project also evaluated evapotranspiration data, including data from (1) CIMIS weather stations; (2) the three weather stations operated by the Irvine Ranch Water District (IRWD); (3) NOAA weather stations, and (4) the CIMIS spatial reference evapotranspiration (ETo) system. Spatial CIMIS utilizes CIMIS stations, satellite imagery, and geographic computer modeling to estimate ETo and related data at a spatial resolution of 2 km. Researchers compared annual and monthly ETo values from the three IRWD sites, some CIMIS stations, and the CIMIS spatial system. At a coastal location, differences in monthly ET values between IRWD and CIMIS spatial data ranged from 1% to 44%. Annual standard deviations of the monthly percentage differences ranged from 0.10 to 0.17. For a foothill location, differences ranged from 1% to 37% based on four years of data. The CIMIS spatial measures of ETo reflected local conditions more accurately than did data from a central location.

The authors state: “This research found statistically significant improvements in ET data when using both precipitation data and spatially accurate CIMIS measures of ETo. Water savings per site were estimated from the statistical impact evaluation to be on average, 9.4% at single-family residential sites and 27.5% at commercial sites.” The report attributes the disparity in savings rates to the nature of the sites: because single-family sites tend to be smaller than commercial ones, they offer lower potential savings.

2.3.5 City of Petaluma Smart Yard Program Will Save 45 Million Gallons of Water

Press release by T. Mitchell published on http://www.fierceenergy.com.
August 8, 2011

This press release describes a program by the City of Petaluma, CA, to provide a HydroPoint Smart Yard Controller (WeatherTRAK Smart Water Management irrigation controller) to qualifying residential water customers. The controllers use satellite technology to match irrigation schedules automatically to current local weather conditions, reducing run-off and saving water. According to the Smart Yard program, "Sixty-five percent of the city’s water supply is estimated to be used outdoors, and experts believe that the majority of landscaping (including those with drought-tolerant planting) is over-watered anywhere from 30% to a shocking 300%." Although the homeowner would face no upfront costs for joining the program, participants would cover program costs, estimated at $897 each, through a zero-interest $14.95 added to their water bill each month for five years.

2.3.6 Low-Cost Outdoor Irrigation Optimization Using the Spray Smart™ Valve

Supported by Metropolitan Water District's Innovative Conservation Program.
233 pages plus pre- and post-retrofit studies.
June 2011.
Aeromaster Innovations appears to be the manufacturer.
http://www.bewaterwise.com/icp/91698.pdf

This project was a small-scale evaluation of a valve restrictor called Spray Smart, used to control watering by zone and plant type in installed irrigation systems. Participants, selected from among 32 applicants, received the valves at no cost. There were two groups of participants: semi-skilled homeowners who performed their own installations, and homeowners whose upgrades were performed by a professional irrigation designer. Water savings were calculated by audits before and after installation. Both groups reduced water use by an average of 34%. On average, 16 valves were installed per site. Given an average savings of 662 gallons per valve, the per-site annual average savings would be 10,592 gallons.

2.3.7 Water Conservation Potential of Landscape Irrigation Smart Controllers

By M.D. Dukes.
Transactions of the American Society of Agricultural and Biological Engineers, Vol. 55, No. 2, pages 563–569.
March/April 2011. ISSN 2151-0032.
http://abe.ufl.edu/mdukes/pdf/publications/SW/SW9331_water-conservation-potential-smart-controllers.pdf

This article notes that although formal research studies using statistical analyses have indicated controllers can provide water savings of from 40% to more than 70%, real-world savings in large pilot projects typically have demonstrated savings of less than 10%. The author maintains that differences between apparent potential savings and realized savings reflect a lack of (1) targeting high irrigation users; (2) educating contractors and end users; and (3) assessing water savings through timely follow-up. In addition, the author notes that much of the scientific research on smart controllers has been conducted in humid climates, where potential savings likely are higher because irrigation is needed only to supplement rainfall. The author suggests that future pilot projects include comprehensive educational components and a focus on high-irrigation sites that offer large potential savings. The author recommends that future work include large demonstrations (hundreds of users or more) to fully evaluate the true water conservation potential of smart controllers.

2.3.8 Landscape Irrigation with Evapotranspiration Controllers in a Humid Climate

By S.L. Davis and M.D. Dukes.
Presented at the 5th National Decennial Irrigation Conference, December 5–8, 2010, as Paper No. IRR109573.

Transactions of the ASABE American Society of Agricultural and Biological Engineers, Vol. 55, No. 2, pages 571–580. March/April 2011.
http://abe.ufl.edu/mdukes/pdf/publications/SW/SW9330_landscape-irr-humid-climate.pdf

This article summarizes findings of multiple research studies of ET controllers and provides information concerning performance and implementation techniques for providing successful integration. Most studies reviewed in this article examined three brands of ET controller: the Weathermatic SL1600 controller with SLW15 weather monitor; the Toro Intelli-sense using WeatherTRAK ET Everywhere service (Hydropoint Datasystems); and the ETwater Smart Controller 100. The Rain Bird ET Manager was tested in one field study. The authors conclude that when used in areas that need moderate to high irrigation, and if programmed correctly, ET controllers can save as much as 63% in irrigation water use without harming landscape quality. During a SWAT test in Florida, however, the controllers only rarely exceeded an irrigation adequacy of 80% and a scheduling efficiency of 95%. At most 10% of SWAT scores were passing during any of the three evaluation periods that involved frequent rainfall (indicating that accounting for rainfall is a challenge for many controllers). In southwest Florida, the only households that achieved savings from an ET controller were those that applied more than 450 mm per year of irrigation. The authors state that SWAT scores predict water savings only when there was over-irrigation before the ET controller was installed. If irrigation was conservative before the ET controller was installed, the controller likely will increase irrigation water use.

Although estimates of ETo generally are standardized and consistent among controller brands, the authors note that the crop coefficients the controllers use are less consistent. Using an annual crop coefficient does not adjust ETo appropriately for seasonal variations, for example. In addition, using crop coefficients for a specific location does not account for seasonal or regional fluctuations.

2.3.9 Irrigation Scheduling Performance by Evapotranspiration-Based Controllers

By S.L. Davis and M.D. Dukes.
Agricultural Water Management, Vol. 98, No. 1, pages 19–28.
December 2010.
http://www.sciencedirect.com/science/article/pii/S0378377410002374

This study aimed to determine the scheduling effectiveness of three brands of ET-based irrigation controllers compared to a theoretically derived soil-water balance model based on the SWAT protocol. A daily soil-water balance model was used to calculate the theoretical irrigation requirements for comparison with applied irrigation water. Calculated in 30-day running totals, irrigation adequacy and scheduling efficiency were used to quantify under- and over-irrigation, respectively. The five irrigation treatments were: Weathermatic SL 1600 with SLW15 weather monitor, Toro Intelli-sense, ETwater Smart Controller 100, a time-based recommendation determined by local conditions, and a reduced time-based treatment (60% of the aforementioned recommendation). Each treatment was replicated four times on a total of 20 field plots. The study period, May 25, 2006–November 27, 2007, was drier than the historical average, which was 1,979 mm or rainfall, compared to only 1,326 mm during the study period. Although ET timers were able to adjust regularly to real-time weather conditions, the authors note that the incorporation of site-specific rainfall measurements is extremely important, and at a minimum a rain sensor should be used.

2.3.10 Pilot Implementation of Smart Timers: Water Conservation, Urban Runoff Reduction, and Water Quality

By Kennedy/Jenks Consultants.
Prepared for the Municipal Water District of Orange County (MWDOC).
K/J project no. 0753001*01. 145 pages.
September 2010.

This report was a follow-on to Kennedy/Jenks' 2008 report for MWDOC. Numbers of installations remained the same, as did program focus (residential and commercial water savings; runoff and water quality). Many topics are treated identically in both reports, such as water savings by season and savings for homeowner-installed timers versus savings for professionally installed units. The 2010 report, however, focuses strongly on evaluating the effect of ET on controller performance. Only after detailed analyses of the three ET zones in the study area (coastal, central, and foothill) are overall results given. In the 2008 report, the effect of ET was evaluated briefly after overall program results were presented as the primary findings. Re-evaluation of data led to some changed results.

2.3.11 Sensor-Based Automation of Irrigation on Bermudagrass during Dry Weather Conditions

By B. Cardenas-Lailhacar, M.D. Dukes, and G.L. Miller.
Journal of Irrigation and Drainage Engineering, Vol. 136, No. 3, pages 184–193.
March 2010.
http://abe.ufl.edu/mdukes/pdf/publications/SMS/Sensor-BasedAutoIrr.pdf

This study evaluated soil moisture sensor (SMS) systems operating under dry weather conditions. The first part of the study, which took place during the first half of 2006, sought to evaluate the water savings potential of several SMSs. In the second half of 2006, the objectives were to quantify irrigation water use and evaluate differences in turfgrass quality among (1) a timer-based irrigation schedule with and without a rain sensor; (2) timer-based schedules compared to SMS-based systems; and (3) SMS-based systems using different irrigation frequencies. The experimental area, located in Gainesville FL, consisted of plots of common bermudagrass. Four brands of SMSs (Acclima, Rain Bird, Irrometer, and Water Watcher) were installed to bypass scheduled irrigation cycles when the soil water content at a depth of 7 to 10 cm exceeded field capacity. Timer-based treatments with and without rain sensor feedback were used to study depth of applied irrigation, and a non-irrigated area was used to compare turf quality. Because rain was infrequent during the experiment, the turf quality in the non-irrigated plots (as well as for a broken SMS treatment) declined below the minimum acceptable level. The other plots demonstrated at least minimally acceptable turf quality. Having a rain sensor used 13% to 24% less water than no rain sensor. Compared to having no rain sensor, three of the four SMS brands saved a significant amount of water, from 16% to 54% in the first half, and from 28% to 83% in the second half of 2006.

2.3.12 Improving Urban Irrigation Efficiency by Capitalizing on the Conservation Potential of Weather-Based "Smart" Controllers

By P.W. Mayer and W.B. DeOreo.
Journal AWWA, Vol. 102, No. 2, pages 86-97.
February 2010.
http://www.waterdm.com/sites/default/files/JAWWA%20(2010)%20The%20Conservation%20Potential%20of%20Weather-Based%20'Smart'%20Controllers.pdf

This article examines the effect of 3,112 smart controllers (49.1% of the total) installed at 2,294 sites throughout California. The sites met the data requirements for inclusion in the study: one full year each of pre- and post-installation billing data, corresponding climate data, and a measurement of the site's landscape area. For each site, data on the daily gross ETo and precipitation from the nearest CIMIS weather station were aligned with historical billing data. A daily model was used to deduct each site's effective precipitation from the daily ET. The theoretical irrigation requirement (TIR) was determined by assuming an irrigation efficiency of 100%, which likely resulted in underestimating irrigation requirements. The application rate (AR) in inches for each site was calculated by dividing the outdoor water use by the landscape area and applying a standard unit conversion factor. The AR is a measure of how closely a site's irrigation applications match the TIR derived from proximal ET weather stations.

2.3.13 Landscape Irrigation with Evapotranspiration Controllers in a Humid Climate

By S.L. Davis and M.D. Dukes.
Presented at the 5th National Decennial Irrigation Conference, December 5-8, 2010 as paper no. IRR109573.
Transactions of the ASABE American Society of Agricultural and Biological Engineers, Vol. 55, No. 2, pages 571–580.
March/April 2011.
http://abe.ufl.edu/mdukes/pdf/publications/SW/SW9330_landscape-irr-humid-climate.pdf

This article summarizes the findings of research studies concerning ET controllers. Based on the studies, ET controllers can save as much as 63% of irrigation water use without sacrificing landscape quality when implemented in moderate to high water use situations and programmed correctly. In southwest Florida, only homes that irrigated more than 450 mm per year saw irrigation savings from an ET controller. The irrigation adequacy and scheduling efficiency of the ET controllers that underwent SWAT testing fluctuated depending on rainfall. Assuming that acceptable levels for irrigation adequacy and scheduling efficiency are 80% and 95%, respectively, SWAT scores for the Florida controllers exceeded those thresholds during only a few periods. A maximum of 10% of scores were passing in any of the three evaluation periods that experienced frequent rainfall, indicating that many controllers had trouble accounting for rainfall. SWAT scores predict water savings only when there is a potential for savings because there was excess irrigation before the ET controller was installed.

2.3.14 Water Conservation Potential of Smart Irrigation Controllers on St. Augustinegrass

By M.S. McCready, M.D. Dukes, and G.L. Miller.
Agricultural Water Management, Vol. 96, No. 11, pages 1623–1632.
November 2009.
http://www.sciencedirect.com/science/article/pii/S0378377409001784

This research evaluated the effectiveness of ET-based irrigation controllers, soil moisture sensor (SMS) controllers, and rain sensors based on irrigation applied and turfgrass quality. Testing took place on St. Augustinegrass during four periods: April 22–June 30, 2006; September 23–December 15, 2006; May 1–August 31, 2007; and September 1–November 30, 2007. Two brands of SMS controllers were tested: LawnLogic LL1004 and Acclima Digital TDT RS500, with individual units set at three different soil moisture thresholds. Mini-Clik rain sensors (RS) were set at rainfall thresholds of 3 and 6 mm and at three irrigation frequencies (1, 2, and 7 days per week). Two ET controllers were tested, the Toro Intelli-Sense and the Rain Bird ET Manager. For comparison, a timer-based treatment provided 2 days of irrigation per week with no sensor to bypass irrigation. Testing involved 72 plots of turf. All controller programming reflected settings that might be used in residential or commercial landscapes.

2.3.15 Evaluation of California Weather-Based "Smart" Irrigation Controller Programs

Prepared by P. Mayer, W. DeOreo, M. Hayden, and R. Davis, Aquacraft, Inc.; E. Caldwell and T. Miller, National Research Center, Inc.; and P.J. Bickel.
Presented to the California DWR by the Metropolitan Water District of Southern California and the East Bay Municipal Utility District. 277 pages.
July 2009.
http://www.irrigatoinessentials.com/userfiles/file/DWR_SMARTcontroller_eval_09.pdf.

The authors evaluated on-site sensor-based controllers and signal-based WBICs at urban (residential and commercial) landscapes in California. As of the report date, the EPA had filed its intent to apply the WaterSense label to smart controllers, but had not identified a testing protocol. The authors discuss water savings by brand of controller, the factors that affect water savings, and cost-effectiveness. The authors state, "Even the best, most water-efficient controller cannot make up for poor system design, installation, and maintenance...." Also: "In this study, 41.8% of the study sites increased their irrigation water use after installation of the smart controller."

The authors analyzed controller cost-effectiveness using the average and median water savings per customer estimated for sites measuring 4,000; 12,000; 25,000; or 150,000 square feet. Those areas reflect the usual range of residential and non-residential landscapes found in northern and southern California. The avoided cost of water for the California water agencies in the study ranged from about $100 to $1,000 per acre-foot.

2.3.16 Evaluation of Sensor-Based Residential Irrigation Water Application on Homes in Florida

By M.D. Dukes and M.B. Haley, Univ. of Florida.
2009.
http://www.irrigation.org/Resources/Technical_Papers.aspx
**Abstract only, obtained through search of the Irrigation Association Website.*

This project aimed to determine whether an automatic residential irrigation system with soil moisture sensor controllers could reduce irrigation while maintaining turfgrass quality. Approaches tested were (1) automatic timer-based irrigation set and operated by the participant; (2) automatic timer with a soil moisture sensor; (3) automatic timer with a rain sensor; and (4) automatic timer with a rain sensor plus educational materials, including a recommended run-time schedule. Irrigation water use, quarterly turf quality ratings, and weather data were collected continuously for 59 homes during 26 months. Both weekly and hourly irrigation water use were recorded, and the fraction of total household use was calculated. The soil moisture sensor system provided the largest savings, cumulatively applying 65% less water for irrigation than the timer-only method.

2.3.17 Landscape Irrigation by Evapotranspiration-Based Irrigation Controllers under Dry Conditions in Southwest Florida

By S.L. Davis, M.D. Dukes, and G.L. Miller.
Agricultural Water Management, Vol. 96, No. 12, pages 1828–1836.
2009.
http://econpapers.repec.org/article/eeeagiwat/v_3a96_3ay_3a2009_3ai_3a12_3ap_3a1828-1836.htm

Based on positive water savings reported for ET controllers used in arid climates, the authors tested three brands of controllers: Toro's Intelli-sense utilizing the WeatherTRAK ET Everywhere service (Hydropoint Datasystems, Inc.); SL1600 controller with SLW15 weather monitor (Weathermatic, Inc.); and Smart Controller 100 (ET Water Systems LCC). The controllers' irrigation applications were evaluated compared to a timer schedule intended to replicate that of a typical homeowner. Other methods tested were TIME, based on the historical net irrigation requirement, and RTIME, which was 60% of TIME. Each technique was replicated four times in a total of 20 plots of St. Augustine grass, each of which was irrigated by one individual irrigation system. Techniques were compared to each other and to a timer-based schedule without rain sensor (derived from TIME). The study period, August 2006–November 2007, was dry compared to the 30-year historical average.

2.3.18 Irrigation by Evapotranspiration-Based Irrigation Controllers in Florida

By S.L. Davis, M.D. Dukes, and G.L. Miller.
Presented at the 29th Annual International Irrigation Show, Anaheim, CA.
9 pages.
November 2–4, 2008.
abe.ufl.edu/mdukes/pdf/publications/ET/2008-Final-IA-Manuscript-SLD.pdf

This presentation reported on the same research as described in reference 2.3.18, above. The study evaluated the ability of three brands of ET-based controllers to schedule irrigation compared to a timer. Five systems were evaluated: three ET controllers, a timer method set according to recommendations from the University of Florida Institute of Food and Agricultural Sciences, and 60% of the first timer-based treatment. The ET controllers provided an average of 35% to 42% water savings compared to a timer schedule without a rain sensor and maintained acceptable turfgrass quality. Also, potential water savings from using a rain sensor set to a 6 mm threshold averaged 21% throughout the study.

2.3.19 Effectiveness of Runoff-Reducing Weather-Based Irrigation Controllers (SmarTimers)

By S.D. Jakubowski, Municipal Water District of Orange County.
Slides presented at WaterSmart ’08 Innovations Conference, Las Vegas, NV.
October 2008.
http://www.newportbeachca.gov/Modules/ShowDocument.aspx?documentid=6208

This study examined the pollution prevention, reduction in urban runoff, and improvement in water quality, as well as water savings, attributable to WBICs. The author defined a weather-based irrigation controller (SmarTimer) as a controller that (1) estimates or measures depletion of available plant soil moisture; (2) replenishes water as needed while minimizing excess irrigation; and (3) requires minimal human intervention to modify irrigation appropriately throughout the season. The study, which ran from 2004–2006, used direct, targeted marketing including a rebate offered to participants. The study spanned three ET zones (coastal, central, and foothills) and utilized eight brands of WBIC. The study calculated average calendar monthly usage both pre- and post-retrofit and statistically compared the two periods. Of the 899 single-family residential water accounts included in the study, 49% saw no significant difference and 51% showed significantly different water usage (64% saved, 36% used more). Participants realized a net average savings of 35.7 gallons per day (gpd). Of the 323 commercial accounts included in the study, 59% saw no significant difference; 41% had significantly different water usage (73% saved, 27% used more); and net savings averaged 460 gpd.

2.3.20 Evaluation of Evapotranspiration-Based and Soil-Moisture-Based Irrigation Control in Turf

By G. Grabow, A. Vasanth, D. Bowman, R. Huffman, and G. Miller.
Presented at the 2008 World Environmental and Water Resources Congress, American Society of Civil Engineers, May 12–16, Honolulu, Hawaii. Pages 1-9.
http://ascelibrary.org/doi/abs/10.1061/40976(316)117

This study, performed in fall 2006 in Raleigh, NC, compared amounts of water applied and resulting turf quality for one ET-based irrigation system, two SMS-based systems, and a timer-controlled schedule. The effect of irrigation frequency also was examined. Turf ET was estimated using both an atmometer and the Penman-Monteith equation applied to weather data. This 20-week study showed that on average the add-on SMS system applied the least water, whereas the ET-based system applied the most. Averaged across all technologies, weekly irrigation frequencies used the least amount of water, followed by biweekly and then daily frequencies. All technologies and frequencies maintained minimally acceptable turf quality throughout most of the study period. During the last month, however, turf quality declined considerably for both the add-on SMS and the timer-based system. The on-demand sensor-based system provided the best combination of water use efficiency and turf quality.

2.3.21 Summary of Smart Controller Water Savings Studies: Literature Review of Water Savings Studies for Weather and Soil Moisture Based Landscape Irrigation Control Devices

Prepared by the U.S. Department of the Interior, Bureau of Reclamation, Southern California Area Office, Temecula, CA; and Technical Service Center Water Resources Planning and Operations Support Group, Denver, CO.
Final Technical Memorandum No. 86-68210-SCAO-01. 21 pages.
April 2008.
http://www.usbr.gov/waterconservation/docs/WaterSavingsRpt.pdf

This document summarizes results from about 26 studies of water savings achieved for residential landscapes by weather-based controllers, soil moisture-based controllers, and controllers based on both weather and soil moisture. The purpose of this summary report was to document the overall status of emerging controller technologies for weather- and soil moisture-based landscape irrigation, with the intent of assisting water agencies in their efforts to promote such technologies. Topics include urban runoff, turf, scheduling, and reported water savings. Most of the studies reviewed are described elsewhere in this list of resources.

2.3.22 Pilot Implementation of Smart Timers: Water Conservation, Urban Runoff Reduction, and Water Quality

By Kennedy/Jenks Consultants.
Prepared for the Municipal Water District of Orange County, K/J project no. 0753001. 130 pages plus appendixes.
March 2008.
http://www.mwdoc.com/documents/SmarTimerReport.pdf

This report describes detailed analyses of pre- and post-retrofit data for Smart Timers installed at 323 commercial and 899 residential sites. The project also involved evaluating associated changes in runoff and water quality. The results for installation of Smart Timers at single-family residential (SFR) sites were: irrigation water use declined in 33% of SFRs; increased significantly in 15% to 20% of SFRs; and showed no change in about 50% of SFRs. The results for installation of Smart Timers at commercial sites were: irrigation water use decreased significantly in 15% to 30% of the sites. For about 10% to 20% of commercial sites, water consumption increased after Smart Timers were installed.

2.3.23 Sensor-Based Automation of Irrigation on Bermudagrass, During Wet Weather Conditions

By B. Cardenas-Lailhacar, M.D. Dukes, and G.L. Miller.
Journal of Irrigation and Drainage Engineering, March/April 2008, pages 120-128.
DOI: 10.1061/ASCE0733-94372008134:2120.
http://abe.ufl.edu/mdukes/pdf/publications/SMS/Cardenas-SMS-paper-JID.pdf

The objectives of this research were to quantify irrigation water use and evaluate differences in turf quality for (1) timer-based scheduling with and without a rain sensor; (2) a timer-based schedule compared to a system that uses a soil moisture sensor (SMS); and (3) various commercially available SMS systems. The experimental area comprised 3.7 m x 3.7 m plots of common bermudagrass in Gainesville, FL. Monitoring took place from July 20 to December 14, 2004, and from March 25 to August 31, 2005. Four SMS brands were tested, each of which was scheduled to irrigate one, two, or seven days a week. Because sustained wet weather occurred during both monitoring periods, there were no significant differences in turfgrass quality detected among the plots. The rain sensors applied 34% less water than no rain sensor. The water savings for three of four SMS brands, compared to no sensor, ranged from 69% to 92%, depending on irrigation frequency.

2.3.24 Residential Water Savings Associated with Satellite-Based ET Irrigation Controllers

By D.A. Devitt, K. Carstensen, and R.L. Morris.

Journal of Irrigation and Drainage Engineering, Vol. 134, No. 74, pages 74–82. DOI:10.1061/(ASCE)0733-9437(2008)134:1(74).
January 2008.
http://ascelibrary.org/doi/abs/10.1061/(ASCE)0733-9437(2008)134:1(74)

This study monitored the irrigation water use of 27 residential sites in Las Vegas, NV. The sites, which had various percentages of turfgrass in mixed landscapes, were monitored to quantify savings from satellite-based irrigation controllers. Seventeen sites were equipped with ET-based satellite controllers, and 10, serving as control sites, were retrofitted with non ET-based controllers. Thirteen of 16 sites equipped with ET-based controllers saved water compared to 4 of 10 control sites.

2.3.25 Expanding Disk Rain Sensor Performance and Potential Irrigation Water Savings

By B. Cardenas-Lailhacar and M.D. Dukes.
Journal of Irrigation and Drainage Engineering, Vol. 134, No. 1, pages 67–73. 2008.
http://www.abe.ufl.edu/mdukes/pdf/publications/RS/Cardenas-Dukes-RS-paper-JID.PDF

This article reports on an experiment performed to: (1) evaluate two types of rain sensors (RS) for setpoint accuracy, number of irrigation cycles bypassed, and duration of bypass mode; (2) quantify the amount of water RS could save; and (3) estimate payback period. The authors tested 12 Mini-click and 4 wireless rain-click rain sensor models by Hunter Industries, Inc. The study was performed in Florida, from March 25 through December 31, 2005, a period when 62% of days had rainfall. Three rainfall setpoints were established for the Mini-click devices: 3, 13, and 25 mm thresholds. On average, all RS responded close to their setpoints.

2.3.26 Residential Irrigation Water Use in Central Florida

By M.B. Haley, M.D. Dukes, and G.L. Miller.
Journal of Irrigation and Drainage Engineering, September/October 2007, pages 427–434.
http://abe.ufl.edu/mdukes/pdf/irrigation-efficiency/Haley-FL-residential-irrig-JID.pdf

The first objective of this study was to document irrigation water use on typical residential landscapes (T1) in the Central Florida ridge region. The second objective was to determine whether (1) scheduling irrigation by setting controllers based on historical ET (T2) and (2) reducing the percentage of turf area along with setting the controllers based on historical ET (T3) would reduce irrigation water use. This study lasted 30 months beginning in January 2003. The average T1 or T2 irrigated landscape contained approximately 75% turfgrass (60% to 88%

range). The T3 landscapes averaged 31% (5% to 66% range) turfgrass. The rest of the landscaped area contained Florida native plants or low-water-use species.

Irrigation accounted for 64% of residential water use for all homes during the study. T1 irrigation averaged 74% of total water use, T2 averaged 66%, and T3 averaged 51%. Average monthly water use at T2 homes was 105 mm per month, 30% less than at T1 homes. T3 homes showed a 50% reduction in water use (74 mm per month). Average monthly water use among the three irrigation treatments differed statistically ($p<0.001$). Increasing the proportion of landscape area from 23% ornamental plants irrigated with sprinklers (T1 and T2) to 62% ornamental plants irrigated with micro-irrigation (T3) saved the most water. Micro-irrigation applied low volumes of water to only some of the landscaped beds and then only to the root zone.

2.3.27 Evaluation of Evapotranspiration and Soil Moisture-based Irrigation Control on Turfgrass

By M. Shedd, M.D. Dukes, and G.L. Miller.
Presented at the World Environmental and Water Resources Congress 2007: Restoring Our Natural Habitat, pages 1–21.
May 2007.
http://cedb.asce.org/cgi/WWWdisplay.cgi?159624

This study evaluated the effectiveness of various technologies for reducing residential irrigation in terms of amount of water applied and quality of turfgrass. Two types of soil moisture sensors (LawnLogic and the Acclima Digital TDT RS500) were tested at low, medium, and high soil moisture thresholds. Mini-Clik rain sensors were incorporated in seven timer-based experiments. Three of the rain sensors were set to bypass irrigation at 3 mm of rainfall; four were set for 6 mm. Two ET controllers were tested, the Toro Intelli-Sense controller and the Rain Bird ET Manager. Timer-based irrigation without a rain sensor irrigating two days per week (2-WORS) provided a baseline. SMS systems reduced water use by 0% to 63% compared to 2-WORS. Rain sensors reduced water use by 7% to 33%. ET-based irrigation reduced water use 36% to 59% compared to 2-WORS. At low thresholds, the SMS systems saved significant amounts of water, but reduced turf quality to unacceptable levels. The SMSs set at a medium threshold, timer-based irrigation, and both ET-based systems produced good turfgrass quality while reducing irrigation water use compared to 2-WORS. Water savings for the medium-threshold SMS systems ranged from 11% to 28%.

2.3.28 Evaluation of Soil Moisture-Based and ET-Based Irrigation Control in Turf

By A. Vasanth, G.L. Grabow, D. Bowman, R.L. Huffman, and G.L. Miller.
2007.
http://www.irrigation.org/resources/technical_papers/
**Abstract only, found through search of the Irrigation Association website.*

A study initiated in the fall of 2006 compared two types of commercially available irrigation control technologies, one based on ET estimates, and the other on feedback from soil moisture sensors. The amount of water applied and the turf quality from one ET- and two SMS-based systems were compared to results of a standard timer-based irrigation schedule. Irrigation frequency was another component of the study. On average, the add-on soil-moisture-based system applied the least amount of water, whereas the ET-based treatment applied the most. Once-a-week irrigation used the least amount of water and daily frequencies the most when averaged across all technologies. In general, all technologies and frequencies maintained minimally acceptable turf quality, although some systems resulted in noticeably stressed turf during the last month of the study. The on-demand, SMS-based system provided the best combination of water efficiency and turf quality.

2.3.29 Precise Irrigation Scheduling for Turfgrass Using a Subsurface Electromagnetic Soil Moisture Sensor

By J.M. Blonquist, S.B. Jones, and D.A. Robinson.
Agricultural Water Management, Vol. 84, No. 1–2, pages 153-165.
2006.
http://www.usu.edu/soilphysics/rsrch/SBIrrigation/2006_AgWatMan_Blonquist-etal_IrrigationMan.pdf

Research objectives were to (1) examine the effects of scheduling irrigation of turfgrass based on ET estimates from a weather station compared to data from a novel time-domain transmission (TDT) SMS, and (2) apply a computer-based numerical model to simulate volumetric soil water content dynamics at the burial depth of the sensor and to evaluate any drainage occurring below the turfgrass rooting depth.

This article describes an electromagnetic technology that automates irrigation based on sensed soil moisture. Researchers installed an Acclima Digital TDT sensor in a plot measuring about 280 m^2 on the Utah State University Greenville Research Farm. The sensor connected to a CS3500 controller, which can log estimated water content as well as control irrigation. The experiment was conducted July 30–September 16, 2004 (a total of 39 days). Two different sprinkler heads were used, the first a single-impact Rainbird130IBH with a 3/16-inch nozzle that was used July 30–August 15. During that period the Acclima TDT system applied approximately 13.0 mm of water (13%) more than the amount recommended based on ET estimates from a local weather station. From August 16–September 16, the sprinkler head was a lower-flow, gear-driven Hunter1 PGP with #9 nozzle. During that period, the Acclima system used approximately 20.0 mm, or 16%, less water than the recommended amount and 53% less than an average fixed irrigation rate of 50 mm week. The cumulative totals for the TDT and both sprinklers were comparable to irrigating based on the ET estimate.

The authors used the HYDRUS-2D numerical model to simulate the dynamics of volumetric soil water content at the burial depth of the sensor. The model estimated irrigation and precipitation inputs and ET outputs from the soil profile to predict drainage occurring below the grass rooting depth of 10 cm. The TDT system could save an estimated $5.00 to $100.00 per month based on average water prices in the United States and a 1,000 m^2 irrigated turfgrass plot, providing a payback period of 6 to 12 months.

2.3.30 LADWP Weather-Based Irrigation Controller Pilot Study: Executive Summary

By A. Bamezai, Western Policy Research.
Submitted to the Los Angeles Department of Water and Power. 8 pages.
August 2004.
ftp://ftpdpla.water.ca.gov/users/prop50/09610_Mojave/Regional%20Water%20Conservation%20Program/EXCERPTS%20Regional%20Water%20Conservation%20Program/LADWP%20Weather%20Based%20Irrigation%20Controller%20Pilot%20Study%20EXCERPT.pdf

This study evaluated two weather-based irrigation scheduling technologies: (1) Hydropoint Inc.'s ET controller sold under the trade name WeatherTrak, which replaces a controller; and (2) Water2save LLC's weather-based irrigation scheduler, which is added to an existing controller. WeatherTrak utilizes paging technology to receive weather-related data signals, internally processes them, and generates an irrigation schedule. Water2save is an interrupt and control device equipped with wireless Personal Communications Service technology that allows two-way communication between Water2save and the device.

The goals of the study were to (1) assess the performance of weather-based irrigation technologies, and (2) assess customer acceptance of those technologies in predominantly non-single family residential and small commercial settings. The study recruited 25 sites comprising about 83 acres of landscape (35 acres of turf, the rest shrubs), including homeowner associations, schools, commercial sites, and public parks. Water use was tracked for at least a year after the controller retrofits, and statistical models were used to compare two years of pre-retrofit to 1 year of post-retrofit consumption, accounting for weather. Both technologies rely on broadcast signals and adjust irrigation patterns to respond to weather conditions. Water2save's and Hydropoint's technologies reduced irrigation by 28.3% and 17.4%, respectively. Because Water2save's sites experienced more wasteful irrigation before the retrofits, they had a higher conservation potential. The percentage of pre-retrofit conservation potential converted into savings was higher for Hydropoint's landscapes (95%) than for Water2save's (71%), however. The authors estimated that both technologies together reduced outdoor consumption by 27%, achieving about 78% of total pre-retrofit conservation potential. Estimated outdoor water consumption savings across all test sites in the study was roughly 17 inches per year for pure turf landscapes and an assumed half of that for pure shrub landscapes. Savings estimates from this study closely matched the results of at least two previous studies in Irvine, CA.

2.3.31 The Residential Runoff Reduction Study

By The Municipal Water District of Orange County and Irvine Ranch Water District.
256 pages.
July 2004.
http://www.mwdoc.com/documents/R3Study-FINALREVISED10-28-04.pdf

The Residential Runoff Reduction (R3) study tested the effects of weather-based (ET) irrigation controllers and an education program on irrigation water use and the quantity and quality of dry-season runoff. The study also sought to gauge consumer acceptance of controllers as a means of water management. This 18-month study in Irvine, CA, involved five similar neighborhoods, each having its own single point of discharge into the urban storm drain system. Runoff volume was monitored and water quality samples collected at the points of discharge. The five sites were divided into three study areas. The first area, representing the retrofit group, received ET controllers and public education. The second area received educational materials but no controllers. The third study area, the control group, contained three neighborhoods that received neither ET controllers nor educational materials. This was one of the first studies to attempt to quantify the effectiveness of public education alone versus a technology-based plus education approach in reducing residential irrigation water use.

In the retrofit group, 72% of participants indicated they were satisfied with the WBIC's performance, which either maintained or improved landscape appearance. Data show households accepted the controller as a method of saving water, reducing runoff, and watering their landscape. The study found that twice the number of retrofit households observed a decrease in their water bills than did education-only households. However, 58% of retrofit households said they would not be willing to pay for an ET signal (the study calculated the controller cost and annual signal fee at $198 per year and water savings at $168 per year). In terms of water savings per controller (and cost-effectiveness), the study indicated that larger landscape areas (parks and street medians) represent the best initial targets for similar programs.

2.3.32 Evaluation of Weather-Sensing Landscape Irrigation Controllers, January through December 2003

By D.R. Pittenger, D.A. Shaw, and W.E. Richie.
Submitted to the Office of Water Use Efficiency, California DWE, by the University of California Cooperative Extension, Center for Landscape and Urban Horticulture. 25 pages.
June 2004.
http://ucanr.edu/sites/UrbanHort/files/131533.pdf

The study reported on in this document examined irrigation controllers that adjust water application in response to ETo or other environmental parameters. The study aimed to provide a scientific analysis of the ability of such controllers to meet plant water demands. In 2003, the authors evaluated weather-sensing irrigation controllers to determine what climatic data the controllers utilize, how easy they are to set up and operate, and how closely their irrigation systems match landscape needs. The authors studied Aqua Conserve ET-6, WeatherSet WS16, WeatherTRAK, and Calsense ET1 incorporating an electronic ET gauge. The manufacturer’s directions were followed in programming stations on each controller to schedule irrigation automatically from January through December 2003. The authors tested controllers on the following hypothetical landscape plantings: cool-season turfgrass, trees/shrubs, annual flowers, mixed high water use plants, and mixed low water use plants. The following points are major conclusions from the study.

- Greater complexity and technicality of setup does not necessarily result in more accurate, water-conserving irrigation schedules.

- Adoption of Smart Water Application Technologies will not eliminate the need for human involvement in managing landscape irrigation.
- Weather-sensing controllers generally require professional monitoring and follow-up adjustment of their initial settings.
- Use of weather-sensing controllers does not assure landscape water conservation or acceptable landscape plant performance.

The study summarizes the performance of each controller. They found Aqua Conserve to be the "most appropriate for homeowner use," but ultimately concluded that no product was able to produce highly accurate irrigation schedules consistently for every landscape setting when compared to reference treatments used in a research setting.

2.3.33 Santa Barbara County ET Controller Distribution and Installation Program Final Report

By HydroPoint Data Systems, Inc.
8 pages.
June 30, 2003.
http://www.hydropoint.com/documents/2013/09/santa-barbara-county-et-controller-distribution-and-installation-program-report.pdf

Six water agencies near Santa Barbara, CA, developed the Santa Barbara County ET Controller Distribution and Installation Program, which in May 2001 received funding from a Water Use Efficiency Grant through the CALFED Bay Delta Program. The program chose to install the WeatherTRAK ET controller based on the Irvine Ranch Water District's positive experience with the device. Throughout the 2-year study, program staff did significant planning, organizing, educating, and outreach to make the program a success. Starting in July 2002, the program began utilizing Hydropoint's Data Systems Customer Service and worked with Hydropoint to present installation training workshops. The county planned to distribute 300 ET controllers with rain sensors and soil probes at no cost to participating customers. To encourage customer buy-in, participants had to pay Hydropoint Data Services 3 years' worth of signal fees when they joined the program (a total of $144 billed at $4/month).

Costs associated with the program included the cost of controllers ($200 each); installation fees ($100 to $150); soil probes ($12 each); and consultant fees for marketing assistance, training workshops, and customer service (all paid for through grant funding).Two installer training workshops and one training lab were held to develop a list of trained installers for the program. HydroPoint reports that initial data indicate an average overall savings in water use of 26%, with a highest overall water savings of 59% and lowest of 8%. Using the factory settings for precipitation rates in the WeatherTRAK controllers did not result in reliable savings.

2.3.34 Final Report—Evaluation of a Soil Moisture Sensor to Reduce Water and Nutrient Leaching in Turf

By S.M. Pathan, L. Barton, and T.D. Colmer.
Horticulture Australia Project number TU 02006. 23 pages.

June 2003.

This research project, funded by Horticulture Australia Limited and Holman Industries, evaluated the Holman soil moisture sensor, WaterSmart™. Experiments were conducted for 12 months at the field facilities of the University of Western Australia and the nearby public Lanchester Park. Irrigation water was applied to turf plots either as recommended by the Western Australia Water Corporation (in periods of no watering restrictions), or when indicated by the soil moisture sensors (SMSs).

In summer the total volume of water applied to turfgrass plots controlled by the WaterSmart SMSs was 25% less than the volume applied based on the water corporation's best-practice watering schedule. Results were similar for the test site in Lancaster Park. Between late spring and early autumn (October 2002–April 2003), the volume of water applied to SMS-controlled plots was 34% less than at plots subject to conventional scheduling. Three replicates were tested. Turf quality was maintained at acceptable levels throughout the study.

2.3.35 Residential Landscape Irrigation Study Using Aqua ET Controllers

By S. Addink and T. W. Rodda.
Denver Water, Denver, CO; City of Sonoma, CA; and Valley of the Moon Water District, CA.
June 2002.

The effectiveness of Aqua ET controllers for residential landscape irrigation was evaluated in Denver, CO, and in two water districts in Northern California during 2001. 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. The data collected from the studies indicated that participants experienced a total outdoor water savings of 21%, 23%, and 28% in Denver, City of Sonoma, and Valley of the Moon Water District, respectively. Total savings of 7.64 acre-feet are reported, with average savings for individual residences ranging from 7% to 25% for the three study areas.

2.3.36 Water Efficient Irrigation Study: Final Report

By the Saving Water Partnership.
May 2003.
http://www.seattle.gov/util/groups/public/@spu/@foodyard/documents/webcontent/watereffi_200312021244026.pdf

This report describes a study conducted in Seattle in 2002 to examine water savings and customer satisfaction related to (1) WBICs with or without rain sensors, (2) hardwired and wireless rain sensors, and (3) an irrigation scheduling service. The study sought participants who demonstrated historically high water usage, especially during the peak season. During the peak season, the participants historically used an average of 375 gal/day above daily winter use. Aqua

Conserve controllers were installed in 35 high-usage residential sites. Twenty installations included rain sensors; 15 used a controller only. Water savings were calculated relative to historical consumption during 1998 and 2001, adjusting for weather conditions. The water savings were 20,735 gallons per year for each site that had a controller plus rain sensor, and 10,071 gallons per year for each site that had a controller only. Most participants reported satisfaction with controller performance, although many said the devices were difficult to operate. Because precipitation rates during the study were only 53% of the historical average, the study period was not the best for testing rain sensors. A theoretical analysis, however, indicated that rain sensors potentially could reduce watering by 20%.

2.3.37 Report on Performance of ET-Based Irrigation Controller: Analysis of Operation of WeatherTRAK™ Controller in Field Conditions During 2002

By Aquacraft, Inc.
Prepared for the Cities of Boulder, Greeley, and Longmont, CO. 23 pages.
April 2003.
http://www.hydropoint.com/documents/2013/09/aquacraft-colorado-weathertrak-field-study-2000-2002-ii.pdf

Residents of Boulder, Longmont, and Greeley, CO, participated in a 3-year field study (2000–2002) of the WeatherTRAK™ irrigation controller. The goal was to determine whether (1) the controller functioned reliably, and (2) the system could match water applications accurately to ETo. Pager technology connected the ET-based controllers to local weather stations. Signals sent periodically to each controller adjusted the irrigation schedule to provide the appropriate amount of water for the plant types in each zone. In 2002 seven of the nine study participants were single-family residences. WeatherTRAK decreased irrigation from an average of 34.4 inches applied in 1998–2000 to an average of 27.2 inches—a 21% reduction. The seven sites saved an average 35,000 gallons of water each compared to their historical water use. The four participants who saved the most averaged annual savings of 64,000 gallons, showing the great savings potential for programs focused on high water users. The study concluded that the WeatherTRAK system performed well and was capable of translating ET data into irrigation schedules, adjusting for drought measures when necessary.

2.3.38 Irvine Ranch Water District's Application of Signal Paging to ET Controllers for Medium-Size Commercial Landscapes

By T. Hunt and N. Mrvos, Irvine Ranch Water District (IRWD).
2003.
http://www.irrigation.org/Resources/Technical_Papers.aspx
**Abstract only, obtained through search of the Irrigation Association website.*

The IRWD found that WBICs are capable of supporting good water management. In its Residential Run-off Reduction (R3) study, IRWD replaced 112 residential irrigation controllers with weather-based controllers that used a combination of local (at the controller) programming and weekly remote schedule adjustments based on changes in ET. A remote operator sent a pager signal to adjust the schedule in response to rain, heat, cloud cover, or high wind. The R3 study took place in a residential setting that included parks, streetscapes, and condominiums, landscapes typically viewed as commercial sites or medium-sized landscapes (MSL). This report defines a MSL as 0.14 to 2 acres. The authors concluded that the most effective water conservation can occur at MSL sites.

2.3.39 Performance Evaluation of WeatherTRAK™ Irrigation Controllers in Colorado

By Aquacraft, Inc.
Study began in 2000; testing performed in 2001.
15 pages plus appendix.
http://www.hydropoint.com/documents/2013/09/aquacraft-colorado-weathertrak-field-study-2000-2002.pdf

This report describes a successful field test of WeatherTRAK ™ ET-based irrigation controllers, which link via pager technology to a network of local weather stations. The field study took place in Boulder, Longmont, and Greeley, CO. Ten sites were selected— nine residential and one office—a combination of volunteers and high water-using accounts. The irrigation water applied by each system were tracked and compared to the theoretical ETo requirements for the 2001 season.

Overall, the 10 sites saved an average of 26,000 gallons of water each compared to their historical usage. Including only the five participants who saved significant amounts of water results in an average annual savings of 68,000 gallons per site, indicating the large savings potential of programs targeting major users. based on the authors' calculations, the WeatherTRAK system appeared to capture about 88% of the potential savings on the 10 sites The WeatherTRAK system also appeared to perform well technically, providing a reasonably good translation of the ET data into irrigation schedules. Most users liked the system and appreciated its ability to make adjustments automatically, but a couple of people considered the system to be less flexible than it could have been. Although only one customer indicated a willingness to pay for the system, most said they would adopt it if the utility paid for it.

2.3.40 Residential Weather-Based Irrigation Scheduling: Evidence from the Irvine "ET Controller" Study

By representatives of the Irvine Ranch Water District, Municipal Water District of Orange County, and the Metropolitan Water District of Southern California, plus various consultants.
June 2001.
http://www.hydropoint.com/documents/2013/09/irvine-ranch-water-district-irwd-metropolitan-water-district-1-mwd-1998-1999.pdf

This study field-tested a reasonably priced prototype ET controller that adjusts irrigation in response to weather data received via a broadcast signal. Despite targeting high water users, the study attracted households that already were interested in water conservation, making the conservation potential relatively low. The ET controllers were able to convert almost 85% of the pre-retrofit conservation potential into achieved savings, however. The controllers reduced total water consumption by about 37 gallons per household per day, representing a 7% reduction in total household use, or roughly a 16% reduction in outdoor use.

2.3.41 Soil Moisture Sensors for Urban Landscape Irrigation: Effectiveness and Reliability

By R.J. Qualls, J.M. Scott, and W.B. DeOreo.
Journal of the American Water Resources Association, Vol. 37, No. 3, pages 547–559.
June 2001.
http://www.irrometer.com/pdf/research/SOIL_MOISTURE_SENSORS_FOR_URBAN_LANDSCAPE-Aquacraft_JAWRA_2001.pdf

The study described here involved 23 test sites, all of which had sensors that were installed at least 3 years previously during earlier studies. The field durability of the systems exceeded expectations: all the granular matrix sensors (GMS) in contact with the ground remained functional and required no replacement. One sensor was located in a city park and 1 in a traffic median; 4 were on residential properties; and the other 17 were installed in two residential communities maintained by two landscape contractors.

The authors compare the amount of water allowed by the sensors to the irrigation requirement based on net evapotranspiration (ETN), which is the amount of water in excess of rainfall that vegetation requires to satisfy its metabolic requirements. To measure ET, the authors relied on the Soil Conservation Service's 1970 modification of the Blaney-Criddle (1952, 1960) equation, which relates ET to mean monthly temperature and daylight hours, with corrections for effective precipitation.

The study found that the soil moisture sensors successfully reduced water applications during rainfall. The systems reduced irrigation applications well below theoretical requirements, and tracked ETN well. Maintenance and repair costs were minimal, as was the time required to adjust and operate the systems.

2.3.42 Demonstration of Potential for Residential Water Savings Using a Soil Moisture Controlled Irrigation Monitor: Project Completion Report

By R.G. Allen, Dept. Biological and Irrigation Engineering, Utah State Univ.
U.S. Bureau of Reclamation Provo, Utah Office, Project 6-FC-40-19490.
19 pages.
October 1997.
http://www.kimberly.uidaho.edu/water/swm/cons96p_rp_full.pdf

This 1-year project demonstrated a then-new technology for helping residential users conserve irrigation water. For the 1996 irrigation season, small electronic soil water control systems were installed in residential sprinkler systems in two Utah cities. The WaterWatcher system, an electronic control unit made by Turf Tech, was installed in-line between a resident's irrigation clock and valves. The control unit automatically disrupted voltage signals to the valves whenever the soil was wet. Twenty-eight units were installed in Providence and 9 in Salt Lake City. Of those 37, 27 provided water use data of sufficient quality and completeness to enable comparison with data from prior years. Compared to prior years, the 27 residences used an average of 10% less water during the 1996 season than did the control group. Twenty-eight of 36 users said they were impressed by the system's simplicity, automation, and lack of maintenance. The authors found no statistically significant differences in water use patterns or savings between the two cities, indicating that the cost of water (which was higher in Providence) did not affect the degree of conservation.

2.3.43 Performance of Soil Moisture Sensors During Field Operations: Update

By Aquacraft, Inc.
93 pages.
1997.
http://www.aquacraft.com/sites/default/files/pub/Aquacraft-%281997%29-Performance-of-Soil-Moisture-Sensors-During-Field-Operations-Update.pdf

This report updates a study Aquacraft performed in1994 (reference 2.3.44). The update was performed partly because the irrigation industry continued to express reluctance to use the SMS technology. Working with the City of Boulder, CO, Aquacraft tested Watermark soil moisture sensors and Watermark electronic modules for single- and multi-family residences, commercial sites, and urban parks. Aquacraft evaluated system performance, including the ability to match irrigation to requirements, after the systems had operated for several years in the field. Aquacraft found that, with minor exceptions the devices effectively controlled automatic irrigation systems and limited application rates to ET. The authors found that the time and cost of maintaining and operating the systems were minimal; the systems remained reliable after several years.

2.3.44 Performance of Soil Moisture Sensors During Two Years of Field Operations

By Aquacraft Water Engineering.
26 pages.
1994.
http://www.aquacraft.com/sites/default/files/pub/Aquacraft-%281994%29-Performance-of-Soil-Moisture-Sensors-During-Two-Years-of-Field-Operations.pdf

This report adds a second year of data to the information Aquacraft reported in December 1993. One goal was to enable a detailed comparison of water application verses demand in SMS systems. The second goal was to distribute as many sensors to contractors and homeowners as practical to discover whether, with limited input from the project team, laymen could install and operate the devices properly.

Data on water use, rainfall, and temperature were collected during the 1993 and 1994 irrigation seasons to estimate daily ETN using the Blaney Criddle procedure. Then the Aquacraft could compare the theoretical irrigation requirement (based on ETN, irrigation efficiency, and soil moisture capacity) to applied irrigation water. Not only did the soil moisture sensors reduce water use compared to the control group, but they managed to limit irrigation to levels well below the theoretical ET requirements.

2.4 Evaluation and Testing

The following resources represent efforts to test or standardize smart controllers or to evaluate their overall performance in actual use. Several studies listed under controller water savings review other aspects of controller performance, such as irrigation adequacy and turfgrass quality. Those studies are not repeated here.

2.4.1 Innovative Conservation Program (ICP)

By the Metropolitan Water District of Southern California.
Projects started in 2011 and completed in June 2013.
http://www.bewaterwise.com/icp.html

Metropolitan's ICP, in cooperation with the U.S. Bureau of Reclamation, funds research that documents the water savings and reliability of innovative water-saving devices, technologies, and strategies. New projects are chosen every other year. The 2011 program focused on landscape irrigation and commercial, institutional, and industrial water use efficiency. One project was titled, "Evaluate water savings from Cyber-Rain's XCI Cloud irrigation controller at 12 commercial sites." Real-time web-based irrigation water use data based on local tiered water rates was to be used to motivate and evaluate customer conservation. The project, performed by Cyber-Rain, Inc., was to be completed by June 2013.

2.4.2 Evaluation of Smart Irrigation Controllers: Year 2012 Results

By C. Swanson and G. Fipps.
Funded by the Texas Water Resources Institute, Technical report TR-443.
29 pages.
June 2013.
http://twri.tamu.edu/publications/reports/2013/tr-443/

This report summarizes the evaluation of smart controller performance during 2012. In 2008 Texas A&M University at College Station established a facility for testing controllers from the point of view of an end user (that is, a landscape or irrigation professional). Controllers were tested using a Texas virtual landscape, which comprised 6 zones having varying plant materials, soil types and depths, and precipitation rates. For 2012 nine controllers were evaluated for 216 days, from April 30 to December 2. Controller performance was analyzed for both the summer and fall seasons. Controller performance was compared to irrigation recommendation of the

TexasET Network and website. Testing also sought to identify controllers that applied excessive or inadequate amounts of water.

The report notes that programming smart controllers for individual site conditions continues to be difficult. Only two of the nine controllers could be programmed directly with all the parameters needed to define each zone. ET values recorded off the controllers were inconsistent throughout the study, often greater than 150% of ET from the TexasET Network weather stations.

2.4.3 Long Term Expanding-Disk Rain Sensor Accuracy

By L. Meeks, M. Dukes, K. Migliaccio, and B. Cardenas-Lailhacar.
Journal of Irrigation and Drainage Engineering, Vol. 138, No. 1, pages 16–20. 2012.
ascelibrary.org/doi/abs/10.1061/(ASCE)IR.1943-4774.0000381
**Abstract only*

Throughout almost 5 years, researchers evaluated the accuracy of expanding-disk rain sensors. Researchers evaluated seven combinations of rain sensor model and rainfall setpoint: the Wireless Rain-Clik (WL) rain sensor; Mini-Clik (MC) rain sensors with rainfall setpoints of 3, 6, 6, and 13 mm (3MC, 6MC, Hunter, and 13MC); Irritrol RFS 1000 at a 6 mm setpoint (Irritrol); and Toro TWRS at a 6 mm set point. The WL and MC configurations plus four replicates were studied for 1,182 days. The Hunter, Irritrol, and Toro configurations plus eight replicates were monitored for 1,150 days. The authors collected data to determine the total time each configuration spent in interrupt mode and to compare those results with rainfall measured on site. The authors conclude that for the most accurate and consistent behavior, Hunter Mini-Clik and Hunter Wireless Rain-Clik rain sensors should be replaced after 1 year; Irritrol RSF 1000 and Toro TWRS rain sensors do not require replacement for at least 3 years. Rain sensors could increase water savings to homeowners and have environmental benefits but should not be used in applications requiring an accuracy consistently greater than 70%.

2.4.4 Smart Water Application Technologies: 2012 Update

By B.E. Vinchesi, Chairman, Irrigation Association Smart Water Application Technology Committee and Standards and Codes Committee.
Presented at the WaterSmart Innovations Conference, 2012. 26 slides.
http://www.watersmartinnovations.com/PDFs/2012/12-T-1213.pdf

The author presented slides to describe the status of smart water application technology (SWAT) as of 2012. He reviewed the history of and participants in the development of SWAT testing. At the time the Irrigation Association was developing testing protocols for high-uniformity sprinkler nozzles and check valves. Both draft protocols were open for public comment. A technology to be evaluated next is system interruption devices.

2.4.5 Examination of SWAT Protocol Utilizing a Performance Analysis of Weather-Based Irrigation Controllers: Update with Extended Data

By M.D. Dukes and S. Davis, Univ. of Florida.
Submitted to Eastern Research Group (ERG) under ERG Project 0264.01.005; UF Project 000 898 65. 48 pages.
January 2011.
http://www.epa.gov/watersense/docs/controller_2010-epa-report.pdf

The objective of this report was to analyze the effects of variable weather conditions on performance of the SWAT test. SWAT tests were performed in Florida on three brands of ET controller. The controllers—two signal-based systems and one stand-alone controller—had been tested previously under the SWAT protocol. For this study, controllers were evaluated under a range of weather conditions, such as frequent/infrequent rainfall and high/low ETo. The controllers met the proposed minimum threshold of 80% for irrigation adequacy, but throughout the study generally failed to meet the threshold of 95% for scheduling efficiency based on the minimum score for the six zones established for SWAT testing. Over-irrigation was a frequent issue. The study also found that, in general, the addition of a rain sensor increased or did not affect the SWAT scores.

2.4.6 Maximizing Effective Agronomics in Landscapes with Soil Moisture Sensors

By J.J. Peters, American Society of Agronomy.
Irrigation Show, San Antonio, TX, December 2–4, 2009,.
http://irr.confex.com/irr/2009/webprogram/Paper2821.html
**Abstract only*

This presentation reviewed the information needed to make agronomically sound irrigation decisions, including the consideration of soil type, soil water-holding characteristics, and plant water requirements. The presenter discussed optimal water management and described the benefits and challenges of making irrigation decisions based on weather-based or soil moisture-based systems. The capabilities of soil moisture-based irrigation controls were discussed, including long-term performance, control, and effectiveness. The presenter reviewed the performance of various techniques for measuring soil moisture and summarized the agronomic benefits of smart watering approaches.

2.4.7 Examination of SWAT Protocol Utilizing a Performance Analysis of Weather-Based Irrigation Controllers: Final Report

By M.D. Dukes and S. Davis, Univ. of Florida.
Submitted to Eastern Research Group (ERG) under ERG Contract GS-10F-0036K; UF Project 000 759 98.
July 2009.

WaterSense adopted the SWAT protocol for testing the suitability of various WBICs for inclusion in the WaterSense labeling program. The objectives of this study were to (1) determine the reproducibility and transferability of the SWAT protocol for testing climate-based controllers; (2) analyze the test requirements such as rainfall, ETo, and minimum test length; and (3) determine the significance of the penalty for rainfall and irrigation occurring on the same day.

2.4.8 Irrigation Association Smart Water Application Technologies Scores & Water Conservation Potential

By M.D. Dukes, C.C. Romero, and M.S. McCready, Univ. of Florida.
2009.
http://www.irrigation.org/Resources/Technical_Papers.aspx
**Abstract only, obtained through search of the Irrigation Association website.*

This study aimed to compare SWAT scores for irrigation adequacy and scheduling efficiency of controllers to the water conservation potential evaluated under field conditions. The field results showed that the efficiency of irrigation scheduling generally decreased as rainfall and irrigation adequacy increased. High scores were not mandatory for guaranteeing good turf quality and did not guarantee significant water conservation. Although SWAT protocol testing screens controllers for their ability to adjust to the conditions of irrigated landscapes, it does not guarantee water conservation.

2.4.9 Monitoring & Control of Smart Irrigation Systems

By D.D. Adhikari, D. Zoldoske, D. Goorahoo, and F. Cassel S., Center for Irrigation Technology, California State Univ. Fresno, and P. Gupta, i-Linc Technologies, LLC.
http://irrigationtoolbox.com/ReferenceDocuments/TechnicalPapers/IA/2008/2265translated.pdf

The authors describe progress on a web portal for compiling and communicating weather data that can be used to control irrigation. At the time of their writing, the authors had finished and tested the beta version of the web portal. Data were collected remotely from four locations (Idaho, Fresno, Riverside, and Chile); stored; processed; tabulated; and presented on a graphic dashboard on the web portal. The data included soil moisture, soil temperature, and electronic flowmeter readings. The authors then began testing the control components, the recommendation module, and the crop model that is incorporated into the control module. The crop model is intended to control soil moisture thresholds for a given crop automatically throughout the growing season. Tests were being performed on a 0.8-acre plot divided into 12 beds 400 feet in length. Of the 12 beds, 6 were being irrigated manually and the other 6 were being managed by a SMART irrigation controller. The water usage for the test beds will help quantify water use efficiency. The authors also planned to examine crop yields to calculate a return on investment.

2.4.10 How to Design, Implement, and Evaluate a Smart Controller System

By T. Ash.
HydroPoint Data Systems, Inc.
2005.
**Abstract only, obtained through search of the Irrigation Association website.*

The author notes that results of research into controller performance differ widely depending on study design. The author described basic requirements for conducting effective studies of smart controller systems. Using cases from successful and unsuccessful studies by municipal and private water utilities, the author highlighted lessons learned and advantages gained.

2.4.11 The Irrigation Association Smart Water Application Technologies (SWAT)

http://www.irrigation.org/SWAT/

The Irrigation Association (IA) acts as the center and clearing house for efforts related to smart water application technologies (SWAT). The IA website has a link to tested products: http://www.irrigation.org/SWAT/swat.aspx?id=298, including climate-based controllers, sensor-based controllers, and rain sensors. The website also has a link to the testing protocols the IA has developed: http://www.irrigation.org/SWAT/swat.aspx?id=299, which apply to controllers, rain sensors, and sprinklers.

2.5 Shipments

Data on shipments of products that either do or do not carry the WaterSense label are necessary for building the national water savings model for outdoor water use (the NWS-O model). The expectation is that shipments of WaterSense-labeled devices will increase. Annual data on shipments improve the accuracy of the model's predictions of water and monetary savings attributable to the WaterSense program.

2.5.1 Irrigation Controller Manufacturer Annual Reporting 2013

Form developed by and to be returned to EPA WaterSense.

The reporting form asks WaterSense manufacturer partners to provide annual data on (1) total number of controllers shipped, (2) total number of WBICs shipped that meet WaterSense specifications, (3) total number of WaterSense-labeled controllers shipped, and (4) information regarding the company's certification as a WaterSense partner.

2.6 Marketing and Market Penetration

WaterSense is a market transformation program that affects consumer purchases by labeling high-efficiency water-using products. Market conditions for past years are described by historical data. Historical and base-case data will be input to the NWS-O model, which is under development by Lawrence Berkeley National Laboratory (LBNL). The estimated future increase in market share of efficient controllers represents the influence of the WaterSense program at the unit level and demonstrates the results of the program's informational and promotional efforts. Some resources in this section were discussed previously but are described here in relation to market conditions.

2.6.1 Soil Moisture Sensor Technical and Market Research Report

By the Eastern Research Group, Inc. (ERG), for the U.S. EPA Municipal Support Division Office of Wastewater Management under EPA Contract No.EP-C-09-008, Work Assignment 3-05. 55 pages.
April 2013.

This ERG report describes SMS products, their attributes, and their installation. The authors were unable to quantify current or potential market penetration for SMSs because they found no applicable market information. The authors describe barriers to market penetration. One conclusion: "The preliminary cost-effectiveness assessment demonstrates that soil moisture sensors are cost-effective only where there is the potential for end users to save large amounts of water." Among outstanding issues (described in chapter 8 of the report) is the lack of an industry-accepted performance testing protocol.

2.6.2 Water Use Efficiency and Market Transformation: Smart Irrigation Timer Case Study

By J.M. Berg, Water Use Efficiency Programs Manager of the Municipal Water District of Orange County (MWDOC).
Presented at La Verne Water Technology Conference, Water Conservation Agency Panel. 13 slides.
January 2013.
http://laverne.edu/news/files/2013/02/Joseph-Berg-Municipal-Water-District-of-Orange-County.pdf

The presenter described the issue of over-irrigation and the MWDOC smart timer program. The program began in the 1990s, completed pilot and field studies, and then reached full implementation. The process began when water agencies and the Irrigation Association (IA) began a partnership in 2002. After the IA developed SWAT, water agencies relied on it for more than 5 years to identify products suitable for rebate programs. In 2012, the U.S. EPA began to encourage voluntary design efforts.

The presenter noted that based on MWDOC studies, average savings from SmarTimers were always positive. For all brands there were sites that saved water, those that showed no significant change in water use, and those where water use increased. MWDOC studies also found home owner-installed smart timers outperformed professional installations, perhaps because owners had more incentive to learn how to use and maintain the controllers. The presenter noted that although SmarTimers are a new technology that requires a consumer learning curve, controller manufacturers are developing significant technical resources to assist consumers, such as online videos for installation and programming and calculators for developing irrigation schedules.

2.6.3 2006 Residential Water Conservation Benchmarking Survey and Attribution/Consumption Analysis: Final Report

By Dethman & Tangora LLC, Seattle, WA.
Prepared for Seattle Public Utilities. 80 pages.
November 2007.
http://www.allianceforwaterefficiency.org/WorkArea/showcontent.aspx?id=2540

In 2006 researchers conducted telephone interviews of a random but representative sample of residential water customers. The interviews, which lasted 20 to 25 minutes, found that the percentage of households that did not water their lawns during the summer had grown from 30% in 1999 to 53% in 2006. Those who watered their lawns, however, appeared to do so more often. In 1999, 21% of households with lawns watered at least every 3 days; in the drought of 2001 that figure dropped to 11%. By 2006, the percentage had risen to 19%. Gardens were watered more frequently than lawns, with 25% of respondents saying they watered their gardens at least every other day (compared to 10% for lawns), and 23% saying they watered garden areas every 3 days (compared to 9% for lawns). Nineteen percent of households overall had automatic underground sprinkling systems, more among wholesale customers (25% compared to 15%).

Per-person, average consumption during the peak summer season was 11% less for households that had been made aware of the need and methods for conserving water than households that were unaware. Researchers recommended ways to spread awareness of water use issues and increase adoption of smart irrigation controllers. Sixty percent of survey respondents voiced strong concerns about looming environmental issues. Researchers recommended that Seattle's Saving Water Partnership increase its leadership presence in helping customers understand the future of water supply in the Puget Sound region. The authors also noted that utilities serve as an essential impetus for saving water—the majority of customers (58%) said that utility efforts have influenced them to take water-saving actions. Additional recommendations included developing tools to help consumers better grasp their household’s water use, expanding the definition of “high-use households,” and targeting avid gardeners as well as households that have automatic underground sprinkler systems (both of which tend to be high peak users.)

2.6.4 Statewide Market Survey: Landscape Water Use Efficiency

By the Institute of Applied Research and Policy Analysis and the Water Resources Institute at California State Univ., San Bernardino.
With funding from the California Urban Water Conservation Council, the U.S. Bureau of Reclamation, and the California Urban Water Agencies.

65 pages, including 4 appendixes.
June 2007.
http://wri.csusb.edu/documents/LandscapeMarketingSurvey_Final.pdf

This survey revealed areas of potential promise for advancing landscape water conservation programs—both for individual water users and for professionals who manage large urban landscapes. The authors surveyed homeowners and landscape managers about their irrigation behaviors and their attitudes toward water conservation messages. Results were similar to those of other studies (e.g., a 2006 advertising study performed by Metropolitan Water District of Southern California, and a marketing survey done in 2007 by the San Diego County Water Authority). The authors found that almost two-thirds of properties managed by landscape managers did not have irrigation systems that shut off in response to rain. The authors concluded that all market segments ultimately need information, well-crafted messages, and targeted incentives to help them make necessary changes to water use.

2.6.5 Draft Weather-Based Irrigation Controller Technical and Market Research Report

By Eastern Research Group, Inc. (ERG), for the U.S. EPA Municipal Support Division Office of Wastewater Management under Contract No. GS-10F-125P, Work Assignment BPA-05-02/TO 8. 75 pages.
May 2007.

This report describes irrigation controller products and current and proposed water efficiency standards. The report also describes the state of the market for WBICs: market size and growth rate, major manufacturers, distribution channels, degree of market penetration, and market potential.

At the date of this publication, WBICs made up a relatively small part of the residential irrigation market. ERG noted that as the market transforms and the technologies become more widespread, “a market penetration rate of 10% may be achievable.”

2.6.6 Water Conservation Market Penetration Study

By Water Resources Engineering.
46 pages: 118 pages of text plus appendixes.
March 2002.
http://www.ebmud.com/sites/default/files/pdfs/market_penetration_study_0.pdf

In 2001 the East Bay Municipal Utility District (EBMUD) conducted a market penetration survey to (1) collect data on attitudes and behavior regarding water conservation, (2) determine the types and saturation of water-conserving hardware, (3) assess water conservation potential for identified market sectors, and (4) relate the findings to those of previous studies. The survey's findings expanded the ability to make inferences about the market penetration of water-conserving hardware, the rate of hardware replacement, and customer behavior. EBMUD conducted telephone interviews, developed databases, and scheduled appointments to visit single- and multi-family customers in the district. Although the survey focused strongly on indoor water uses and fixtures (toilets and showerheads), it also examined outdoor use at both single- and multi-family residences.

Although the survey obtained no water consumption data that enabled quantifying potential water savings from improved irrigation efficiency, results provided the breakdown of landscapable and irrigated areas at each site and gathered information on types of irrigation systems used. In summer the outdoor water use of residents east of the Bay Area hills averaged from 120% to 390% of winter use (ratios of summer to winter water use of between 1.2 and 3.9). The ratios of summer to winter water use west of the hills ranged from 0.75 to 1.25 for all but one group; houses built after 1990 showed a ratio of 1.42.

2.6.7 SmartWater Forum/SWAT survey

By the Irrigation Association (IA).
http://www.irrigation.org/Resources/Survey_Results.aspx

Following the SWAT forum at the 2009 WaterSmart Innovations conference, the IA surveyed participants regarding irrigation technology and consumer marketing and education. Although only 41 people responded, the IA used the results, summarized below, to help shape SWAT's direction.

- Respondents indicated that, of available irrigation technologies, they would like to see customers use smart controllers, drip and micro-irrigation, and multi-stream rotating nozzles.
- Respondents wrote that product education should focus on why the products are needed, their effects (e.g., statistics on resulting water savings), and system maintenance.
- Participants recommended high-level messaging rather than technical details, with an emphasis on verified data rather than costs.

2.7 Lifetime, Payback Period, and Cost-Effectiveness

One input to the NWS-O model is product lifetime, because purchase, repair, and maintenance costs are distributed over a product's lifetime. The model will compare the lifetime value of water savings to the initial higher cost associated with higher-efficiency controllers. Some resources in this section were discussed previously but are described here in relation to information on cost.

2.7.1 Soil Moisture Sensor Technical and Market Research Report

By Eastern Research Group, Inc. (ERG), for the U.S. EPA Municipal Support Division Office of Wastewater Management under EPA Contract No.EP-C-09-008, Work Assignment 3-05. 55 pages.

April 2013.

This study projected potential water and cost savings from soil moisture sensors (SMSs). Table 6-1 in the report describes studies that estimate potential water savings from SMSs. Appendix B describes how ERG calculated potential water savings and cost-effectiveness. If a household that had a SMS used 15% less water than one with no SMS, that household could save as much as 8,700 gallons per year based on an average outdoor water use of 58,000 gallons per year (from REUWS; reference 1.2.7). The report concludes, "The preliminary cost-effectiveness assessment demonstrates that soil moisture sensors are cost-effective only where there is the potential for end users to save large amounts of water."

2.7.2 Soil Moisture Sensor Landscape Irrigation Controllers: A Review of Multi-Study Results and Future Implications

By B. Cardenas-Lailhacar and M.D. Dukes.
Presented at the 5th National Decennial Irrigation Conference as Paper No. IRR109600. Transactions of the American Society of Agricultural and Biological Engineers, Vol. 55, No. 2, pages 581-590.
2012. ISSN 2151-0032.
http://abe.ufl.edu/mdukes/pdf/publications/SW/SW9335_soil-moisture-sensor-review.pdf

When the authors began experimenting on soil moisture sensor (SMS) systems in 2004, prices commonly approached $500 per unit. By 2011, some of the tested units could be purchased for less than $200. Considering the high price of potable water in some localities of Florida and potential water savings from using an SMS, the payback period for an SMS unit could be 2 years or less at an average single-family home in Florida. Results under normal to wet conditions (fairly common in Florida and other parts of the Southeast) showed that commercially available SMSs can reduce irrigation by 42% to 72% on average, while maintaining turf quality ratings above 6. Under dry weather conditions, however, every SMS-based treatment resulted in lower water savings, ranging from -1% to 64%, and turf quality at or below the minimum acceptable level.

2.7.3 Final MWDOC Smart Timer Rebate Program Evaluation

By A & N Technical Services, Inc., Encinitas, CA.
Prepared for the Municipal Water District of Orange County (MWDOC).
59 pages.
November 2011.
http://www.mwdoc.com/cms2/ckfinder/files/files/SmartTimerRebateEval_Final.pdf

This evaluation estimated the cost-effectiveness of the Smart Timer Rebate Program. The authors estimated the total volume of water savings from the rebate program including residential and commercial sites, to be 2,615 acre-feet during an expected 10 year product lifetime. The cost per acre-foot for the rebate program provides savings that are favorable compared to the cost of additional water supplies imported into Orange County. At the time imported water cost $869 per acre-foot (Metropolitan's 2011 Tier 2 treated water rate) and was projected to increase to $1,700–$1,800 per acre foot by 2020. Water savings per site were estimated to be 9.4% (about 49.3 gpd) at single-family residential sites and 27.5% at commercial sites (about 726.6 gpd).

2.7.4 Evaluation of California Weather-Based "Smart" Irrigation Controller Programs

By P. Mayer, W. DeOreo, M. Hayden, and R. Davis, Aquacraft, Inc.; E. Caldwell and T. Miller, National Research Center, Inc.; and P.J. Bickel.
Presented to the California Department of Water Resources by the Metropolitan Water District of Southern California and the East Bay Municipal Utility District.
July 2009.

This study involved surveys of water agencies and of customers. Acceptable survey data were available from 625 sites having smart controllers. The goals of the evaluation were to determine (1) the water savings (if any) associated with the use of smart controllers, and (2) factors that affect water savings. A cost-effectiveness analysis examined the level of investment that might be appropriate given estimated water savings from targeted and non-targeted smart controller programs.

The cost-effectiveness analysis estimated the justified expense of an upgrade (or new installation) over an expected product lifetime of 10 years. The authors calculated the net present value of the cost of water during that 10-year period using an annual discount rate of 3%. The present worth of 10 years of water savings was calculated for customers purchasing a smart controller at a range of retail price values. For utilities, the authors calculated 10 years of savings for a range of avoided costs for water. The authors analyzed cost-effectiveness using the estimated average and median water savings per customer for sites measuring 4,000; 12,000; 25,000; or 150,000 square feet. Those areas reflect the usual range of residential and non-residential landscapes in Northern and Southern California. The avoided cost of water for the California agencies in the study ranged from about $100 to $1,000 per acre-foot.

2.7.5 Expanding Disk Rain Sensor Performance and Potential Irrigation Water Savings

By B. Cardenas-Lailhacar and M.D. Dukes.
Journal of Irrigation and Drainage Engineering, Vol. 134, No. 1, pages 67-73. 2008.
http://www.abe.ufl.edu/mdukes/pdf/publications/RS/Cardenas-Dukes-RS-paper-JID.PDF

The experiment described in this article evaluated two brands of rain sensors. Results indicated that where water costs exceed $0.53 per cubic meter ($2.00 per thousand gallons), the payback period is less than a year for the Wireless Rain-Click and Mini-Click rain sensors set at 13 mm or less.

2.7.6 Draft Weather-Based Irrigation Controller Technical and Market Research Report

By Eastern Research Group, Inc. (ERG), for the U.S. EPA Municipal Support Division Office of Wastewater Management under Contract No. GS-10F-125P, Work Assignment BPA-05-02/TO 8. 75 pages.
May 2007.

This report presents a cost-effectiveness analysis of smart controllers. The authors developed low and high values for estimated water savings based on studies that examined households before and after installing WBICs. Savings were based on an irrigation water use of 58,000 gallons per year per home, the total outdoor water use per home reported in the REUWS. The authors estimated cost savings using a water rate of $2.65 per kgal. Their preliminary assessment indicated that WBICs were cost-effective only for high-end water users who had the potential for water savings of more than 20%. The water rate of $2.65 per kgal the authors used likely differs throughout the United States. Cost-effectiveness for a water agency would depend on the agency's cost of water and the expected water savings.

2.7.7 Los Angeles Department of Water and Power (LADWP) Weather-Based Irrigation Controller Pilot Study: Executive Summary

By A. Bamezai, Western Policy Research.
Submitted to the LADWP. 8 pages.
August 2004.
ftp://ftpdpla.water.ca.gov/users/prop50/09610_Mojave/Regional%20Water%20Conservation%20Program/EXCERPTS%20Regional%20Water%20Conservation%20Program/LADWP%20Weather%20Based%20Irrigation%20Controller%20Pilot%20Study%20EXCERPT.pdf

This pilot study evaluated two products that provide weather-based irrigation scheduling: (1) Hydropoint Inc.'s ET controller sold under the trade name WeatherTrak, and (2) Water2save LLC's weather-based scheduler. A customer who has a quarter-acre of (turf-equivalent) landscape, supplied by a dedicated irrigation meter, could expect to save about $1,124 to $1,527 during 10 years (the assumed device lifetime), depending on whether a 6% or 0% discount rate is assumed. If the site is connected to a mixed-use meter, the customer's water savings during 10 years would reach a value of between $2,062 and $2,801 because LADWP charges higher water rate for such meters. For mixed-use accounts that include sewer charges, the dollar benefits would about double. Avoided water costs to LADWP during a 10-year period would range from

$1,153 to $1,566. The estimates depend greatly on landscape area, rising proportionally with size.

3 ANALYTICAL AND MODELING EFFORTS

This section describes the efforts of others to analyze and model outdoor water savings, as well as the modeling efforts of staff of the Lawrence Berkeley National Laboratory (LBNL). Some of the resources have been discussed previously.

3.1 Analytical Efforts

Below we describe resources that attempted to analyze financial and water-saving effects of smart irrigation programs.

3.1.1 Final MWDOC Smart Timer Rebate Program Evaluation

By A & N Technical Services, Inc., Encinitas, CA.
Prepared for the Municipal Water District of Orange County.
59 pages.
November 2011.
http://www.mwdoc.com/cms2/ckfinder/files/files/SmartTimerRebateEval_Final.pdf

The authors used historical account-level water use records and several climatic measures to develop climate-adjusted estimates of water savings from installation of smart timers. The authors utilized regression methods based on panel data (time-series cross sections). Their evaluation of 70 single-family accounts showed an average 9.4% water savings, or about 49.3 gpd, from use of smart timers. The authors stated that their high-resolution evaluation methods could distinguish minor water savings with great statistical confidence. By contrast, they said, simpler evaluation techniques (t-statistics of difference of mean annual use) were unable to distinguish a 10% difference in water use.

3.1.2 The California Water Smart Irrigation Controller Project—Results and Perspective on a Large Field Study of an Important Emerging Technology

By P. Mayer et al., Aquacraft, Inc.
Presented by A. Webb-Cole, Metropolitan Water District of Southern California; J. Bauer, East Bay Municipal Utility District; R. Eagle, Contra Costa Water District; K. Galvin, Santa Clara Valley Water District; and P. Mayer, Aquacraft.
Presented at the WaterSmart Innovations Conference, Las Vegas, NV, October 7-9, 2009. 84 slides
http://www.watersmartinnovations.com/PDFs/Wednesday/Sonoma%20C/1500-%20Peter%20Mayer-%20The%20California%20Water%20Smart%20Irrigation%20Controller%20Project.pdf

Tasks for the project encompassed a process evaluation (including surveys of both customers and agencies) and an impact evaluation (analyses of water savings and cost/benefit). Representatives of water agencies in both Southern and Northern California described their efforts to put more smart controllers into service at residential and commercial properties. The data required to perform the project's impact analysis were at least 1 full year of pre- and at least 1 full year of post-installation water consumption data; weather data for the concurrent period from CIMIS and the National Climatic Data Center (more than70 weather stations); and site-specific landscape area.

3.2 Modeling Efforts

The following resources describe the methodology behind various models that enable us to estimate water use and potential savings. -.

3.2.1 Chapter 5, Research Methods, and Chapter 9, Models of Water Use, Outdoor Models

By W.B. DeOreo et al., Aquacraft, Inc.
In California Single Family Water Use Efficiency Study.
Sponsored by the California DWR; managed by the Irvine Ranch Water District.
June 2011.
http://water.cityofdavis.org/Media/PublicWorks/Documents/PDF/PW/Water/Documents/California-Single-Family-Home-Water-Use-Efficiency-Study-20110420.pdf

This report describes development of a project database based on household location and meter information, billing data, ET data, water event data from flow traces (approximately 2 million records), survey responses, and landscape information. Based on the variables obtained from all the data sources, Aquacraft developed an outdoor water use model that had the best overall fit to the data and could best predict outdoor water use based on empirical observations. The model utilizes aerial photographs of houses and available data to identify areas and rates of irrigation.

3.2.2 National Water Savings Models for (1) Residential and (2) Commercial and Institutional Sectors

By Lawrence Berkeley National Laboratory.
Prepared for the EPA WaterSense Program.
Residential model: March 2008; commercial and institutional: 2010.

The authors collected data and developed model inputs regarding baseline water consumption; water prices; product shipments, efficiencies, and lifetimes; and annual, cumulative, and discounted savings. The authors developed two models: the national water savings model for the residential sector (NWS-R), and the national water savings model for the commercial/institutional sector (NWS-CI). The models enable users to project shipments, efficiency trends, and savings under base-case and policy scenarios. Market shares of efficient products and price impacts also are evaluated.

3.2.3 Appendix G, Water Savings Simulation Program

By the California Department of Water Resources.
In Urban Water Use in California. Bulletin 166-4.
August 1994.
http://www.water.ca.gov/historicaldocs/irwm/b166-1994/apgndx.html

Forecasted water use was modeled first under current laws and levels of conservation (baseline use). Then estimates were made of the expected water savings from implementation of increasingly intensive conservation efforts such as Best Management Practices. The expected savings were subtracted from the baseline to estimate future water use.

The simulation program produces multiple estimates of future water consumption for each year of a given forecast period. Each estimate is based on randomly selected values from distributions of each of the uncertain parameters in the forecast and savings formulas. The forecasting model combines the selected values to produce a single estimate of water use for each forecast year. Forecasts are presented as point estimates plus confidence intervals to describe each estimate's uncertainty, which increases as the forecasts consider longer periods.