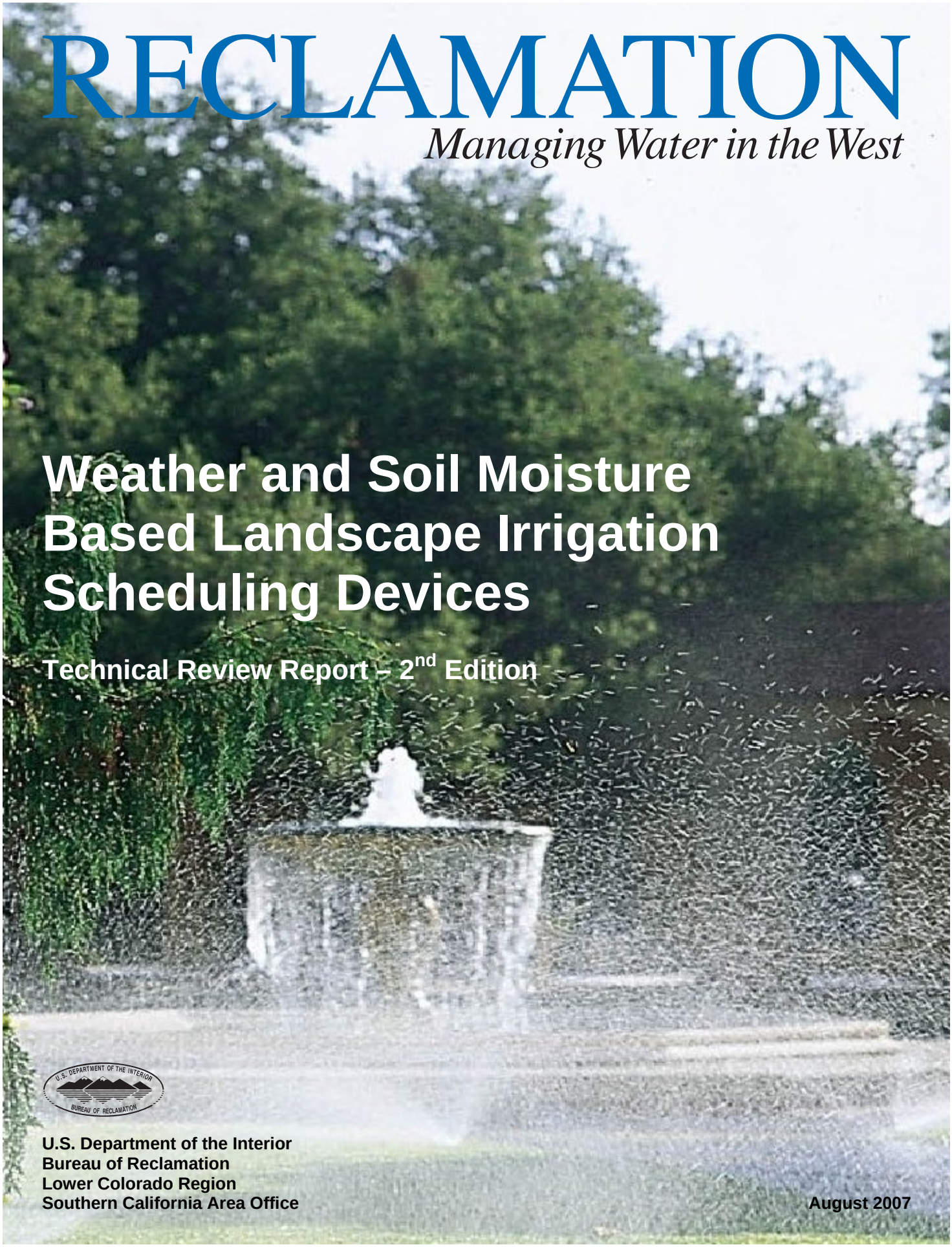


RECLAMATION

Managing Water in the West

Weather and Soil Moisture Based Landscape Irrigation Scheduling Devices

Technical Review Report – 2nd Edition

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region
Southern California Area Office

August 2007

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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

For copies of this report contact
Reclamation's Southern California Area Office at 951-695-5310
or download at http://www.usbr.gov/waterconservation/docs/SmartController.pdf

Weather and Soil Moisture Based Landscape Irrigation Scheduling Devices

Technical Review Report – 2nd Edition

prepared by

Southern California Area Office
Temecula, California

and

Technical Service Center
Water Resources Planning and Operations Support Group
Denver, Colorado

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region
Southern California Area Office

August 2007

Contents

Page

List of Tables iv
List of Figures v
Acknowledgements vii
Disclaimer vii
Introduction 1
Smart Irrigation Technology Overview 2
Weather Based Irrigation Control System Principles 5
Weather Based Control Product Features and Comparison Criteria 7
- Installation 7
- Stand-Alone Controller Versus Add-on Device 7
- Irrigation Schedules and Run Time Calculation and Adjustment 8
- Application Rates and Distribution Uniformity 8
- Irrigation Run and Soak Cycles 8
- Landscape Establishment/Fertilizer and Syringe Programs 9
- Crop Coefficients 9
- Rain Sensors and Gauges and Rain Interrupt or Delay 9
- Other Sensors 10
- Power Supply and Surge and Lightning Protection 10
- Station Circuit Rating, Wiring and Terminal Wire Sizes 10
- Clock Mode Operation 11
- Display and Data Review 11
- Non-volatile Memory and Batteries 11
- Warranty and Reliability 11

Weather Based Product Descriptions 12
- Accurate WeatherSet 12
- AccuWater 15
- Alex-Tronix 19
- Aqua Conserve 23
- Calsense 27
- Cyber-Rain 32
- ECO Research 35
- ET Water Systems 38
- Hunter 43
- HydroPoint 46
- Hydrosaver 51
- Irrisoft 53
- Irritrol 56
- Rain Bird 59

Rain Master 62
Toro 67
Tucor 70
Water2Save 73
Weathermatic 78
Weathermiser 83
Soil Moisture Based Irrigation Control System Principles 88
Soil Moisture Based Control Product Features and Comparison Criteria 89
Soil Moisture Sensor Types 89
Installation 91
Stand-alone Versus Add-on Controller 92
Irrigation Schedules and Run Time Calculation and Adjustment 92
Single Versus Multiple Soil Moisture Sensors 92
Soil Temperature and Conductivity Measurement and Display 93
Soil Moisture Sensor Accuracy and Calibration 93
Power Supply and Surge and Lightning Protection 94
Station Circuit Rating, Wiring and Terminal Wire Sizes 94
Warranties and Reliability 94
Soil Moisture Based Product Descriptions 95
Acclima 95
Agrilink 100
Baseline 103
Calsense 106
Dynamax 108
Irrometer 113
LawnLogic 117
Waternomics 120
References Cited 123
Summary of Weather Based Product Information and Features 124
Summary of Soil Moisture Based Product Information and Features 126

List of Tables

Table 1 - Accurate WeatherSet Prices (Include Solar and Rain Sensors) 14
Table 2 - Retail Prices for Aqua Conserve Controllers 26
Table 3 - Calsense ET2000e water budget feature data 29
Table 4 - Calsense Products Price Summary 31
Table 5 - WeatherTRAK Controller and Accessories Prices and Fees 49
Table 6 - Summary of WeatherTRAK Demonstration Projects 50
Table 7 - Irrisoft Product Prices 55
Table 8 - Summary of Irrisoft Demonstration Projects 56
Table 9 - Irritrol Smart Dial Controller, Module and Accessory Prices 58
Table 10 - Rain Bird ET Manager and Accessories Prices 61

Table 11 - Toro Intelli-Sense Controller and Accessories Prices 69
Table 12 - Tucor Controller Product Prices 72
Table 13 - Weathermatic SmartLine Controllers and Component Prices..... 81
Table 14 - Weathermiser Prices 85
Table 15 - Acclima Product Prices 99
Table 16 - Baseline Product Suggested Retail Prices 106
Table 17 - Dynamax Products Retail Prices 112
Table 18 - Irrometer Products Retail Prices..... 116
Table 19 - LawnLogic Current Retail Prices 119

List of Figures

Figure 1 - Accurate WeatherSet ET compared to AMETS ET 15
Figure 2 - AccuWater prescribed irrigation quantity relative to reference ET 19
Figure 3 - Alex-Tronix temperature budget compared to CIMIS ET 22
Figure 4 - Graph of Calsense 2000e water budget feature data 30
Figure 5 - Cyber-Rain graphical interface example..... 33
Figure 6 - Cyber-Rain Watering Index settings example 34
Figure 7 - ECO 100 calculated ET versus CIMIS reference ET..... 38
Figure 8 - Rain Master Weather Center II ET versus CIMIS reference ET 64
Figure 9 - Water2Save water savings data..... 77
Figure 10 - Comparison of Weathermatic ET to CIMIS ET 82
Figure 11 - Sample of Weathermatic field study results..... 83
Figure 12 - Weathermiser performance related to weather data..... 86
Figure 13 - AquaBlu Demo Site Irrigations and Soil Moisture Tracking..... 103
Figure 14 - Watermark performance compared to turf water requirement..... 117

Acknowledgements

This report was prepared with the assistance of Bureau of Reclamation Technical Service Center staff and numerous individuals from other government agencies and private industry. The Technical Service Center's Water Resources Planning and Operations Support Group, Water Resources Division performed research and product review activities, and coordinated report preparation. Staff from the U.S. Environmental Protection Agency (EPA), Metropolitan Water District of Southern California (MWDSC), Municipal Water District of Orange County (MWDOC), Irvine Ranch Water District (IRWD), and Northern Colorado Water Conservancy District (NCWCD) provided comprehensive reviews of the draft report.

The preparers of this report acknowledge the significant input provided by these agency and district staff and extend their thanks to the following individuals: Ms. Stephanie Tanner, EPA; Ms. Joanna Kind and Ms. Christy Milstead, Eastern Research Group, Inc. for EPA; Mr. John Wiedman, MWDSC; Mr. Steve Hedges and Mr. Joe Berg, MWDOC; Ms. Fiona Sanchez, IRWD; and Mr. Brent Mecham, NCWCD.

Representatives of the reviewed product manufacturers provided product information and approval of their respective product discussion sections of the report. The preparers of this report very much appreciate each of these individuals' input. It is acknowledged the report's level of detail could not have been achieved without the significant assistance provided by the product manufacturers' representatives. These individuals are identified in the product information and features summary tables located at the end of the report.

Disclaimer

Nothing in this report constitutes endorsement by the Bureau of Reclamation of a particular product or method. A significant portion of the information presented in this document was provided by the product manufacturers' representatives. Some of this information was verified by third parties as appropriate and as possible given the scope of the review. Every effort was made to accurately incorporate the information provided and to avoid errors and oversights, but it is recognized some may exist. The Bureau of Reclamation plans to update this report periodically and any identified deficiencies will be corrected at that time. Errors, omissions and new product information should be reported to Mark Spears at 303-445-2514 or mspears@do.usbr.gov or to Reclamation's Southern California Area Office at 951-695-5310.

Introduction

Water agencies implementing water use efficiency programs have long struggled to achieve quantifiable and reliable water savings. Historically, programs targeting landscape savings have focused on education pertaining to irrigation system maintenance, irrigation scheduling and climate appropriate plantings. Although these efforts have garnered savings, much potential exists for further landscape irrigation efficiency improvements.

In the late 1990's, the Irvine Ranch Water District, Municipal Water District of Orange County and Metropolitan Water District of Southern California learned of an emerging irrigation management technology using weather based irrigation scheduling devices. This technology removes the need to make manual scheduling adjustments because the "smart" device adjusts the schedule automatically as weather changes. A water savings evaluation of this technology was implemented which is known as the "Residential Weather-Based Irrigation Scheduling – The Irvine ET Controller Study". This evaluation identified an average single-family home savings rate of 37 gallons per day (irwd.com, 2001).

In an effort to address non-point source pollution, a second weather based irrigation scheduling study was performed to evaluate the linkage between improved residential irrigation management and reduced dry-weather runoff. The "Residential Runoff Reduction (R3) Study" reported comparable water savings of 42 gallons per day per single-family home (irwd.com, 2004). Savings at non-residential sites were 545 gallons per day. The R3 Study also quantified a reduction in runoff ranging from 64 to 71 percent. With this change in runoff volume, concentrations of pollutants did not change therefore pollutants were reduced by a like amount.

Although soil moisture sensors have been used in agricultural and research applications for many years, this technology has only recently been applied successfully in the landscape irrigation field. Initial attempts to use soil moisture sensors to control landscape irrigation were unsuccessful due to the state of the technology, maintenance requirements and cost. Within the past several years, soil moisture sensor technology has advanced significantly with accurate and maintenance free systems being offered by several companies at competitive prices. Recent study findings indicate water savings resulting from soil moisture based smart systems are similar to those discussed above for weather based systems (Allen, 1997; Cardenas-Lailhacar et al., 2005; DeOreo et al.; Mecham).

Water agencies throughout the country recognize smart irrigation control as an emerging tool to achieve landscape water savings and reduce non-point source pollution. When the first study began, the study team was aware of only a few

smart technologies. Today, nearly 30 smart irrigation control manufacturers exist and others are quickly emerging into the marketplace.

In 2003, the Municipal Water District of Orange County approached the Bureau of Reclamation, Southern California Area Office and requested an objective evaluation of weather based residential irrigation scheduling technologies available to consumers. A technical review was performed to document the overall status of weather based residential technologies and provide general descriptions of these products. The purpose of the review was to compile existing information and allow water agencies to quickly gain knowledge about the technologies for use in their residential incentive programs.

The results of the review were published in Reclamation's May 2004 Technical Review Report "Weather Based Technologies for Residential Irrigation Scheduling." Since 2004 Reclamation has monitored the status of the products reviewed in the original report and researched many other smart irrigation scheduling products, including soil moisture sensor based and commercial products. An updated technical review report entitled "Weather and Soil Moisture Based Landscape Irrigation Scheduling Technologies" was published in August 2006, which included information on smart irrigation control products by 26 companies that were available as of June 2006.

This report includes information on smart irrigation control products by 28 companies that were available as of June 2007. Three additional companies have been added and one companies' products are no longer available in the U.S. Previously reported product information (models, pricing, etc.) has been updated and minor revisions have been made throughout the document. It is Reclamation's intention to continue to update the report as often as needed in an attempt to keep all information current.

Smart Irrigation Technology Overview

Smart irrigation control systems typically include either a stand alone controller or an add-on device which interfaces with a conventional clock-type controller. The weather or soil moisture based technologies incorporated into these devices allow them to function similar to a thermostat. Like a thermostat, the devices permit irrigation to occur when needed rather than on a preset schedule. Regardless of the specific method or technology, the concept is for the appropriate irrigation quantity to be applied at the appropriate time.

Most of these systems are available in a variety of sizes appropriate for small residential to large commercial applications. For this report, a device with more than a 12 station (zone) capacity is considered large residential or light

commercial. In most cases, light commercial products possess the same features as the residential products, but have greater station capacity. Larger industrial type commercial products possess high station capacity and offer additional features such as flow sensing, surge and lightning protection, multiple master valve circuits, concurrent station operation, and other sophisticated features.

Computerized central control system type products are beyond the scope of this review. These consist of multiple "satellite" controllers that are controlled through a centralized computer system allowing for monitoring and control of multiple irrigation system parameters including flow rates, pressures, pumps, master valves, etc. from a single location. Several of these systems are mentioned since they are offered by the companies that sell stand-alone devices. Also, some of the stand-alone controllers reviewed possess central control system type features.

SWAT Testing

In an effort to set an industry conservation standard, the Irrigation Association® (IA) has organized the Smart Water Application Technologies™ (SWAT™) initiative. This initiative functions as a partnership with constituents from public entities and private companies from the landscape irrigation industry. The first products for which testing protocols have been developed are for climatologically based irrigation control products. The current climatologically based testing protocol (7th Draft) was approved in November 2006 and has been implemented for testing. The current draft soil moisture sensor based protocol (Phase 2, 1st Draft) was posted in April 2006 and implementation is pending further review and preliminary testing.

The Center for Irrigation Technology at California State University – Fresno (CIT) has been contracted by the IA to conduct SWAT bench mark testing. Climatologically based testing began in 2005. The testing is done in a laboratory environment using a "virtual landscape" that is subjected to a representative climate based on weather station data. The purpose of the testing is to evaluate the ability of a device to adequately and efficiently irrigate the virtual landscape. Although actual irrigation does not occur, the test measures the irrigation quantities prescribed by the device for 6 different zones with varying site conditions (soil and plant types, ground slope, sun/shade, irrigation system, etc.) The test duration is for 30 consecutive days with total minimum rainfall and evapotranspiration (ET) of 0.4 and 2.5 inches, respectively. Testing results are summarized in performance reports (performance summaries and technical reports) which are posted on the IA's website (http://www.irrigation.org/SWAT/Industry/ia-tested.asp) as test results are released by manufacturers. The summaries include percentage scores in the categories of Irrigation Adequacy and Irrigation Excess. The technical reports include details associated with these scores.

At the time of this report, performance reports for 9 manufacturers had been posted. Since the IA does not disclose which products have been tested until a performance report is released, it is unknown how many of the other weather based products have been submitted for testing. Certain manufacturers have indicated concerns regarding the SWAT testing and reported they will not submit their products for testing unless certain protocol changes are made. Whether or not a device has been submitted for SWAT testing and the status of the testing, when a performance report is not posted, is discussed in this report only if this information was made available by the manufacturer.

EPA WaterSense Program

In 2006, the EPA introduced its voluntary public-private partnership WaterSense Program. The mission of the WaterSense Program is to protect the future of our nation's water supply by promoting and enhancing the market for water-efficient products and services. It is being modeled after the EPA's successful Energy Star Program. The WaterSense logo will be displayed on the labels of certified products. EPA staff are evaluating the potential for adoption of the SWAT protocols discussed above for WaterSense certification of weather and sensor based landscape irrigation control devices.

Reported Water Savings

Most of the product descriptions in this report discuss water savings. In some cases, water savings associated with various studies and demonstration projects are discussed. In most cases the water savings discussed are as reported by the manufacturer. It is discussed if water savings related study reports were submitted as part of this review, and or if the reports are publicly available. It is significant to understand water savings can be calculated by numerous methods and verification can be difficult.

In some cases the reported water savings are average values for multiple installations, and in other cases savings for a selected site are reported. Regardless of a product's reported water savings potential, actual savings will vary significantly from user to user depending on weather, irrigation system and site conditions, and previous irrigation practices. A properly installed irrigation system (piping and sprinkler heads) with acceptable distribution uniformity is critical to realizing water savings and maintaining a healthy landscape.

No Rating of Products

No attempt has been made to rate the products relative to each other. Certain comparison criteria are discussed, and it is left to the reader to research further and determine which products may suit various applications most appropriately.

Weather Based Irrigation Control System Principles

All of the weather based products reviewed operate on the principle of scheduling irrigation as a function of weather conditions. Most of the products use real time or historic weather data to schedule irrigation based on evapotranspiration (ET), which is a function of weather conditions and plant type. ET is defined as the quantity of moisture that is both transpired by the plant and evaporated from the soil and plant surfaces.

The American Society of Civil Engineering's (ASCE) standardized reference ET equation parameters are maximum and minimum air temperature, net solar radiation, average vapor pressure and average wind speed. Vapor pressure can be calculated from humidity, dry and wet bulb, or dew point data and solar radiation can be derived from pyranometer or sunshine recorder data. The standardized reference ET equation is widely recognized as the best empirical method for estimating ET (Allen et al., 2005). Other less accurate equations are also used which require only temperature and solar radiation parameters, and solar radiation is sometimes estimated as an average value based on historic data for a given site latitude. The problem with using estimated solar radiation values is the significant variability due to cloud cover is neglected, and solar radiation is the single most important parameter in ET calculation using the ASCE standardized equation. Some of the products evaluated use these empirical ET equations in their scheduling algorithms. It is significant to consider which equation is used with regard to ET estimation accuracy, or what parameters are measured if the equation used is not referenced.

Each of the weather based irrigation scheduling systems evaluated utilize micro-processing devices which calculate or adjust irrigation schedules based on one or more of the following parameter sets: weather conditions (temperature, rainfall, humidity, wind and solar radiation), plant types (low versus high water use and root depth), and site conditions (latitude, soils, ground slope and shade). Some of the systems are fully automatic, and others are semi-automatic. The semi-automatic systems typically require the user to enter a base daily irrigation schedule, and then the device determines the frequency (which days) irrigations occur or adjusts run times. Some of the semi-automatic system manufacturers provide guidelines for establishing the base schedule and others do not.

A significant factor in comparing the products that use real time weather data is the quality of the data used. The cost to install and maintain a complete weather station onsite in order to collect the data necessary to use the standardized reference ET equation is prohibitive in most cases. Two techniques are used to collect current weather data as alternatives to onsite weather stations. Specifically, irrigation demand is calculated either using a limited set of on-site

measurements, or using a full set of weather station data from a remote site. There are trade-offs associated with both methods.

If only a limited set of data are used to calculate ET with onsite sensors, the accuracy of the calculated ET may be poorer than ET calculated with a full set of weather station data. Conversely, if the remote weather station data used are not representative of the irrigator's site, the calculated ET value and or rainfall sensing or measurement may not be accurate. Some of the weather station data being used may not be adequate for ET calculation. Specifically, some weather stations being used do not measure radiation, but calculate it from other parameters, and some stations are not properly located for ET parameters data collection.

Certain products reviewed use on-site temperature measurements combined with historic monthly ET or solar radiation data in the daily ET calculation. The historic data used are a function of the site location. An obvious consideration with this technique is the accuracy of the historic data relative to a specific site. In one case only five sets of data are available for the entire U.S.

Several of the products reviewed calculate ET using a full set of remotely collected data from local weather stations or a network of weather sensors. The weather station data are collected from public and or private weather stations. The weather station and sensor network data are processed by a centralized computer server, and transmitted to the irrigation sites. There are ongoing service provider costs associated with the operation of the weather stations, sensor networks, computers, and information transmission systems associated with these products. These costs are either absorbed by water entities or are paid by the users.

In some cases, compelling study results were submitted by the manufacturers showing accurate ET calculation and or significant water savings associated with their product as discussed under the product descriptions. In addition to the SWAT testing discussed above, a science-based evaluation of 4 of the weather based products reviewed was conducted by the University of California Cooperative Extension in 2003 and the results are reported by Pittenger et al. (2004). Most studies to date have evaluated individual products rather than comparing the performance of multiple products. Given the general lack of data, it is difficult to draw conclusions about the overall performance of one product or technique versus another.

Weather Based Control Product Features and Comparison Criteria

Significant weather based controller product components and features are discussed below. The discussion also identifies different methods used to achieve similar results by the various products, and associated advantages and disadvantages.

Installation

Although most of the manufacturers recommend professional installation and programming of their products, several indicate installation and programming of its residential models can be done by “do-it-yourself” type homeowners. Most of the individuals associated with residential product demonstration programs and pilot studies who were interviewed during this review expressed concerns about homeowner installation and programming. Based on the review of installation and programming instruction materials only, it appears some devices could be more difficult to install and program than others. The degree of difficulty to install any of the products can vary significantly depending on site-specific conditions. It appears that all of the commercial products should be professionally installed. Installation and programming instructions are available for many of the products at their websites. All potential customers should review this information when shopping for a device regardless of whether they plan to do their own installation and programming.

In the development of Smart irrigation device promotion programs, water agencies should consider requiring professional installation or requiring users to attend workshops to receive training before performing self-installation.

Stand-Alone Controller Versus Add-on Device

The primary component of most of the products reviewed is an automatic irrigation controller in place of a traditional clock type controller. Alternatively, several of the products include a receiver or scheduler that is connected to an existing controller. In some cases, the lower cost of the add-on device is a significant attraction. Regardless of cost, the quality of an existing controller should be a factor when considering replacement. If the existing controller is a high quality unit with adequate features, an add-on receiver may be an attractive alternative. The level of automation is limited with some of these units relative to some of the stand-alone controller systems. Specifically, some devices only prescribe irrigation frequency or adjust preset run times and do not automatically calculate run times.

Irrigation Schedules and Run Time Calculation and Adjustment

Some of the products reviewed will automatically generate irrigation schedules and run times for various zones as a function of sprinkler application rate, plant and soil types, slope and sun/shade conditions, and distribution uniformity. The ability of the automatic controllers to accurately generate an efficient schedule is dependent on the controller, the user's knowledge of the landscape parameters and proper programming. Other devices require a base irrigation schedule with specific run times which are entered by the user. In which case, the user must manually calculate run times based on experience and or guidelines provided by the manufacturer. Some of these controllers adjust the preset run times based on weather conditions, and others only control the irrigation run frequency. The product descriptions identify the manufacturers that provide guidelines for determining appropriate run times for the devices that require a base schedule. Automatic run time calculation can be a significant advantage if the required programming inputs are known and the controller calculates accurately.

Regardless of automatic or manual run times, many of the products have a fine-tune feature which allows adjustment of station run times by a percentage factor or by minutes giving the user the ability to compensate for inadequate run times.

Application Rates and Distribution Uniformity

Some of the products reviewed allow the user to enter actual sprinkler application rates versus preprogrammed rates based on irrigation type (spray, rotor, drip, etc.). Application rates can be measured by the user if not provided by the sprinkler manufacturer.

The irrigation system's distribution uniformity or efficiency factor (typically a percentage) describes the effectiveness of the sprinkler head coverage, and reflects the quality and layout of the sprinklers. This setting allows the controller to compensate for low uniformity. The majority of a system with low distribution uniformity must be over irrigated in order for all areas to receive adequate water.

Irrigation Run and Soak Cycles

All of the stand-alone controllers reviewed provide for multiple run and soak times to limit runoff. Some calculate them automatically by zone based on soil and ground slope conditions, and others require manual programming. Of those that require manual programming and for the add-on devices, certain manufacturers provide guidelines or computer programs for calculating the times.

Regardless of automatic or manual calculation, by zone multiple run/soak cycles ability is a very advantageous feature.

Landscape Establishment/Fertilizer and Syringe Programs

Some stand alone controllers provide landscape establishment or fertilizer programs which allow for programming high irrigation quantities for a certain time frame before reverting to the weather based programming. Plant establishment programs can preclude over-irrigation and runoff occurring for extended periods due to a landscape contractor programming for establishment of a new landscape.

Syringe programs are designed for installation and system testing purposes. The program provides a convenient means of executing a short run time for each station.

Crop Coefficients

All of the controllers that automatically calculate run times can utilize pre-programmed crop coefficients set by the manufacturer by plant type. Some provide the user the option of programming custom crop coefficients. This can be advantageous since crop coefficients typically vary geographically.

Rain Sensors and Gauges and Rain Interrupt or Delay

Most of the products reviewed include a rain sensor or gauge with the system, or as an optional add-on accessory. These have a rain interrupt and or delay feature triggered by the sensor or gauge, or irrigation schedule adjust feature. Some of the products' only interrupt ongoing irrigation when significant rainfall is detected and others initiate an adjustable irrigation delay period. Some systems adjust the irrigation schedule based on the amount of rainfall measured. Although no documentation was reviewed for this report on the measurement accuracy of different types of rain gauges and sensors, it is assumed the tipping bucket type gauges are more accurate than hygroscopic type rain sensors (sensors that absorb rainfall). Some of the receiver type systems have the ability to initiate a rain interrupt/delay or adjust the irrigation schedule based on rainfall detected or measured at a nearby weather station. Other receiver type systems use an on-site rain sensor or gauge that has the advantage of detecting or measuring rainfall that actually occurs at the site.

Other Sensors

Some of the products reviewed include standard or optional solar radiation, humidity, wind, temperature and flow sensors. In addition to calculating irrigation demand using temperature data, some of the devices interrupt or delay irrigation when wind and or temperature conditions are adverse to irrigation. Alternatively, some of the systems delay irrigation based on wind and temperature conditions measured at a local weather station. Most of the commercial products include flow sensor input terminals. In addition to monitoring to detect for high and low flows indicative of irrigation system problems, some of the controllers factor flow conditions into automatic scheduling decisions.

Power Supply and Surge and Lightning Protection

With one exception, all of the stand-alone controllers include a power transformer that converts 110-120 volts of alternating current (VAC) to 24 VAC. The transformers are either hardwired inside the controller cabinet (internal), or plugged into a power outlet (external). The Alex-Tronix controller operates on a pulsed 9 volts of direct current (VDC) using battery power. The add-on scheduling devices operate on either 24 VAC, 9 VDC or 12 VDC and either receive power from the existing controller or from an external transformer. Most of the transformer devices include some type of current overload protection such as a fuse or breaker switch. Some controllers include lightning and or surge protection, or offer these as an optional feature. Surge and lightning protection limits damage to the controller's circuitry from transient voltage and current from the power source (surge) and from the valve circuits (lightning).

Station Circuit Rating, Wiring and Terminal Wire Sizes

The compatibility of the existing electrical circuits (wiring from the controller to the station valves) should be considered in the selection of a replacement irrigation controller. If the station wire terminals on the controller will not accept the existing wire, adapters must be used. Also, the circuit current capacity required for an existing system should be checked prior to installing a new unit. Reports from demonstration studies indicate installation problems associated with insufficient circuit capacity to operate some irrigation valves with high circuit resistance.

The traditional wiring system (circuitry) used for most controllers consists of a common and a dedicated wire from the controller to each valve and sensor. Some controllers utilize "2-wire" circuitry that consists of a single pair of wires connected to all of the valves and sensors in the system. These systems require the installation of a decoder device for each valve and sensor. Applications

include large systems and linear systems (e.g., highway corridors) with large quantities of wiring required for traditional circuitry.

Clock Mode Operation

Most of the controllers reviewed will operate in a standard clock mode. Some of them can be programmed for clock mode operation by station. One of the controllers that receives a scheduling signal does not have clock mode capability. Therefore, if the signal subscription is cancelled the controller must be replaced.

Display and Data Review

It is advantageous for a device to have a large easy-to-read display which displays settings and data. Ideally, the data review control should be backlit and easy to use. It should display information by zone for run times, soak times, irrigation amounts, percent adjustments, ET and other weather information, watering window and irrigation history.

Non-volatile Memory and Batteries

All of the products reviewed have non-volatile memory to protect their programming during power outages. Some of the products also include a backup battery for maintenance of the date and time during power failures, and those that do not provide this back-up protection within the non-volatile memory.

Warranty and Reliability

All of the products reviewed come with a warranty. Warranty periods are discussed separately in the review of each product. In some cases, the manufacturers' warranty periods vary for its different products. Although the warranty periods may or may not be indicative of the life expectancy of the products, in some cases there appears to be a correlation between the cost and overall quality of the product to the warranty period. It is assumed the cost of a product somewhat reflects the quality of the construction materials and electronic components. Hence the less expensive residential devices should not be expected to last as long and function as reliably as the more expensive residential and commercial products. Since most of the devices are relatively new products, it is difficult to speculate on how long they should last.

Depending on site conditions and maintenance, the weather sensors and other outdoor components may be vulnerable to degradation due to exposure to the elements. The availability of replacement sensors and their costs should be considered for those systems with on-site weather sensors.

Weather Based Product Descriptions

The following product descriptions address operational characteristics and features, and include discussions of available information from demonstration and pilot studies relative to documented water savings and operation. Each of the manufacturers was provided with copies of the product descriptions for their input prior to being incorporated into this report.

Accurate WeatherSet

Accurate WeatherSet is located in Winnetka, California. WeatherSet has manufactured commercial weather based irrigation controllers for landscapes, golf courses and greenhouses since 1979. The company started development of its first residential controller prototypes in 2000, and began marketing the residential controllers in September 2001. All WeatherSet controllers utilize a solar sensor and rain sensor to automatically adjust irrigation schedules. The solar sensor, designed and fabricated by WeatherSet, measures solar radiation which is the major factor affecting the controller's ET calculation.

The WeatherSet controller is called the Smart Timer™, and it comes in 8, 12, 16, 24, 32, 40 and 48 station models. The Smart Timer is a stand-alone controller and does not require communication with remote servers to obtain weather data or irrigation schedules, and there are no ongoing service costs. The controller calculates ET with input from an onsite solar radiation sensor. WeatherSet reports the solar sensor has functioned reliably in demanding environmental conditions to control greenhouse and outdoor misting systems since the early 1990's.

Operational Features

The WeatherSet controller calculates a daily ET estimate based on solar sensor SunFall™ measurements that are logged by the controller on a 2-minute frequency. The sensor must be installed in a mostly sunny location in order to function accurately. Adaptive control logic allows the controller to function with some shading. From their work with commercial controllers, WeatherSet reports

that SunFall reduces by about two-thirds from a clear day in summer to a clear day in winter, and that their 5 self-adjusting programs follow these changes.

The calculated ET information is combined with rain sensor data and user programmed information to schedule irrigation. To program the controller for automatic adjustments, the user assigns each station to one of three programs, which are labeled Flowers™, Lawns™ and Shrubs™. The Flowers, Lawn, and Shrubs programs are for shallow, medium and deep-rooted plants, respectively. A fourth program called LWU (low water use) will deliver water to California native plants that expect no rain from May through September and winter rains from October through April. A runoff limit, in minutes per hour, may also be entered for each station to stop runoff. The user enters a MAX Runtime for each station and the Smart Timer automatically adjusts the watering days and runtimes for each valve. The controller has a manual start function, and an optional irrigation history review function. With the H-option, the controller keeps a running tab of total run time for each station.

The controller's rain sensor is an Ecologic RainBrain™. The sensor signals the controller to interrupt irrigation in its rain shut-off mode, and the rain sensor signals are also used by the controller for irrigation scheduling. The WeatherSet controller is preprogrammed to account for the duration that the rain shut-off circuit has been interrupted when scheduling irrigations.

The WeatherSet irrigation controller provides 7 different runoff limits that are set for each station. A maximum cycle run time of 2, 4, 6, 8, 11, 15, 20 and unlimited number of minutes per hour may be set for each valve. The default cycle limit factor is four minutes per hour. As an example, if the controller calculates a total 12-minute run time for a station, this station will be irrigated in three 4-minute increments over a 3-hour period, with the default setting. For stations that generate runoff, WeatherSet recommends the user measure the time required to cause runoff (using the manual run mode), divide the time by two and use that time to choose the runoff factor for the station. The runoff factor may be shut off to allow continuous watering when required. For example, valves controlling drip systems in LWU programs may best be watered with the runoff limit shut off.

Descriptions, Prices and Warranty

Two Smart Timer indoor residential controller models and seven outdoor commercial models are available. The indoor controller cabinets are constructed of aluminum with dimensions of 5.5" x 7.5" x 1.5", and the indoor power transformer is an external plug-in type unit. The lockable outdoor cabinets are constructed of zinc plated steel with powder coating and stainless steel hinges, and they come in three sizes. The respective dimensions for 8-12, 16-24 and 32-48 station models are 9" x 10.5" x 4", 10.5" x 9.5" x 4.5" and 14" x 12" x 4.5". The outdoor models include internal power transformers. The 16-station and larger models include flow sensor connectivity, station circuit testing and

surge/lightning protection features. The station circuit current rating for the indoor units is 0.75 amperes and it is 1.5 amperes for the outdoor units. All models' station circuit terminals will accommodate wiring sizes from 12 to 20 gauge. The controller's program memory is non-volatile, and the time-keeping microprocessor chip uses a 3.3-volt coin-type battery that has a reported life of ten years.

Low volume rebate program prices are summarized in Table 1. (Retail prices are approximately 150 percent higher.) The prices include the solar and rain sensors. The controllers are available directly from WeatherSet by telephone (818-993-1449) or e-mail (www.weatherset.com). The company plans to also distribute the product through select specialty irrigation contractors. The Smart Timer controllers come with a 3-year warranty.

Table 1 - Accurate WeatherSet Prices (Include Solar and Rain Sensors)

Controller Type	Model No.	Price
8-Station Indoor	ST8R	$148
12-Station Indoor	ST12R	$168
8-Station Outdoor	ST8C	$240
12-Station Outdoor	ST12C	$275
16-Station Outdoor	ST16C	$320
24-Station Outdoor	ST24C	$480
32-Station Outdoor	ST32C	$640
40-Station Outdoor	ST40C	$800
48-Station Outdoor	ST48C	$960
Solar and Rain Sensor Unit		$50
Irrigation History Function	H-option	$35

Installation

WeatherSet reports that 95 percent of homeowners included in the Municipal Water District of Orange County rebate program using the Smart Timer installed the controller themselves. Based on this, it appears that the typical homeowner can understand and program the WeatherSet Smart Timer. Technical support is available by telephone and through the company's internet site. Service by factory-trained contractors is limited to California, Oregon, Washington, and Colorado at this time. WeatherSet reports this area will grow as their market expands. The installation and programming instructions, which include directions for locating the solar sensor, appear to be adequate and easy to follow.

Track Record, Water Savings and SWAT Testing

WeatherSet has provided data showing close correlation between ET estimate calculation by their controller and that calculated by an AZMET (Phoenix, Arizona ET network) weather station. A graph of this data is shown in Figure 1.

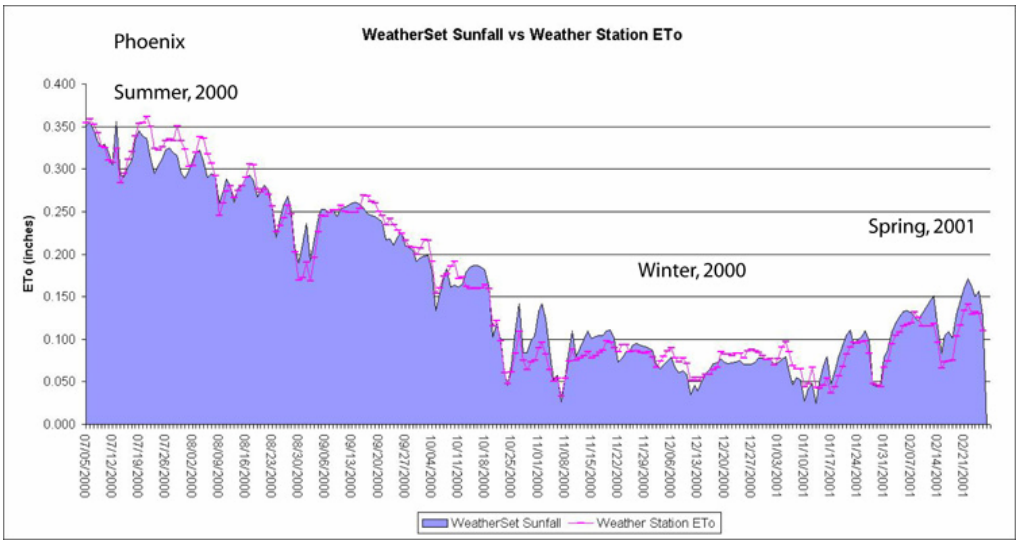


Figure 1 - Accurate WeatherSet ET compared to AMETS ET

WeatherSet controllers have not been included in any formal demonstration studies and no water savings data were evaluated for this report. A SWAT test performance report for the Smart Timer controller was not available for this report. The WeatherSet controller appears to be a simple and relatively economical stand-alone weather based irrigation controller which comes with onsite rain and solar sensors.

AccuWater

AccuWater, Inc. was incorporated in October 2002 and is based in Austin, Texas. The company has developed a centralized, weather-based irrigation management system for residential and commercial property applications. The AccuWater system has been in development since mid-2000 and pilot testing was performed from October 2002 through July 2004. The company has been actively marketing their system within Texas since July 2004. Sales outside of Texas began in July 2005.

AccuWater™ is a network-centric irrigation control system that is based on the latest Internet hardware and software technologies. AccuWater controllers are designed to irrigation industry standards and connect directly to all 24 VAC valves, replacing any existing “clock.” The AccuWater data center is located in Austin, Texas in a professionally managed Internet co-location facility. Communication and data transfer between the controllers and the data center is accomplished through an Internet connection.

Currently supported configurations include: wireless (802.11b/g), wired (Cat5 Ethernet), GPRS (digital cellular) radio.

The AccuWater system schedules irrigation based on calculated soil moisture in each irrigation zone. Soil moisture is updated hourly for each zone taking into account local weather (rainfall and ET) and actual irrigation (as reported by the AccuWater controller). To ensure the accuracy and timeliness of the weather data, AccuWater utilizes a combination of attached weather sensors and publicly available weather sources including the National Oceanic and Atmospheric Administration (NOAA), the California Irrigation Management Information System (CIMIS), and the Missouri Agricultural Bulletin Board (AgBB). A backup schedule, based on recent ET, allows the controller to irrigate for up to 21 days without network connectivity. This schedule can be modified through an ethernet computer connection to the controller.

One of the unique attributes of the AccuWater system is that it can share weather data between nearby units via the AccuWater data center. The AccuWater controllers send weather data to the data center, and the data center fills in missing data elements from nearby sites by searching a pre-defined hierarchy. The server then sends each controller a complete weather context for that location including temperature, humidity, barometric pressure, wind speed and rainfall. As a result, AccuWater controllers can receive current weather conditions and make decisions (adjust, delay or abandon) without the benefit of on-site weather sensors.

Operational Features

AccuWater controllers are configured and managed by the end user on the company's website.

Configuration information for each controller includes:

- Location (latitude, longitude and elevation)
- Environmental limits (temperature and wind speed)
- Watering window (including "no water" days)

Configuration information for each zone includes:

- Plant type
- Soil type and depth
- Precipitation rate
- Flow rate
- Distribution efficiency
- Sun and rain exposure
- Cycle-and-soak
- Soil moisture depletion limit
- Minimum and maximum irrigation limits

Controllers can be grouped into “locations” and any location can be delegated to another user (free accounts) or to one of AccuWater’s landscape maintenance partners. This allows owners to maintain control and monitor water usage while simultaneously allowing authorized third parties to manage AccuWater systems remotely. AccuWater provides a free, cell phone remote control program. This program enables the end user (or their authorized delegate) to access and control his/her AccuWater controller from anywhere.

At 6:30 pm local time each day, the AccuWater data center calculates a one-time-use irrigation event for each irrigation zone based on calculated soil moisture and the National Weather Service (NOAA) local rain forecast. If the forecast includes a high probability of rain and soil moisture levels allow, irrigation may be deferred for 24 hours. Irrigation events are sent to and stored on the controller for execution during the watering window. If weather conditions are not appropriate for irrigation, the controller will wait for conditions to improve. If conditions do not improve before the watering window closes, no irrigation will occur. In the event data are not available, a 21-day back-up schedule is calculated based on recent ET.

Descriptions, Prices and Warranty

The model R116 AccuWater controller is an indoor unit with a 16-station capacity, including one station terminal that may run concurrently with all the other stations to control a master valve or pump start relay. The controller housing is constructed of injection-molded ABS plastic, and the transformer is external to the controller. The station circuit terminals will accept 14 gauge and smaller wire sizes and the station circuit current rating is 0.75 amperes. All AccuWater controllers include percent adjust, syringe cycle, distribution setting features and surge and lightning protection. The retail price for the R116 controller is $549. Up to three R116 controllers can be interconnected to create 32 or 48 station units.

AccuWater also sells commercial grade 16, 32 and 48 station models in ventilated outdoor steel enclosures priced at $1099, $1699 and $2499, respectively. The outdoor unit has an internal transformer with 2.0 ampere circuit capacity. The optional GPRS radio is priced at $495 and requires an Internet wireless plan from T-Mobile or Cingular.

Annual service fees start at $149 for 16 stations. Fees are based on the number of equipped stations at a “location” and the cost per station declines as the number of stations increases. A location is defined as a contiguous property under a single owner/operator.

AccuWater's circuitry is based on a 75 megahertz Java-based central processing unit. It has one megabyte of volatile storage and 4 megabytes of non-volatile memory, as well as a 10-year lithium ion battery just for the onboard clock. All configuration and operating data for AccuWater controllers are stored in the AccuWater data center. After a power or network interruption, the controller will synchronize itself with the data center. If a connection to the data center cannot be made, the controller will reload its operating program and configure data from non-volatile memory.

To ensure accurate rainfall data, AccuWater recommends the use of their wired, tipping bucket rainfall gauge ($150). The gauge is commercial grade and is constructed of UV-resistant, heavy-gauge, white nylon. AccuWater also offers temperature, humidity, barometric pressure, wind speed/direction and solar radiation sensors for direct connection to the controller. Additionally, AccuWater controllers can utilize real-time weather data from Campbell Scientific Turf Weather and WeatherHawk weather stations over an Internet connection. In the absence of a local weather station on the AccuWater network, the system will automatically utilize data from NOAA, CIMIS or AgBB. Other state-wide weather networks will be integrated as needed.

AccuWater provides a one-year limited warranty on their products. AccuWater products are currently available directly from the company or from AccuWater-certified irrigation contractors.

Installation

AccuWater reports that many homeowners are capable of installing and configuring the controller, but professional installation is recommended. The AccuWater website (www.accuwater.com) provides a step-by-step guide to installing and configuring the product. Technical support is available by telephone at 512-331-9283 and through the company's website, and local technical service representatives are available for service calls.

Installation of the AccuWater system involves (1) installing the AccuWater controller in place of the existing controller; (2) installing weather instrument(s) and connecting to the new controller; (3) performing an initial site survey to determine flow and precipitation rates; and (4) configuring the stations and performing a test run of all stations.

Because of its Internet-centric design and web-based controls, the AccuWater system integrates easily into most home automation systems. As of this writing, the following companies have committed to integrating AccuWater into their whole-home automation solutions: Crestron, AMX, Control4, Vantage Controls and Convergent Living.

Track Record, Water Savings and SWAT Testing

As of November 2005, AccuWater had accumulated over 700 controller-months of operating data. AccuWater reports its analysis of these data suggest that average water savings are in the 30 percent range, with individual controllers yielding savings as high as 55 percent. The chart shown in Figure 2 is taken directly from the AccuWater web site for a residential property in Austin, Texas. It shows the AccuWater prescribed irrigation quantity relative to reference ET as reported by Texas A&M University.

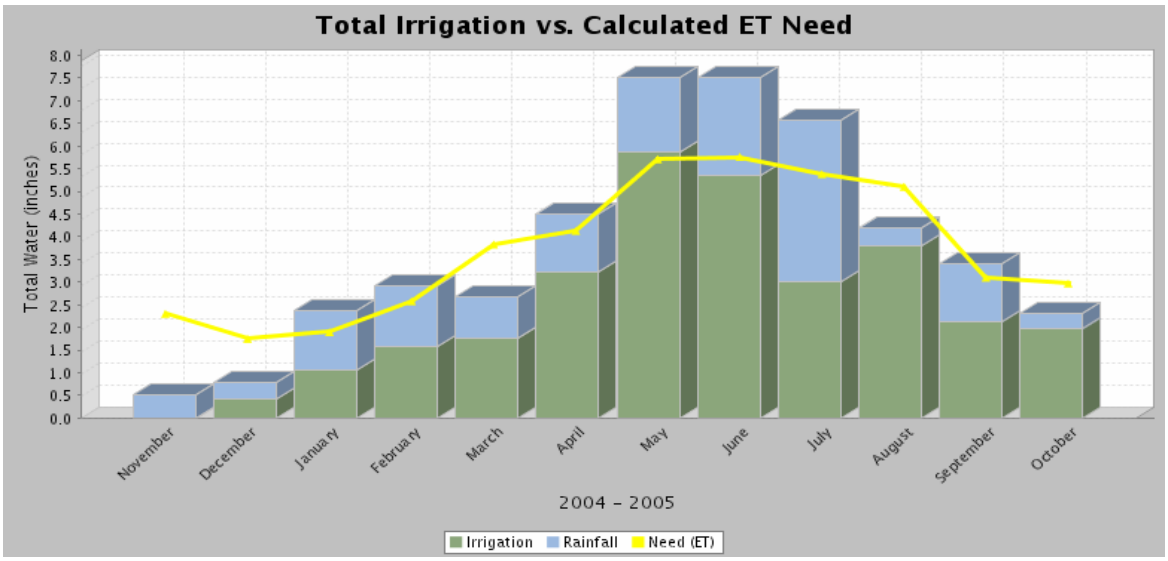


Figure 2 - AccuWater prescribed irrigation quantity relative to reference ET

The Accuwater System's computer interface provides an apparently easy and effective method for monitoring irrigation information and weather conditions. This system should satisfy the more demanding and affluent portions of the residential weather based irrigation controller market. Accuwater has not submitted its product for SWAT testing.

Alex-Tronix

Alex-Tronix® Controls is a division of GNA Industries, Inc. and is located in Fresno, California. This manufacturer of turf irrigation controllers was established in 1977 and specializes in battery operated controllers. The Alex-Tronix Smart Clock® and Enercon Plus are the industries' only battery operated weather based residential and commercial controllers, respectively.

The Smart Clock and Enercon Plus controllers entered the market in 2005 after 3 years of research and development. They are lithium battery powered controllers which operate using the temperature budgeting based Set It, Don't Sweat It® Program. The program incorporates a weather parameter estimation model developed at the University of Oregon known as PRISM (**P**arameter-elevation **R**egressions on **I**ndependent **S**lopes **M**odel). Daily irrigation schedules are calculated by the controller as a function of site latitude (radiation), real time temperature, and maximum annual high temperature. An optional rain switch is available which stops and prevents irrigation when significant rainfall occurs.

The Set It, Don't Sweat It program is based on a temperature budget theory. Once a schedule is programmed into the controller for peak summer irrigation, daily schedules are calculated as a function of the actual temperature for the day relative to the maximum annual temperature. Alex-Tronix believes this simple and logical programming concept is easy for the user to understand, thus encouraging proper utilization.

Operational Features

To program the Smart Clock, the site zip code is entered along with the peak summer irrigation schedule. A minimum irrigation temperature may be entered for cold regions to prevent irrigation during freezing weather. The schedule entered may be based on either days of the week or interval of days.

The key to optimizing this system is proper programming of the peak summer irrigation schedule. Appropriate station run times and soak cycles must be determined and entered manually. Once peak summer run times and the zip code are set; the temperature sensor is connected. The rain delay feature can be triggered manually or automatically, with an optional rain sensor, for an adjustable irrigation delay of up to 99 days.

Descriptions, Prices and Warranty

The Smart Clock controller is suitable for indoor or outdoor installation. It is powered by three 9-volt lithium batteries and is suited for residential applications with 6 stations plus a master valve terminal. Each station may be programmed for up to 4 cycles per day. This allows for the total station run times to be divided into multiple cycles in order to minimize run off. Specific days of the week or interval of days for irrigation may be programmed by the user.

The battery operation of the controller eliminates potential surge problems and burned out coils due to excessive voltage. The pulsed DC current

eliminates capacitive problems associated with AC powered systems and galvanic copper wire deterioration caused by steady DC operation.

The standard Smart Clock is a locking powder coated 8.25” x 7.5” x 5.2” commercial grade metal enclosure. A stainless steel pedestal option for mounting the Smart Clock is available. The controller terminals will accept wire sizes up to 12 gauge. The station circuit capacity is 5 amperes. The controller includes a self-powered removable panel for programming at a convenient location. The controller’s high temperature rated liquid crystal display is 2.4” x 0.7” and is easy to read. The controller possesses a unique valve test function that allows cycling through each station for a programmed amount of time without the need to return to the controller.

The Enercon Plus includes all of the features as the Smart Clock and more, and provides more capacity with 4, 8, 12, 16, 20 and 24 station models. It comes standard with a stainless steel pedestal and internal temperature sensor. An external rain and temperature sensor is also available. The overall dimensions are 35.6” x 7.5” x 5.1”. This arrangement provides a large wiring area for ease of installation and service. Optional output board lightning protection is available for the Enercon Plus.

Alex-Tronix reports the current water and energy savings technologies used by the Smart Clock and Enercon Plus controllers are recognized and sponsored by the U.S. Department of Energy. Alex-Tronix controllers may be purchased through the recognized turf and landscape irrigation distributors Ewing, John Deere and Hughes. The current list price for the standard Smart Clock (with integrated temperature sensor) is $995. The optional stainless steel pedestal is listed at $995. The base Enercon Plus list price with stainless steel pedestal is $1,950 including a 4-station output module, and each additional 4-station module is $199. The optional rain and temperature sensor for pole mounting for either model is $149. Lightning protection for the Enercon Plus is $460.

The Smart Clock and Enercon Plus controllers both come with a two-year warranty, including the batteries.

Installation

Alex-Tronix reports installation and setup are reported to be easy, and it is reported that installation of the residential controller may be accomplished by most homeowners. The time required for an inexperienced user for installation and setup is reported to be 2 hours. An experienced professional should be able to install and setup the Smart Clock in one hour or less. Detailed step-by-step installation and setup instructions are included in the owner’s manual which is available with the controller and at www.alex-tronix.com.

The Alex-Tronix battery powered controllers are compatible with Hunter and Rain Bird latching solenoids as well as the Alex-Tronix latching solenoid. In general, they are compatible with nearly all currently manufactured valves.

Track Record, Water Savings and SWAT Testing

Alex-Tronix performed a five year analytical study comparing their Set It, Don't Sweat It temperature budget calculated irrigation demands at 25 locations to nearby CIMIS station reference ET. Results of the study are summarized in the graph shown in Figure 3. The plot shows monthly percentage of peak temperature budget demand compared to the monthly percentage of peak CIMIS reference ET.

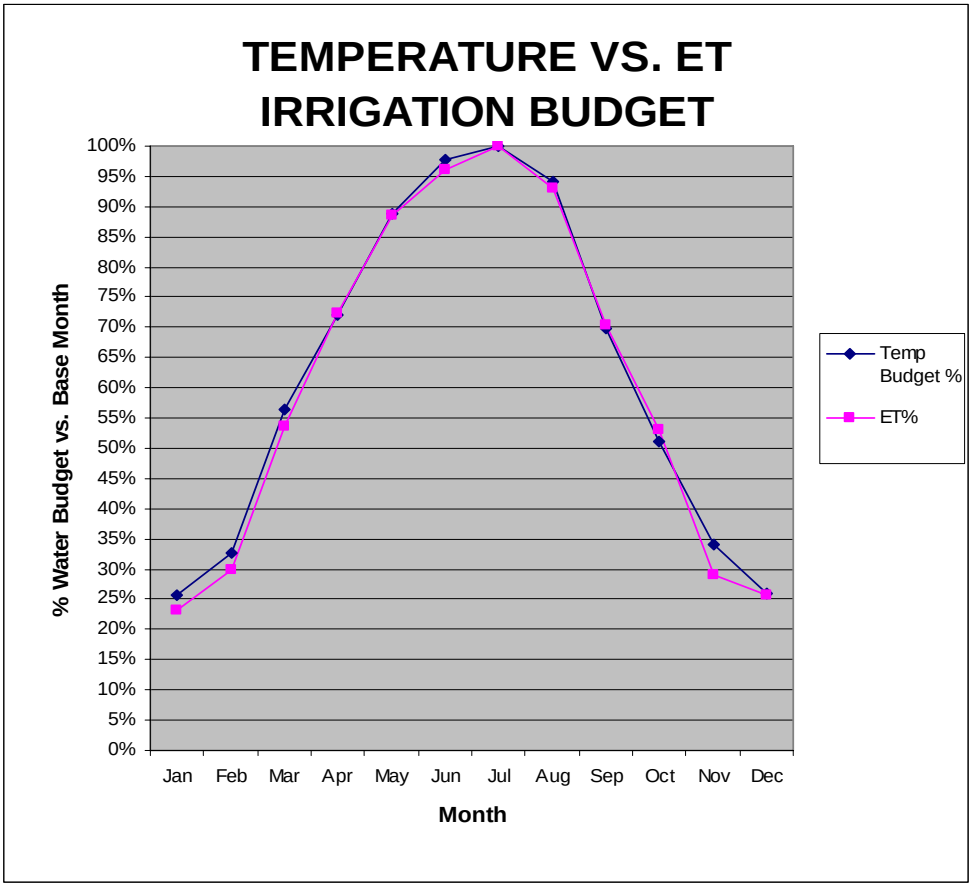


Figure 3 - Alex-Tronix temperature budget compared to CIMIS ET

The Alex-Tronix Smart Clock and Enercon Plus controllers have completed SWAT testing and performance summary reports are posted at the Irrigation Association website. These are the first battery powered controllers to complete SWAT testing.

Aqua Conserve

Aqua Conserve, Inc., located in Riverside, California has been in business since 1996. The company manufactures 5 residential ET controller models, a large variety of commercial ET controllers, and controller replacement panels and accessories. The Aqua Conserve® controller operation is based on adjusted historic ET data, with the adjustment made as a function of on-site temperature sensor readings. Combined rainfall/temperature sensors are included with some controller models and are available as add-on components for the other models which include only a temperature sensor.

Aqua Conserve's residential and commercial controllers have been on the market for approximately 8 years. Three indoor residential models are available, which accommodate 6, 9 or 14 stations, and the two outdoor residential models accommodate 8 or 12 stations. Aqua Conserve offers two types of commercial controllers, both of which come in wall mount and top entry models. The commercial controllers are outdoor units and will accommodate from 16 to 66 stations. Aqua Conserve's basic commercial models come in 16, 24 and 32 station models. The ULTIMO commercial controller series offer additional features and include 16, 26, 36, 46, 56 and 66 station models.

Operational Features

Aqua Conserve's ET controllers are preprogrammed with 16 individual historic ET curves, each representing geographic regions within the states of Arizona, California, Washington, Nevada, New Mexico, Utah, Colorado and Texas. The user enters one of the 16 regions into the controller. The controller then makes automatic seasonal changes to the run-times based on the historic ET curves, and daily changes based on the onsite temperature sensor. July run-times are entered into the controller for each station by the user. Aqua Conserve provides suggested run-times that are specific for plant types and for either spray or rotor sprinkler heads. Suggested run-times for drip systems are not provided. The suggested run-times are available at Aqua Conserve's web site (www.aquaconserve.com) for each of the 16 geographic regions mentioned above. Refinements to the suggested run-times to compensate for soil, slope and shade conditions are also provided. Further refinement of run-times can be made based on visual observations.

The various Aqua Conserve controllers provide 4 programs that allow the user to specify different watering days for different stations. 4 to 8 start times are

available for each program to allow for refinement of total run-times into multiple cycle and soak times to compensate for soil and slope conditions to limit run off. The maximum station run time is 99 to 240 minutes for the various models. The minimum irrigation frequency is once per week for low water plants. A new plant/landscape establishment option (2 additional non-adjusting programs) allows added watering by station for a specified period (1-60 days) to establish new landscaping, and then automatically reverts to the ET based schedule. The controllers include 1 to 4 station circuits that may run concurrently with all the other stations to control a master valve, drip system or other accessories. On residential and small commercial controllers, other stations may not run concurrently. On the ULTIMO controllers, up to 6 stations, on other programs, may run concurrently.

The actual irrigation run-times for a given day are dependant on the programming described above and an automatic adjustment made by the controller, which is based on the measured on-site average temperature and historic ET data. The controllers have an accumulation feature that eliminates short cool period run-times. The short cool period run-times are accumulated until 50 percent of the July run time has been reached and then irrigation will occur.

Descriptions, Prices and Warranty

Aqua Conserve commercial models come with a wired temperature sensor. Combined rain and temperature sensors are included with residential models and are an optional add-on with the commercial models. The combined sensors signal the controller once every second, initiating the rain delay (shut-off) function when significant rainfall is detected. In the rain delay mode, the controller will not re-initiate irrigation for at least a 24-hour period after significant rainfall has ceased. Depending on the duration of the rain event, the rain delay can cause the controller to interrupt irrigation for up to 5 days. The user also has the capability to trigger the controller's rain delay feature manually.

All controllers have non-volatile memory and a 9-volt back-up battery. The back-up battery powers the controller clock in the event of a power outage for the residential and basic commercial units. The ULTIMO controllers include a storage capacitor that maintains the clock in the event of a power outage. All of the controllers can be programmed when powered only by the backup battery. The controller terminals accept 12 to 18 gauge wiring.

The residential indoor controllers provide 4 programs and 4 start times, and the outdoor models provide 4 programs and 4 start times. Both have one station

circuit that may run concurrently with all the other stations to control a master valve or drip system. The indoor models are constructed of plastic and the outdoor controllers are housed in lockable stainless steel cabinets. The indoor models' dimensions are 8.3" x 6" x 2" and the outdoor models' dimensions are 9" x 8.8" x 3.3". The controller panel features dial type controls and a 2-line LCD display. The indoor controller models have a station circuit current capacity of 0.5 amperes, and the outdoor models' station circuit current capacity is 0.75 amperes. All residential indoor controllers are powered through an external transformer (included with purchase). Residential outdoor units are hardwired to the electrical system and supplied with an internal transformer.

All commercial controller models are housed in lockable stainless steel wall mount or top entry cabinets. The top entry units are designed for placement on a concrete foundation and are vandal resistant. The ULTIMO commercial controllers include all of the features of the basic models, plus additional master circuits, flow meter monitoring and other features.

The basic wall mount commercial models are powered through an internal 24VAC transformer (included with purchase), and provide 4 programs and 4 start times. The basic top entry commercial models are powered through an internal transformer, and include 4 programs and 4 start times. The wall mount cabinet dimensions are 9.8" x 10.8" x 4.3", and the top entry dimensions are 34.5" x 17.5" x 11.5". All of the basic commercial models' panels feature dial type controls and a 2-line LCD display. The station circuit capacity for the basic commercial controllers is 0.75 amperes, and one station circuit may run concurrently with all the other stations to control a master valve or drip system.

All of the ULTIMO models are powered through an internal transformer, and provide 4 programs and 8 start times. The wall mount cabinet dimensions are 12" x 14.3" x 14.3", and the top entry dimensions are 34.5" x 17.5" x 11.5". The ULTIMO controllers provide for manual, semi-automatic and timed operations. The ULTIMO controllers can also detect leaks and excessive flows, and notify the operator or shut down the affected zone or master valve. Other ULTIMO features include water meter connections, large 4-line LED display, current and historic programming information access, ATM type push button programming, and start time stacking for all programs. The station circuit capacity for the ULTIMO controllers is 1.0 amperes, and they have four station circuits that may run concurrently with all the other stations to control a master valve or drip system. In addition, up to 6 programs can run concurrently.

All products are available directly from Aqua Conserve by telephone and Internet order, and through a limited number of local distributors. Controller retail prices are summarized in Table 2. The residential models come with combined rain/temperature sensors, which are available as on optional add-on for the commercial models. The additional cost for the wired rain/temperature sensor is $83.50. The commercial models come with wired temperature sensors. There is

no ongoing service cost associated with these controllers, and All Aqua Conserve products come with a limited 3-year warranty.

Table 2 - Retail Prices for Aqua Conserve Controllers

Controller Description	Model No.	2006 Price
6-Station Indoor Residential Wall Mount	ET-6	$264
9-Station Indoor Residential Wall Mount	ET-9	$281.60
14-Station Indoor Residential Wall Mount	ET-14	$393.80
8-Station Outdoor Residential Wall Mount	ET-8B	$477.40
12-Station Outdoor Residential Wall Mount	ET-12B	$581.90
16-Station Commercial Wall Mount	ET-16B	$884.90
24-Station Commercial Wall Mount	ET-24B	$1,024.10
32-Station Commercial Wall Mount	ET-32B	$1,151.70
16-Station Commercial Top Entry	ET-16SP-1	$2,410.10
24-Station Commercial Top Entry	ET-24SP-1	$3,210.80
32-Station Commercial Top Entry	ET-32SP-1	$3,744.40
16-Station ULTIMO Wall Mount	ET-16u	$1,472.90
26-Station ULTIMO Wall Mount	ET-26u	$1,939.30
36-Station ULTIMO Wall Mount	ET-36u	$2,404.60
46-Station ULTIMO Wall Mount	ET-46u	$2,871.00
16-Station ULTIMO Top Entry	ET-16uSP-1	$3,531.00
26-Station ULTIMO Top Entry	ET-26uSP-1	$4,063.40
36-Station ULTIMO Top Entry	ET-36uSP-1	$4,595.80
46-Station ULTIMO Top Entry	ET-46uSP-1	$5,128.20
56-Station ULTIMO Top Entry	ET-56uSP-1	$5,660.60
66-Station ULTIMO Top Entry	ET-66uSP-1	$6,193.00

Installation

The findings of a 2003 study by the University of California Cooperative Extension indicate installation and programming of an Aqua Conserve residential controller is relatively simple and that the controller performed well (Pittenger et al., 2004). Professional installation of commercial controllers is recommended. Aqua Conserve provides toll free telephone technical support and provides technical information on their web site. Aqua Conserve will participate in training contract installers upon request. Aqua Conserve reports that their support system meets or exceeds industry standards and the installation and programming instructions reviewed for this report are complete and easy to understand.

Track Record, Water Savings and SWAT Testing

Reported outdoor water use savings for pilot studies with Aqua Conserve controllers, which were performed by the City of Denver, Colorado, Sonoma, California, and the Valley of the Moon Water District in Northern California were 21, 23 and 28 percent, respectively (Addink and Rodda, 2002).

SWAT test performance reports for Aqua Conserve controllers were not posted at the Irrigation Association's website at the time of this review.

Calsense

Calsense®, started in 1986, is a Carlsbad, California based company that manufactures water management systems for large commercial customers. Since its startup, the company has specialized exclusively in water management systems using weather-based irrigation, real-time flow monitoring, moisture sensors and a wide variety of communication technologies. Calsense markets its products to municipalities, school districts, universities, transportation departments, and other high volume landscape irrigators. Calsense provides free onsite training with its products, and emphasizes their commitment to customer service, support, and successful utilization of its products.

The Calsense ET2000e controller functions as either a stand-alone unit or as a field controller component for their water management central control system. The Calsense Command CENTER Software is the central component of the system. Although the ET2000e is a new product for 2006, its basic design is unchanged from its predecessor, the ET2000 and favorably improved from the ET1, originally introduced in 1993.

Operational Features

The ET2000e can automatically adjust daily irrigation schedules with onsite reference ET measurements from the optional Calsense ET Gauge, a Campbell Scientific Weather Station, California Irrigation Management Information System (CIMIS) real-time data, or with historic average monthly ET. (Use of weather station or CIMIS data require computer interface to calculate ET and communicate it to the controller.) CIMIS based historic monthly average values are preprogrammed into the controller, or the user can enter monthly values to serve as a back-up ET source. Measurements from an optional tipping rain bucket are incorporated into the irrigation schedule calculation to account for effective precipitation. Irrigation can be interrupted in the event of rain, and high winds with the use of optional switch type sensors. A soil moisture sensor can be used with the ET2000e also and override the decision determined through on-site ET. (See Calsense discussion under Soil Moisture Sensor Products section.)

In the ET scheduling mode, the user programs the controller's run times based on field knowledge for the time of year and soil moisture content. This base schedule is adjusted daily as a function of weather conditions. Monthly ET adjustment percentage factors are fine tuned for each station depending on plant types, sun/shade conditions, and soil moisture content. Crop coefficients can be entered as well, for each month for seven different kinds of plant material. Cycle-and-soak times are manually programmed into the base schedule to minimize runoff.

The Calsense ET Gauge is an automated atmometer for estimating reference ET for turf (tall fescue). The covered ceramic evaporator at the top mimics solar energy absorption and vapor diffusion resistance of irrigated plants. A reservoir below the evaporator holds distilled water. The evaporator draws water from the reservoir at approximately the same rate that grass removes water from soil by ET. Water drawn from the reservoir passes through a calibrated measuring vial and corresponds to 0.01 inch of ET. Electronic circuitry components sense when the vial is empty. It is then immediately refilled and the 0.01 inch event is marked by a switch-closure type pulse which is transmitted to the controller. The controller uses a 28-day ET table to calculate runtimes based on station precipitation rates. The ET Gauge operates on 24 VAC supplied from the controller. An optional stainless steel vandal proof enclosure is available for the ET Gauge.

Descriptions, Prices and Warranty

The ET2000e is available in 8, 12, 16, 24, 32, 40 and 48 station models. The controllers have two additional outputs for master valve and pump circuits. In addition, the controllers may be ordered with hardware and software for 4 additional 24 VAC outputs for the operation of lights, gates, water features, etc. at no additional cost. These outputs are controlled independently from the irrigation programs.

The controller has 7 regular programs and several syringe/propagation programs. A maximum number of start times or repeats per station is determined by station total minutes (programmed or ET calculated) and by a fixed set run time per cycle and a fixed set soak time between cycles. The cycle-and-soak times are set manually. The user selects 7, 14, 21 or 28-day watering schedules to accommodate watering requirements, and no-water days can be designated by program. Programs can operate simultaneously based on the system capacity of the mainline and flow management. The ET2000e is typically installed by a landscape contractor and then Calsense provides assistance programming assistance to the user following the landscape establishment period.

A Calsense Model FM flow meter can be connected to the controller to continuously monitor flow through the irrigation mainline and learn each

station's flow rate automatically when irrigation occurs. This feature detects and alerts the user to mainline breaks, no flows, high flows (due to broken risers and pipe) for each individual station, and low flows due to pressure drops, malfunctioning valves, and or clogged heads.

An optional remote control receiver board is integrated into the ET2000e allowing the user to activate valves and view operational details without going to the controller. The Calsense Remote SENSE remote control transceiver allows the user to view valve-on, area description, flow rate, electrical use and remaining time.

A water volume budget feature determines when monthly use, with projected usage, will exceed the programmed monthly budget and alerts the user before the month ends. This capability helps maintain water rates and keep staff accountable to a water management program. Table 3 and Figure 4 show data from an actual site that demonstrates the utilization of the water budget feature, and shows the correlation between historical and measured ET. The adjusted budget shown is the result of the automatic scheduling performed by the controller. The controller also possesses a laptop computer interface for field uploads and downloads so that detailed reports can be produced and potential expansion to a central system can be evaluated.

Table 3 - Calsense ET2000e water budget feature data

Date	# of Days	CONTROLLER HISTORICAL ET	*ACTUAL ET TABLE	ADJ %	**CONTROLLER BUDGET GALLONS	***ADJUSTED BUDGET GALLONS	****USAGE ACTUAL GALLONS	SAVINGS GALLONS	PERCENT SAVED
Jan-2004	31	2.17	1.96	-10 %	135,997	122,836	124,985	-2,149	**-2 %**
Feb-2004	29	2.61	2.51	-4 %	156,722	150,717	93,164	57,553	**38 %**
Mar-2004	31	3.41	3.30	-3 %	199,228	192,801	170,397	22,404	**12 %**
Apr-2004	30	3.30	4.03	22 %	206,679	252,399	203,713	48,686	**19 %**
May-2004	31	4.34	4.46	3 %	264,385	271,694	235,704	35,990	**13 %**
Jun-2004	30	3.90	3.59	-8 %	238,227	219,291	187,099	32,192	**15 %**
Jul-2004	31	4.65	4.86	5 %	276,207	288,681	255,869	32,812	**11 %**
Aug-2004	31	4.65	4.58	-2 %	276,606	272,442	224,724	47,718	**18 %**
Sep-2004	30	3.90	4.59	18 %	232,492	273,625	221,700	51,925	**19 %**
Oct-2004	31	3.41	2.91	-15 %	196,724	167,879	103,225	64,654	**39 %**
Nov-2004	30	2.10	2.17	3 %	133,555	138,007	84,064	53,943	**39 %**
Dec-2004	31	1.86	2.04	10 %	116,526	127,803	63,363	64,440	**50 %**
TOTAL	366	40.30	41.00	2 %	2,433,348	2,475,614	1,968,007	**507,607**	21 %

ET values and usages set to zero when budget is zero
*County and city settings for controller are San Diego and San Diego
** Controller Budget was Calculated at 100% of Controller Historical ET.
*** Adjusted budget uses actual ET to modify the controller budget.
**** Usage based on: Test usage, manual usage, scheduled usage, radio remote usage

Extensive current and historic irrigation information can be viewed at the display or downloaded from the controller. The controller monitors and keeps a record of all site water usage by month for up to 2 years. Scheduled irrigation usage is recorded on a station-by-station basis and on a total controller basis for the current month and the previous month. Unscheduled water usage (pressing the manual water or test key), and non-controller water usage (e.g. quick-couplers, manually bleeding valves, etc.) is recorded separately showing how the water is being applied.

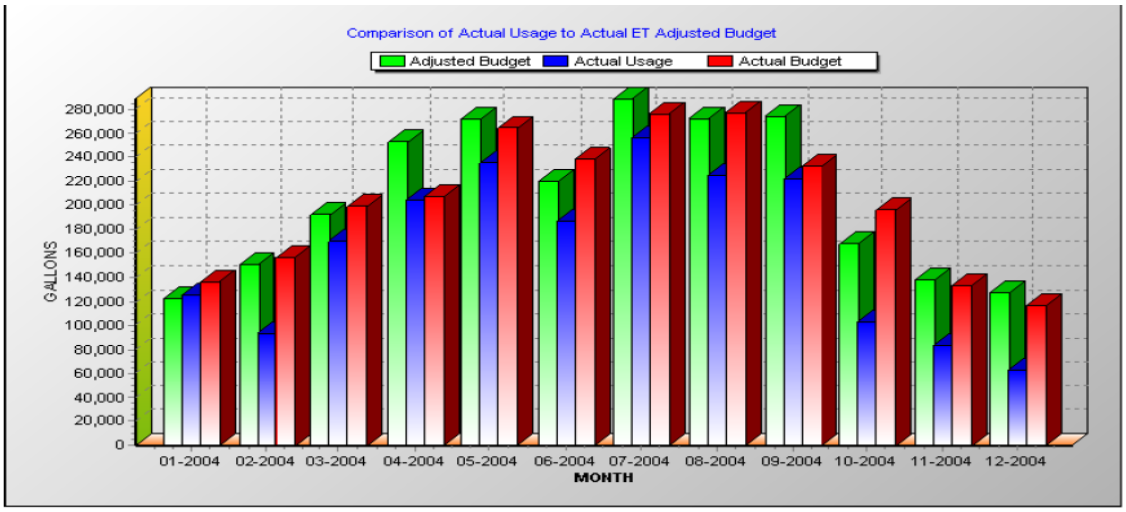


Figure 4 - Graph of Calsense 2000e water budget feature data

The ET2000e is a weatherproof wall mount unit and the cabinet is powder coated rolled steel. The front panel includes an ergonomic key layout and a large16-line by 40-character LCD display (English or Spanish). The cabinet dimensions are 11.4” x 11.1” x 7.3”. The controller has non-volatile memory and the clock maintains time during power outages without the need for a backup battery. It is powered through an internal transformer. The controller accepts up to 14 gauge wire size, and the station current capacity is 1.5 amperes. Optional AC power line overload protection consists of a sealed unit suitable for outdoor installation and carries full UL approval. Optional transient (lightning and surge) protection is provided with the TP-1 board. The transient protection board can be purchased either with or without an outdoor cabinet. The ET2000e will detect, alert and identify open and shorted circuits in field wires and solenoids. The affected station is skipped until repaired.

Calsense products are available from many distributors located throughout the U.S. A list of these distributors is available from Calsense upon request (1-800-572-8608 or www.calsense.com). Current prices for all ET2000e models and certain accessories are summarized in Table 4. All Calsense products come with a 5-year warranty.

Installation

Calsense recommends professional installation of the ET2000e and installation time varies significantly depending on site conditions.

Track Record, Water Savings and SWAT Testing

Although Calsense has not participated in any outside studies or demonstration projects, its track record speaks for itself. During Calsense’s 20 years of existence, they have developed a large data base on its products’ performance and customer success.

Table 4 - Calsense Products Price Summary

Description	Model No.	Price
8-Station ET2000e Controller	ET2000e-8	$1,290
12-Station ET2000e Controller	ET2000e-12	$1,790
16-Station ET2000e Controller	ET2000e-16	$1,980
24-Station ET2000e Controller	ET2000e-24	$2,350
32-Station ET2000e Controller	ET2000e-32	$2,890
40-Station ET2000e Controller	ET2000e-40	$3,280
48-Station ET2000e Controller	ET2000e-48	$3,680
ET Gauge	ETG	$1,310
ET Gauge Controller Interface	-G	$435
Rain Gauge	RG-1	$575
Rain Gauge Controller Interface	-RG	$435
Wind Gauge	WG-1	$545
Wind Gauge Controller Interface	-WG	$435
Soil Moisture Sensor	1000-S	$199
1-inch Brass Flow Meter*	FM1B	$575
1.5-inch PVC Flow Meter*	FM1.5	$490
Transient Protection	TP-1	$265
Enclosure for TP-1	TPB	$199
AC Line Protection	TP-110	$165

* Other brass and PVC flow meter sizes are available up to 3-inches.

Calsense submitted data for this report prepared by their in-house research and development department showing average water savings of 22 and 33 percent for two typical installations. Calsense reports an overall average water savings rate of approximately 20-40 percent depending on past water usage and project history.

Although the controller models have evolved, the Calsense ET scheduling technology has been in place since 1992. Many of the Calsense systems installed since that time continue to function today. Several articles written by end users in Calsense's niche market testifying to the successful operation of their Calsense systems were submitted for this report. The ET2000e has completed SWAT testing and a performance summary report is posted on the Irrigation Association website.

Calsense provides potential clients with a reference list of all past and current users so that they can learn of their personal and professional experiences. In some cases, Calsense loans controllers to potential clients to demonstrate its system. The ET2000e provides a complete water management system as a stand-alone field controller, which can easily be expanded into a central control system.

Cyber-Rain

Cyber-Rain, Inc. came into existence in 2006 and is based in Oak Park, California. The Cyber-Rain XCI is a weather-based wireless stand-alone controller that works with the user's personal computer (PC) and adjusts irrigation scheduling based on weather forecasts downloaded from the Internet. Development of the Cyber-Rain XCI began in 2005 and the company received venture funding and began marketing the XCI in January 2007.

Cyber-Rain has incorporated several new technologies into its 8-station XCI controller. It uses a modern wireless mesh networking system (IEEE 802.15.4 ZigBee) to maintain two-way wireless communication between the controller and the user's PC located anywhere within 300 feet of the controller. Wire-free expansion of the system can occur by adding more controllers (for more zones) and devices such as wireless sensors (moisture, rain, temperature, humidity) and flow meters. The company plans to introduce these complimentary wireless products in 2007. The system adjusts a base irrigation schedule using information from a variety of Internet sources such as the Weather Channel and NOAA websites. Cyber-Rain is currently developing interfaces for local weather stations. The Cyber-Rain system concept is to use state-of-the-art technologies to conserve water and provide broad functionality while hiding the complexities of these technologies from the user.

The Cyber-Rain system allows full control of irrigation scheduling and offers water usage reports using a Windows® graphical user interface as shown in Figure 5. The system monitors weather forecasts and wirelessly transmits irrigation schedule adjustments to the controller. Two-way communication allows each controller's activities, such as manual or scheduled activation of valves, to be centrally reported to the PC and logged.

Operational Features

The Cyber-Rain XCI can be installed as a new controller or one that replaces an existing clock type controller. The XCI controller comes with a small wireless device called an Access Point that is connected to an internet-accessible PC's USB port to let the Cyber-Rain software wirelessly communicate with one or more XCIs. The XCI is programmed using the PC and all scheduling operations can be performed through the PC user interface. In addition, users have the option to operate the XCI using the buttons on the controller.

Cyber-Rain reports that after the initial setup and schedule entry, no further user intervention should be required. The system is designed to run "in the

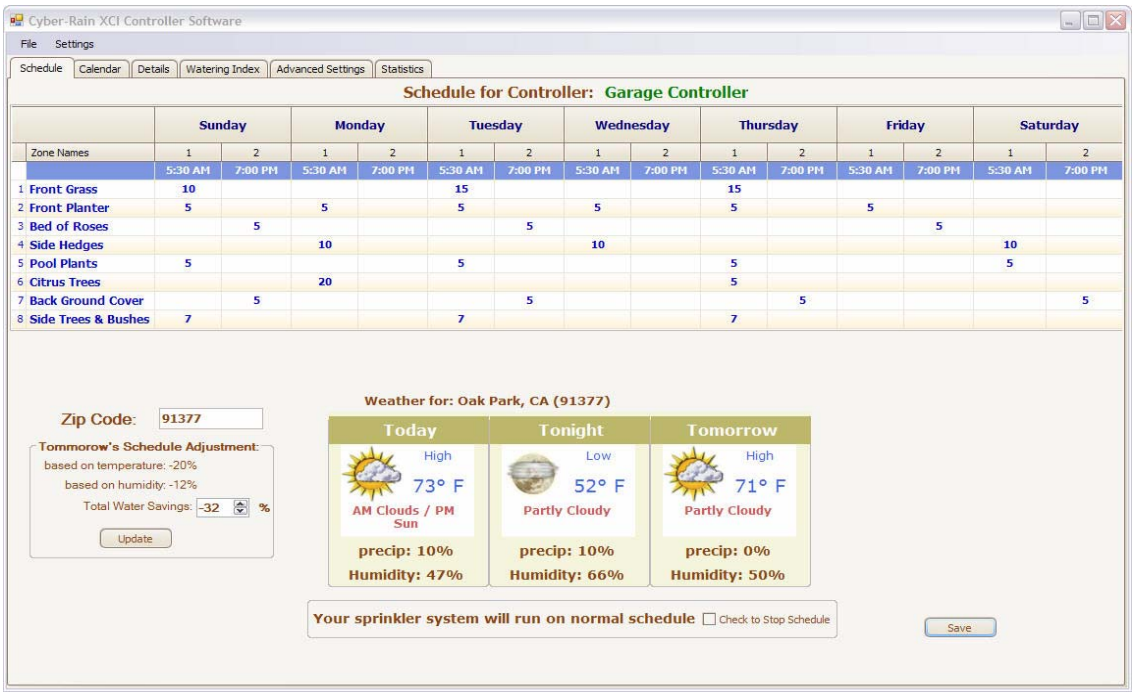


Figure 5 - Cyber-Rain graphical interface example

background" without interfering with any other PC operations. The system does not require that the PC is turned-on to operate, but the PC must be turned-on and connected to the internet for access to weather forecasts. The weather forecast is checked automatically via the PC's internet access and irrigation schedule adjustments are calculated based on temperature and humidity and transmitted to the controller. If rain is forecasted, irrigation is suspended until it stops raining. The suspension may continue to compensate for the duration of the rain.

The XCI includes a cycle and soak feature to eliminate or reduce run-off. Individual zones can be put on a temporary hold for a user-defined number of days. A fertilizer watering feature allows the temporary increase of watering for a user-defined number of days, and then the system returns to its normal schedule. An anti-freeze feature will automatically suspend all watering when the forecast temperature approaches freezing point. Cyber-Rain maintains a log of all water usage and displays a variety of water usage and saving statistics.

During normal usage, Cyber-Rain receives weather forecasts then schedules irrigation accordingly; however, if the PC is offline for many days (e.g., when the homeowner is away on vacation) the system reverts to irrigation schedule adjustments based on a built-in Watering Index. The Watering Index is based on historical temperature, precipitation and other weather patterns for a given geographical area. A graphical example of Watering Index settings are shown in Figure 6.

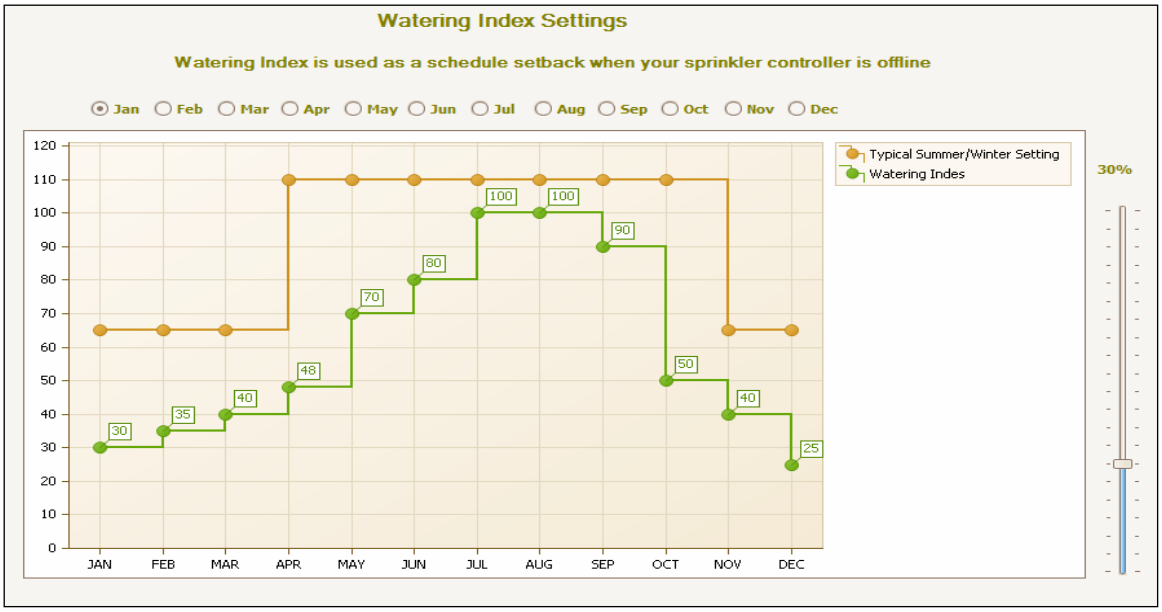


Figure 6 - Cyber-Rain Watering Index settings example

Custom zone names are entered by the user as text such as “Rose Bushes” or “Front Grass” and can be in any language. When the controller operates, the names are displayed. A base irrigation schedule is entered by the user consisting of irrigation days, total run times and cycle and soak times for each zone. Information on determining the base schedule is included in the Cyber-Rain user manual and there are shortcut keys to make the initial entry easier.

Cyber-Rain is designed with remote policy functions that can ensure automatic compliance with city or water district regulations such as limiting watering to certain hours of the day or blocking watering certain days. The system can “look-up” changes in these regulations and apply them immediately. Cyber-Rain can also aggregate individual watering and report, via a central internet reporting site, the percentage of water savings in a given geographical area.

Description, Prices, and Warranties

The Cyber-Rain system consists of one or more 8-station XCI controllers, a wireless USB Access Point device that connects to the user’s PC, and Cyber-Rain computer software. Additional controllers can be added at any time that will integrate through the original Access Control and are all controlled from the same Cyber-Rain XCI software. In this way any size property can be managed from a single PC’s user interface.

The XCI is constructed of fire-retardant ABS plastic and is suitable for indoor installation only. Its dimensions are 8.5” x 4.25” x 1.75” and it includes a 2-line by 24 character LED display panel. The XCI is powered by an external 24VAC transformer. Station circuit capacity is 1A and the controller accepts wire sizes up to 14 gauge solid or 16 gauge stranded. The XCI has non-volatile memory to

retain programming during power outages and its clock is maintained during power outages with a super capacitor and real-time clock chip. Surge and lightning protection is provided with metal oxide varistors (MOV) and extra inductors on each circuit.

A single-controller system is priced at $295 and includes one Cyber-Rain XCI 8-zone controller, wireless USB Access Point, 24VAC transformer, USB cable, software, and user manual. Additional 8-zone controllers (including transformers) may be purchased for $245. Cyber-Rain has a 30-day "satisfaction or money back" guarantee, plus a 1-year limited manufacturer's warranty. There are no monthly fees or additional charges. Software and firmware updates are free and can be downloaded from the Cyber-Rain web site.

Installation

Cyber-Rain reports a typical single-XCI controller system can be installed in less than one hour by anyone who knows how to use a PC. Cyber-Rain does not recommend professional installation.

Track Record, Water Savings and SWAT Testing

Cyber-Rain reports systems installed during January through June 2007 reported an average water savings of 36%. No study data are available on the Cyber-Rain XCI, which is understandable since it is such a new product. A SWAT test performance report was not posted for Cyber-Rain at the time of this review.

ECO Research

ECO Research LLC, located in Nampa, Idaho, began work on the weather based ECO 100™ Sprinkler Optimizer in January 2003. The first prototypes were tested during April to October of 2003. In 2004, production units were distributed for testing at additional locations. In 2005, the ECO 100 was introduced to the general market.

The ECO 100 works with any existing clock/timer controller to irrigate based on calculated ET. The device calculates ET from on-site temperature measurements and site location average solar radiation. No remote or historical data are used, and any industry standard rain sensor can be connected to the system to improve performance. The ECO 100's ET calculation algorithm is based on the Hargreaves equation for estimating ET. The device is connected to an existing controller and interrupts the controller from irrigating until calculated ET accumulates to the appropriate level.

Operational Features

Hourly temperature sensor readings are logged by the ECO 100, and solar radiation is calculated as a function of minimum and maximum temperatures and site latitude. Latitude is entered during system setup as one of 5 zones covering all of the U.S. These data are used to calculate daily ET, and daily ET is accumulated to determine when irrigation should occur. When rain is detected by an optional sensor, the system will stop or prevent watering and adjust ET accumulation. ET accumulation adjustment is based on the amount of time the rain sensor is tripped, and an adjustable delay switch setting. The delay switch is set by the user during setup to delay ET accumulation from 0 to 7 days when the rain sensor is tripped. If no rain sensor is installed, the user can also manually enter a rain delay and cause ET accumulation adjustment.

The ECO 100 Sprinkler Optimizer is an add-on product that can be used with any existing electrical clock/timer type controller. The intent of this design is to minimize product installation and setup costs. It also simplifies operation since the existing controller is not replaced and it is not necessary for the user to learn a totally new system.

The ECO 100 manages watering by controlling watering frequency. This is accomplished by controlling the electrical connection from the common valve circuit to the controller. The controller is typically set to water every day, but watering will only occur when the ECO 100 has determined that the ET accumulation (soil moisture deficit) is equal to the last amount watered. The controller will water the same amount every time, but the frequency of irrigation is controlled by the ECO 100. The user adjusts the individual station times on the controller during setup, as recommended in the installation manual.

The recommended station run times are based on the sprinkler head application rate and irrigation of either 0.5 or 0.75 inches per watering. The manual provides instructions for measuring application rates, and discusses division of total run times to reduce run off. The method discussed for dividing total run times requires the user to observe the irrigation time which induces runoff and adjust accordingly. Specific adjustments based on soil, slope and shade conditions are not included in the manual. Consideration of soak cycles is also discussed. The Wetter/Dryer control is used to make minor frequency adjustments. This allows the user to slightly increase or decrease irrigation frequency as conditions warrant.

The ECO 100 may be programmed to only control certain stations of the controller. This allows the user to have stations irrigate at high frequency for plant germination, or for long run times to accommodate drip irrigation. The clock controller can be set to skip a day of the week and irrigation will occur the following day, if needed. The unit has a low temperature shut off which prevents

irrigation at temperatures below 38° F. Watering history is displayed on the ECO 100, showing irrigation activity for the past two weeks.

The ECO 100 has no specific number of zones that it can control. The only limit is that the zones all have to be set to water in a single 24-hour period. This is because when the ECO 100 determines that watering is needed, it enables the connection from the station valves common circuit to the controller for 24 hours. There are existing installations with 36 station controllers. The ECO 100B Sprinkler Optimizer, planned for later in 2007, will enable watering for up to 48 hours. This will allow additional watering options such as the use of two programs watering on alternate days.

Description, Pricing and Warranty

The ECO 100 cabinet is a 4” x 6” x 1.5” extruded plastic unit and the panel includes a 2.6” x 0.6” two-line LED information display. The panel controls are touch pad type. A lockable steel weatherproof enclosure is available for outdoor installations. The ECO 100 has non-volatile memory and battery backup to retain all settings in the event of a power failure. A 24 VAC power supply must be provided by the controller to which the ECO 100 is connected.

The retail price for the ECO 100 is $198, as is the planned price for its upcoming replacement, the ECO 150. The weatherproof enclosure is priced at $79. The ECO 100 and accessories may be purchased from ECO Research or from its distributors which are listed at www.ecoresearch.com.

Installation

Installation and setup are reported to be easy, and may be accomplished by most homeowners. The time required for an inexperienced homeowner for installation and setup is reported to be 2-3 hours. An experienced professional should be able to install and setup the ECO 100 in one hour or less. Detailed step-by-step installation and setup instructions are included in the owners manual which is available at the ECO Research website (www.ecoresearch.com). Additional setup time (1-2 hours) is required to measure station flow rates if sprinkler head flow rates are not known. This procedure is covered in the owner’s manual.

Track Record, Water Savings and SWAT Testing

During the development of the ECO 100, the ET algorithm was tested by comparing simulated EC100 ET to reference ET for an Orange County, California CIMIS station using the temperature data from the CIMIS station. The results of this test are shown in the graph included in Figure 7. The graph shows the ECO 100 calculated ET pattern generally follows that of the CIMIS ET.

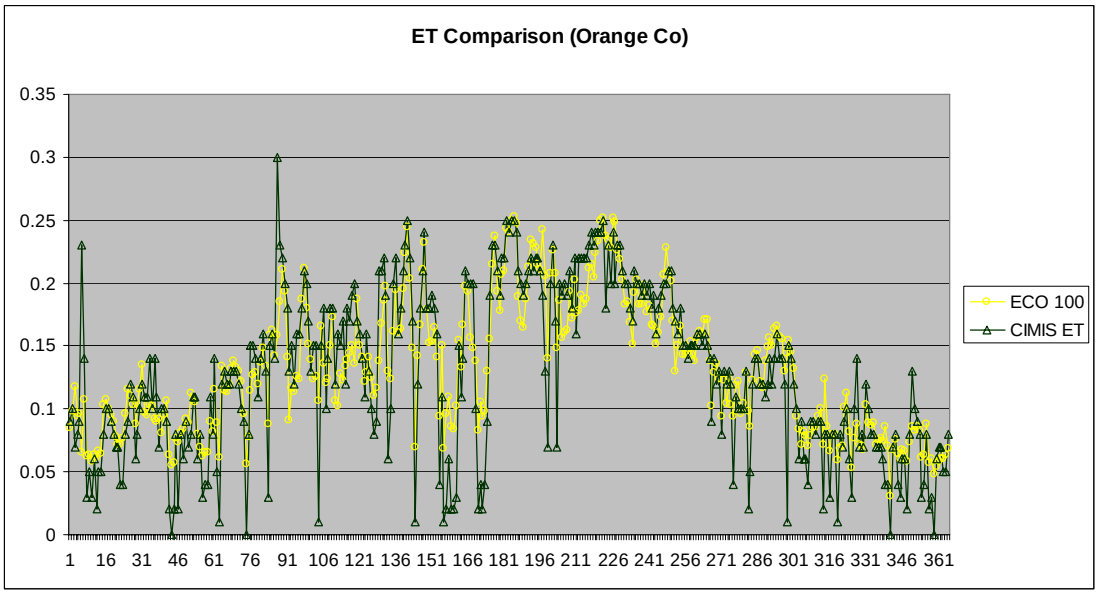


Figure 7 - ECO 100 calculated ET versus CIMIS reference ET

ECO Research reports water savings of 20 to 40 percent with the ECO 100, based on its own pilot testing. The ECO 100 is included in an ongoing study being conducted at Lake City Community College, Lake City, Florida. This study is comparing the performance of several ET and soil moisture based controllers and preliminary results are anticipated late in 2006. The ECO 100 is also included in an ongoing study being conducted by the Salt Lake City, Utah Department of Public Utilities. This study includes ease of installation, landscape appearance and water savings evaluations. Results from the Salt Lake City study will also be available late in 2007. A SWAT test performance report for the ECO 100 was not available for this report.

The ECO 100 provides a relatively economical weather based irrigation system control option, using real time onsite sensors.

ET Water Systems

ET Water Systems LLC, based out of Corte Madera, California, is a manufacturer of weather based irrigation controllers for the residential and commercial markets. ET Water™ controllers operate under its centralized weather-based irrigation management system. ET Water was incorporated in 2002 and began

manufacturing controllers in March 2005. The company sells its system in California, Nevada, Colorado, Texas, Oregon, Washington and Idaho and plans to expand sales to other states.

The ET Water system schedules irrigation based on ET and precipitation data received from existing weather stations and user programmed information associated with specific landscape features. Currently, the ET Water system uses a data network of approximately 8,500 public and private weather stations, most of which are located in populous areas. ET Water controllers are sold in single station increments from 6 to 48 stations, thus the customer only pays for what it uses. Additional stations (up to 48) may later be activated by paying a per station fee. The ET Water commercial controller models begin at 12 stations, and the 2-way communication service offered with the commercial controllers provides features similar to a central control system.

With the ET Water System, ET and precipitation data are automatically retrieved daily from the weather station network by the ET Water's host server. The data are obtained from existing weather stations that provide localized weather, most often available at the town or even the suburb level in most metro areas. A WeatherBug® weather station can be installed on-site and the on-site data is utilized via the ET Water server as discussed below.

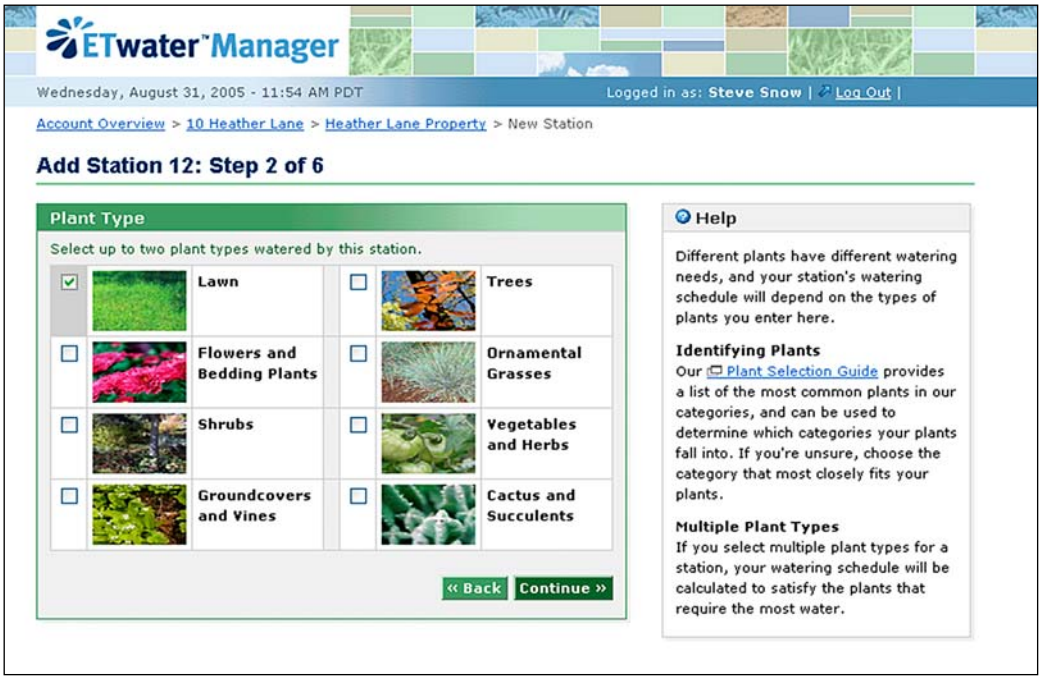
Operational Features

The ET Water server automatically processes the ET and rainfall data in combination with the user-programmed landscape information to develop irrigation schedules. The user enters the landscape information from any computer with an Internet connection via the ET Water website (www.etwater.com); however, a personal computer is not required at the installation site for the system to function. In commercial applications, the user may access special screens that enable selection of multiple accounts and thereafter select any controller or zone for each account. Scores of accounts may be accessed remotely from any computer at any time.

Communication between the user's controller and the ET Water server may be by wireless connection or land-based telephone link. Broadband access is planned for late 2007. The ET Water central server communicates with each field controller on a daily basis to send any required watering adjustments. In addition, all ET Water controllers send a 30-day log of all watering activity so users can review their watering history on the ET Water website. ET Water controllers can operate independently if communication to the server is temporarily interrupted. In such a case, the controller continues to operate using the latest schedule stored in memory, and then revises the schedule once communication is re-established with the server. The ET Water controller can accommodate schedules of any duration and frequency, including schedules that require watering on a very infrequent basis (e.g., every 30 days).

To enter landscape information, users go to the ET Water website and log into their account using a user name and password. The program interface to enter the site-specific landscape information is set up with a choice of either Windows® based pull-down menus or click-on picture options (e.g., plant type pictures) and it is intuitive and easy to use. The program is well organized and covers a comprehensive set of landscape factors including; plant type, irrigation type or optional application rate, soil type, slope, root depth, sun exposure and distribution uniformity. User-defined sprinkler precipitation rate (PR) and distribution uniformity (DU) may be entered or default measures may be selected in the absence of precise PR and DU information. A wide selection of plant types is available. Multiple plant types may be selected for one station and the program will automatically set the watering schedule based on the plants with the highest water requirement. Irrigation types available include spray, rotor, high efficiency matched precipitation rate rotors, impact, stream spray, drip emitter, bubbler and sub-surface inline tubing. The default distribution uniformity factor is 55 percent for pop-up spray heads. The user may specify customized distribution uniformity for any zone. All default settings can be changed at any time by ET Water.

The user may also enter non-irrigation days, adjust the total station run times by a percentage factor, and initiate manual irrigations by station. The user may review system and irrigation history information on the website. The ET Water setup program includes help screens to answer questions common to first time users. Once the user becomes familiar with the program, an advanced setup mode may be used which offers a more efficient means of programming. Adjustments to specific site factors may be made at any time via the ET Water website. Site factor changes will generate new irrigation schedules.



The ET Water controller also has an offline programming feature that allows users to manually set a watering schedule for each station. This feature is intended for use during periods when phone service is temporarily unavailable (e.g., a newly constructed home prior to sale). Offline programming may be performed at the controller using the keypad and the 2-line LCD display. The manual start mode may also be initiated at the controller. ET Water's objective is for the system to automatically generate and execute irrigation schedules. The need for program modification in the field is typically limited.

ET Water provides email alerts when there is a failure of communication between the field controller and central server. It also provides email alerts when manual adjustments are made on the field controller – the user may review such changes and override them remotely from any PC if desired.

ET Water Systems reports the irrigation scheduling algorithms it uses are based on current state-of-the-art horticultural science. The program reportedly incorporates all landscape factors needed to accurately determine soil moisture depletion and irrigation scheduling. ET Water uses a different algorithm for scheduling sprinkler and drip irrigation stations. The company's proprietary algorithms automatically generate daily schedules for each station with run and soak times based on a station's sprinkler application rate, soil intake rate, and slope conditions. The station run/soak cycles for each irrigation period remain constant, based on replenishment of a 50 percent plant root zone moisture depletion level. Irrigations are delayed until a soil moisture depletion level of 50 percent is calculated, based on the measured daily ET and rainfall. If the user desires more frequent watering, it may adjust the depletion level downward.

Descriptions, Prices and Warranty

All ET Water controllers are currently constructed of weatherproof fabricated aluminum enclosures with a key lock. Starting in 2008, ET Water will manufacture residential controllers with an injection molded plastic enclosure. In addition to the regular station circuits, the controllers provide a master valve/pump start circuit. The station circuit capacity is 1.1 amperes and the station terminals will accept 12-20 gauge wire.

The use of a standard rain sensor (approximately $59) will cause circuit interruption and suspend irrigations when significant rainfall occurs. In addition, ET Water enables online set-up and control of station-by-station fertilizer dispensing through the irrigation system. This is achieved by installing an EZ-FLO® fertigation tank that is wired to a terminal on the controller.

Remote monitoring features for commercial applications include email notification of any adjustments to a controller; such as suspend, power interruption, failure to connect to the internet, increase in percent watering for any zone and flow monitoring. For response to these occurrences, the user may remotely re-set or adjust these features from its PC.

An ET Water residential controller sells for approximately $499 to $549, depending upon the number of stations and the communication method – a 6 station telephone connected unit costs about $499, while a 12 station "powerline" connected unit sells for $549. The ET Water controller will accommodate popular brands of rain sensors or rain gauges. The annual residential service fee is $75 per year, but multiple year service plans reduce this amount as discussed below.

An ET Water commercial controller sells for approximately $1,219 to $2,399, depending upon the number of stations and the communication method – a 12 station telephone connected unit costs about $1,219, while a 48 station wireless connected unit sells for $2,399. The ET Water Manager Service includes daily watering schedule updates, telecommunication and wireless access charges, ability to remotely monitor and adjust the controller from any PC, email alerts in case of on-site problems, and online and phone-based customer service. The annual service fee ranges from $139 per year for commercial telephone connect to $199 for wireless connectivity.

Five and ten year service plans are available for both residential and commercial controller service, providing 33 and 50 percent savings off of the annual rate, respectively. This can bring annual service costs down to approximately $40 for residential service, and as low as $70 for commercial service.

ET Water offers panel replacements for certain non-weather based models of popular brand controllers. These panels make installation very rapid and sell for less than a full ET Water controller, saving the customer up to 40 percent off of the price of a new controller.

Since telephone or wireless communication allows two-way information transfer, ET Water can manage the information received from individual controllers. This may be beneficial to water agencies by allowing analysis of customer water use data.

Installation

ET Water Systems reports its controllers do not require professional installation, although the company recommends professional installation and will provide factory trained individuals or irrigation contractors to install all units. A typical professional commercial installation should take 1 to 3 hours, which includes a site assessment and discussion of the assessment with the user. Typical residential installations can be completed in less time. The professional installation/consultation cost is estimated to be $75 - $225 depending on location, size, and other site conditions. Technical support is available by toll free telephone (800-685-5505), in addition to the support provided on the company's website.

Track Record, Water Savings and SWAT Testing

The ET Water system has completed SWAT testing and a performance report is posted on the Irrigation Association website. ET Water submitted information from three of its large commercial customers documenting significant water savings. ET Water reports overall average water savings in the range of 20 to 50 percent.

The ET Water Manager Service includes daily watering schedule updates, telecommunication and wireless access charges, ability to remotely monitor and adjust the controller from any PC, email alerts in case of on-site problems, and online and phone-based customer service.

The ET Water computer interface method of programming and monitoring the system is comprehensive and user friendly. The water use monitoring option should also be attractive to progressive water agencies interested in quantifying water savings.

Hunter

Hunter Industries was established in 1982 and is headquartered in San Marcos, California. Hunter® manufactures and distributes a full line of landscape irrigation products worldwide. Hunter introduced its ET System™ to the market early in 2006. The ET System consists of the ET Sensor (onsite weather station) and the ET Module (add-on irrigation scheduler). It is compatible with most Hunter irrigation controllers less than ten years old, including any Hunter controller equipped with a SmartPort™. The ET System is not compatible with other brands of controllers. Depending on the controller, the ET System is suitable for residential and commercial applications.

The ET System creates an irrigation program automatically based on weather conditions measured onsite. The programs are operated via the compatible irrigation controller and run automatically on water days and at start times set by the user. Compatible controllers include Hunter Models SRC/SRC Plus, Pro-C, ICC, and ACC with SmartPort® technology. The irrigation schedule is based on

the ET Sensor's calculated ET value and programmed plant, soil, slope, sun/shade and sprinkler type information provide the basis for calculation of the irrigation schedule. The result is a new revised irrigation program every water day, based on the weather conditions measured onsite. Once installed, each zone is scheduled from the ET Module, rather than the controller itself.

Operational Features

The ET Sensor calculates ET by its daily measurement of solar radiation, air temperature, and relative humidity. The accuracy of the ET calculation can be improved with the addition of an optional anemometer (ET Wind), along with an automatic wind shutdown capability. The ET System will also shutdown irrigation if the air temperature drops below 35° F. The ET Sensor includes a tipping bucket type rain gauge, which measures rainfall to one-hundredth of an inch. The user programs the ET Sensor to stop irrigation in progress at a specific rainfall depth, and a percentage of the rainfall is accounted for in the irrigation schedule. The ET Module calculates specific run times for each zone individually. The ET Module also possesses an optional wilt guard feature (Wiltgard™) that triggers irrigation when extreme temperatures occur if enabled by the installer. The user-selectable WiltGard triggers emergency irrigation (regardless of time of day) when the ET System determines that plants are threatened by monitored conditions.

To program the ET Module, the user first enters the type of controller used, date and time, water days and start times. Then the site condition settings are made for each station. These settings consist of plant type, soil type, sprinkler type, percent ground slope, sun/shade, and plant maturity. The rain sensor setting is programmed for the minimum amount of rainfall that will cause interruption of irrigation. The minimum shutoff setting is 0.02 inches and it is set in 0.01 inch increments.

Available plant type settings include numerous types of grasses, shrubs, ground covers, vines, trees, perennials and desert plants. Alternatively, a custom crop coefficient setting can be used in place of plant type. Available soil type settings consist of sand, sandy loam, loam, clay loam, silt, clay and silty clay. Soil type selection determines both infiltration rate (used for cycle-and-soak calculation, along with the slope setting) and water-holding capacity of the soil. Sprinkler type can be set to rotor, spray, drip, bubbler or custom. The custom option allows for entering a sprinkler application rate (0.01 inches/hour or 0.254mm/hour increments). The ground slope setting is by percentage. Available sun/shade settings consist of full sun, part shade (75 percent sun), part sun (50 percent sun) and full shade. The maturity setting is set to either new or established. With maturity set to new, the irrigation quantity is doubled and then decreases linearly to the normal or established rate based on the plant type. The ET source setting can be set to manual to override automatic ET calculation. The wilt guard feature is programmed either on or off (default out of the box is Off).

The ET Module is plugged into the controller's SmartPort, and once programmed; it uses the controller's Program "A" to create and run irrigation on water days (except with the Hunter ACC controllers where it works independently of any programs). Each day, the ET System evaluates the current soil moisture depletion level, ET rate, plant type (crop coefficient and root zone), and whether the next day is an allowable watering day. Then the system performs a "look ahead" on the allowable watering days, to see if not watering at that time would deplete soil moisture critically by the time a watering day is scheduled. Irrigation will not occur, however, if the calculated quantity is below the minimum irrigation amount, to prevent shallow watering. The calculation for minimum sprinkler runtime is based upon the soil type and capacity.

Descriptions, Prices and Warranty

The ET Module is housed in a weatherproof extruded plastic cabinet and it dimensions are 6" x 4" x 1.8". The ET Sensor standard model dimensions are 10.5" x 7.3" x 12", and the ET Sensor with ET Wind standard model dimensions are 11.5" x 7.3" x 20". The ET Module operates on 24 VAC from the controller's SmartPort and requires no additional AC wiring. It has non-volatile memory and a replaceable 10-year lithium battery.

The ET System is available from Hunter distributors worldwide and a distributor search engine can be accessed at Hunter's website. The retail price for the ET System basic model is $429, and the optional ET Wind is an additional $429. The price range for the ET System compatible Hunter controllers is from $115 to $799. The ET System comes with a 2-year warranty.

Installation

Installation and programming of the ET System can be performed by the user or irrigation professional. First time installation and programming for a typical setup is reported to require 2 hours. The ET Module is wall mounted near the controller and the ET Sensor is installed within 100 feet of the ET Module. The ET Sensor can be wall mounted or attached to a pole or eave. The ET System owner's manual is available at Hunter's website (hunterindustries.com). It contains detailed installation and programming information.

Track Record, Water Savings and SWAT Testing

The ET System's ET calculation algorithm uses the Modified Penman-Monteith equation. In creating the ET System's crop coefficients for the various plant type settings, Hunter has generally followed the principles of Water Use Classification of Landscape Species as prescribed on the State of California Office of Water Use Efficiency website (www.owue.water.ca.gov/index.cfm). Use in other states may require some adjustment for crop coefficients, which can be customized in the ET System.

The ET System has completed SWAT testing and a performance report is posted on the Irrigation Association website. The ET System was two years in development and beta testing. Hunter has had 10-15 years experience with ET-based irrigation, but this is its first ET System aimed at stand-alone residential applications.

Although Hunter did not provide water savings data for this report, it reports an approximate water savings of 30 percent, which is similar to the study results for other weather based irrigation control products discussed in this report.

HydroPoint

WeatherTRAK® ET is the line of residential and commercial weather based irrigation controller products by HydroPoint Data Systems Inc. of Petaluma, California. WeatherTRAK ET provides a wireless, real-time ET data service combined with the controller's Scheduling Engine™ software that updates irrigation schedules daily for each valve in a landscape. Network Services, which developed patents on the broadcasting of ET data used by HydroPoint, began business in 1997. HydroPoint was incorporated in 2002 and entered into a partnership with The Toro Company in 2003. Toro manufactures irrigation controllers under its name and under its subsidiary, Irritrol, which also use the WeatherTRAK system (see Toro and Irritrol sections).

HydroPoint's WeatherTRAK ET plus residential controller comes in 9, 12, 18 and 24 station models, and its WeatherTRAK ET pro commercial controller comes in 24 station models. The new WeatherTRAK ET Pro^2 commercial controller series provides 12 to 48 station capacity and integrated flow management. The irrigation scheduling features are similar for all models, but the commercial controllers offer optional 2-way communication ability and other features.

The WeatherTRAK system uses data from over 14,000 weather stations across the U.S., including the National Oceanic and Atmospheric Administration's (NOAA) network, state and county networks and private weather stations. The WeatherTRAK system uses advanced climatologic modeling techniques developed at Penn State University. This proprietary system is called ET Everywhere™, and has proven accuracy to a standard deviation of .01 inch of daily ET down to one square kilometer. The WeatherTRAK ET Everywhere service provides local ET (microzone) without the need for any additional

weather stations or single sensors on a site. The WeatherTRAK system calculates ET using the standardized Penman-Monteith equation. The HydroPoint Data Center validates the weather data and transmits calculated ET through three satellite servers to each controller everyday. The three satellite servers provide over-lapping coverage of the U.S. to ensure signal reception to WeatherTRAK controllers located anywhere.

Operational Features

The WeatherTRAK ET controller calculates irrigation schedules for each independent valve on a site. The controller does not use pre-set irrigation schedules input by the user. Instead, it asks a series of questions to define the site variables that influence water need. The controller is programmed by entering the following station specific information: sprinkler type or precipitation rate, plant type, root depth, soil type, microclimate (sun or shade), slope (including if the valve is at the top, middle or bottom of the slope, and system efficiency (percentage). The schedule for each station is adjusted daily according to the local weather data received via the ET Everywhere service.

With these inputs, the WeatherTRAK ET calculates an irrigation schedule for each irrigation valve. Soil moisture depletion tracking, triggered at a 50% depletion level, along with daily ET updates allow the controller to adjust schedules as the weather changes. The number of water days, minutes and cycles (with appropriate soak times between cycles) are generated automatically and change as weather and water need fluctuates. The WeatherTRAK ET has an eight-week scheduling window. This allows for infrequent watering of low water use or native plants.

Programming options for all WeatherTRAK ET controllers include sequential stacking of overlapping start times, or the ability to run two programs simultaneously. The WeatherTRAK ET controllers have a manual feature providing any amount of time setting for plant establishment or to check the irrigation system on a valve by valve basis. An adjust feature provides percentage adjustments (in 5 percent increments) to increase or decrease the run time for any station. The controller accepts rain, wind, freeze and flow sensors and possesses a master valve circuit. A rain pause mode allows the user to shut-off irrigation for up to 14 days during or after rain. HydroPoint can also be contacted to automatically “rain pause” controllers and groups of controllers using the wireless data service. Non-waterering days can be selected. A “help” mode alerts the user to the WeatherTRAK customer service center toll free telephone number (800-362-8774) to answer questions and walk users through any situation occurring on the site.

Other features include inputs for crop coefficient values, community water restrictions (odd/even or selected watering days) and unlimited programs. The independent station adjust feature allows for individual station adjustments from

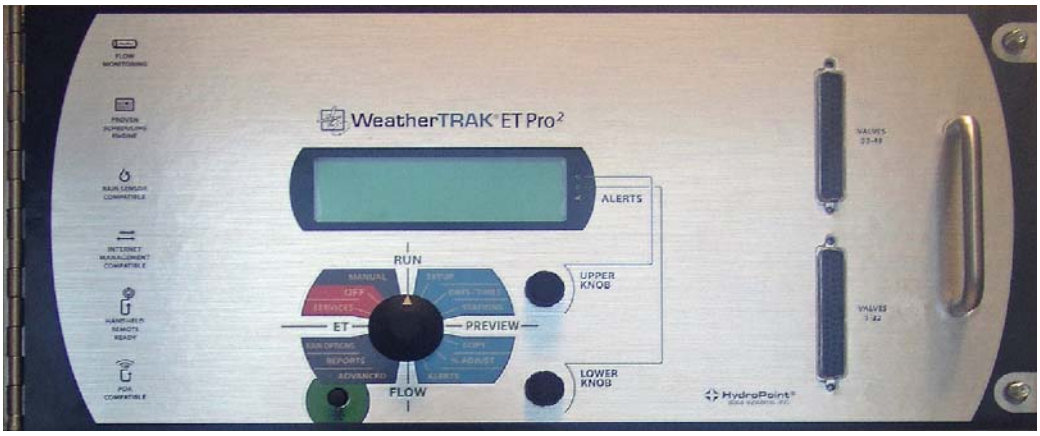
-50 to +25 percent in 5 percent increments. All WeatherTRAK ET controllers have heavy duty surge protection on the 24 VAC output board. The WeatherTRAK ET controllers have non-volatile memory and do not require a back-up battery to maintain date and time information. The controller terminals will accept 12 to 20 gauge size wiring. In some cases, an optional antenna is required to receive the scheduling signal.

Descriptions, Prices and Warranty

The WeatherTRAK ET plus is an indoor/outdoor residential controller. Its cabinet is of extruded plastic with dimensions of 8.6” x 11” x 4.7”. Programming is done with the programming dial, copy button, two selector knobs and three-line LCD display. The internal power transformer for the 9 and 12 station models includes a 2.0 ampere fuse, has a maximum total circuit capacity of 1.0 amperes and the individual station circuit current capacity is 0.375 amperes. The 18 and 24 station models include the same fuse and individual circuit capacity, but the total circuit capacity is 2.0 amperes. The 18 and 24 station models also include a manual valve test program to identify open valves and short circuits. A 2 year subscription to the ET Everywhere service is included with the purchase of 9 and 12 station models, and a 1 year subscription is included with the 18 and 24 station models.

The WeatherTRAK ET pro commercial controller comes in an indoor chassis model with dimensions 14.5” x 27” x 4” and two indoor/outdoor lockable stainless steel cabinet models. The wall mount cabinet dimensions are 8.5” x 18.5” x 8” and the front access pedestal cabinet dimensions are 16.8” x 30” x 8.3”. The ET pro does not include a typical front panel with programming access, but programming is done from a remote location using the WeatherTRAK.net service, as discussed below. Additional features included with the ET pro include automatic short circuit detection and alarm, programming conflict alarm, ability to run two stations concurrently, and additional circuit capacity. The ET pro comes with a vandal resistant antenna. The internal power transformer includes a 2.4 ampere fuse, has a maximum total circuit capacity of 2.4 amperes and individual station circuit current capacity of 0.5 amperes.

The ET pro is compatible with the WeatherTRAK.net service that allows Internet-based irrigation control 24/7 with a secure web-hosted service. With WeatherTRAK.net, the user can manage single or multiple controllers from any location with access to the Internet. WeatherTRAK.net delivers instant



notifications of adjustments made in the field and enables fast, one-click synchronization. Through wireless, two-way communication, WeatherTRAK.net transmits real-time updates and system alerts to the user's personal computer, mobile phone or PDA (personal data assistant). HydroPoint sells a Hewlett Packard® iPAQ PDA with all necessary hardware and software to utilize Weather TRAK.net. A 3-month subscription to WeatherTRAK.net and ET Everywhere is included with the purchase of a WeatherTRAK ET pro.

WeatherTRAK ET controllers are available directly from HydroPoint or local distributors. A distributor search engine can be accessed at HydroPoint's website. WeatherTRAK ET controllers come with a 3 year warranty, and toll-free telephone customer service is available Monday through Saturday during business hours, and on-line customer service is available 24/7. A partial listing of WeatherTRAK ET controller list prices is provided in Table 5 (a complete price list is available from HydroPoint Sales through its toll free telephone number or website).

Table 5 - WeatherTRAK Controller and Accessories Prices and Fees

Description	Model	Price
9-Station Residential Controller	WTPLS-09	$549-$559
12-Station Residential Controller	WTPLS-12	$579-$589
18-Station Residential Controller	WTPLS-18	$759-$769
24-Station Residential Controller	WTPLS-24	$859-$869
24-Station Chassis Commercial Controller	WTPRO-24-CHA	$3,125
24-Station Wall Mount Commercial Controller	WTPRO-24-SSW	$3,325
24-Station Pedestal Commercial Controller	WTPRO-24-SSP	$4,525
Hewlett Packard iPAQ PDA	WT-PDA-KIT	$1,200
WeatherTRAK.net Annual Fee	CIM-PROC-24-1Y	$225
9-12 Station ET Everywhere Annual Fee	ETE-912-1Y	$48
18-24 Station ET Everywhere Annual Fee	ETE-1824-1Y	$84

Installation

Hydropoint reports the WeatherTRAK ET controllers do not require professional installation, although it is recommended. Typical installation times, as seen in public agency studies and distribution programs, range from 1 hour to 2.5 hours, depending upon the size of the landscape covered and mounting issues. Installation should include a site assessment, and discussion with the user about the site irrigation system and how the controller operates with the user. Technical support is available by a toll free number, at HydroPoint's website (www.weathertrak.com) or through field-certified contractors.

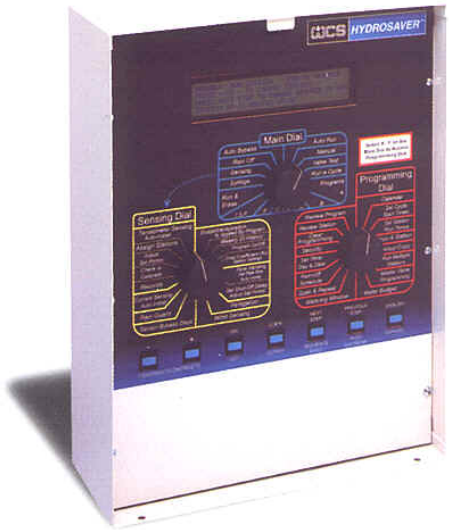
Track Record, Water Savings and SWAT Testing

WeatherTRAK ET has completed SWAT testing and a performance report is posted on the Irrigation Association's website. The WeatherTRAK ET controllers have been tested in 20 public agency settings since 1998. WeatherTRAK reports the overall results from these tests indicate significant water savings (16 to 58 percent) and reductions in runoff (64 to 71 percent). Information provided by WeatherTRAK about several of these studies is summarized in Table 6.

Table 6 - Summary of WeatherTRAK Demonstration Projects

Test Sponsor	No. of Test Sites
Irvine, California	180
Los Angeles Dept. of Water and Power	540
Boulder, Colorado	10
Colorado State University, Ft. Collins	3
University of Las Vegas, Nevada	15
Santa Barbara, California	200
Lake Arrowhead, California	78
Victor Valley, California	12
Marin, California	8
Park City, Utah	24
Santa Clara Valley Water District, California	125
Newhall County Water District	25

Hydrosaver



Water Conservation Services (WCS) Hydrosaver™, of Signal Hill, California, has been a manufacturer of water conservation based commercial landscape irrigation technologies for over 20 years. Hydrosaver entered the Smart controller market in 1992 with a soil moisture based controller. Its current ET controller, the ETIC, was introduced in 1994. The Hydrosaver ETIC functions as either a stand-alone controller, or as a satellite controller of a centralized control system, managed by WCS' partner HydroEarth Solutions. WCS developed its own electronic tensiometer soil moisture sensor, electronic rain sensor and ET sensor. It reports over 2,500 of their commercial weather based controllers have been installed, mostly in Southern California.

The ETIC controller comes in standard sizes from 12 to 56 stations and can be customized with the WCS Hydromaster to handle up to 164 stations. The ETIC adjusts irrigation schedules based on ET data received from the WCS Hydrosaver ET sensor. The controller comes with the ET sensor and the Hydrosaver Rain Guard™ rain sensor. Optional soil moisture and flow sensors may also be connected to the ETIC.

Operational Features

As a stand-alone controller, the user programs the ETIC with a base irrigation schedule. The base schedule includes irrigation days and run times. Total run times are entered for July and the controller automatically decreases the run times based on the accumulated ET sensor inputs since the last irrigation. The controller includes an ET percent feature that allows the user to vary the ET adjustment rate by program up to 300 percent, in 10 percent increments. The ET schedule adjustment function can be switched ON or OFF. The controller's ET scheduling feature is based on real time ET utilizing historical ET as a baseline. Historical ET data are programmed into the controller by the user.

The Hydrosaver ET sensor measures temperature, humidity and solar radiation. The controller calculates ET using these measurements. (The ET calculation assumes a 3 mph wind speed.) The ET sensor is in a vandal resistant housing and is maintenance-free. ET is calculated to within 100th of an inch using the Penman-Monteith equation. When the Rain Guard

detects one-quarter of an inch of rain, irrigation is interrupted and the controller can be programmed for a rain delay up to 99 days. The Rain Guard includes a built-in bypass switch for controller testing during periods of extended rain.

The controller accepts Data Industrial or Fluidyne flow sensors. Once the user programs flow limits, the flow-sensing feature will trigger an alarm and shut off irrigation when flow limits are exceeded in the event of line breaks and valve failure. A shut off delay feature is provided and the flow sensing capability can also be used for fertigation purposes. The controller also possesses a faulty circuit feature that senses valve and wiring problems.

The ETIC includes 6 regular programs with up to 12 start times each. The controller has a valve test program and up to 4 stations may run concurrently. In addition to the regular station circuits, the controller has 3 independently programmable master valve outputs. There is also a pump start output that goes on with all irrigation. The controller automatically divides total run times into appropriate cycle-and-soak times to minimize runoff based on soil and slope conditions entered by the user for each zone. The irrigation schedule calendar options include 7, 14 and 28 day and even or odd day. Irrigation days can be specified and the controller has a watering window feature.

Descriptions, Prices and Warranty

The ETIC comes in standard wall mount models and complete stainless steel (CSS) top entry enclosure models The standard wall mount cabinet is constructed of rolled steel with dimensions of 12” x 16” x 6”. The CSS dimensions are 16” x 14” x 36” and the enclosure must be mounted to a concrete foundation. Both models are designed for outdoor installation and are lockable, weatherproof and vandal resistant. The controller’s 4-line by 48 character LCD display can be set to English or Spanish. Current and historic irrigation, ET, weather and flow information is displayed. All ETIC controllers include an internal transformer and the station circuit capacity is 2 amperes. The controller has non-volatile memory and the date and time information is protected without backup batteries. Surge and lightning protection is provided through a relay system to create circuit isolation protection, separate power transformers for controller processing and valve circuitry, MOVs, and an isolation transformer.

WCS Hydrosaver products are available directly from Hydrosaver and HydroEarth (949-636-7749 or hydroearth.com), or from commercial distributors. The current retail price for a standard wall mount 24-station ETIC controller with the Rain Guard and ET sensor is $1,800. A 24-station CSS controller is currently priced at $2,800. Prices for other controller sizes and accessories can be obtained from Hydrosaver or HydroEarth. The CSS controllers come with a 5-year warranty and the standard controllers come with a 3-year warranty. The warranties include free field service, with a renewable option.

Installation

According to WCS Hydrosaver, the ETIC should be installed by an irrigation professional. Installation and programming time will vary depending on system size and site conditions. Toll-free telephone customer support is available during business hours at 800-821-1322.

Track Record, Water Savings and SWAT Testing

WCS Hydrosaver reports its controllers are being included in several current studies including research work on wireless valves and ET controllers. Hydrosaver reports significant variance in ET measurements by multiple ET sensors tested within close proximity to a CIMIS weather station. Specifically, hill top ET measurements were found to be significantly higher than those at the bottom of the hill and at the nearby CIMIS site. A SWAT test performance report for Hydrosaver controllers was not available at the time of this study.

Irrisoft

Irrisoft Inc. offers weather-based control to residential and commercial irrigation systems through the Weather Reach Water Management System™. Established in 1999, Irrisoft™ became a subsidiary of Campbell Scientific Inc. in 2001 and has now partnered with Rain Bird Corporation to offer weather-based irrigation control solutions to both homeowners and commercial water users. Rain Bird® has a longstanding relationship with Irrisoft and Campbell Scientific, Inc.

The Weather Reach Water Management System provides wireless, real-time ET data to any standard irrigation controller through a Weather Reach Receiver. There are two “smart” receivers offered with this system; the WR-7 Weather Reach Receiver and the ET Manager™, which is offered through Rain Bird Corporation (see Rainbird Section).

The Weather Reach Water Management System uses Campbell Scientific weather stations with a full set of sensors to gather accurate weather data. The Weather Reach Signal Providers maintain computer servers with an Irrisoft computer software program to communicate with the weather stations (often using existing stations in an area), and broadcast weather information hourly through a pager network to Weather Reach Receivers. Data includes temperature, wind speed, relative humidity, solar radiation and rainfall. Weather Reach Receivers use this

information to calculate ET accumulation on an hourly cycle, and process it into a running ET balance.

The WR-7 and ET Manager are used in combination with a user's existing irrigation controller to schedule irrigation based on ET demand. These receivers are compatible with any standard irrigation controller and interrupt irrigation until it is needed.

Operational Features

Weather Reach manages the frequency of irrigation and does not adjust run times. To help a user create an irrigation schedule for a controller, Weather Reach provides a free program called InSite Irrigation Scheduling™. InSite tailors the schedule to a specific sprinkler controller's capabilities as well as the capabilities of the sprinkler system and factors in the landscape dynamics such as plant type, soil type, root depth, slope and sprinkler precipitation rates.

Users enter the information through a series of questions that help to tailor the schedule to each station on the property. InSite performs all the calculations automatically but still allows a user to adjust any of the calculations for a custom schedule and gives users the opportunity to see how the calculations are made. InSite can also calculate accurate settings for programming the Weather Reach Receiver.

Once the schedule has been created, the user enters it into the sprinkler controller, and programs the Weather Reach Receiver with the proper settings. Weather Reach will then automatically manage the frequency of irrigation based on ET. Weather Reach Receivers can accommodate any available or non-available watering day requirement.

Most weather conditions are relatively constant over large areas, but rainfall can be very localized. A tipping bucket rain gauge is offered as an optional add-on component to a receiver to measure on-site rain as opposed to the rain measurement provided at the weather station. This allows the receiver to more accurately calculate the amount of water a landscape will need, and to interrupt irrigation when a user specified amount of rainfall occurs.

A growing network of Weather Reach Signal Providers exists throughout the U.S. For a covered area, data from multiple weather stations are received, processed, and then transmitted by a Signal Provider. The Weather Reach Receivers are programmed to receive data from the appropriate weather station based on a weather region code. The data are transmitted hourly by the provider using a Motorola® Flex® paging system.

Potential ongoing costs are dependent on the signal provider for a given area. Public providers typically absorb the cost of the weather stations, computer server

and software, and paging system, and there is no ongoing user cost. Commercial providers pass on these costs to the end user. Private providers offer the service to a specific entity such as a Home Owners Association. A list of current Signal Providers is maintained at www.irrisoft.net. The typical price range for private providers surveyed for this report is $50 to $350 per year. Where a signal is not available, Irrisoft offers a variety of solutions to establish a public or private Weather Reach Signal. (Irrisoft should be contacted for details.)

The existing controller is programmed based on a plant root zone moisture depletion and ET threshold balance concept using the InSite software. This balance is maintained based on ET minus effective rainfall. This type of schedule will allow the root zone to dry out to a manageable level before irrigation occurs, and then irrigation is set to refill the root zone without over-watering.

The controller schedule is set to irrigate every day, unless certain days are to be excluded for a variety of reasons. The receiver then allows the controller to irrigate when the ET threshold is reached, and the prescribed irrigation amounts are applied to replenish the root zone depletion. The receiver includes two programs so that two ET thresholds and landscape adjustment percentages may be used. This provides for different stations to be scheduled separately to meet the needs associated with varying plant types and conditions.

Descriptions, Prices and Warranty

The WR-7 is a small (4.8” x 5.3” x 1.5”) plastic cabinet designed for indoor installation. A lockable fiberglass outdoor enclosure is available as an accessory for both receivers. In the event a power supply is not available from the existing controller, an optional power transformer is available. A 9-volt backup battery is included for operation during power outages. In some cases, an external antenna is required for the receivers. Receiver and add-on component prices are summarized in the Table 7. The WR-7 comes with a one year warranty.

Table 7 - Irrisoft Product Prices

Component	Model No.	Price
Weather Reach Receiver	WR7	$795
Pronamic Rain Gauge	WR-PRG	$165
Power Supply	WR-PS	$42
External Antenna	WR-ANT-B	$58
Outdoor Enclosure	WR-OE	$230

Installation

Irrisoft recommends installation by a professional irrigation system specialist, and it markets its products through specialty irrigation product suppliers. The typical installation cost ranges from $100 to $400.

Track Record, Water Savings and SWAT Testing

Irrisoft reports that during recent years, numerous demonstration projects using the Irrisoft System have proven its ability to save water. Irrisoft reports the overall results from these projects indicate water savings of 20 to 50 percent. A sampling of these projects is provided in Table 8. A SWAT test performance report for the WR-7 was not available at the time of this study

Table 8 - Summary of Irrisoft Demonstration Projects

Sponsor	No. of Test Sites
Denver Water Department	12
Utah Division of Water Resources	8
Northern Colorado Water Conservancy District	10
Southern Nevada Water Authority	10
EPA Evaluation Project (Massachusetts)	25
Aquasave, Ipswich, Massachusetts	118
WaterLogic, Houston, Texas	40

Irritrol

Irritrol™ Systems is a brand of professional irrigation products manufactured by the Toro™ Irrigation Division, located in Riverside, California. The Toro Company was established in 1914, and acquired the Irritrol brand of products in the early 1990s. The Irritrol Smart Dial™ series of residential and commercial weather based irrigation system controllers entered the market during 2005.

The Smart Dial controllers utilize the ET Everywhere™ subscription service and WeatherTrak™ scheduling engine to provide weather based irrigation control. Toro and Irritrol are partners with Hydropoint Data Services. Toro and Hydropoint controllers also utilize ET Everywhere and WeatherTrak, as discussed in the Toro and Hydropoint sections of this report.

The Smart Dial series includes six residential controllers, comprised of indoor and outdoor models for 6, 9 or 12 zones (plus a pump/master valve circuit), and a 24 zone commercial model. The controllers' WeatherTrak-enabled software creates a scientifically calculated zone-specific baseline irrigation schedule. The

schedule is updated daily using weather data delivered by the ET Everywhere subscription service.

ET Everywhere uses data from the NOAA's system of 14,000 nation-wide weather stations to deliver ET to any area in the US. ET Everywhere has a proven accuracy to a standard deviation of .01 inch of daily ET at a resolution of one square kilometer. The ET Everywhere data service provides local ET (microzone) without the need for a weather station on site. The ET Everywhere Data Center validates the weather data and transmits calculated ET through three satellite servers to each controller everyday. The three satellites provide overlapping coverage of the U.S. to ensure signal reception anywhere.

Operational Features

The Smart Dial controllers calculate schedules for each irrigation zone. The controller does not use pre-set irrigation schedules input by the user. Instead, a series of questions are answered by the user to define the site variables that influence water need. The controller is programmed by entering the following station specific information: sprinkler type or precipitation rate, plant type, soil type, microclimate (sun or shade), slope (including if the zone is at the top, middle or bottom of the slope), and system efficiency (percentage). The schedule for each station is adjusted daily according to the local weather data received via the ET Everywhere service.

With these inputs, the controller calculates an irrigation schedule for each zone. Soil moisture depletion tracking, triggered at a 50 percent depletion level, along with daily ET updates allows the controller to adjust schedules as the weather changes. The number of water days, minutes and cycles (with appropriate soak times between cycles) are generated automatically and change as weather and water need fluctuates. The controllers have an eight-week scheduling window. This allows for infrequent watering of low water use plants. The controllers can initiate irrigation even if the daily ET page is not received by using the last download and loop-up table included in the WeatherTrak software. Non-watering days can be specified in the controllers' schedule programming. The controllers are compatible with Irritrol's Wireless RainSensor™ series (rain and rain/freeze), which eliminate irrigation during rainfall and freezing weather if added as an optional accessory.

Descriptions, Prices and Waranties

Both the indoor controller models' cabinet is constructed of ABS plastic while the outdoor units are comprised of Lexan. The dimensions of the indoor models are 7.8" x 7" x 3.8" and the dimensions of the outdoor models are 7.8" x 10.8" x 4". The controllers have a large (3.5" x 0.8") LED information display, dial type controls, and a copy button for simplifying setup. All controllers include internal UL/CSA listed transformers. The current capacity for each zone circuit is 0.5 amperes, and the current capacity for pump/master valve circuit is 0.375 amperes. The controllers will accept wire sizes from 12 to 18 gauge. The non-volatile

memory maintains programming, and the back-up battery maintains the date and time during power outages.

Other controller features include surge protection up to 6 kilovolts and valve malfunction detection. The irrigation schedule, irrigation history and program review can be viewed with the LED information display. In addition to the wireless rain and rain/freeze sensors, an external bow tie antenna kit, pump starter relay and wired rain sensor are available as optional accessories.

A snap-in Smart Dial Module is also available which directly interchanges with a users existing Rain Dial™ Plus controller panel to convert it to a WeatherTRAK-enabled controller. A converted controller possesses all of the same features as the Smart Dial controllers.

The Smart Dial controllers, modules and accessories may be purchased from authorized Irritrol distributors and retailers. Current controller, module and accessory prices are summarized in Table 9. Purchase of a Smart Dial controller requires a paid subscription to the ET Everywhere service. The ET Everywhere annual service fee is $48 for the 6 to 12 station controllers and $84 for the 24 station controller, as discussed in the Hydropoint section of this report. The Smart Dial products come with a 5-year warranty.

Table 9 - Irritrol Smart Dial Controller, Module and Accessory Prices

Description	Model	Price
6-station Indoor Controller	SD-600-INT	$399
9-station Indoor Controller	SD-900-INT	$449
12-station Indoor Controller	SD-1200-INT	$499
6-station Outdoor Controller	SD-600-EXT	$419
9-station Outdoor Controller	SD-900-EXT	$469
12-station Outdoor Controller	SD-1200-EXT	$524
24-station Outdoor Controller	SD-240-OD	$889
6-station Module	SD-600-MOD	$299
9-station Module	SD-900-MOD	$349
12-station Module	SD-1200-MOD	$399
Wireless Rain Sensor	RS1000	$85.33
Wireless Rain/Freeze Sensor	RSF1000	$114.71
Wired Rain Sensor	RS500	$25.20
Pump Starter Relay	SR-1	$75.60
External Bow Tie Antenna	SD-ANT	$87.50

Installation

The Smart Dial controllers and modules do not require professional installation, although trained installation is recommended. Typical installation times range from 1 hour to 2.5 hours, depending upon the size of the landscape covered and mounting issues. Installation should include a site assessment and discussion with

the user about the irrigation system and how the controller operates. Installation and setup instructions are included in the owner's manual. Technical support is available from Irritrol at its website (www.irritrolsystems.com), by toll free telephone (800-634-8873) and through field certified contractors.

Track Record, Water Savings and SWAT Testing

Irritrol reports the technology behind the Smart Dial controller and module series is proven by several multi-year independent studies showing water savings. These studies were performed using Hydropoint's WeatherTrak controller and the ET Everywhere service. The studies are discussed in the Hydropoint section of this report.

A Smart Dial controller SWAT test performance report is posted at the Irrigation Association's website.

Rain Bird

Rain Bird Corporation, based in Glendora, California, began business in 1933. Over 4,000 Rain Bird® products are sold domestically and in more than 120 countries. Rain Bird owns more than 130 patents and 30 additional trademarks. For more than two decades Rainbird has used weather technology in the golf and commercial irrigation markets with their central control products, including the Maxicom™, SiteControl™ and Nimbus™ II systems.

Rain Bird recently joined forces with Irrisoft Inc., a Campbell Scientific company, to offer a weather-based solution for homeowners and commercial water users. The ET Manager™, or ETMi, is an add-on scheduler that works with an existing controller to manage irrigation frequency based on weather conditions. Rain Bird began field testing the ET Manager in the Fall of 2005 and it entered the market in June 2006. Its predecessor, Irrisoft's WR7 Weather Reach Receiver, has been in use since 2001. Rain Bird has used private-labeled Campbell Scientific weather stations for nearly 20 years with its central control systems.

The Rain Bird ET Manager uses weather information, typically from fully instrumented Rain Bird and or Campbell Scientific weather stations. The ET Manager receives the weather data in the form of an hourly broadcast through a paging network provided by a local Weather Reach Signal Provider. This approach enables thousands of users to benefit from accurate, reliable weather data from a single or network of weather stations depending on the size of the region covered. The weather data broadcast includes temperature, wind speed,

relative humidity, solar radiation, and rain. An optional rain gauge is available for on-site rainfall measurement, and to interrupt irrigation when a user specified amount of rainfall occurs.

A growing network of Weather Reach Signal Providers exists throughout the U.S. Potential ongoing costs are dependent on the Signal Provider for a given area. Public providers typically absorb the cost of the weather stations, computer server and paging system, and there is no ongoing user cost. Commercial providers pass on these costs to the end user. Private providers offer the service to a specific entity such as a Home Owners Association. A list of current Signal Providers is maintained at Irrosoft's website (www.irrisoft.net). The typical price range for private providers surveyed for this report is $50 to $350 per year.

Operational Features

The ET Manager uses the ASCE standardized ET equation to calculate ET on an hourly basis and maintain a user specified soil moisture balance. Typically, controllers irrigate on time-based (day, time, and minutes to water) schedules regardless of changing weather and landscape needs, whereas the Rain Bird ET Manager interrupts the controller only allowing it to irrigate when calculated soil moisture levels reach user set levels. Historical ET is programmed into the ET Manager and used as back-up in the event the Weather Reach Signal is not received.

The ET Manager is compatible with nearly any existing standard irrigation controller by interrupting the common wire thus managing the frequency of irrigation. The Rain Bird ET Manager schedules the irrigation frequency (how often watering occurs), but not controller run times. Additionally, the ET Manager provides pulse output of ET and rainfall to compatible controllers (0.01-inch per pulse). This feature allows for automatic scheduling by the clock controller based on ET accumulation and rainfall amounts as reported by the ET Manager.

To help users create an irrigation schedule for an irrigation controller and program settings in the ET Manager, Rain Bird offers the ETMi Scheduler. This computer program tailors an irrigation schedule to a specific irrigation controller's capabilities, and the characteristics of the irrigation system. The user enters information for each station and landscape characteristics including plant type, soil type, root depth, ground slope, and sprinkler precipitation rates to create the schedule. All calculations are done automatically and the user has the ability to adjust any of the results for a custom schedule. Once a schedule has been created with ETMi Scheduler, it can be printed out and entered into the irrigation controller. The ETMi Scheduler program can be downloaded at no charge from Rain Bird's website (www.rainbird.com).

The optional ETMi Programming Software allows settings for the ET Manager to be programmed quickly and easily. Users select the appropriate local weather station, site elevation, and available watering days (the ET Manager can accommodate any available or non-available watering day requirement). When the required parameters have been entered, the user can transfer the settings automatically into the ET Manager through the cable supplied with the optional ETMi Programming Software kit. This kit is very convenient for professionals performing higher volumes of ET Manager installations.

The controller schedule is set to irrigate every day, unless certain days are to be excluded for a variety of reasons. The ETMi then allows the controller to irrigate when the Irrigation Amount is reached. The Irrigation Amount is the amount of water that is allowed to evaporate and be used by the plants before irrigation will occur. The ET Manager "enables" watering cycles to refill the plant root zone by applying the Irrigation Amount. The irrigation controller is programmed to apply the Irrigation Amount. By applying the Irrigation Amount, the root zone is refilled without over-watering.

The ET Manager includes two programs so that two Irrigation Amounts may be used. This provides for different stations to be scheduled separately to meet the needs associated with varying plant types and conditions.

Descriptions, Prices and Warranty

The Rain Bird ET Manager has a large graphic display and is designed for indoor installations for convenient viewing of hourly weather conditions, ET and irrigation amounts. Its dimensions are 5.6" x 6.5" x 2". A lockable outdoor enclosure is available as an accessory. In the event power is not available from the existing irrigation controller, an optional external power transformer is available. A 9-volt backup battery is included for operation during power outages. In some cases, an external antenna is required for the receiver.

Rain Bird products are available from irrigation supply distributors throughout the U.S. A distributor search engine can be accessed at Rainbird's website. Current suggested list prices for the ET Manager and accessories are summarized in the Table 10. All Rain Bird controller products come with a 3-year warranty.

Table 10 - Rain Bird ET Manager and Accessories Prices

Description	Model No.	Price
ET Manager	ETMi	$741.00
Optional ET Manager Antennae	ETM-ANT	$238.10
Optional ET Manager Outdoor Cabinet	ETMi-OE	$230.00
Optional Transformer Power Supply	ETMi-TRAN	$23.95
Optional Tipping Rain Gauge	ETM-RG	$200.00
Optional ETMi Programming Software Kit	ETM-PS	$603.18

Installation

Although installation by a Rain Bird trained professional is preferred, Rain Bird reports installation may be performed by some homeowners.

Track Record, Water Savings and SWAT Testing

Rain Bird has field tested 150 ET Managers throughout the U.S. and a SWAT test performance report is posted at the Irrigation Association's website for the ET Manager. Water savings information for the ET Manager's predecessor, the Weather Reach WR-7, is included in the Irrisoft section of this report.

The ET Manager combined with any standard irrigation controller should provide users with accurate real-time weather based irrigation scheduling and help maintain healthy landscapes.

Rain Master

For the past 25 years, Rain Master Irrigation Systems has specialized in the design and manufacture of commercial irrigation controllers, handheld remote controls, and central computerized irrigation control systems. Located in Simi Valley, California, Rain Master introduced its first ET based water management system in 1990. In 2002, Rain Master introduced the RME Eagle™, weather based commercial irrigation controller that functions either as a stand-alone unit, or as a satellite controller component of the Rain Master iCentral™ Internet-based system. The RME Eagle /iCentral system (Patent No. 6,823,239) was designed to address the single controller as well as low to mid-sized control system markets.

Rain Master provides several ET source options for the Eagle. ET may be manually entered into the controller; alternatively the controller may be directly connected to a Rain Master Weather Center II weather station, or receive CIMIS data. When configured with Rain Master's iCentral 2-way wireless card, ET may be disseminated over the Internet using Rain Master's ZipET national dissemination weather service, or California users may obtain their daily ET from CIMIS.

Operational Features

When the Eagle's programs are enabled for ET operation, station runtimes are automatically adjusted on a daily basis when connected to the Internet or a Weather Center II weather station. If daily ET is unavailable, the controller will intelligently utilize average monthly historic ET entered by the user to adjust its daily schedules. Historic ET data by zip code are available at Rain Master's website (www.rainmaster.com). The controller computes ET adjustment granularity to the nearest second, which eliminates rounding errors commonly found in controllers that round on incremental minute basis (i.e., a 5 percent programming error can occur based on just a 10 minute run time).

Rain Master's ZipET is an ET data collection and dissemination service for Rain Master iCentral Internet customers. Rain Master collects raw weather information on a daily basis from thousands of Federal Aviation Administration and NOAA weather stations throughout the U.S. The weather information is validated, and converted as necessary to generate industry accepted ET values. The ET values are interpolated by zip code using a three-dimensional surface regression model. Site-specific ET information is then automatically delivered to each controller via the 2-way wireless communications card (iCard). Rain Master's iCentral website provides daily reports on all ET weather information which was successfully delivered to each controller (2-way confirmation).

An alternative to the ZipET service is available for users who require the accuracy of an on-site weather station. Rain Master's commercial grade, computer controlled, Weather Center II measures wind, rain, temperature, solar radiation and relative humidity and calculates ET at a frequency of ten seconds. A contact closure signal is transmitted from the weather station to the controller by wired connection to signal accumulation of 0.01 inch of ET. The electrical signals are counted and stored in the memory of the controller, which uses the ET data to adjust the irrigation schedule. The Weather Center II measuring devices are permanently mounted on a 10-foot tall, vandal-resistant tower with all connections made within the tower's terminal block. The controller supplies power to the system. The graph in Figure 8 shows the accuracy of the Weather Center II as compared to a nearby CIMIS station.

The Eagle user also has the ability to manually enter daily ET information at any time. When used in conjunction with historic ET, manually input ET can mitigate for extreme conditions. Utilization of manually entered ET data in conjunction with historical ET data can significantly improve irrigation efficiency. The controller will utilize the manually entered ET value for a period of one week, and

then automatically revert back to the use of the selected ET data source. Manual ET data can be entered at any time; each time it is entered it will over-write the last data value stored and supersede all other ET data sources.

When the RME Eagle controller is coupled with the optional 2-way wireless iCentral plug-in card, irrigation control and monitoring may be performed via the Internet. Activation of the wireless service to the controller is performed directly from the Rain Master website. Because it is wireless, installation is reportedly

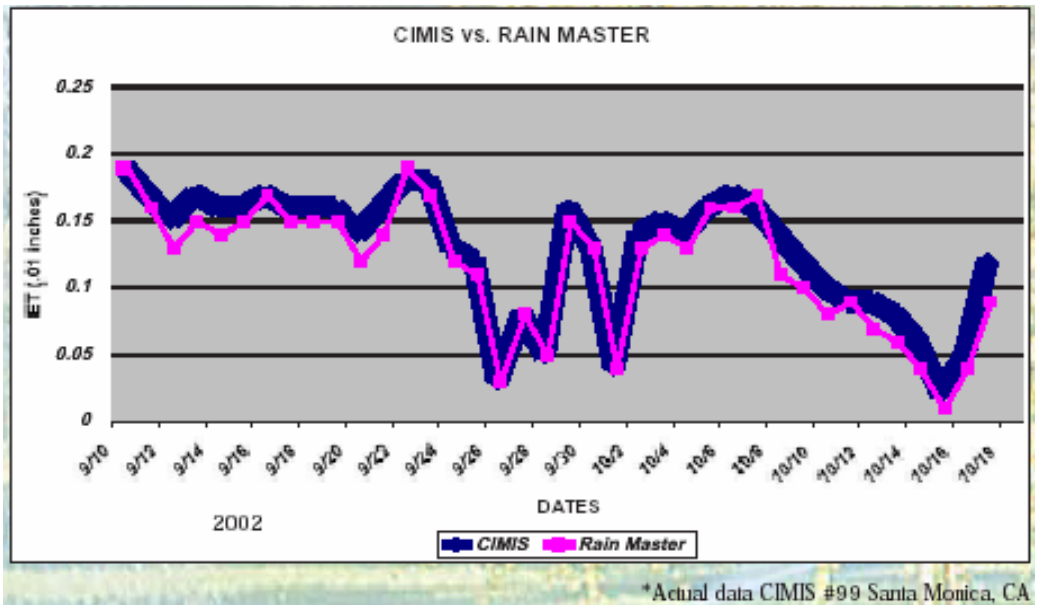


Figure 8 - Rain Master Weather Center II ET versus CIMIS reference ET

simple for either new or retrofit applications. A knock-out at the bottom of the controller enclosure is provided for mounting the 3-inch antenna.

The iCentral website automatically informs the user anytime a field change has occurred, including controller alarms (sensors and wiring fault detection) which are also e-mailed to the user. The website allows the user to command a rain shutdown, modify controller setup information, and manually turn on/off any station or program. The website also provides an automatic schedule generator so that users may generate representative irrigation schedules taking into consideration plant type, irrigation system design, and climatic conditions. Once the user enters all the *scheduling constraints and station attributes* for a controller, as described below, suitable programs are downloaded throughout the year in addition to the daily ET adjustments that are sent to the controller. The scheduler algorithms utilize the Irrigation Association "Landscape Irrigation Scheduling and Water Management" equations dated March 2005.

The *scheduling constraints* define the irrigation season, the controller water window, the stations, programs, and the allowable water days that are available for the scheduler, and any hydraulic constraints the system may have.

The *station attributes* include plant type, precipitation rate, soil type, root zone depth, slope, station efficiency, allowable soil moisture depletion, distribution uniformity, and seasonal plant crop coefficients.

In the absence of the iCentral scheduler, the user must program the controller with a base schedule. The base schedule's total run times and soak/cycle times are adjusted automatically each day by the controller based on ET.

Descriptions, Prices and Warranty

The RME Eagle controller is available in 6, 12, 18, 24, 30, and 36 station configurations. It has four independent programs each with five start times. Water days may be programmed on a weekly basis or by skip-by-day water day cycles with skip days ranging from 1 to 30 days. Station runtimes may be programmed up to 10 hours in one-minute increments, and may be increased/ decreased using the program percent feature from 0 to 300 percent in 1 percent increments. Programmable overlap protection provides for programs to be stacked or run concurrently, and provision is made for a separate master valve and or pump. The controller has non-volatile memory and the time and date are updated without backup batteries. Electronic overload protection is provided, with automatic reset (no fuses or circuit breakers). The Eagle's standard water savings features are summarized in the bullets below.

- Programmable rain shut off in order to delay the start of irrigation after a rain event (1 to 7 days)
- Manual Rain Switch (Automatic Watering – No Watering) provides a means of quickly turning off all irrigation programs without disturbing the stored program(s)
- Connectivity for any one of the following options: rain, moisture, or freeze sensor devices on a per program basis - when the sensor is "active" irrigation will stop and the display will indicate that the sensor is active
- The ability to select either ODD or EVEN day watering on a per program basis
- Selectable cycle-and-soak irrigation programming or conventional programming on a per-program basis
- Programmable cycle runtime, Max Cycle Time, and Soak time on a per station basis
- Automatic minimization of the water window by intelligently scheduling station starts when other stations are satisfying their SOAK TIMES

- The controller provides the ability to display total program duration, real time flow in GPM, alarm information related to flow and station field wiring conditions, daily ET values, sensor status and total water usage

When connected to an optional Rain Master Flow sensor, the RME Eagle controller will suspend irrigation in the event of a station break, catastrophic main line failure, or unscheduled flow. Station limits may be automatically "learned" by the controller and irrigation will be suspended for any station that fails its limit checks while it irrigates. The controller display shows real-time flow measured in GPM as well as flow and station field wiring fault conditions.

The standard size RME Eagle controller dimensions are 13.1" x 10.4" x 4.4", and the extended size cabinet is approximately 7 inches taller. The enclosures are constructed of rolled steel with jet coat®, and are suitable for outdoor installation. An optional stainless steel pedestal mount is available. The controller is UL approved and includes an internal 24 VAC transformer and the current capacity is 1.0 ampere per station or master valve circuit. The controller has terminal screw connections and will accept 12 gauge wire. Optional heavy duty lightning and surge protection is available.

Rain Master's products are available throughout the U.S. at all major irrigation distributors. A distributor search engine can be accessed at Rain Master's website. The MSRP for the standard RME Eagle 6 station controller starts at $640. A 36 station price of $4,264 includes a full year of on-line technical support, internet service and ZipET. Individual internet service plans for wireless 2-way communications range from $9.95 to $14.95 per month. The MSRP for the Weather Center II is $3,500. All Rain Master Controllers come with a 5-year warranty. Nationwide product support is available by a network of Rain Master sales representatives. Toll free factory phone support is available from 8:00 AM thru 5:00 PM PST at (800) 777-1477.

Installation

Rain Master reports installation of the controller is straightforward. The AC power however has to be hard-wired, and a contractor is recommended. Installation time and cost varies depending on site-specific conditions.

Track Record, Water Savings and SWAT Testing

Rain Master reports that thousands of Eagle controllers have been installed throughout the U.S. and that the Rain Master RME Eagle controller has been recognized and accepted by more than 40 water purveyors/agencies across the nation. A list of water agencies that accept Rain Master's products in their water saving incentive programs can be accessed at Rain Master's website.

Although water savings data were not available for this report, Rain Master reports average water savings of 25 to 40 percent. Rain Master's reputation and the controller's 5-year warranty are significant factors when considering the

reliability and overall performance of their products. A SWAT performance report for the RME Eagle was not posted at the time of this report.

Toro

The Toro Company, which was established in 1914, is a Fortune 1000 internationally recognized supplier of irrigation and landscape products. Toro's corporate headquarters is located in Bloomington, Minnesota and its Irrigation Division resides in Riverside, California. Toro's Intelli-Sense series of residential and commercial controllers utilize the ET Everywhere™ subscription service and WeatherTrak™ scheduling engine to provide weather based irrigation system control. Toro also manufactures Irritrol products and is a partner with HydroPoint Data Services. Irritrol and HydroPoint controllers also utilize ET Everywhere and WeatherTrak, as discussed in the HydroPoint and Irritrol sections of this report.

The Intelli-Sense series entered the market in 2005 and includes seven controllers, comprised of indoor and outdoor models for 6, 9, 12 and 24 zones (plus a pump/master valve circuit). The WeatherTrak-enabled software creates a scientifically calculated zone-specific baseline irrigation schedule. The schedule is updated daily using weather data delivered by the ET Everywhere subscription service.

ET Everywhere uses data from the NOAA system of 14,000 nation wide weather stations to deliver ET to any area in the U.S. ET Everywhere has a proven accuracy to a standard deviation of .01 inch of daily ET at a resolution of one square kilometer. The ET Everywhere data service provides local ET (microzone) without the need for a weather station on site. The ET Everywhere Data Center validates the weather data and transmits calculated ET through three satellite servers to each controller everyday. The three satellites provide over-lapping coverage of the U.S. to ensure signal reception anywhere.

Operational Features

The Intelli-Sense controllers calculate irrigation schedules for each zone. The controller does not use pre-set irrigation schedules input by the user. Instead, a series of questions are answered by the user to define the site variables that influence water need. The controller is programmed by entering the following station specific information: sprinkler type or precipitation rate, plant type, soil

type, microclimate (sun or shade), slope (including if the zone is at the top, middle or bottom of the slope, and system efficiency (percentage). The schedule for each station is adjusted daily according to the local weather data received via the ET Everywhere service.

With these inputs, the controller calculates an irrigation schedule for each zone. Soil moisture depletion tracking, triggered at a 50 percent depletion level, along with daily ET updates allows the controller to adjust schedules as the weather changes. The number of water days, minutes and cycles (with appropriate soak times between cycles) are generated automatically and change as weather and water need fluctuates. The controllers have an eight- week scheduling window. This allows for infrequent watering of low water use plants. The controllers can initiate irrigation even if the daily ET page is not received by using the last download and loop-up table included in the WeatherTrak software. Non-watering days can be specified in the controllers' schedule programming. The controllers are compatible with Toro's wired & wireless rain and rain/freeze sensors, which eliminate irrigation during rainfall and freezing weather if added as an optional accessory.

Descriptions, Prices and Warranty

The indoor controller models' cabinet is constructed of ABS plastic while the outdoor units are comprised of Lexan. The dimensions of the indoor models are 7.5" x 6.5" x 3.3", and the dimensions of the outdoor models are 7.5" x 9.5" x 5.8". The controllers have a large (3.5" x 0.8") LED information display, dial type controls, and a copy button for simplifying setup. All controllers include internal UL/CSA listed transformers. The current capacity for each zone circuit is 0.5 amperes, and the current capacity for pump/master valve circuit is 0.375 amperes. The controllers will accept wire sizes from 12 to 18 gauge. The non-volatile memory maintains programming, and the back-up battery maintains the date and time, during power outages.

Other controller features include surge protection up to 6 kilovolts and valve malfunction detection. The irrigation schedule, irrigation history and program review can be viewed with the LED information display. In addition to the rain and rain/freeze sensors, pancake and bow tie antennas are available for sites with poor reception.

The Intelli-Sense controllers may be purchased from authorized Toro distributors and retailers. Current controller and accessories prices are summarized in Table 11. The Intelli-Sense controllers come with a 5-year warranty. The purchase of an Intelli-Sense controller requires a paid subscription to the ET Everywhere service through WeatherTrak. The ET Everywhere annual service fee is $48 for the 6 to 12 station controllers and $84 for the 24 station controller, as discussed in the HydroPoint section of this report.

Table 11 - Toro Intelli-Sense Controller and Accessories Prices

Description	Model	Price
6-station Indoor Controller	TIS-06-ID	$399
9-station Indoor Controller	TIS-09-ID	$449
12-station Indoor Controller	TIS-12-ID	$499
6-station Outdoor Controller	TIS-06-OD	$419
9-station Outdoor Controller	TIS-09-OD	$469
12-station Outdoor Controller	TIS-12-OD	$524
24-station Outdoor Controller	TIS-24-OD	$889
Wireless Rain Sensor	TWRS	$99.70
Wireless Rain/Freeze Sensor	TWRFS	$120.70
Wired Rain Sensor	TRS	$27.25
Pancake Antenna	TIS-ANT	$87.50

Installation

The Intelli-Sense controllers do not require professional installation, although trained installation is recommended. Typical installation times range from 1 hour to 2.5 hours, depending upon the size of the landscape covered and mounting issues. Installation should include a site assessment and discussion with the user about the site's irrigation system and how the controller operates. Installation and setup instructions are included in the owner's manual. Technical support is available from Toro by a toll free number (800-664-4740), or www.Toro.com, and through field certified contractors.

Track Record, Water Savings and SWAT Testing

Toro reports the technology behind the Intelli-Sense controller series is proven by several multi-year independent studies showing water savings. These studies were performed using Hydropoint's WeatherTrak controller and the ET Everywhere service. The studies are discussed in the Hydropoint section of this report.

An Intelli-Sense controller SWAT test performance report is posted at the Irrigation Association's website.

Tucor

Tucor, Inc. is headquarted in Wexford, Pennsylvania and has been in business since 1995. Tucor®, along with their Danish partner, SRC, manufactures commercial irrigation controllers which use decoder-based two-wire technology. Two-wire technology carries both power and signal to each irrigation valve, eliminating the need to run individual wires by instead using decoders at each valve, sensor or pump. Two-wire systems are easily extended without the need to install additional wires back to the controller.

The Tucor PROCOM© is a stand-alone controller with weather-based irrigation scheduling capability. The PROCOM is a modular, commercial grade controller that comes in its base form as a 50 valve (station) model. The controller's capacity can be increased through simple software registrations to 100, 200, 300, 400 or 500 valves. The controller connects to a PC (via wired or wireless) using software supplied with the controller, which provides a Windows®-based interface for programming and monitoring.

The Tucor ProCom ET-100 Weather Station is connected to the PROCOM controller to provide automatic weather-based irrigation scheduling. The controller calculates ET from the weather station sensor inputs and develops a daily irrigation schedule that provides efficient landscape watering. Housed in a sealed enclosure, the weather station is powered by a rechargeable (AC or solar panel) battery.

Weather station standard sensor inputs include solar radiation, air temperature, relative humidity, rainfall and wind speed and direction. Optional sensor inputs include soil temperature and moisture content. The station's battery charger is powered by either a 10 watt solar panel or AC power.

The weather station data are transmitted to the controller by telephone modem, and ET is calculated using the FAO-56 Penman Monteith equation. The irrigation schedule is calculated based on station application rates entered by the user. Other parameters that can be used in calculating the irrigation schedule include vegetation type, growing degree days, wet bulb temperature, dew point, and wind chill. The ET-100 comes with software and modem, a two or three meter pole mount, battery charger with solar panel or AC transformer and optional sensor inputs.

Operational Features

The PROCOM can run up to 40 stations simultaneously, manage up to 16 pumps and monitor up to 10 flow sensors. It can execute up to 30 schedules with up to 12 start times per schedule. Schedules can be executed sequentially as programmed, in priority as programmed with automatic execution based on flow data, or fully automatic based on a flow optimization protocol. Scheduling is based on a 14 day cycle.

The controller includes a rain sensor input for utilizing the automatic rain delay feature. The rain delay feature can be independent of the weather station. An auxiliary sensor input can be used for non irrigation related alarms. These are typically pump related. Additionally, the controller will actuate an alarm on wind speed, rain limits and temperature.

The PROCOM can monitor and react to flow conditions for up to 10 flow points. The controller can distinguish between multiple flow meters that are used for water sources and those flow meters that are used for monitoring main and sub main failures within a large system. Select flow meters can be identified for inclusion in the water consumption reports. In the event of a high flow condition during irrigation, the controller can shut down that sequence, continue to the next sequence, send an alarm to a pager, and report to an Excel® file. In the event of an unscheduled flow event (main line failure), the user has the option to activate or deactivate a valve or device. The controller can then alarm to a pager and report to an Excel file.

While considered to be a stand alone controller, the PROCOM must be programmed through the RMS management software that is included with the controller. The RMS software allows for the management of up to 25 individual controllers. All data logged by the controller can be exported to the Tucor Logviewer program, which is a series of Excel-based reports. This format allows for the customization of usage reports, unique to each application. The controller can perform a dry run prior to the actual running of a schedule, to project total run times and water usage. The dry run can be displayed as a flow graph to help manage the efficient use of water and time. The controller allows for the option to apply water based on time, application rate, or ET. Communication to the controller can be a choice of a direct serial connection, phone line, cellular, or GSM/GPRS. Internet connectivity is also available utilizing an existing LAN/WAN or WIFI broadband. A WIFI network, featuring mesh technology, can be created in the event of the existence of multiple controllers on a single site.

Descriptions, Pricing and Warranty

The PROCOM is designed for indoor installation, but several optional outdoor cabinets are available. The controller's dimensions are 11.5" x 13" x 3". The outdoor cabinets come in wall mount or top entry models.

The PROCOM has automated diagnostics capabilities. The controller detects wiring faults and turns off power and sends an alarm to the user when detection occurs. Diagnostics can be performed with the controller, to trace short circuits, line current and solenoid ground faults. Optional lightning protection is available for protection against lightning on the two-wire path.

Tucor products are available through certified distributors. A list of distributors is available from Tucor upon request (800-272-7472). Current retail prices for the PROCOM controller, ProCom ET-100 Weather Station, and accessories are summarized in Table 12. Tucor products come with a 3-year warranty that can be extended to 5 years through an installation certification process.

Installation

Tucor controller systems require professional installation.

Table 12 - Tucor Controller Product Prices

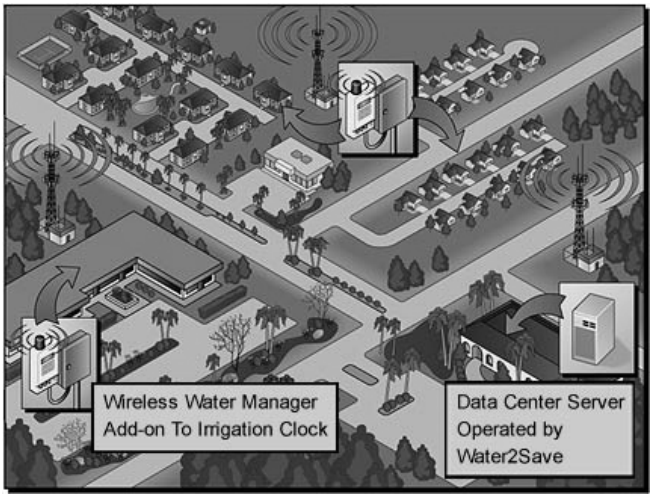
Description	Model No.	Price
50 Station PROCOM Controller	ProCom 50	$ 7,150
100 Station PROCOM Controller	Procom 100	$ 7,750
200 Station PROCOM Controller	Procom 200	$ 8,500
300 Station PROCOM Controller	ProCom 300	$ 9,250
400 Station PROCOM Controller	ProCom 400	$ 10,000
500 Station PROCOM Controller	ProCom 500	$ 10,750
Stainless Steel Outdoor Wall Mount Cabinet	CAB-200	$ 740
Weather Station	ProCom ET-100	$ 13,000
Surge Protection	SP-100	$ 55
1-inch Inline Flow Sensor*	FS-100	$ 730
4-inch Inline Flow Sensor*	FS-400	$ 730
Decoder: 1 address	LD-050	$ 95
Decoder: 1 address, 2 valves per address	LD-100	$ 120
Decoder: 2 addresses, 2 valves per address	LD-200	$ 190
Decoder: 4 addresses	LD-400	$ 270
Decoder: 6 addresses	LD-600	$ 330
Sensor decoder	SD-100	$ 280

* Inline flow sensors in intermediate sizes and larger saddle models are available. Flow sensors require an SD-100.

Track Record, Water Savings and SWAT Testing

Although Tucor did not provide water savings data for this report, it appears proper use of the PROCOM controller may potentially result in water savings and runoff reductions similar to the other weather based irrigation control products discussed in this report. A SWAT test performance report is not posted for the Tucor PROCOM.

Water2Save



Water2Save, LLC is located in San Diego, California, and is a subsidiary of WaterLink Systems, Inc. WaterLink specializes in weather-based irrigation control and conservation management. In 1992, WaterLink began research and development, patent applications, and beta testing of a weather based irrigation control and feedback monitoring system using wired and wireless data telecommunications. WaterLink obtained two patents in 1997 and 1999 for a method of using forecasted weather and ET data to adjust irrigation schedules. Water2Save was formed in 2000 under a technology license from WaterLink to market and sell the patented technology along with its patented forecasted weather based ET adjustment service to optimize irrigation water use for large residential and commercial irrigation systems. Both Look-Ahead ET ™ and WaterLink System® are trademarks or registered trademarks of WaterLink Systems, Inc.

Property owners contract with Water2Save to be their remote irrigation water manager on a performance guarantee basis. Water2Save offers a multiple-controller add-on hardware package, fully automatic Look-Ahead ET irrigation scheduling, landscape audits, historic and real time irrigation runtime monitoring, savings tracking/reporting, and guaranteed savings.

Two patents, Evapotranspiration Remote Irrigation Control System and Evapotranspiration Forecasting Irrigation Control System, cover methods of using forecasted ET, called Look-Ahead ET, with any type of wired or wireless communications to provide weather-based irrigation system control. According to patent claims, approximately 15% more water savings can be achieved when predictive data are used with the ET equations versus when only real-time or historic weather data are used. Water2Save is the only ET irrigation control service provider that can offer its patented forecasted weather based irrigation control.

In 1993, Water2Save began testing its first prototype ET controller. The initial technology replaced the existing controller and required site-specific data for each irrigation zone (plant type, soil type, root depth, irrigated area, flow rate, precipitation rate, and distribution uniformity). The programmed site information and Look-Ahead ET weather data were used to automatically calculate the irrigation schedule.

After years of testing, the company concluded that obtaining and entering site-specific data for each landscape zone was impractical and too labor intensive for most users. In addition, the company determined that many users did not want to learn how to install and operate a new high-tech controller. Therefore, in 1996, the company developed a 2-way (send and receive) add-on technology using its patented method which factors down runtimes set in the controller in accordance with forecasted and measured weather data. Further, the technology monitors watering schedule changes made by the user for each zone and sends such information to Water2Save's Data Center for analysis. This technology has now been in operation with customers for over 12 years.

Operational Features

Water2Save's add-on technology is fully transparent and independent of the irrigation controller and is not operated by the user. Hardware is operated remotely by Water2Save and no training is required for the user. The user continues to use the familiar irrigation controller to set and "fine tune" baseline watering schedules. Water2Save is developing a commercial controller that will function similar to the add-on unit for those customers that wish to replace their existing controller with an integrated wireless ET based controller using Water2Save's Look-Ahead ET, valve runtime monitoring service and water usage/savings reporting.

With Water2Save, the user is responsible for setting a baseline schedule that is consistent with recommended summertime irrigation schedules and runoff guidelines established by Water2Save. Baseline schedules are set to the maximum peak ET or 100 percent that remain set at the summertime level the entire year. However, the user may "tune" specific valve schedules as needed. These changes are remotely monitored by Water2Save. The installed technology will interrupt runtimes and reduce irrigation based on normalized weather data (ratio of Look-Ahead ET to the peak summer ET). Normalizing the data reduces the need to obtain site-specific absolute values for ET. Such percent adjustments are not a straight percentage per cycle. The technology considers both daily and weekly runtime minutes. This allows the technology to "store-up" minutes so as to drop cycles and or drop days from the irrigation schedule as appropriate. Water2Save monitors all start-times for daytime irrigation runs and records all manual valve activations that are made by the landscaper using the existing controller.

Although the user can manually run one or more stations during a daytime window of time with no interrupt, Water2Save can prevent all daytime manual watering from the controller if over-watering occurs from excessive runtime programs. Water2Save remotely monitors and manages each valve independently (e.g., color, turf, shrubs, ground cover, drip, slopes, etc.).

Measured weather data and weather forecasts are reviewed daily from numerous sources including the National Weather Service and other government operated weather stations such as CIMIS and AZMET in California and Arizona. Weather data review is done by qualified technical staff knowledgeable in meteorology and evapotranspiration, as well as weather forecasting. Water2Save retrieves forecasts and weather changes for numerous climate zones where its systems are installed. Once the climate zone adjustments are determined, sending weather adjustment factors to the technology installed at customer sites is done via the Internet and wireless networks with confirmation of receipt of the adjustment update.

Water2Save operates a dual redundant server Data Center that retrieves data from properties installed with the company's equipment and monitors both the runtimes programmed by the landscaper and those adjusted by Look-Ahead ET factors. These factors (updated with both forecasts and corrections from measured weather data) are sent and then "receipt" is confirmed by Water2Save staff at its Data Center everyday. Water2Save staff review the meteorological measurements for bad data, out of range data, calibration problems with weather instrumentation, and rainfall errors. This allows Water2Save staff to troubleshoot and then correct problems before processing, thus preventing incorrect adjustments from occurring.

Using 2-way wireless cellular data communications, Water2Save's Data Center retrieves irrigation runtime minutes (those programmed by the user into the controllers and those actually watered after the daily weather adjustments were made). Irrigation history is compiled into a database for analysis by Water2Save and is also made available to the user via the Internet. Servers automatically scan data to find baseline schedule changes that have been made by the user, which are flagged for investigation by Water2Save staff.

Water2Save's staff also obtains monthly or bi-monthly utility billing information to track water meter consumption. A baseline is established using water consumption history prior to installation and the monthly or bi-monthly use after install allows Water2Save to track and calculate achieved savings for "like periods" of the year. Utility meter read data are correlated with watering minutes to identify potential discrepancies. Water2Save mails or e-mails utility meter specific savings reports to its customers to document if and how much savings is being achieved.

The company's Wireless Water Manager (WWM) is designed to enable Look-Ahead ET control for up to 64 irrigation valves on up to 4 separate existing or new irrigation controllers (any type of electronic controller with low voltage solenoid operated valves). Each WWM receives weather-based adjustments via wireless data communications from the Data Center over a national cellular data network and optimizes irrigation. WWM adjusts runtimes using an electronic relay to turn-off water when a daily allowance is reached.

Modular multi-valve sensing monitoring cards are used with the WWM. Each electronic card measures activation time for 12 or 16 separate irrigation valves and records the number of seconds-on of all watering cycles. Up to 4 sensing monitoring cards (maximum of 64 valves) can be connected to one WWM via direct cable or wireless link. Each multi-valve sensing monitoring card is connected between the existing irrigation controller and solenoid driven valves. Also, the common wire is connected between the card and controller to turn-off water to each valve according to the Look-Ahead ET requirement. Each valve is programmed to run a specific schedule at the controller and the sensing monitoring card interrupts the run time specific for each valve in accordance with the adjustments.

Descriptions, Pricing and Warranty

The WWM panel, wireless cell modem (activated on Cingular's network) and antenna are shipped inside a steel housing (10.8" x 6.5" x 2.5") that is to be mounted next to the existing irrigation controller. The valve sensing monitoring cards are usually mounted below each of the existing controllers to be enabled with Look-Ahead ET. The wireless modem is a completely separate module (not designed into the electronic circuit board) and is easily upgradeable should wireless technology infrastructure change over time. A standard rain sensor or rain gauge can be connected to the WWM to enhance the system's scheduling capability by triggering rain delays and or accounting for effective precipitation. The WMM power supply is an external 9 VDC transformer that is fused for power line surges, and the multi-valve sensing monitoring cards have opto-isolation type surge protection.

The price for a basic add-on WWM model, with the capacity to schedule up to 16 valves on a single controller is $1,598. This price includes the main panel and CPU, a 5-year lithium ion battery, housing, power supply, wireless 2-way cell modem, antenna, a 16-valve sensor card, and all necessary cables. When connected to 4 controllers with three additional valve sensing cards for up to 64 valves, the price is $ $2,108 (or about $527 per controller). The basic service fee for wireless airtime and Look Ahead ET daily adjustments is $39 per month ($468 per year total or $117 per year per controller- $9.75 per month assuming that all 4 controllers are connected to one WWM) and includes feedback confirmation that schedule data were received. Equipment rental plans are also

available directly from Water2Save. Water2Save provides a 3-year parts and labor warranty with equipment purchase.

Planned pricing on Water2Save's forthcoming commercial ET controller was not available at the time of this report.

Additional services include tracking runtimes, number of cycles, start times, time of day watering, and manual watering time. The Data Center also checks to confirm that each valve's runtime does not exceed a range of weekly watering minutes established by Water2Save for specific head type and plant type. The Data Center checks if the number of cycles set for slopes have been modified in the existing controller. If so, user follow-ups are conducted until such issues are resolved.

Additional data monitoring includes power outages, future day factors, daytime irrigation, start-time of each valve, end time, number of cycles, and the default factors (based on long-term meteorological conditions). Should wireless communications be interrupted, the WWM will use a set of specific climate zone default factors (provided that updated factors are not received over a several day period).

Installation

Water2Save reports the typical installation time for a WWM system with one controller is 2 hours and that professional installation is usually required.

Track Record, Water Savings and SWAT Testing

Water2Save reports its systems have proven to deliver maximum achievable savings reliably year after year with a guarantee. In-house savings reports show typical savings of over 2,000 gallons per day from installation of Water2Save on a one-acre site as shown in Figure 9.

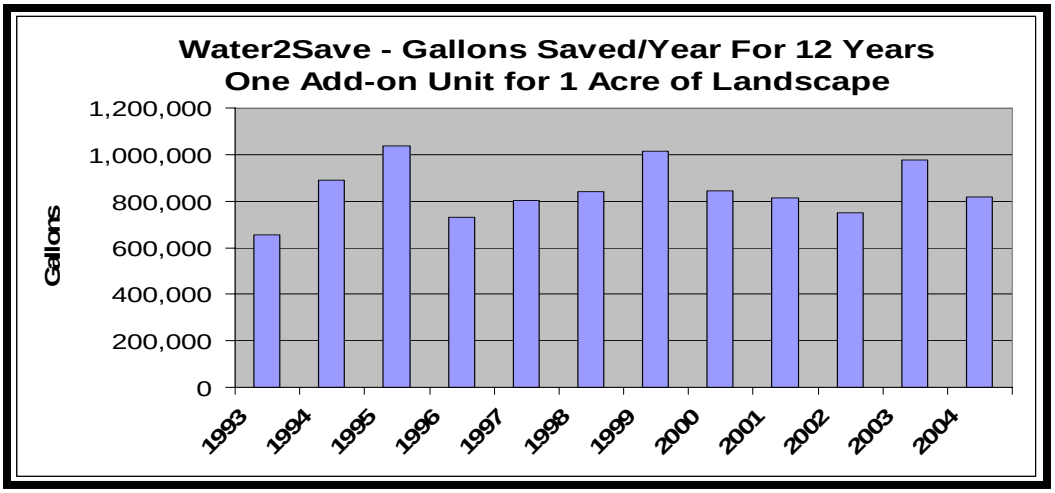


Figure 9 - Water2Save water savings data

The City of Los Angeles, California Department of Water and Power recently performed a pilot study of Water2Save over a one-year period. Water2Save reports the average percentage water savings achieved for the properties installed with its system was over 28 percent.

A SWAT test performance report for the WWM was not available for this report.

Water2Save offers a complete turn-key water manager package which includes hardware, patented Look-Ahead ET adjustments with receipt confirmation, runtime monitoring, flagging of problems, on-site field support, full reporting via the Internet, consumption tracking and guaranteed performance savings agreements.

This system appears to provide significant water savings and requires minimal on-site monitoring and adjustment. The Data Center interface appears to provide an easy and effective method for remotely monitoring an extensive set of irrigation related information.

Weathermatic

Weathermatic®, established in 1945, is a worldwide manufacturing company of a full line of irrigation products. The company, headquartered in Dallas, Texas, began developing water conserving products in the 1950's when it used soil moisture sensors which were later followed by its innovation of the industry's first rain sensor shut off device in the 1970's. Weathermatic's SmartLine™ residential and commercial irrigation controllers operate based on weather conditions using onsite sensors.

Operational Features

The Weathermatic SmartLine controller technology patent was filed in 1998 and granted in 2000. SmartLine controllers accept user inputs by zone for sprinkler type, plant type, soil type, slope, and a zone fine-tune adjustment factor. The units then incorporate a ZIP code input (for solar radiation) and an on-site weather monitor (sensing temperature and rainfall) to calculate real time ET estimates that are used with user inputs to calculate proper zone run times, including cycle/soak, at user selected start times and watering days. The Weathermatic SmartLine controller/weather monitor package operates stand-alone and does not require communication with remote servers to obtain weather data or irrigation schedules

and no ongoing service costs are associated with the unit. After 8 years of development, testing, and field trials, the SmartLine controller line entered the market in November of 2004. As of July 2005, Weathmatic reports shipment of tens of thousands of SmartLine controllers with less than 60 units returned.

The Weathermatic controller platform is built around zone modules that allow expandability from 4 to 8 zones for their SL800 model and 4 to16 zones for the SL1600 to accommodate various size residential and commercial landscapes. The SL1620 and SL1624 have fixed zone capacities 20 and 24. A larger commercial model, the SL4800 (scheduled for release in June 2007) will provide module and wiring space for up to 48 zones. The SL1600, SL 1620, SL1624 and the SL4800 are all suitable for indoor or outdoor installation. The SL800 is an indoor model.

Descriptions, Prices and Warranty

The SL800 is a fixed 4-zone unit that can be expanded to 6 or 8 zones with 2-zone modules. The SL1600 controller is shipped standard with a 4-zone module and can be expanded to 8, 12 or 16 zone with additional 4-zone modules. The SL1620 and SL1624 controllers are fixed 20-zone and 24-zone units. The SL4800 will be shipped with 12 zones included. The controller housing dimensions are: SL800 – 7” x 7.8” x 1.8”; SL1600 series – 9.1” x 10.1 x 4 and SL4800 – 15” x 16.5” x 5.8”. The SL800 has an external transformer power supply with a barrel connector that plugs in to the side of the controller for fast installation. The SL1600 Series controllers have internal transformers with a pre-wired plug-in cord that will accept 120V or 240V. The SL4800 will also have a 120/240V internal transformer but without a pre-wired plug-in cord (professional installation required). For the SL800 controller, either a 120V power supply or a 240V power supply with connectors for the EU or Australia can be specified when ordering. The controller output circuit capacities are 1.0A for the SL800 and 1.2A for the SL1600 series and the SL4800. Weathermatic reports these capacities are adequate for running 3 zone valves concurrently with a master/pump valve for the SL800 and SL1600 series, and 5 zone valves concurrently plus a master/pump valve for the SL4800. Accepted wire sizes range from 14 to 18 gauge.

The SmartLine controllers have advanced functions including zone-to-zone and master valve timing delays, a built-in valve locator, as well as a unique diagnostic function that displays the electrical current by zone for troubleshooting. Additionally, the user can omit specific calendar event dates, days of the week, and times of the day when no watering is allowed. A remote control option planned for 2008 will feature a handheld remote nested in the back of the programming module. The handheld will have a 600 foot line-of-sight range. Units with the remote capable operating panel will also enable a second remote capable operating panel to be mounted independent of the base.

Weathermatic offers a 2-wire option with the SL1600 series controllers. The SmartWire^{TM} decoder module for 2-wire systems (model SLM48DM) can be

integrated into these controllers and is considered cost effective for 18 zones and larger systems. The SLM48DM includes connections for up to 3 different 2-wire paths and includes an LED display and status lights for programming, operation status and troubleshooting. The valve decoders used to decode the signals from the SLM48DM come in 1-, 2- and 4-valve capacity (models SLDEC-1, SLDEC-2 AND SLDEC-4). Additional valve decoder features include: shock and freeze/heat resistant, 14-guage wiring, surge protection and functional distance up to 100-feet from the valve.

The on-site weather monitor includes a temperature sensor and rain sensor. The unit has a microprocessor to record and process measurements. The temperature-sensing unit is encased in a solar shield. The hygroscopic disc type rain sensor can be set to trigger rain delay at rainfall depths from 1/8” to 1”. A wired weather monitor is currently available and a wireless unit is planned for 2008.

SmartLine controllers are distributed through Weathermatic’s established wholesale suppliers (specialty irrigation suppliers) and installation professionals. The list prices for currently available and planned residential controllers and components are listed in Table 13.

Programming of the “Auto Adjust” ET portion of the controller requires inputs by zone for sprinkler type, plant type, soil type, and slope. Sprinkler type can be entered on a basic level by the user by selecting the type of sprinkler in a zone – SPRAY, ROTOR, or DRIP. A more advanced user can scroll past these basic inputs with default precipitation rates and prescribe an exact numerical precipitation rate for the zone from 0.2”/hour to 3.0”/hr. Plant type works similarly to the sprinkler type input in that the user can simply select the type of plant life in the zone – COOL TURF, WARM TURF, ANNUALS, SHRUBS, NATIVE, or TREES. Again, a more advanced user can scroll past these basic inputs with default percentages and prescribe an exact numerical percentage for the zone from 10 to 300% based on the plant life in the zone and sun/shade consideration. The soil type – CLAY, SAND, LOAM - and slope (numerical degree of slope 1 – 25+ degrees) are used to automatically calculate the cycle/soak function by zone.

In addition to these inputs by zone, the user programs the ZIP CODE of the site, or primarily for locations outside the United States, the latitude of the site. This input and the calendar day of the year is used to determine the solar radiation at the site, which is a variable in ET calculation. These static inputs are combined with the dynamic on-site weather monitor inputs to perform the overall equation that determines proper zone run times.

The SmartLine user has the ability to fine tune the zone run times by zone through a MORE/LESS function. This allows the user to increase watering by zone up to 25 percent or decrease watering by up to 50 percent.

Table 13 - Weathermatic SmartLine Controllers and Component Prices

Description	Model	Availability	Price
4 to 8 Zone Indoor Controller*	SL800	Currently Available	$99.95
4 to 16 Zone Residential Controller*	SL1600	Currently Available	$159.95
20 Zone Commercial Controller	SL1620	Currently Available	$389.95
24 Zone Commercial Controller*	SL1624	Currently Available	$549.95
48 Zone Commercial Controller*	SL4800	June 2007	na
2-Zone Module for SL800	SLM2	Currently Available	$24.95
4-Zone Module for SL1600	SLM4	Currently Available	$49.95
12-Zone Module for SL4800	SLM12	June 2007	na
2-Wire Decoder Module	SLM48DM	Currently Available	$699.00
2-Wire Decoder for 1 valve	SLDEC1	Currently Available	$99.00
2-Wire Decoder for 2 valves	SLDEC2	Currently Available	$185.00
2-Wire Decoder for 4 valves	SLDEC4	Currently Available	$295.00
Wired Residential Weather Monitor	SLW10	Currently Available	$199.95
Wireless Residential Weather Monitor	SLW15	2008	na
Wired Commercial Weather Monitor	SLW20	Currently Available	$299.95
Hand-held Remote Control for SL1600	SLHRR	2008	na
Control Panel Remote Module for SL1600	SLCPX	2008	na

*Weather Monitor required for weather-based irrigation scheduling not included in price

The controller's irrigation schedule is based on the user prescribed irrigation days, start times, and omit times (dates, days, and times of day) so as to conform to local watering restrictions and also accommodate site-specific hydraulic issues, which vary by time of day. Once programmed, the controller calculates ET for the period beginning at the end of the last irrigation cycle, or measurable rainfall, and ending at the next prescribed irrigation day. Irrigation will occur if the calculated run time is sufficient for an effective irrigation watering. If sufficient demand has not been reached, irrigation will not occur and the controller will carryover the accumulated ET to the next prescribed irrigation day and time. This accumulation threshold, which prevents ineffective irrigation, is calculated based on a default accumulation factor.

Installation

Installation and programming of SmartLine controllers are designed to be simple and intuitive for both the novice homeowner and the advanced professional who are familiar with the unit's industry standard programming dial. Advanced user functions are located in an "Advanced Functions" position on the programming dial so as to not complicate the set up for novice users. While programming the unit is simple, Weathermatic recommends installation by a professional who will give the site the highest rate of success not only for controller programming, but also for complete system operations with an emphasis on water conservation. Based on Weathermatic's solid reputation and well-established support network, it appears the SmartLine controllers' technical support system is outstanding. Installation and programming instructions are available on Weathermatic's

internet site (weathermatic.com), and a programming video and DVD are available to supplement the standard user manual.

Track Record, Water Savings and SWAT Testing

Weathermatic tested its Hargreaves equation based ET calculation algorithm and controller functionality extensively for 8 years. For comparing ET calculations, CIMIS weather station reference ET values were compared to those using the Weathermatic controller/weather monitor methodology at 10 geographically diverse sites over a seven-year period for 70 years of combined data. Weathermatic reports good correlation between the CIMIS and Weathermatic ET data at all sites. The graph shown in Figure 10 is one example that is representative of the study.

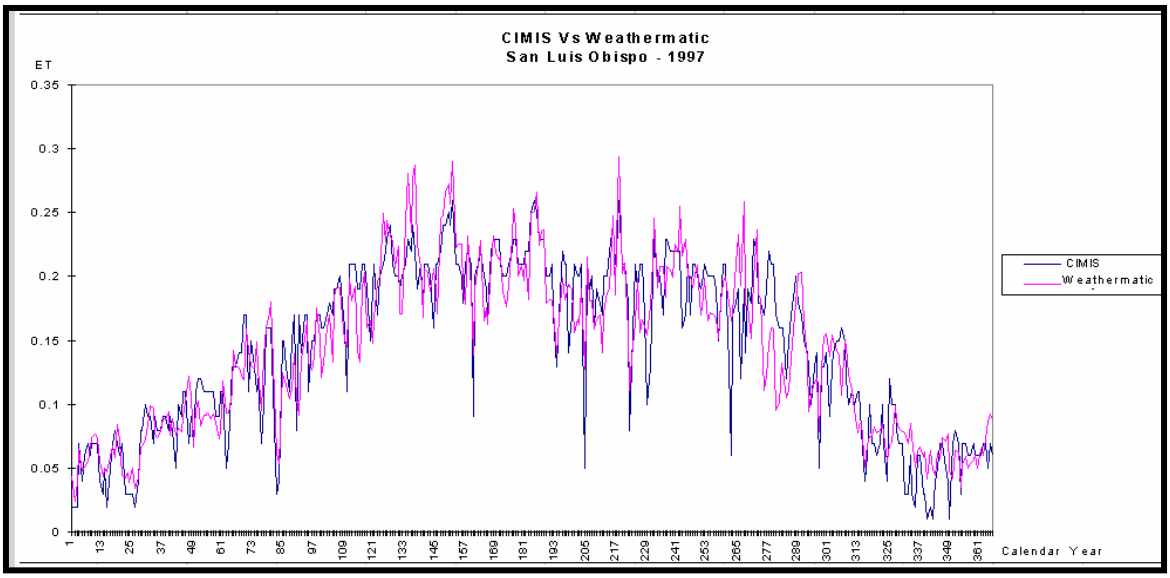


Figure 10 - Comparison of Weathermatic ET to CIMIS ET

In addition to comparing the ET calculation, the Weathermatic SmartLine controllers were included in a field study performed by a Rocky Mountain Region Water Conservancy District. This three-year study analyzed the Weathermatic controller's accumulated water output in comparison to actual ET (as measured by lysimeter), reference ET (ET_o calculated with on-site weather station data), and net plant watering requirements (PWR). The study results sample graph of Figure 11 shows the Weathermatic unit watered consistent with plant demand.

The Weathermatic SmartLine controllers were also part of a field pilot program conducted by the Marin Municipal Water District. In this study, 13 controllers were installed at 7 sites to compare water usage in 2002 and 2003 to the base year usage in 2001. Weathermatic reports that in 2002, sites installed with the Weathermatic ET controller saved 26%. In 2003, the water savings climbed to 32%. Based on documentation from this program submitted by Weathermatic, it

appears the Weathermatic controller performs well and yields significant water savings.

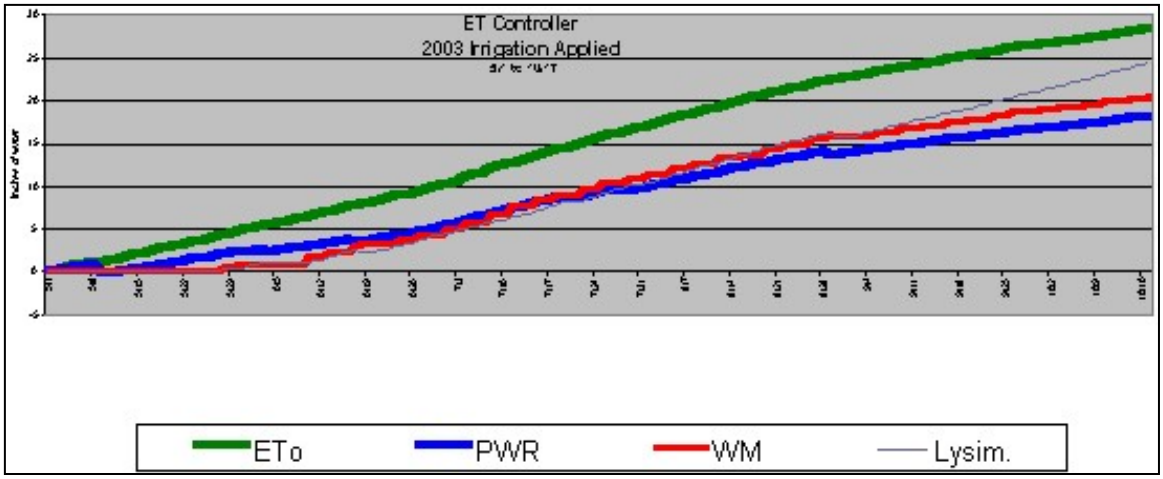


Figure 11 - Sample of Weathermatic field study results

Weathermatic's test center has conducted testing on the controllers and weather monitors in the following areas affecting reliability: mechanical stress testing, environmental testing, software testing, and functional/characterization testing. The Weathermatic SmartLine has completed SWAT testing and a performance report is posted on the Irrigation Association website

The SmartLine controllers are relatively economical and appear to offer effective real time onsite ET measurements and inputs by zone for key programming parameters.

Weathermiser

The Weathermiser Company, based in Albuquerque, New Mexico manufactures a patented add-on controller device that works with any clock-type irrigation controller to schedule irrigation based on weather conditions. Weathermiser has been in business since 1997 and its first controller models entered the market in 2003. The Weathermiser devices include integrated temperature and humidity sensors, and these sensor inputs provide the basis for scheduling irrigation. Weathermiser reports the ability to forecast precipitation and as a result, the ability to interrupt irrigation cycles before precipitation occurs.

The Weathermiser monitors humidity in real-time to determine the need to irrigate. Irrigation may be delayed when humidity readings are high, since ET is

lower and since humidity is high before, during and after rainfall. Irrigation frequency increases as a function of high temperatures and low humidity. The temperature sensor is factory set to interrupt irrigation at temperatures below 37 degrees F and an optional high-wind interrupt is also available.

Operational Features

The relative humidity sensor setting is adjustable and the controller interrupts irrigation when the ambient relative humidity exceeds the variable dial set point. The dial is set just above the highest average relative humidity for a given geographical area, at a specific time of day. Two relative humidity settings for all major cities are included in the Weathermiser instructions. The user programs the higher setting for morning irrigation and the lower setting for irrigation after dusk. The controller is designed to track dew point, evaporation rate and solar radiation based on temperature, humidity and optional wind sensor readings. The Weathermiser device interrupts the common valve circuit from the clock-type controller until it determines irrigation is needed. The clock controller is set to irrigate every day and then irrigation occurs on the days the Weathermiser initiates it. A base schedule is programmed into the clock-type controller by the user.

Descriptions, Prices and Warranty

The Weathermiser controller models include the basic model (RSFI), basic steel enclosure model (RSFIS), wireless model (WLRSFI) and steel enclosure wireless model (WLRSFIS). Each of the Weathermiser controllers includes a dial-type humidity sensor setting control and a bypass dial position. Setting the dial to the bypass position deactivates irrigation interruption by the device. The RSFI and RSFIS have no power requirement; and the clock controller common valve circuit is interrupted by the action of the spring operated humidity and temperature sensors. The RSFI is housed in a polycarbonate enclosure and its dimensions are 7” x 2” x 1.5”. The RSFIS is simply a RSFI mounted in a 7” x 5” x 3.5” vented steel security enclosure, and includes lock and key. The wireless WLRSFI is a 2-component system consisting of a combined controller and radio frequency transmitter and a receiver. The controller/transmitter is housed in a polycarbonate enclosure (7” x 2” x 2”) and is powered by two 3V lithium batteries. The controller/transmitter communicates an on/off signal to the receiver that is connected to a clock controller (not included). The receiver is housed in a polycarbonate enclosure (2” x 4” x 1”) that is mounted in or near the clock controller and is powered by the controller 24VAC supply. The WLRSFIS includes the same controller/transmitter electrical components as the WLRSFI, housed in a lockable and vented steel security enclosure (7” x 7” x 4”), and the same receiver.

An optional wind sensor can be connected in series between the RSFI or RSFIS and the clock controller. The wind sensor is a Hunter® Wind-CLIC with a variable setting control, which is set to interrupt irrigation at high wind speeds.

Weathermiser also sells a freeze sensor that interupts irrigation when the temperature falls below 37 degrees.

Current Weathermiser controller prices are summarized in Table 14. Products can be ordered directly from Weathermiser by telephone (505-235-6999). Weathermiser provides a 5-year warranty on all controller devices (including batteries) and a 1-year warranty on the transmitter, receiver and wind sensor.

Table 14 - Weathermiser Prices

Description	Model	Price
Basic Weathermiser System	RSFI	$85.95
Basic System with Steel Enclosure	RSFIS	$124.95
Wireless Weathermiser System	WLRSFI	149.95
Wireless System with Steel Enclosure	WLRSFIS	$159.95
Remote Control	RSFIE	$1,295.00
Hunter Wind-CLIC Wind Sensor	na	na
Freeze Sensor	FSI	$64.75

Installation

The Weathermiser controller devices are mounted on a shady outside surface, free from the influence of irrigation spray, and machinery exhaust. Relative humidity dial settings for major cities are included in the instructions and may require a seasonal adjustment depending on the user's mini-climate and preferences for determining landscape needs. Monthly and yearly settings are available.

Weathermiser reports its systems can be installed by most "do-it-yourselfers" or any landscape professional. The typical first-time installation is estimated to be 1-2 hours, depending on site conditions.

Weathermiser product service is offered through a hotline and an internet troubleshooting guide. Field consultations are offered for large commercial and residential installations.

Track Record, Water Savings and SWAT Testing

The performance of the Weathermiser controller is illustrated by the graph shown in Figure 12. The maximum relative humidity (RH) and average temperature information is actual weather data from a Western Regional Climate Center weather station. The graph illustrates the Albuquerque, New Mexico daily interrelationship between relative humidity, temperature and precipitation for the

month of April. The rise in relative humidity that precedes precipitation and/or drop in temperature are evident except during the gusty windy period that occurred on the 6th and 10th and the steady windy period that occurred between the 15th and 22st of the month. The relative humidity limit setting shown in the figure is 70 percent and the freeze limit is also shown. The Weathermiser interrupted irrigation on the days the relative humidity and temperature were outside these limits (19 days) and irrigation occurred on the days when the readings were within the limits (11 days).

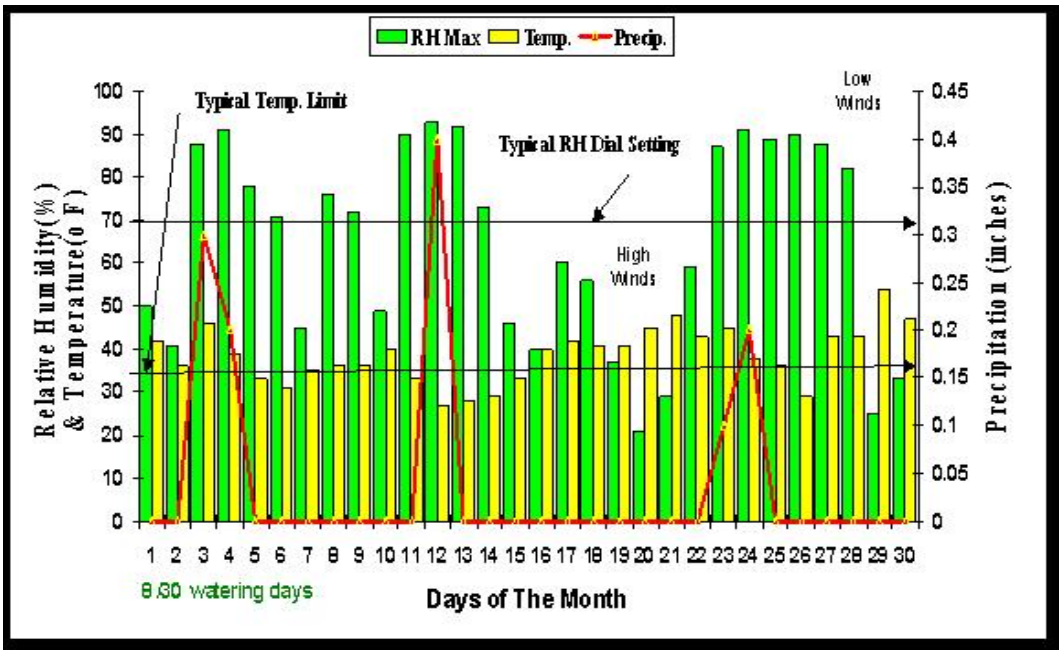


Figure 12 - Weathermiser performance related to weather data

Track Record, Water Savings and SWAT Testing

Weathermiser reports that over two thousand Weathermiser controllers were installed and water savings were evaluated in the Denver, Colorado and Albuquerque, New Mexico areas. Weathermiser reports the results of these studies indicated an average savings between 34 and 52 percent after four years of formal testing between 2000 and 2004. The water savings for the Denver area were calculated by comparing the water savings of 100 Weathermiser users to that of a 800 control group of typical Denver Water customers having no weather sensing devices applied. An adjustment factor based on the past 5 year rolling average usage for each of the participants was applied to the water meter readings taken by the Denver Water Company. Based on the results of the Denver Water Board study, which included 12 other products, Weathermiser received a water conservation award by the Denver Water Board.

Weathermiser and the Albuquerque Academy won the 2003 New Mexico Green Zia award for its cooperative water conservation efforts.

Weathermiser began developing its weather based controller over nine years ago. Weathermiser's inventor, Alphonse E. Caprio holds a patent for applying differential relative humidity and temperature to control irrigation.

Weathermiser reports its product is currently in the SWAT testing process, but a performance report was not available for this report.

Soil Moisture Based Irrigation Control System Principles

All of the soil moisture based products reviewed operate on the principal of scheduling irrigation as a function of soil moisture conditions measured onsite with one or more soil moisture sensors. The concept is for an appropriate amount of irrigation to occur when needed to maintain adequate soil moisture levels.

Landscape soil moisture conditions should be maintained such that root zone moisture levels are between field capacity and the wilting point. Field capacity conditions occur following irrigation or precipitation when the maximum amount of water is retained in the soil after seepage and surface drainage ceases. The wilting point occurs when soil moisture is depleted to the point at which plants wilt without recovery during the night. The soil moisture levels at which field capacity and wilting point occur are a function of soil characteristics.

Soil moisture is typically reported in terms of volumetric soil water content, or as soil tension. Soil moisture content is the ratio of the volume of water in the soil to the volume of void spaces between the soil particles, and is reported as a percentage value. Soil tension is a measure of the negative pore pressure that occurs in the void spaces (increasingly negative as the moisture level drops), and is reported as a negative pressure reading.

Most of the soil moisture based products reviewed function such that a preset irrigation quantity is applied when the measured soil moisture level drops to a threshold point set by the user. Ideally, the irrigation quantity applied replenishes the soil moisture to field capacity with minimal surface runoff and seepage below the root zone (over-watering). Some of the products reviewed begin and end irrigation based on two preset thresholds; the first is set at a moisture level well above the wilting point and the second is set at near field capacity. One product adjusts run times based on soil moisture data. Most of the devices, however, do not automatically calculate total run times or cycle and soak times.

As with the weather based products, some of the soil moisture based systems include a stand-alone controller and others include an add-on device that works with an existing clock-type controller. Regardless of stand-alone versus add-on controller type, some of the devices control the irrigation of all zones based on measurements from one soil moisture sensor. Others control individual zones or groups of zones based on measurements from multiple sensors placed in representative zones.

In general, all of the soil moisture based systems' operate similarly and comparison is more straight-forward relative to that of the weather based systems. Most of the products possess similar components and features. All of the systems reviewed provide potentially effective methods for scheduling irrigation based on soil moisture sensing, which should result in water savings.

Several different types of soil moisture sensors are used with the systems reviewed. In recent years, significant technological advances have been made in the field of soil moisture sensors. In general, the accuracy of all types of sensors has improved and costs have gone down significantly for some types of sensors. However, all types of soil moisture sensors possess one or more inherent deficiencies that should be considered. Several types of sensors function based on the dielectric properties of the soil, which vary depending on the soil type. Hence, calibration of these devices is soil specific to varying degrees depending on the specific type of device. Specifically, a factory calibrated sensor may not function accurately for certain soil types and should be field calibrated. Salinity or fertilizer content, as well as temperature, affect the measurement accuracy of some sensors. Certain tensiometer type sensors will not tolerate freezing temperatures and or require maintenance anytime the soil becomes exceedingly dry.

Soil Moisture Based Control Product Features and Comparison Criteria

Significant product components and features are discussed below. The discussion identifies different methods used to achieve similar results by the various products, and associated advantages and disadvantages.

Soil Moisture Sensor Types

Soil moisture sensors have been used for laboratory and outdoor testing purposes and for agricultural applications for over 50 years. There are many types of sensors, but only those used in the present generation of landscape irrigation scheduling systems are discussed.

Electrical Resistance Granular Matrix – This type of sensor consists of two electrodes embedded in a reference matrix material which is confined within a corrosion-proof and highly permeable case. The matrix material includes gypsum to buffer against the effects of salts and fertilizer, but these sensors do not dissolve like gypsum block sensors. Soil moisture is constantly absorbed or released from the sensor as the surrounding soil moisture conditions change. As the soil moisture changes, the sensor moisture reacts as reflected by the change in electrical resistance between the electrodes. Reaction time, however, is relatively

slow compared to some other types of sensors. As the moisture level increases, conductivity increases and the sensor is calibrated to output the moisture level in terms of soil tension. Calibration is temperature and soil type dependant. This type of sensor has been used in agricultural and landscape applications for approximately 20 years, and their performance is well documented. They are relatively inexpensive and their manufacturer reports a minimum useable life of 5 to 7 years.

Electrical Conductivity Probes – This type of sensor measures soil moisture by how well a current of electricity is passed between two probes (electrodes) that are inserted directly into the soil. As the soil moisture changes, the sensor moisture reacts as reflected by the change in electrical resistance between the electrodes. Reaction time is relatively fast. As the moisture level increases, conductivity increases and the sensor is calibrated to output the moisture level in terms of volumetric soil water content by percentage. Since the probes have direct contact with the soil there is no buffer against salt and fertilizer affects on the measured conductivity. These devices are very sensitive to the spacing of the probes as well as being influenced by soil type, salts and fertilizers. Specifically, bent probes and improper calibration for soil type can result in poor performance. Also, fluctuations in salt and fertilizer levels can affect measurement accuracy/consistency.

Time Domain Transmissometry (TDT) – This type of sensor measures the time required for an electromagnetic pulse to travel a finite distance along steel rods or length of wire (wave guide), and the travel time is dependent of the dielectric properties of the soil surrounding the wave guide. As moisture increases in the soil, the pulse travel time decreases and the sensor's time signal is converted into a volumetric soil water content measurement by percentage. This technology, which evolved from and is similar to time domain reflectometry, provides high accuracy which is independent of low and moderate salt and fertilizer levels in the soil. The original time domain reflectometry type sensors were expensive and difficult to use. The recently developed time domain transmission devices are less expensive, and more suitable for landscape irrigation applications. The manner in which a TDT signal is processed is unique to its manufacturer and at least one manufacturer has a patented its digital signal analysis process. The significance of the signal processing method, with regard to accuracy and consistency, is beyond the scope of this review and it is recommended the reader research this matter as warranted.

Frequency Domain Reflectometry (FDR or Capacitance) – This type of sensor contains a pair of electrodes (either an array of parallel spikes or circular metal rings) which form a capacitor with the soil acting as the dielectric in between. The electrodes are inserted into the soil or in an access tube in the soil. An oscillating frequency is applied to the electrodes, which results in a resonant frequency, the value of which depends upon the dielectric constant of the soil. The moisture

content changes the dielectric constant of the soil, thereby changing the resonant frequency. The change in frequency is then converted to a soil moisture measurement. FDR sensors which operate at high frequency (greater than 20 mega hertz) are relatively independent of soil salt and fertilizer levels. This type of sensor is especially sensitive to undisturbed soil contact. (See discussion of undisturbed soil contact under the Installation heading below.)

Tensiometers – This type of sensor measures the soil moisture tension, or negative pore pressure, as it changes with soil moisture content. Tensiometers operate by allowing the soil solution to come to equilibrium with a reference pressure indicator through a permeable ceramic piece that is in contact with the soil. A vacuum gauge measures the soil moisture tension and high tension reflects low soil moisture. Tensiometers accurately measure wet soil moisture levels independent of salt and fertilizer levels, but are less accurate for dry soils. They can require maintenance to refill the tensiometer with liquid and maintain the integrity of the soil/ceramic tip interface. (This typically occurs only when the soil dries beyond the wilting point.) Some tensiometers must be removed from the soil during winter months in northern climates where the soil freezes.

Installation

All of the soil moisture system manufacturers recommend professional installation and programming of their commercial products, and report that installation and programming of their residential models can be done by a non-professional. Based on discussions with third party individuals with experience installing most of the reviewed residential models, it appears homeowner installation may not be a realistic option with certain products. The degree of difficulty to install any of the products can vary significantly depending on site specific conditions. A significant factor is the soil moisture sensor wiring configuration. Some sensors are connected to the existing nearby valve wiring, and some must be connected to the controller with potentially long runs of new wiring. Wiring the sensors to the irrigation valves should be easy in most cases, but the ease of connecting to the controller depends on site specific conditions (distance, obstacles, etc.). It is difficult to determine what percentage of homeowners successfully install and program the various residential products. Installation and programming instructions are available for some of the products at their websites. All potential customers should review this information when shopping for a device regardless of whether they plan to do their own installation and programming.

Additional installation issues to be considered are associated with the placement of the soil moisture sensor(s) in the root zone. A soil moisture sensor should be in contact with relatively undisturbed soil that is representative of the irrigated landscape. Contact with disturbed soil with a higher void space ratio may result in soil moisture readings that are not representative of the landscape. Some sensor types are more sensitive to this than others. Therefore, the sensor shape

and method of placing the sensor with regard to undisturbed soil contact should be considered when comparing systems. Installation of the sensor may also result in disturbance of the turf root system and affect the health of the turf for a period following installation. This may cause the soil moisture in the vicinity of the sensor to be higher than typical due to reduced ET by the disturbed turf until it "heals".

Stand-alone Versus Add-on Controller

The controller component for most of the soil moisture products reviewed is an add-on device which works with an existing clock type controller. The other products include a stand-alone controller with many of the features of typical clock type controllers. In some cases, the cost of the add-on device is a significant attraction. Regardless of cost, the quality of an existing controller should be a factor when considering replacement with a stand-alone control device. If the existing controller is a high quality unit with adequate features, an add-on device may be an attractive alternative.

The primary stand-alone controller features which should be considered include: automatic scheduling, number of programs and start times, cycle and soak, master valve circuits, compatibility with other sensors (rain, flow, temperature, wind, etc.), remote control, and system testing capabilities.

Irrigation Schedules and Run Time Calculation and Adjustment

Most of the devices reviewed do not automatically calculate irrigation run times, although some adjust user-entered run times based on soil moisture measurement data or control run times with on and off soil moisture thresholds. None of the soil moisture sensor devices automatically calculate cycle and soak times. Some manufacturers (stand-alone and add-on) provide guidelines or computer programs to assist the user in calculating total run times and cycle and soak times. The product descriptions identify the manufacturers that provide guidelines or computer programs for determining appropriate run times and cycle and soak times.

Single Versus Multiple Soil Moisture Sensors

Most of the residential systems reviewed use one soil moisture sensor to control operation of the entire system, and varying zone conditions are accommodated for by adjustment of run times. For complex residential landscapes and commercial systems, some systems have the capacity to use multiple sensors to control a

single valve or groups of valves. For complex systems, the user should consider the sensor capacity of the controller. In some cases, multiple controllers with single sensor capacity can be used to build a multiple sensor system. Some of the multiple sensor controllers allow for bypassing the soil moisture control mode and running in clock mode by station. All of the products reviewed will allow for system-wide clock mode operation.

Soil Temperature and Conductivity Measurement and Display

Some of the sensors included with the products reviewed measure soil temperature and conductivity in addition to soil moisture. Soil temperature is necessary for calibration of the soil moisture measurement by certain types of sensors. Some of the controllers allow for display of the temperature and conductivity measurements. Display of the conductivity measurements is a significant feature for users irrigating with wastewater effluent or water that contains high levels of salts in order to know when to flush the soil. When the user is informed that the salt levels in the soil have reached a critical point based on the conductivity readings, the landscape should be irrigated heavily to leach (flush) the salts to below the root zone.

Soil Moisture Sensor Accuracy and Calibration

As previously discussed, the measurement of soil moisture by some sensors is affected by soil type, temperature and salinity. All of the sensor products reviewed are factory calibrated to measure moisture content for a spectrum of soil types. The manufacturers typically report a level of accuracy that is good for a range of soil types. In some cases, the accuracy may vary significantly for the different soil types. Also, the accuracy may be inconsistent for different moisture, temperature and salinity levels.

For the purpose of landscape irrigation scheduling, the consistency of a sensor is as important as, or more so, as its accuracy. For practical purposes, the user of a sensor based landscape irrigation control system typically performs a quasi-calibration of the sensor during set-up. This is accomplished when the user observes the moisture level reading that occurs with the soil at field capacity. Regardless of the accuracy of the reading, the user typically sets the irrigation trigger moisture level as a percentage of the field capacity reading. If the sensor does not read consistently, the percentage relationship between field capacity and the irrigation trigger will be affected. As an example, if a sensor reads 36 percent at field capacity and the user wants to set the irrigation trigger at 50 percent of field capacity the controller would be set to irrigate at a reading of 18 percent if the sensor reads consistently. If the sensor does not read consistently, the

controller would need to be set to irrigate at a reading higher or lower than 18 percent.

Power Supply and Surge and Lightning Protection

Most of the controllers and devices operate on 24 VAC and few are battery powered. The stand-alone devices typically include a power transformer that converts 110-120 VAC to 24 VAC. The transformers are either hardwired inside the controller cabinet (internal), or plugged into a power outlet (external). The add-on scheduling devices that operate on 24 VAC either receive power from the existing clock/controller or from an external transformer. Most of the transformer devices include some type of current overload protection such as a fuse or breaker switch. Some of the controllers include lightning and or surge protection, or offer these as an optional feature. Surge and lightning protection limits damage to the controller's circuitry from transient voltage and current from the power source (surge) and from the valve circuits (lightning).

Station Circuit Rating, Wiring and Terminal Wire Sizes

The compatibility of the existing electrical circuits (wiring from the controller to the station valves) should be considered in the selection of a stand-alone controller. If the station wire terminals on the controller will not accept the existing wire, adapters must be used. Also, the circuit current capacity required for an existing system should be checked prior to installing a new unit. Installation problems associated with insufficient circuit capacity to operate some irrigation valves with high circuit resistance are a possibility.

The traditional wiring system (circuitry) used for most controllers consists of a common and a dedicated wire from the controller to each valve and sensor. Some controllers utilize "2-wire" circuitry that consists of a single pair of wires connected to all of the valves and sensors in the system. These systems require the installation of a decoder device for each valve and sensor. Applications include large systems and linear systems (e.g., highway corridors) with large quantities of wiring required for traditional circuitry.

Warranties and Reliability

All of the products reviewed include a warranty. Warranty details are discussed in the product descriptions section. In some cases, the manufacturers' warranty periods vary for its different products. Although the warranty periods may or may not be indicative of the life expectancy of the products, in some cases there appears to be a correlation between the cost and overall quality of the product to

the warranty period. It is assumed the cost of a product somewhat reflects the quality of the construction materials and electronic components. Hence the less expensive residential devices should not be expected to last as long and function as reliably as the more expensive residential and commercial products. Since most of the devices are relatively new products, it is difficult to speculate on how long they should last.

Soil Moisture Based Product Descriptions

The following product descriptions address operational characteristics and features, and include discussions of available information from demonstration and pilot studies relative to documented water savings and operation. Each of the manufacturers were provided copies of the product descriptions for input prior to being incorporated into this report.

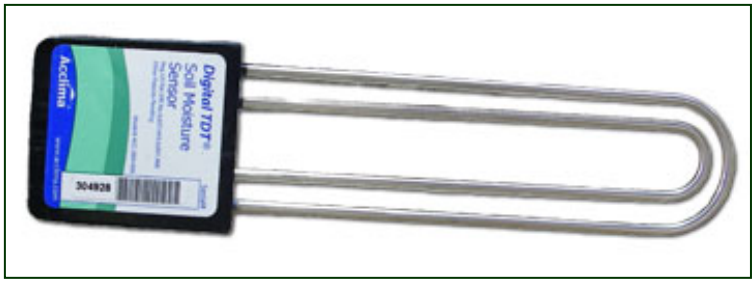
Acclima

Acclima, Inc., of Meridian, Idaho, manufactures soil moisture sensor based landscape irrigation control systems. Acclima began development of its system components in 1997, and Acclima products entered the market in 2003. Acclima's sensor technology is sold throughout the United States, Europe, South Africa, Asia and Australia.

Acclima Closed Loop Irrigation® systems are governed by real-time root zone soil moisture content as measured by its patented Digital TDT® absolute soil moisture sensor. The Acclima sensor is the industry's only digital process time domain transmissometry soil moisture sensor. Acclima reports its digital process sensors measure the absolute soil moisture content regardless of changing soil types, electrical conductivity and temperature. All systems accommodate one or more soil moisture sensors and either an add-on or stand-alone controller. Controllers suitable for all residential and commercial applications are available.

Sensor Description and Operation

The heart of all Acclima irrigation systems is the sensor. The sensor dimensions are 8" x 2" x 0.5", and the sensor is constructed of Type 316 stainless steel rods and electronic components embedded in moisture-resistant epoxy resin molded in heavy duty plastic. Sensor rods are electrically isolated from the circuit board to prevent galvanic corrosion and each sensor includes lightning protection. Sensors



are buried in the soil among the active rootlets of turf, trees and shrubs. The sensor reports the moisture content to the controller via the same wiring used for valve control in resolution of tenths of one percent. A typical residential installation employs one sensor. Commercial systems typically use multiple sensors, one for each microclimate or landscape vegetation type. Various zones may be programmed to track any sensor.

Acclima reports its patented Digital TDT sensor is unique because it provides *absolute* percentage volumetric water content whereas other sensors provide only *relative* moisture data. The sensor generates a unique high frequency pulse along the sensor rods with a sampling interval of 5 picoseconds -- the time required for light to travel 1.5 millimeters. This high speed sampling minimizes the dielectric relaxation properties found in clay soils. Acclima reports this characteristic, combined with its patented digital analysis process, produces superior stability and accuracy in all soil types. The Acclima sensor can detect the addition of 0.002 inches of water to 4 inches of soil, yielding maximum water savings.

Upon installation, the soil surrounding the sensor is doused to saturation and then allowed to percolate to field capacity. A sensor reading is taken at this time to determine the unique field capacity of the microclimate and the irrigation threshold is calculated.

All Acclima irrigation controllers use the Digital TDT sensor as a “closed loop” feedback mechanism in controlling the irrigation process. The controller polls the sensor for accurate soil moisture readings; if the sensor returns a reading below the irrigation threshold, the system will intelligently replace only the amount of moisture lost through ET since the last irrigation cycle. Thus, root zone moisture levels are perpetually maintained at user-specified levels, resulting in optimized economy and healthier landscapes.

Controller Description, Prices and Warranty

Acclima offers a variety of control devices suitable for any application. All stand-alone Acclima controllers allow multiple sensors with highly flexible programming. On all models, volumetric soil moisture content is displayed from 0 to 100 percent. Soil temperature is displayed in degrees Fahrenheit or Celsius and soil conductivity in dS/m (10^{-1} Siemens per meter).

Acclima’s Suspended Cycle® systems are programmed just as a standard irrigation clock. When the programmed time arrives, the system polls the sensor to see if irrigation is allowed. If not, the cycle is suspended; if water is required,

irrigation takes place. Acclima's Water on Demand® systems require no programming whatever. The user enters the irrigation threshold, specifies times when irrigation is *not* allowed, and the system irrigates only as needed, without any programming.

The Acclima RS500 is an add-on controller that supports most existing clock type controllers. It sets, maintains and monitors any desired moisture level by suspending an irrigation cycle when there is sufficient moisture in the soil. The sensor is linked to the controller through the existing wiring for the valve irrigating the sensor location. Sensor readings are periodically transmitted to the controller. When the programmed existing timer prompts an irrigation cycle, the RS500 first checks the moisture level and either allows or suspends the cycle, depending on the moisture level. The RS500 includes a Moisture Control ON/OFF switch to by-pass the controller if necessary. Moisture readings continue, but there will be no interruption of the programmed cycles. Also, one or two zones may be operated by the existing controller independent of interruption by the RS500 to assure special zones such as xeriscape or newly-seeded areas receive appropriate moisture. The RS500 cabinet dimensions are 4.5" x 2.4" x 1" and it is suitable for indoor installation. The 24V power supply comes from the existing controller or external transformer. Each RS500 is sold with a Digital TDT soil moisture sensor.

The Acclima SC Series Controllers are stand alone Suspended Cycle control units. It is available in 6, 12, 24 and 36 zone configurations and in two cabinet models. These controllers employ standard zone wiring with typical programming processes.

The Acclima SC6/12 controller is designed for residences and light commercial applications with up to 12 zones. The controller has an LCD display and accepts as many sensors as there are zones. The controller's programming features include timer or sensor control; simple push-button control; pre-set factory default schedules including, sod, new seed, rotors and spray pop-ups; three independent programs with six start-times each; automatic threshold set-up; non-volatile program memory which preserves programming during power and battery failures; program and circuit test modes; zone error reporting; master valve/pump start capability; rain sensor/accessory terminal and enhanced surge protection. This controller has an exterior 24V transformer and includes a weatherproof cover, making it suitable for outdoor mounting.

The Acclima SC24/36 controller uses traditional valve wiring with four available programs and six start times. Each controller accommodates as many sensors as it has zones, and each sensor adds a new program to the controller. For multiple sensor set-up, each sensor is connected to the valve for each reference zone and sensor readings are transmitted to the controller via the valve wiring. Zones without sensors are assigned to a reference zone and irrigation occurs based on the soil moisture measured in the reference zone. Unique soil moisture thresholds may be programmed for each reference zone.

The controller may be operated in automatic soil moisture based, timed or manual modes. Up to 4 zones, plus a master valve circuit, may run concurrently, dependent on system water volume capacity. Multi-zone watering may be configured per-zone based on the water usage of that zone versus available water. This may be done automatically when a flow meter is attached to the system, or the configuration can be adjusted manually at any time. These controllers support rain, wind, and freeze sensor inputs to shut off the water when weather does not permit irrigation. Flow meter support checks for broken pipes and valves. Connection of a flow meter requires an interface device manufactured by Acclima.

The controller's calendar/clock automatically compensates for leap years. The clock can be maintained for up to 2 months without power using 2-AA alkaline batteries. The non-volatile program memory maintains configuration information even if the power fails and the batteries are dead. Watering day schedules include Custom, Every Day, Odd Day, Even Day, Every nth Day watering (where n may range from 3 to 31). Zone stacking ensures that all zones will eventually be watered even though program start times may overlap. Other features include soak/cycle, valve circuit test, programmable pause, rain delay (0-14 days) and water budget adjustment (5 to 500 percent). Remote control is available with optional hand-held radio and interface devices.

The controller cabinet measures 12.3" x 10" x 5.9" and is weather resistant extruded ABS plastic, suitable for outdoor installation. The internal power transformer includes over-under detector that automatically detects loads exceeding 2.1 amperes and over-load backup fuse (slow-blow, self-healing fuse: 2.5 A). Station circuit capacity is 0.6 amperes. The controllers possess surge and lighting protection consisting of the following:

Input:	Transient voltage suppressor (TVS)
Common Wires, Signal Ground:	5,000 Amp gas discharge tube to earth ground
Each Terminal:	Metal oxide varistor (MOV)
Earth Ground Terminal:	Up to #6 copper wire to divert surges to ground

The Acclima CS 3500 controller is a Water on Demand® device operating over a 2-wire communications line, saving copper and allowing flexibility for system modification. Up to 60 sensors may be used with this 64 zone system. The controller operates without programming. The user identifies blocks of time when irrigation is restricted, and sets an upper and lower irrigation threshold. Water is applied when the sensor reports moisture below the lower threshold and will irrigate until the upper threshold is reported.

The 2-wire circuit requires valve adapters (decoders) to establish the 2-wire communications bus to valve interface. These adapters contain electronic switches that apply power to the solenoid valves upon command from the controller. Acclima sensors also contain a single electronic switch so that there is no need for a valve adapter when a sensor is installed in the valve circuit.

The CS3500 offers features similar to the Acclima SC Series, and has central control capabilities using the Acclima Irrigation Manager™ software and advanced communications capabilities through serial cable, dial-in modem, cell phone or radio communications. The clock can be maintained for up to 10 years without 24 volt power using a CR2032 battery. The CS3500 cabinet is the same size and material as the SC24/36 and is suitable for exterior mount. Surge and lightning protection are also similar to the SC24/36.

Prices for selected Acclima products are summarized in Table 15. Acclima products may be purchased through distribution by referring to the Acclima website, www.acclima.com or by contacting Aquarius Brands, Inc. of Ontario, California. Acclima products carry a 2-year warranty.

Table 15 - Acclima Product Prices

Description	Model No.	Price
RS500 Add-on Controller*	ACC-SYS-0500	$ 265
SC6 Residential Controller*	ACC-SYS-0006	$ 292
SC12 Residential Controller*	ACC-SYS-0012	$ 358
SC24 Commercial Controller	ACC-SYS-0024	$ 995
SC36 Commercial Controller	ACC-SYS-0036	$1,495
CS 3500 Commercial Controller	ACC-SYS-3500	$2,978
Digital TDT Soil Moisture Sensor	ACC-SEN-006	$ 198
Flow Meter Interface	ACC-FPM-015	$ 650

*Includes one (1) Digital TDT Soil Moisture Sensor

Installation

Detailed installation instructions, manuals and videos are available on the Acclima website. Acclima reports the RS500, SC6 and SC12 controllers may be installed by homeowners, but recommends professional installation of the SC24, SC36 and CS3500 control systems.

Track Record and Water Savings

The accuracy of Acclima's Digital TDT soil moisture sensor is well documented by independent laboratories, and their patented irrigation systems have been tested and researched by numerous academic institutions. Acclima's sensor technology was first evaluated by the Center for Irrigation Technology in 2003. Since then, dozens of independent university studies have validated unprecedented savings of water and fertilizer. Acclima reports average water savings are approximately 30 to 40 percent. Acclima submitted their technology for independent verification before placing their products on the market. Testing entities include the following:

University of Arkansas
Oregon State University

New Mexico State University
University of Tennessee

University of Florida
Utah State University

Brigham Young University
California State University, Fresno

Information on the above testing and research, and certain study report documents are available on Acclima's website.

Agrilink

Agrilink Holdings Pty Ltd is a manufacturer of irrigation management products headquartered in Adelaide, South Australia. Agrilink has been in business since 1997 and has U.S. offices in Santa Rosa and Santa Ana, California.

Agrilink supplies a range of soil moisture sensing products and a specific soil moisture based landscape irrigation scheduling device.

The AquaBlu® soil water regulator was introduced by Agrilink in December 2006. This device works with any 24VAC clock-type controller to schedule irrigation based on soil moisture sensor input from an Agrilink AquaBlu Sensor.

Sensor Description and Operation

The AquaBlu Sensor is a capacitance (or FDR) type soil moisture sensor. It is a fully sealed double sided "paddle" shaped sensor made from ABS plastic. The sensor has overall dimensions of 7.5" x 2.8" x 0.5". The AquaBlu Sensor comes with 16 feet of multicore cable for connection to the regulator. The soil moisture signal and power supply for the sensor are transmitted through the cable. The

cable can be extended up to 90 feet without signal degradation using conventional multicore irrigation cable (4 cores are required). Further distances (up to 660 feet) can be covered using specialized cable available from Agrilink.

Agrilink recommends installing the sensor using a flat spade to slice a groove in the soil to the required root zone depth. The sensor is inserted into the groove and the surrounding soil is pressed in from both sides of the sensor to ensure complete contact around the sensor.

The AquaBlu system interrupts irrigation when soil moisture exceeds the threshold set by the user. Irrigation is interrupted immediately as opposed to interrupting before the next cycle. A base irrigation schedule is programmed into the clock type controller by the user which typically would irrigate every day without interruption imposed by the AquaBlu regulator. The total run times and cycle and soak times programmed into the clock controller must be calculated by the user.

Controller Description, Prices and Warranty

The AquaBlu regulator has two parts, a body and an opaque dust cover. It is designed to be wall mounted indoors in the vicinity of the clock controller, and can also be mounted outdoors or within a valve box if placed in a watertight housing. The body is made of ABS plastic and its overall dimensions are 6.5" x 3" x 1". The irrigation interruption threshold is set with its dial type adjustment component and two LED indicator lights show power and interruption status. The system can be powered by either AC or DC, at 9V to 14V at 100mA with a maximum power consumption of 1W. Agrilink's optional "Line Regulator (24V to 12V)" can be used to convert from the clock controller's 24VAC supply or an optional "AC power pack" can be used.

The soil moisture threshold adjustment dial has settings corresponding to the spectrum of soil types over a 270 degree control range. Confirmation that the AquaBlu is powered on is provided by a green LED. Indication of soil moisture being at or over the set point is provided by a red 'superbright' LED.

AquaBlu updates soil moisture readings once every second. This allows for the setup of the selected soil moisture point on the regulator to be intuitive and instant. When selecting the desired moisture point with the dial on the regulator, the red 'superbright' LED will come on and correspond with the current soil moisture content without waiting a day for a response.

For a simple residential installation, a single AquaBlu system is installed. The AquaBlu can be connected to the 'sensor' input on most modern clock controllers

to cancel irrigation across all zones when soil moisture is sufficient. Alternatively (for older controllers that do not have a 'sensor' input) the AquaBlu is connected to interrupt the valve common wire within the controller.

Multiple AquaBlu devices can be used to control irrigation for different zones or groups of zones. This is achieved by connecting the AquaBlu to interrupt the active valve wire for a single zone or to interrupt a common valve wire for a group of zones. A typical split would be to use one AquaBlu for lawn areas and another for garden areas.

The listed retail price for the AquaBlu Soil Regulator, including the AquaBlu Sensor, is $139. The optional “Line Regulator (24v to 12v)” and optional “AC power pack” are $10 each. Agrilink warranties the AquaBlu for 2 years.

Installation

Agrilink recommends professional installation by a contractor with an understanding of where to best locate the sensor(s) and how to adjust the AquaBlu based on soil conditions. Installation time will vary according to how much digging is required to install the cable. If this is completed during irrigation system installation, minimal additional time is required. Agrilink reports it takes about 15 minutes to install the AquaBlu and wire it to the clock controller, and that a homeowner with some basic skills could retrofit an existing clock controller with an AquaBlu in under an hour if minimal digging is required.

Track Record and Water Savings

Agrilink submitted information for this review showing how multiple AquaBlu devices tracked soil moisture levels at the Townsend House (Adelaide, South Australia) demonstration project.

Data collection for the demonstration project began in early 2007, with initial results being positive. Figure 13 includes a graph of soil moisture status with increases due to irrigation and rainfall and decreases due to daily turf water use as a result of ET. Soil moisture was measured with a commercial probe (AquaSpy™ Turf Probe) documenting the current irrigation practice for a period of time before the AquaBlu was engaged. What followed was the documentation of the reduction of the number of irrigations when the clock controller was interrupted by the AquaBlu after it was engaged.

There were 14 irrigations prevented out of a possible 20 irrigations that were scheduled by the clock controller during the time the AquaBlu was active. Irrigations were also prevented over the period in response to minor and major rainfall events while the soil moisture was still adequate for viable plant and turf growth.

Timed irrigation events that would have normally occurred by the irrigation timer and were switched off by the AquaBlu are indicated by the red arrows.

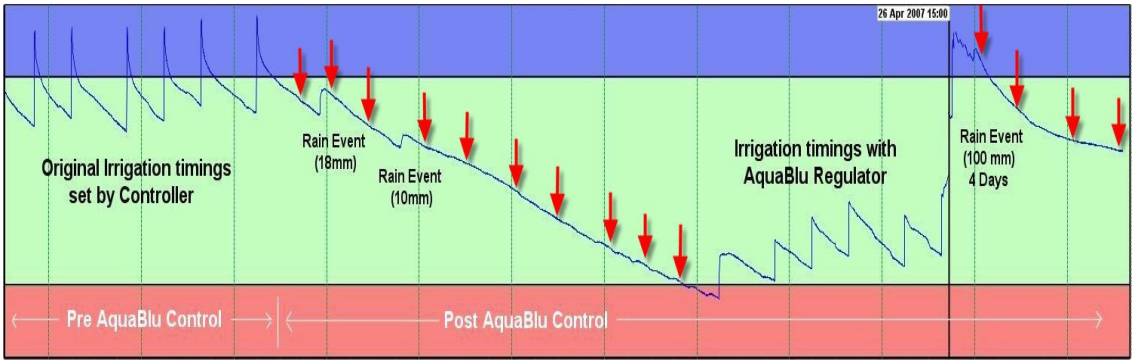


Figure 13 - AquaBlu Demo Site Irrigations and Soil Moisture Tracking

The locations of twenty other commercial installations were also provided. No other information on the product's track record or water savings studies was available, which is understandable for such a new product.

Baseline

Baseline, LLC, located in Boise, Idaho, manufactures soil moisture sensor based landscape irrigation control systems. Baseline began business in 1998, and its first soil moisture sensing products entered the market in 2002. Its systems include add-on and stand-alone controllers, as well as centralized control systems.

The Baseline irrigation control systems are based on real-time soil moisture content as measured by Baseline's patented biSensor™ TDT (time domain transmission) soil moisture sensor. All systems (non-centralized) function with one or more soil moisture sensors that are offered with three controller options: a stand-alone controller, an add-on controller that interfaces with an existing clock-type controller, or a computerized system of multiple stand-alone satellite controllers. Baseline manufactures systems that are suitable for both residential and commercial applications.

Sensor Description and Operation

The biSensor comes in three models: a 6-inch rigid sensor used with the S100 controller, a 1.5-foot rigid sensor and a 5-foot flexible sensor. All measure the

volumetric soil moisture content near the sensor. The sensors are buried in the root zone, and transmit soil moisture and temperature information to the controller via the same wiring used for valve control. A single sensor can control multiple irrigation zones. A typical residential system includes just one sensor. A commercial system may use numerous sensors associated with various microclimates or landscape types. Baseline recommends installation in a v-shaped trench to minimize soil disturbance where contact is made to the sensor. The biSensor is constructed of corrosion-resistant fiberglass.

The biSensor functions by sending an electronic pulse along an imbedded wire path. The wire is embedded in fiberglass providing desired characteristics by not being in contact with the soil, but the speed of the pulse is delayed by the soil's water content. The higher the water content, the slower the pulse moves around the biSensor. The biSensor measures the pulse speed to determine the amount of water in the soil. biSensors can reportedly resolve the travel time in increments as small as 10 pico seconds. Baseline's biSensors measure distortion caused by salts and temperature changes and adjust moisture readings accordingly. All sensor-related electrical components are insulated from the soil, including the actual sensing elements.

Controller Descriptions, Prices and Warranty

Baseline's controllers include one add-on model and four stand-alone models. Three of the stand-alone controllers utilize two-wire valve control wiring and the other supports conventional valve wiring. The add-on model is designed for use with a single biSensor and functions with any clock/controller. The standalone models can be connected to multiple biSensors. All of Baseline's controllers are rain sensor compatible and have a bypass feature that disables the soil moisture based control. The soil moisture reading for all controllers is displayed as volumetric water content from 0 to100 percent. The stand-alone models include an internal power transformer and the add-on models power supply is from the clock/controller or from an external transformer. The standalone controllers operate on Baseline's Time/biSensor control system allowing for several smart watering strategies from fully automatic to timer type controls and many options in-between.

The Baseline WaterTec™ S100 controller is an add-on device for use with an existing clock/controller and a single biSensor. The S100 cabinet is constructed of heavy duty plastic and is available in an indoor model. Its dimensions are 5.8" x 2.6" x 1.5" and it has a 3-character, one line LCD display and touch pad type controls. The S100 comes with a 6-inch biSensor soil moisture sensor.

Guidelines for performing a site audit and determining appropriate total run times and soak and cycle times are available from Baseline for programming the clock/controller connected to the Watertec S100.

The BaseStation 3000R is a stand-alone commercial controller supporting new or existing conventional irrigation wiring and scales from 12 to 200 zones. Baseline biSensor moisture sensors may be connected directly to existing valve lines for existing (or new) sites. The BaseStation 3000R also includes a two-wire expansion port, which allows system expansion using either conventional wiring or two-wire. The 3000R offers 10 programs with 8 start times for each program. The user programs a base schedule and then the total run times are adjusted by the controller based on its evaluation of soil moisture data. (Guidelines are provided for determining an appropriate base schedule.) Other features include day interval calendar, event scheduling, self-test diagnostics and adjustable soak cycles. The 3000R is remote access capable with Baseline's BaseManager™ computer software package.

The 3000R is available in lockable indoor wall mount and outdoor pedestal models. The wall mount cabinet is constructed of powder coated steel, and its dimensions are 12" x 10" x 4". The pedestal cabinet is constructed of stainless steel and its dimensions are 36" x 17.5" x 12.5". The controller face includes a dial and touch pad controls. The controller's 3.5-inch QVGA display provides 240x320 resolution. The BaseStation BL3000 is a stand-alone commercial controller with two-wire biLine™ valve wiring configuration. The two-wire system requires the use of biCoder™ devices at each valve to convert the two-wire signal to power and control the valve. The BL3000 has 200 zone and 25 biSensor capacities. This controller offers the same features of the BL3000R including 10 programs with 8 starts and an event scheduling feature that allows for restrictions for future events. Also, the user has the option of setting the controller to adjust run times or run frequency. The BL3000 is available in wall mount or pedestal cabinets of the same construction and sizes as the BL3000R. The control and display features are also the same.

Current suggested retail prices for Baseline products are summarized in Table 16. Baseline products are available from its distributors, and a distributor list is available at the Baseline website (www.baselinesystems.com). Baseline

controller products have a 1-year warranty (with ability to extend up to 5 years) and the biSensors have a 5-year warranty.

Table 16 - Baseline Product Suggested Retail Prices

Description	Model No.	Price
Indoor Add-on Controller	S100	$149*
200-Zone Stand-alone Wall Mount Controller	BL3000C	$1,599
200-Zone Stand-alone Pedestal Controller	BL3000P	$3,199
12-Zone Expandable to 200 Wall Mount Controller	BL-3000CR-12	$1,999
24-Zone Expandable to 200 Wall Mount Controller	BL-3000CR-24	$2,399
12-Zone Expandable to 200 Pedestal Controller	BL-3000PR-12	$3,495
24-Zone Expandable to 200 Pedestal Controller	BL-3000PR-24	$3,695
48-Zone Expandable to 200 Pedestal Controller	BL-3000PR-48	$4,295
biSensor Soil Moisture Sensor (1.5-foot)	BL5315B	$249
biSensor Soil Moisture Sensor (5-foot)	BL5305B	$249
biCoder Two-wire Valve Adapter (single zone)	BL5201	$137.50
biCoder Two-wire Valve Adapter (two zone)	BL5202	$192.50
biCoder Two-wire Valve Adapter (four zone)	BL5204	$270.00

* Price includes biSensor

Installation

Although Baseline recommends installation by a landscape professional, it reports the S100 can be installed by most homeowners. The reported average homeowner installation time is about an hour.

Track Record and Water Savings

Although no information was submitted for this report on formal studies and testing, Baseline submitted documentation from numerous customers reporting significant water savings (30 to 50 percent) resulting from installation of Baseline systems.

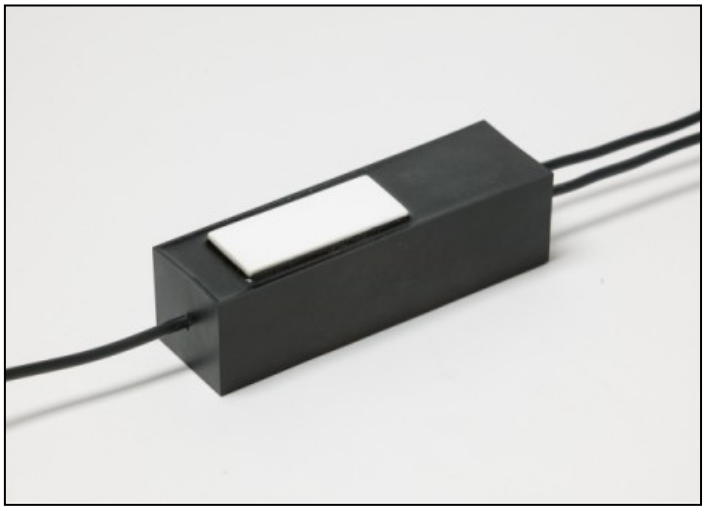
Calsense

As discussed in the Weather Based Product Descriptions section, Calsense manufactures water management systems for large commercial customers. The Calsense Model 1000-S soil moisture sensor measures and transmits soil moisture readings to a Calsense ET2000e irrigation controller to provide efficient landscape irrigation. The ET2000e will automatically suspend

irrigation when the soil moisture level is above the threshold set by the user. A full description of the ET2000e and its features is included in the Calsense discussion in the Weather Based Product Descriptions section.

Sensor Description and Operation

The 1000-S is a solid-state tensiometer type soil moisture sensor that provides consistent long-term soil moisture readings to the Calsense irrigation controller. The moisture sensor electronics are encased in epoxy and the sensor is constructed of heavy duty plastic. There is no maintenance or calibration required for the life of the sensor. The 1000-S readings are unaffected by temperature, salinity or changes in soil pH. The sensor's dimensions are 6.4" x 1.9" x 1.6".



The 1000-S is installed in the root zone and is connected to the valve that controls the area where the sensor is located. Soil moisture data are transmitted to the irrigation controller via the valve control wiring. Special wire runs between the irrigation controller and the sensor are not necessary. The only additional wiring required is between the valve and the 1000-S sensor. The total combined maximum wire run between the moisture sensor and the irrigation controller is 3,000 feet. Calsense reports that maintenance of the 1000-S is only required when the soil becomes extremely dry, requiring the device be removed and soaked and then placed into moist soil. If the soil freezes, removal is not required.

The Calsense ET2000e controller, using the sensor to measure available water in the pore space of the soil, makes a decision before the start of each cycle/soak run whether or not to apply water. This decision is based on the actual moisture reading compared to the user-input moisture set point. Total run times and cycle and soak times are included in the base program entered by the user, based on field knowledge and soil moisture content for the time of year.

A 1000-S is connected to a representative station for each different climatic and plant material zone, which is defined as a master station. Slave stations are stations without sensors and are assigned to a master station that shares similar water requirements. The user chooses groups of stations controlled by the same sensor during initial setup. Stations can be easily changed or moved from one sensor to another through user friendly programming. Calsense recommends a general guideline of one moisture sensor per four active valves to cover varying

moisture needs. Up to one soil moisture sensor per every valve may be connected using the ET2000e controller.

Controller Description, Prices and Warranty

The 2000e features are discussed in more detail under the Calsense portion of the Weather Based Products section.

Calsense products are available from many distributors located throughout the U.S. A list of these distributors is available from Calsense upon request (800-572-8608 or www.calsense.com). The current retail price for the 1000-S is $199. It has a 5-year warranty. The price range for the various ET2000e models is from $1,290 to $3,680, as detailed in the Calsense discussion in the Weather Based Products section. Calsense provides technical support at no-charge to assist in the proper installation of the moisture sensors for the most efficient system.

Installation

Calsense recommends professional installation of the ET2000e and installation time varies significantly depending on site conditions.

Track Record and Water Savings

Although Calsense has not participated in any outside studies or demonstration projects, its track record speaks for itself. During Calsense's 20 years of existence, they have developed a large data base on its products' performance and customer success.

Dynamax

Dynamax, Inc. manufactures a wide variety of products used for water status applications, water cycle measurement, plant-water relations, carbon flux instruments, as well as weather stations. Dynamax is located in Houston, Texas and has been in business for 20 years. Distribution of its soil moisture based landscape irrigation control systems began in 1999.

Dynamax offers two add-on systems and a third system that works as an add-on or stand-alone device. The Moisture Clik™ (IL200-MC) and the Moisture Switch™ (IL200-MS) are add-on only devices that function with newer model non-mechanical clock type controllers. Dynamax's Data Logger/Irrigation Monitor (GP-1) can function as a stand-alone controller

or as an add-on device. All three systems utilize the Dynamax SM200 soil moisture sensor.

Sensor Description and Operation

The SM200 is a frequency domain reflectometry (FDR) type of dielectric sensor that measures volumetric soil moisture content from 0 to 60 percent with a Dynamax reported 3.0 percent accuracy. The SM200 soil moisture sensor consists of a waterproof housing that contains the electronics and two sharpened stainless steel rods that are inserted into the soil. The rods are threaded and may be removed from the housing for replacement if damaged or bent. Each SM200 is adjusted during manufacture to provide a consistent output when measuring media of known dielectric constant, making them readily interchangeable without system re-calibration. Specifically, Dynamax reports soil temperature effects and low to moderate salt and fertilizer (conductance levels below 2,000 micro siemens) effects are negligible. The overall length of the sensor is 5.4” and the housing diameter is 1.6”. It comes with 85-feet of 4-wire cable. The SM200 is installed into the root zone by pushing the rods into the wall of a shallow trench, resulting in contact with relatively undisturbed soil. The sensor cable is connected to the irrigation scheduling device.

The SM200 is designed to measure volumetric soil water content using a novel technique that the manufacturer reports matches other methods, such as time-domain reflectometry, for accuracy and ease-of-use, while reducing the complexity and expense. A simplified standing wave measurement is used to determine the impedance of a sensing rod array and hence the volumetric water content of the soil matrix.

The SM200 applies a 100-megahertz sinusoidal signal via a specially designed transmission line to a sensing array whose impedance depends on the dielectric constant of the soil matrix. Because the dielectric constant of water (80) is significantly greater than that of the other soil matrix materials (3-4) and of air (1), the dielectric constant of the soil depends primarily on soil water content. The signal frequency has been chosen to minimize the effect of ionic conductivity.

Controller Descriptions, Prices and Warranty

The Dynamax add-on only systems (Moisture Clik and Moisture Switch) regulate irrigation by continuously monitoring the soil condition at the sensor, and interrupting the clock controller schedule when enough water is available in the root zone. As soon as the soil dries out below the user programmed set point, an

internal switch closes the signal to the clock controller to irrigate. The clock controller to which the device is connected operates as programmed by the user to replenish the depleted soil moisture. The Dynamax owner's manuals include information regarding appropriate run, cycle and soak times. The GP-1 Irrigation Monitor controls irrigation frequency and run times automatically with on and off soil moisture triggers that are programmed by the user.

The Moisture Clik and Moisture Switch devices come with normally open, and separate hot or neutral outputs providing for several connection options. Specifically, a single Moisture Clik or Moisture Switch controller may be connected to the existing clock controller such that one Dynamax controller and soil moisture sensor will control all stations or multiple Dynamax controllers and sensors may be used to control groups of stations, or individual stations.

The Moisture Clik is recommended for residential and smaller commercial applications. It is typically connected to a clock controller to control and regulate all valves, and up to 3 valves may operate simultaneously. The Moisture Clik controller may also be used where multiple sensors are desired for individual soil moisture control of one or more stations. However, only one SM200 soil moisture sensor may be attached to each individual Moisture Clik. The Moisture Clik may be programmed using its dial settings based on soil type and the desired allowable soil moisture depletion level. Alternatively, advanced users may verify sensor settings and measure soil moisture field capacity with a voltage meter to improve performance.

The Moisture Clik controller cabinet is constructed of polycarbonate and ABS plastics, and is rated for indoor or outdoor installation. Its dimensions are 4.6" x 4.6" x 2.4". The 24 VAC, 3 amperes power supply is either from the clock controller or from an external transformer. (Dynamax recommends using its optional external transformer.) It possesses a 3 ampere input fuse and 0.5 ampere internal fuse. Approximately 6-foot of minimum 12 gauge wire is required to connect the Moisture Clik to the existing controller.

The Moisture Switch controller features are suited for large landscape applications where simultaneous control of multiple valves is necessary. It is typically connected to a clock controller to control and regulate all valves, and up

to 10 valves may operate simultaneously. Multiple Moisture Switch controllers may be used where multiple sensors are desired for individual soil moisture control of stations. However, only one SM200 soil moisture sensor may be attached to each individual Moisture Switch. The Moisture Switch requires the use of a standard voltage meter for installation and programming.

The Moisture Switch controller cabinet is constructed of fiberglass reinforced polycarbonate plastic, and is rated for indoor installation only. Its dimensions are 5” x 3.5” x 3”. The 24 VAC, 10 amperes power supply is either from the clock controller or from an external transformer. (Dynamax recommends using its optional external transformer.) The Moisture Switch possesses a 10 ampere input fuse and 1.0 ampere internal fuse. Approximately 6-foot of minimum 12 gauge wire is required to connect the Moisture Switch to the existing controller. The Moisture Switch includes an alarm display and a terminal for connection of an external alarm mechanism. As discussed above, installation of the Moisture Switch requires the use of a voltage meter to determine the irrigation set point.

Dynamax’s GP-1 Data Logger/Irrigation Monitor is a more sophisticated commercial product with numerous applications, including use as a stand-alone or add-on landscape irrigation scheduling device. One or two SM200 soil moisture sensors may be connected to it, and it has terminals for up to two temperature sensors, a flow sensor and a rain gauge. It also has a terminal for connection of an external alarm mechanism. The GP-1 has several unique features, including two soil moisture level thresholds for irrigation on and off.

As a stand-alone controller, the GP-1 can be programmed to initiate continuous irrigation at a prescribed soil moisture level and then discontinue irrigation at a second soil moisture level. This is best suited for precision irrigation applications and or drip irrigation systems. As an add-on device, irrigation frequency and total run times are controlled automatically by utilizing the two soil moisture level set points. When the soil moisture drops to the first trigger, irrigation run and soak cycles are initiated. The cycles are discontinued when the second soil moisture level is measured. With the GP-1 connected to a clock controller, it will control and regulate all valves with one SM200 sensor or two groups of valves with two sensors. Up to 10 valves may operate simultaneously, and multiple GP-1 units can be used to control individual valves or groups of valves as with the other devices.

The GP-1 is constructed of polycarbonate and ABS plastics and is suitable for outdoor installation. Its dimensions are 5.5” x 4.1” x 1.8”. The GP-1 operates on 11-24 VDC power from batteries (alkaline or lithium) or an external transformer. Approximately 6-foot of minimum 12 gauge wire is required to connect the GP-1 to the existing controller. The GP-1 is programmed using a personal computer or a personal digital assistant (PDA) device. Programming software is included with the GP-1 and an optional PDA and PDA kit is available.

Current retail prices for Dynamax soil moisture sensor based irrigation control products are summarized in Table 17. (Moisture Clik, Moisture Switch and GP-1 prices include one SM200 soil moisture sensor, cable and owner’s manual.) Dynamax products may be ordered directly by contacting the sales department through their website (www.dynamax.com) or toll free telephone (800-896-7108), and through its distributors and irrigation design consultants. A distributor search engine is also available at its website. Dynamax provides a one year warranty with its soil moisture sensor control systems.

Table 17 - Dynamax Products Retail Prices

Description	Model No.	Price
Moisture Clik Add-on Controller	IL200-MC	$425*
Moisture Switch Add-on Controller	IL200-MS	$575*
Data Logger Irrigation Monitor	GP-1	$911*
Moisture Sensor	SM200	$276
Temperature Sensor	ST3	$90
Tipping Bucket Rain Gauge	TR4-L25	$350
Pocket PC (iPAQ® 2200) PDA	PPC-1	$950
Pocket DeltaLINK Kit	PDLK1-M8	$247
24 VDC Power Transformer		
24 VAC Power Transformer	IL200-ADP	$20

* Price includes one soil moisture sensor, 82-feet of cable and owners manual

Installation

Dynamax recommends installation by an irrigation professional, however, it reports installation and programming of the Moisture Clik is relatively easy and may be accomplished by some homeowners. Dynamax reports installation time reportedly varies from 1 to 1 1/2 hours.

Track Record and Water Savings

The Macaulay Land Use Research Institute, Aberdeen, UK and Delta-T Devices, Cambridge developed Theta Probe soil moisture sensors jointly. Since its’ development and release, Delta-T has sold over 17,500 of its Theta Probe ML2 units into the scientific and research community. The SM200 is very similar to the ML2, but is constructed to meet a slightly less stringent specification.

Copies of several published reports from studies including the Theta Probe ML2 were submitted as part of this review, all reporting favorably on the ML2. A list of websites with product comparisons, technical reports, and completed studies pertaining to Dynamax products are available from Dynamax. Dynamax will also provide a list of their SM200 customers upon request.

Irrometer

The Irrometer Co., Inc., located in Riverside, California, has been in business since 1951. Irrometer manufactures irrigation optimization equipment including soil moisture sensors and control devices, soil solution access tubes for nutrition management, and pressure gauges. Their original tensiometer type soil moisture sensing products have been on the market since 1951. The Watermark resistance type sensor was introduced in 1985.

Irrometer offers 4 different add-on control devices for soil moisture based residential and commercial landscape irrigation control. The controllers use one or more of the Watermark soil moisture sensors to interrupt the existing clock/controller schedule until the soil moisture reaches the user prescribed level. Included with the purchase of an Irrometer control system is its WaterPerfect turf and landscape irrigation scheduling and water management software. This software program aids the user in the proper scheduling of irrigation utilizing Watermark soil moisture sensors, including calculation of total run times and cycle and soak times based on site conditions.

Sensor Description and Operation

The Watermark is a solid state electrical resistance type sensor which Irrometer reports provides accurate readings from 0 to 200 centibars. This covers the entire soil moisture range required in irrigated landscapes, including heavy clay soils. The sensor is installed by placing it into a hole made with a 7/8” diameter rod to the desired sensor depth. If a larger diameter hole is made, then a “grout” of the soil and water is poured into the hole.

The sensor consists of two concentric electrodes embedded in a reference matrix material, which is surrounded by a synthetic membrane for protection against deterioration. The exterior surface is of ABS plastic and a stainless steel mesh. The internal matrix includes gypsum, which provides some buffering for the effects of salinity levels normally found in irrigated landscapes. The sensor is 7/8” in diameter by 3” long. The original Watermark (model 200) was improved in

1993 to the current model 200SS, which has improved its soil moisture response characteristics. The sensors are maintenance free and are not damaged by freezing. The reported minimum life span for a Watermark sensor is five to seven years.

Irrometer's soil moisture sensor based control devices include the WaterSwitch (WS1), Watermark Electronic Module (WEM), Battery WEM (WEM-B), and Watermark Multiple Hydrozone System (MHS). As mentioned above, all of these devices use the Watermark sensors and interrupt the common power supply to the clock/controller or interface with the controller's sensor circuit, and the WEM may be used to control individual valves. The sensor wiring is connected directly to the control module, which is connected to either the clock/controller or the valve(s). The maximum run between the sensor and controller is 1,000 feet using 18 gauge wire. Larger wire sizes can be used for longer distances.

Controller Descriptions, Prices and Warranty

The Watermark Electronic Module is Irrometer's flagship controller. It is a versatile device that can be used in multiple connection scenarios, and in combination with the Multiple Hydrozone System as discussed below. The WEM can be used to control an individual valve, a group of valves watering areas of similar water demand, or all the valves on any clock/controller. In a typical residential application, a pair of Watermark sensors is connected to the WEM and the wiring configuration for the connection to the clock/controller provides for interruption of the power supply common connection. Alternatively, a pair of sensors and a WEM may be installed and connected to a single valve at the valve box. When a new system is being installed for a large landscape with a need for multiple sensor pairs, multiple common wires can be installed to provide for the use of multiple WEMs and sensors. For a retrofit of an existing system where multiple sensors are needed, a Multiple Hydrozone System device should be used rather than installing the needed additional common wiring.

The WEM's cabinet is constructed of heavy duty plastic and it can be installed indoors or outdoors. It may be installed at the controller or at the valve. The WEM's dimensions are 3" x 2" x 1.5". The WEM is adjustable from 10 to 120 centibars by a simple dial that has an OFF position to allow for overriding the sensors. The WEM's indicator light comes on when the clock/controller is powering a valve controlled by the WEM, and the soil moisture conditions are drier than the selected setting indicating irrigation is allowed. It is powered by a 24 VAC supply from the clock/controller.

The WaterSwitch and the Battery WEM are designed for use with clock/controllers that possess switch terminals (rain, master valve, etc.). This provides for a simple wiring configuration and easy installation. Both function similar to the WEM and possess the same features.The WaterSwitch is constructed of heavy duty plastic and is suitable for indoor or outdoor installation. Its cabinet dimensions are 2” x 2” x 1.25” which make it small enough to mount inside many controller cabinets. The WaterSwitch is powered by the 24 VAC supply from the clock/controller.

The Battery WEM is designed for use with a DC powered clock/ controller. It is constructed of heavy duty plastic and is suitable for outdoor installation. Its cabinet dimensions are 2.5” x 1.5” x 2”. The Battery WEM is powered by a 9-volt battery housed inside its waterproof battery compartment.

The Multiple Hydrozone System device functions with multiple WEMs and is designed for commercial applications where numerous sensor pairs are used, or retrofit of an existing system with a need for more than one sensor pair. The MHS can control valves for up to 8 separate moisture sensing areas. Each area is monitored using a WEM and Watermark sensors allowing for individual adjustment of the soil moisture threshold and a manual override feature is included. This device communicates with the clock/controller such that individual valves or groups of valves can be controlled without the need for multiple power supply common connections.

The MHS is constructed of heavy duty plastic and is suitable for indoor installation. A weatherproof stainless steel cabinet (shown in photograph) is available for outdoor installations. Its dimensions are 11” x 16” x 2” and the outdoor cabinet dimensions are 18” x 18” x 7”. The MHS is powered by a 24 VAC supply from the clock/controller.

Current retail prices for Irrometer soil moisture sensor based irrigation control products are summarized in Table 18. Irrometer products are available through irrigation equipment distributors, some

of which are listed at its website (www.irrometer.com). Irrometer provides a one year warranty with its soil moisture sensor control systems.

Table 18 - Irrometer Products Retail Prices

Description	Model No.	Price
WaterSwitch Add-on Controller	WS1	$100*
WEM Add-on Controller	WEM	$200**
Battery WEM Add-on Controller	WEM-B	$250**
MHS Device	MHS-_-_	$655 and up
MHS Stainless Steel Cabinet	-CM	$870
Watermark Soil Moisture Sensor	200SS-5	$31

* Price includes one Watermark soil moisture sensor
** Price includes two Watermark soil moisture sensors

Installation

Irrometer recommends professional installation, but it reports a typical residential system can be installed by some homeowners in approximately 2 to 4 hours.

Track Record and Water Savings

Irrometer's Watermark sensors have been used in soil science research by universities, as well as in production agriculture and landscape applications, worldwide for over 15 years. Their use in landscape applications has been documented for the longest period of time by a study that originated in 1993 for the city of Boulder, Colorado. The consulting firm conducting the study, Aquacraft, Inc., published numerous papers from 1995 to 2001 for the Irrigation Association, the American Society of Agricultural Engineers, the American Water Resources Journal and the American Water Works Association. The graph shown in Figure 14 is from one of these papers and the following is an excerpt from one of the papers:

"The results of this study were quite encouraging from the standpoint of both irrigation efficiency and cost effectiveness. On a seasonal basis, the systems limited applications to an average of 76% of theoretical requirement when all sites are combined."

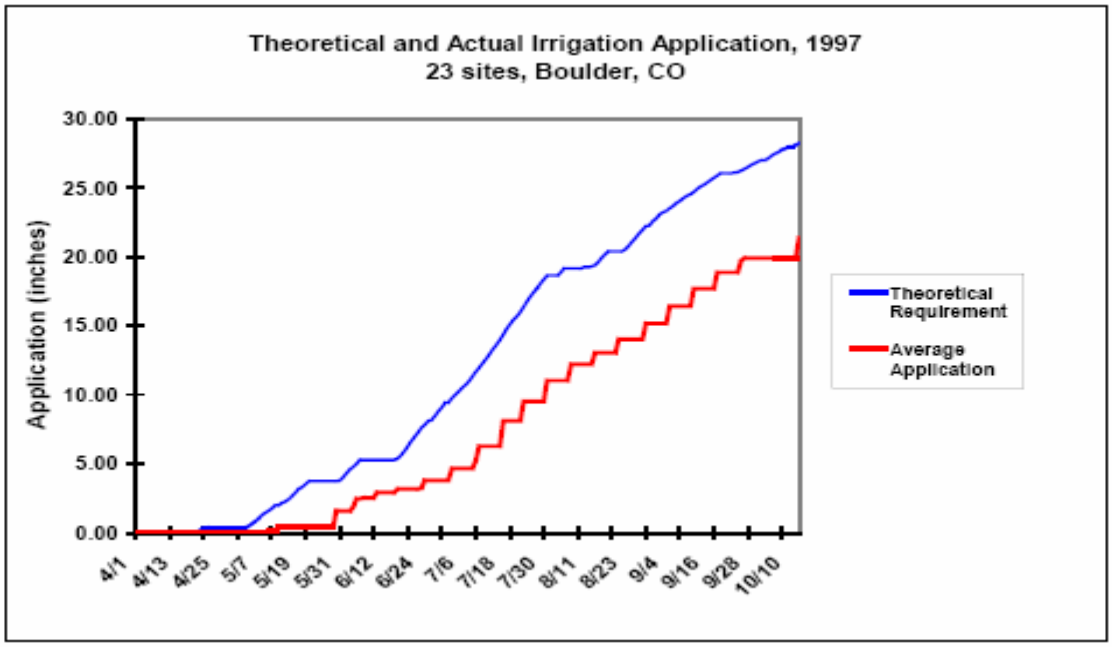


Figure 14 - Watermark performance compared to turf water requirement

Irrometer's Watermark control products have also received the *Smart Approved WaterMark* designation**,** Australia's water saving labeling program for products to reduce outdoor water use.

LawnLogic

LawnLogic® products are manufactured by Alpine Automation, Inc., of Aurora, Colorado. The company began business in 1997 as a soil moisture based irrigation systems supplier. Research and product commercialization began on the LawnLogic system in 2003 and it was introduced in the spring of 2004. In June 2006, it was reported that over 400 LawnLogic systems were in place, many of which were operating in their third irrigation season.

The LawnLogic system works with any clock/ controller to independently control individual irrigation zones. Each system consists of one or more control modules and four soil moisture sensors per module. The system is compatible with any combination of sub-surface, pop-up and rotary irrigation system designs.

Sensor Description and Operation

The LawnLogic soil moisture sensor is an electrical conductivity type sensor. It measures the current and resistance between two non-corrosive stainless steel probes that are 3” long and 3” apart from each other. The sensor body is 1/2” wide. Sensor readings are calibrated to volumetric soil moisture content. The probes are embedded in an impact resistant plastic housing and the wiring and electronics are encased in electrical potting epoxy. The sensors are installed by pushing the probes into relatively undisturbed soil in the wall of a shallow trench and connecting the sensor wiring to the appropriate valve solenoid connectors within the valve box.

The sensors communicate with the control module via the valve wiring and clock controller. When a sensor determines the moisture level is at or above the user-defined set point the system does not allow an irrigation cycle. When moisture levels drop below the user adjustable setting, irrigation cycles are allowed. The control module wiring is connected to the existing clock/timer and the sensor wiring is connected to the valve for each respective zone. The user must program a base schedule into the clock controller, and LawnLogic does not provide information on calculation of total run times and cycle/soak times.

Controller Description, Prices and Warranty

The LawnLogic controller module (model No. LL-1004) connects to any existing 24 VAC clock type controller. The instrument operates with exclusive Alpine Automation developed MLD (Mixed Logic-Dynamic) and MCC (Measurement and Control) software. The LawnLogic system automatically tailors a moisture profile for each zone when the appropriate zone button is held down. For example, the switch marked “2” controls irrigation zone 2 and when the switch is held down for 5 seconds, the LCD displays the message “READING ZONE 2”. The LawnLogic sensor buried in zone 2 measures the amount of soil moisture present. The message “CALIBRATING 2” then appears on the screen. The system is then operational and the user can increase or decrease the soil moisture threshold in each zone by four levels. If no sensor is present in the zone the message “NO SENSOR 2” appears.

Each module has a one-line,16 character backlit LCD display which displays auto-prompt information for installation and programming. Zone selection, bypass and moisture adjustment controls are two position rocker switches. The module is rated for use with solenoid valves holding 0.5 ampere circuit capacity

maximum. Power to the control module is typically from the existing clock/controller, but an external transformer may be used. Surge suppression is integrated into the measurement and control circuitry.

Each irrigation zone can be bypassed independently, which allows the clock/controller to operate without the benefit of the LawnLogic system. All settings are stored in non-volatile memory and no battery backup is required in the case of a power outage. Soil moisture status is updated every 15 minutes and the real time status of each zone is displayed 24/7.

The module enclosure is constructed of heavy duty plastic. Its dimensions are 5” x 3.2” x 2.5”. It is designed for indoor installation, but an optional locking outdoor plastic cabinet is available for mounting outdoors. Up to four modules can be installed in the outdoor cabinet. The dimensions of the outdoor cabinet are 12” x 12” x 4”. Up to 6 modules can be combined to control up to 24 zones, and up to 32 zones can be accommodated for custom projects.

Current retail prices for LawnLogic systems are summarized in Table 19. Prices include the control module and all sensors. LawnLogic products are available through its distributors, which are listed at its website (www.lawnlogic.com). Alpine Automation provides a one year warranty with its LawnLogic soil moisture sensor control systems.

Table 19 - LawnLogic Current Retail Prices

Description	Model No.	Price*
4-Station Add-on Controller System	LL-1004	$379.95
8-Station Add-on Controller System	LL-1008	$749.00
12-Station Add-on Controller System	LL-1012	$1,099.00
16-Station Add-on Controller System	LL-1016	$1,449.00
20-Station Add-on Controller System	LL-1020	$1,799.00
24-Station Add-on Controller System	LL-1024	$2,149.00

* Prices include soil moisture sensors to compliment the number of zones

Installation

Alpine Automation recommends installation of large systems by an irrigation professional, however, it reports most homeowners can install a small system. The reported first-time installation time for a small system is estimated to be 1 hour, depending on site specific conditions. The company can make arrangements for professional installation through its distributor/dealer network.

Track Record and Water Savings

Based on performance and warranty tracking, Alpine Automation reports successful overall performance of LawnLogic systems and negligible problems.

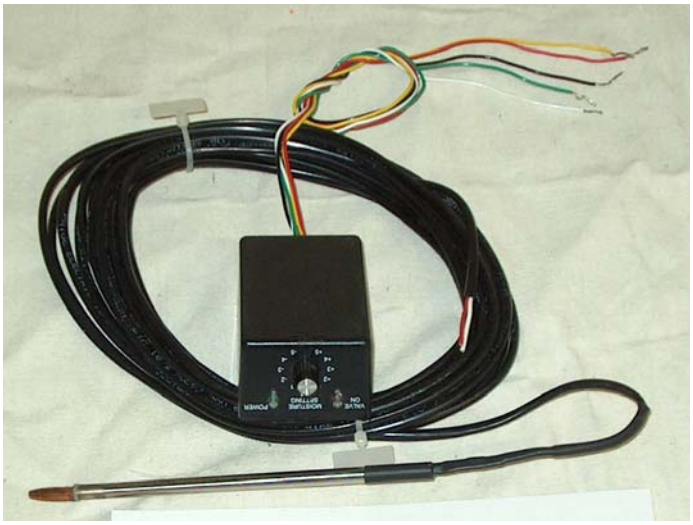
LawnLogic was included in the University of Florida County Extension Madera home project study of soil moisture sensor based irrigation control. Study results

submitted for this report showed a 44 percent average water savings during April to October 2005 for a single study site.

Alpine Automation reports LawnLogic systems have been successfully integrated with dozens of different clock/controllers ranging from unsophisticated 25 year old controllers to state of the art systems.

LawnLogic systems are installed across North America and Australia, and are in use on a variety of landscapes. The University of Florida recently initiated a study that incorporates LawnLogic systems on St. Augustine grass. Alpine Automation is working with both standard and ET controller manufactures, and companies that produce automated fertilization systems to facilitate the integration of LawnLogic with their products.

Waternomics



Waternomics soil moisture sensor based irrigation control products are manufactured by ManyWaters, Inc. of Denver, Colorado. ManyWaters has been in business since 2001, and carries a variety of water conservation related products. Distribution of its soil moisture based landscape irrigation control systems began in 2001.

ManyWaters offers the WW1 System which is an add-on soil moisture sensor landscape controller system that functions best with any clock/controller and utilizes an electrical conductivity type soil moisture sensor. The WW1 can also be used to control individual valves with or without the use of a clock/controller.

Sensor Description and Operation

The WW1 soil moisture sensor consists of a stainless steel and plastic probe that is inserted into the root zone. The sensor measures volumetric soil moisture content based on the electrical impedance measured between the probe's two electrodes. Each sensor is calibrated at the factory to provide a consistent output when measuring media of known dielectric constant. The reported accuracy of the sensor is plus or minus 5 percent, but no information on sensitivity to salts/fertilizer was provided for this report. The overall length of the sensor is 6" and the housing diameter is 0.25". It comes with 25 feet of 4-wire cable. The sensor is installed into the root zone by pushing it into the wall of a shallow

trench, resulting in contact with relatively undisturbed soil. The sensor cable wiring may be connected to the existing valve wiring or to the add-on controller.

The WW1 System regulates water applied by continuously monitoring the soil condition at the sensor, and interrupting the clock/controller schedule or individual valve when enough water is available in the root zone. When connected to a clock/controller, the WW1 serves as a switch by overriding the common circuit to all station valves. When one or more controllers are used without a clock/controller, the controller causes irrigation to occur when the soil moisture falls below the user specified threshold and then irrigation ceases once the soil moisture content is measured to be at the threshold. This mode does not allow for prescribing irrigation days, times or soak/cycle periods.

Controller Description, Prices and Warranty

The WW1 controller comes with normally open, and separate hot or neutral outputs providing for several connection options. It may be integrated with an existing clock/controller such that one soil moisture sensor will control all stations or multiple sensors may be used to control groups of stations. The controller may be set from zero to 100 percent saturation soil moisture content in 5 percent increments.

For control of all stations using one sensor, the WW1 controller is typically installed near the clock/controller. When using multiple sensors, the controller may be installed in the individual valve box(es) or at the clock/controller.

The WW1 controller cabinet is constructed of high impact shock resistant plastic, and is rated for indoor or outdoor installation. Its dimensions are 3” x 2” x 1” with a rotating moisture level control knob and LED indicator lights. The controller’s circuitry is epoxy-encapsulated. The power supply is either from the clock/controller or from an external transformer. Approximately 6-foot of minimum 12 gauge wiring is required to connect the WW1 to the existing clock/timer.

The current retail price for the Waternomics WW1 System is $179. Waternomics products may be ordered directly from ManyWaters by contacting them at 720-529-3980. ManyWaters provides a one year warranty with their Waternomics soil moisture sensor control systems.

Installation

ManyWaters recommends installation by an irrigation professional; however, installation and programming a one sensor setup may be accomplished by some homeowners. Reported installation time for a simple residential system is less than 1 hour.

Track Record and Water Savings

Waternomics is participating in an ongoing demonstration program with the State of New Mexico which includes the installation of its soil moisture based irrigation control systems at several urban parks and school grounds. These systems are being monitored to evaluate performance and water savings, and monitoring results should be available from Many Waters during 2007.

References Cited

Addink, Sylvan and Tom W. Rodda. 2002. Residential Landscape Irrigation Study Using Aqua Conserve ET Controllers

Allen, Richard G. 1997. Demonstration of Potential for Residential Savings using a Soil Moisture Controlled Irrigation Monitor. Retrieved April 25, 2006 from the World Wide Web at http://www.kimberly.uidaho.edu/water/swm/cons96p_rp_full.pdf

Allen, Richard G, Ivan A. Walter, Ronald L. Elliot and Terry A. Howell. 2005. The ASCE Standardized Reference Evapotranspiration Equation. American Society of Civil Engineers

Cardenas-Lailhacar, Bernard, Michael K. Dukes and Grady L. Miller. 2005. Sensor-Based Control of Irrigation in Bermuda Grass. Proceedings of the 2005 American Society of Agricultural Engineers Annual International Meeting

DeOreo, William B., Paul W. Lander, Russel J. Qualls and Joshua M. Scott. Soil Moisture Sensors: Are They a Neglected Tool. Retrieved April 25, 2006 from the World Wide Web at http://www.cuwcc.org/irrigation_controllers/Soil_Moisture_Sensors_Boulder_CO_2003.pdf

Irwd.com. 2001. Residential Weather-Based Irrigation Scheduling: Evidence from the Irvine "ET Controller" Study. Retrieved July 13, 2006 from the World Wide Web at http://www.irwd.com/Conservation/FinalETRpt%5B1%5D.pdf

Irwd.com. 2004. Residential Runoff Reduction (R3) Study. Retrieved July 13, 2006 from the World Wide Web at http://www.irwd.com/Conservation/R3-Study-Revised11-5-04.pdf

Mecham, Brent Q. A Practical Guide to Using Soil Moisture Sensors to Control Landscape Irrigation. Retrieved April 25, 2006 from the World Wide Web at http://www.ncwcd.org/ims/ims_info/practi1d.pdf

Pittenger, Dennis R., David A. Shaw and William E. Richie. 2004. Evaluation of Weather-Sensing Landscape Irrigation Controllers. Retrieved August 3, 2006 from the World Wide Web at http://www.plantbiology.ucr.edu/documents/files_of_Pittenger/doc9_water_management.pdf

Weather Based Irrigation Technologies - Summary of Product Information and Features

Company Name	Accurate WeatherSet	AccuWater	Alex-Tronix	Aqua Conserve	Calsense	Cyber-Rain	ECO Research	ET Water Systems	Hunter Industries	HydroPoint WeatherTRAK
Telephone	(818) 993-1449	(512) 331-9283	(888) 224-7630	(951) 352-3891	(800) 572-8608	(818) 585-7178	(208) 562-3680	(415) 945-9383 ext. 205	(760) 591-7344	(800) 362-8774
Contact Person	Andrew Davis	Tom Watson	George Alexanian	Dan Oshaben	Rick Capitanio	Reza Pourzia	Larry Haley	Bruce Cardinal	Dave Shoup	Chris Manchuck
Website	www.weatherset.com	www.accuwater.com	www.alex-tronix.com	www.aquaconserve.com	www.calsense.com	www.cyber-rain.com	www.ecoresearch.com	www.etwater.com	www.hunterindustries.com	www.weathertrak.com
Number of Residential Model Types	2	1	1	2	0	1	1	2	1	1
Number of Commercial Model Types	1	1	1	2	1	1	1	4	1	1
Date Product(s) Entered Market	1994	2004	2005	1998	1993	2007	2005	March 2005	February 2006	1997
Method of Operation and Water Savings										
Basis for Schedule – Historical Data			●	●	●	Back-up				Back-up
Basis for Schedule – On-site Sensor(s)	●	●[1]	●	●	●[1]		●	●[1]	●	●[1]
Basis for Schedule – Remote Weather Station(s)/Sensors		●						●		●
Basis for Schedule – Weather Forecasts						●				
Weather Data Source	On-site solar and rain sensors	On-site sensors or weather station and/or public data managed by centralized server	On-site temperature sensor and solar radiation estimated based on geographic location	16 preprogrammed ET curves with on-site temperature sensor	Historic ET data, evaporative atmometer type ET sensor, weather station or CIMIS data	Weather forecasts automatically from Internet and historic weather data	On-site temperature sensor and solar radiation estimated based on geographic location	Public & ETWS weather station data managed by centralized computer server	On-site weather station with full set of sensors	Public and private weather stations managed by central computer and wireless delivery
Manufacturer Reported Water Savings (Percent)	Not Available	30	Not Available	21 to 28[2]	20 to 40[2]	36	20 to 40	20 to 50	30	16 to 58[2]
Product Features										
Stand-alone Controller or Add-on to Existing	Stand-alone	Stand-alone	Stand-alone	Stand-alone	Stand-alone	Stand-alone	Add-on	Stand-alone	Add-on	Stand-alone
Station or Zone Capacity	8-48	16-48	4-24	6-66	8-48	8-unlimited	Not Applicable	1-48	1-48	6-48
Master Valve or Pump Circuit(s)	1	1	1	1-4	2	0	Not Applicable	2	Not Applicable	1
Internal Power Transformer	Outdoor Models Only	Commercial Only	Not Applicable	Commercial Only	●			●	Not Applicable	●
Battery Powered - DC			●						Not Applicable	
Station Circuit Current Rating (Amperes)	0.75 and 1.5	0.75	5.0 (DC pulse)	1.0	1.5	1.0	Not Applicable	1.1	Not Applicable	0.375 and 0.5
Terminal Wire Size Range (Gauge)	12-20	14 and smaller	12-18	12-18	14	max 14 solid & 16 stranded	Not Applicable	12 and smaller	Not Applicable	12-20
Outdoor Installation	●	Commercial Only	●	All Comm. & 2 Res.	●		●[1]	●	●	●
On-site Rain Gauge or Sensor w/ Rain Shutoff/Delay	●	●[1]	●[1]	Incl. w/ Res, Comm Option[1]	●[1]	Planned for late 2007	●[1]	●[1]	●	●[1]
Rain Shutoff/Delay by Remote Sensor or Rain Forecast		●				●			●	●
Rainfall Irrigation Schedule Compensation	●	●			●		●	●	●	●
On-site Wind Gauge w/ High Wind Shut-off		●[1]			●[1]				●[1]	●[1]
High Wind Shut-off by Remote Sensor		●							●[1]	●[1]
On-site Temperature Sensor w/ Freeze Shut-off		●[1]	●	●		Planned for late 2007	●		●	●[1]
On-site Temperature Sensor w/ High Temp On or Off		●[1]				Planned for late 2007			●	
Freeze or High Temp Shut-off by Remote Sensor		●								●[1]
On-site Evaporative Atmometer Type "ET Sensor"					●[1]					
On-site Solar Radiation Sensor	●	●[1]			●[1]				●	
On-site Humidity Sensor		●[1]			●[1]	Planned for late 2007			●	
Flow Sensor(s) Connectivity	5 models	●		12 Models	●	Planned for late 2007		●		●[1]
Additional Sensor Terminals		●		With Adaptor[1]	●			●	●	●
Internet or Computer Interface		●			●	●		●		
Remote Control Device(s) for Controller		●[1]			●[1]			●	●[1]	●[1]
Two-way Communication between Server and Receiver		●						●	Not Applicable	Commercial Model
Station Circuit Testing	5 models	●	●		●			Planned for Late 2007	Not Applicable	●
Surge and/or Lightning Protection	5 models	●	●	Etu & ET-SP Models	●[1]	●		●	●	●
SWAT Test Performance Report Available			●		●			●	●	●
Scheduling Features										
Fully Automatic Schedule (No Base Schedule Required)		●						●	●	●
Base Irrigation Schedule Required	●		●	●	●	●	●	Optional		
User May Define Non-Irrigation Days	●	●	●	●	●	●	●	●	●	●
Operable in Manual Clock Mode	●	-[5]	●	●	●	●	●	●	●	●
Manual Operation by Station or Program	●	●	●		●	●	●	●	●	●
Variable Total Run Times	●	●	●	●	●	●		●	●	●
Irrigation Schedule Period(s)	Weekday or daily to 40 days	Unlimited Days	Week or up to 99 Day	Week or Odd/Even	7, 14, 21 or 28 Day		Not Applicable	Unlimited Days	Weekday,1-31 day, odd/even	8 Weeks,Odd/Even&Weekday
Available Start Times	10	Unlimited	4 per program	4-8	6 per manual program	4	Not Applicable	9		8 starts with 20 repeat cycles
Cycle/Soak Manual Input	●	●	●	●	●	●	Not Applicable			Optional
Cycle/Soak Periods Automatically Calculated		●					Not Applicable	●	●	●
Runs Concurrent Stations	●		●		●		Not Applicable	Planned for August 2007		●
Number of Programs	5	Unlimited	4	4	7	4	Not Applicable	Unlimited	Not Applicable	Unlimited
Percent Irrigation Adjust Feature		●	●	●	% of ET Adjust per station		Not Applicable	●	●	●
Station Distribution Uniformity/Efficiency Setting		●						●		●
Syringe Cycle or Program	●	●		●	●			●		●
New Landscape Establishment/Fertilizer Program				●	●	●	Not Applicable	●	●	
Review of Weather Information		Using Web Browser			●	●		●	●	●
Review of Irrigation or Water Use Information	●	Using Web Browser	●	●	●	●	●	●	●	●
English and Spanish Languages Display		Cell Phone Remote Only			●	●				
Product Support and Warranty										
Warranty	3 Years	1 Year	2 Years	3 Years	10 Years	1 Year	1 Year	3 Years	2 Years	3 (Res) and 5 (Comm) years
Support – On-site Service Technicians	In Southern California	●	●		●			●		●
Support – Telephone Technicians	●	●	●	●	●	●	●	●	●	●
Support – Local Distributors	In Southern California		●	●	●		●	●	●	●
Installation and Maintenance Requirements										
Professional Installation & Programming Recommended	●	●	●	Commercial Models	●			●	●	●
Ongoing Maintenance Required		Clean Sensors			Clean Sensors				Clean Sensors	
Battery Replacement Required			●	●			●	●	●	
Cost										
Suggested Retail Price	$220-$1,440	$549-$2,999	$995-$2,695	$240-$5,630	$1,290-$3,680	$295 and up	$198	$419-$2,399	$429	$449-$3,675
Annual Service Cost	0	$149 minimum	0	0	0	0	0	$40-$199	$0	$48-$225

1 - Optional add-on feature not included in controller price(s) shown
2 - Reported water savings documentation is published or publicly available
3 - Scheduling guidelines or assistance provided with purchase
4 - Complete pricing information was not available for this report
5 - Controller back-up schedule based on recent ET good for 21 days without network connectivity which can be modified by user
6 - Includes remote monitoring of irrigation operation and tracks meter usage for savings reports

Weather Based Irrigation Technologies - Summary of Product Information and Features (cont.)

Company Name	HydroSaver	Irrisoft Weather Reach	Irritrol Systems	Rain Bird	Rain Master	Toro Company	Tucor	Water2Save	Weathermatic	Weathermiser
Telephone	1-562-494-8686	(435) 755-0400	(800) 664-4740	(520) 741-6162	(805) 527-4498	(800) 664-4740	(800) 272-7472	(858) 361-9700	(972) 278-6131	(505) 235-6999
Contact Person	Tom Carr	Steven Moore	Robert Starr	Kraig Wilson	Steve Springer	Robert Starr	Larry Sarver	Gary Gelinas	Brodie Bruner	Al Caprio
Website	www.hydrosaver.net	www.irrisoft.net	www.irritrol.com	www.rainbird.com	www.rainmaster.com	www.toro.com	www.tucor.com	www.water2save.com	www.smartline.com	www.weathermiser.com
Number of Residential Model Types	0	1	1	1	0	1	0	1	2	1
Number of Commercial Model Types	1	1	1	1	1	1	1	1	1	1
Date Product(s) Entered Market	1994	2002	2005	April 2006	2002	2005	1995	1996	2004	2003
Method of Operation and Water Savings										
Basis for Schedule: Historical Data	●	Back-up		Back-up	●			Back-up		
Basis for Schedule: On-site Sensor(s)	●	●[1]	●[1]	●[1]	●[1]	●[1]	●	●[1]	●	●
Basis for Schedule: Remote Weather Station(s)/Sensors		●	●	●	●[1]	●	●	●		
Basis for Schedule: Weather Forecasts										
Weather Data Source	Historic ET data and on-site "ET sensor"	Public & private weather stations data managed by centralized computer server	Public weather stations data managed by centralized computer server	Public & private weather stations data managed by centralized computer server	Automatic, historic or manually entered ET or with optional on-site weather station	Public weather stations data managed by centralized computer server	On-site weather station	Public & patented forecasted weather data managed by their centralized computer server	On-site temperature sensor and solar radiation estimated based on geographic location	On-site temperature and humidity sensors
Manufacturer Reported Water Savings (Percent)	Not Available	20 to 50	Not Available	Not Available	25 to 40	Not Available	Not Available	28[2]	20 to 50	34 to 52
Product Features										
Stand-alone Controller or Add-on to Existing	Stand-alone	Add-on	Stand-alone	Add-on	Stand-alone	Stand-alone	Stand-alone	Add-on (up to 4 controllers)	Stand-alone	Add-on
Station or Zone Capacity	12-56	Not Applicable	6-24	Not Applicable	6-36	6-24	50-500	12-64	4-48	Not Applicable
Master Valve or Pump Circuit(s)	1	Not Applicable	1	Not Applicable	1	1	16	Not Applicable	1	Not Applicable
Internal Power Transformer	●		●		●	●				
Battery Powered - DC										
Station Circuit Current Rating (Amperes)	2.0	Not Applicable	0.5	Not Applicable	1.0	0.5	Not Reported	Not Applicable	1.5	Not Applicable
Terminal Wire Size Range (Gauge)	12-20	Not Applicable	12-18	Not Applicable	12	●	14	14-22	14-18	Not Applicable
Outdoor Installation	●	●[1]	●	●[1]	●	3 Models		●	●	●[1]
On-site Rain Gauge or Sensor w/ Rain Shutoff/Delay	●	●[1]	●[1]	●[1]	●[1]	●[1]	●	●[1]	●	
Rain Shutoff/Delay by Remote Sensor		●	●	●	●[1]			●		
Rainfall Irrigation Schedule Compensation		●	●	●	●[1]			●	●	
On-site Wind Gauge w/ High Wind Shut-off			●[1]				●			●[1]
High Wind Shut-off by Remote Sensor				●	●[1]					
On-site Temperature Sensor w/ Freeze Shut-off	●		●[1]		●[1]	●[1]	●		●	●
On-site Temperature Sensor w/ High Temp On or Off					●[1]					
Freeze or High Temp Shut-off by Remote Sensor		●		●	●[1]					
On-site Evaporative Atmometer Type "ET Sensor"										
On-site Solar Radiation Sensor	●				●[1]		●			
On-site Humidity Sensor	●				●[1]		●			●
Flow Sensor(s) Connectivity	●				●		●			
Additional Sensor Terminals					●				●	
Internet or Computer Interface							●			
Remote Control Device(s) for Controller					●[1]					
Two-way Communication between Server and Receiver					●[1]			●		
Station Circuit Testing			●		●	●				
Surge and/or Lightning Protection	●		●		●[1]	●	●[1]	●	●	
SWAT Test Performance Report Available			●	●		●			●	
Scheduling Features										
Fully Automatic Schedule (No Base Schedule Required)			●		●[1]	●	●		●	
Base Irrigation Schedule Required	●	●[3]		●[3]	●			●[3]		●
User May Define Non-Irrigation Days	●	●	●	●	●	●		●	●	
Operable in Manual Clock Mode	●	●	●	●	●	●		●	●	●
Manual Operation by Station or Program	●				●			●	●	
Variable Total Run Times			●		●	●	●	●	●	
Irrigation Schedule Period(s)	7,14 & 28 Days, Odd/Even	Not Applicable	Not Applicable	Not Applicable	7 or 30 Day	Not Applicable	14 Day	Not Applicable	Up to 31 Days & Odd/Even	Not Applicable
Available Start Times	12	Not Applicable		Not Applicable	5		12	Not Applicable		Not Applicable
Cycle/Soak Manual Input		Not Applicable		Not Applicable	●				●	Not Applicable
Cycle/Soak Periods Automatically Calculated	●	Not Applicable	●	Not Applicable	●	●		●	●	Not Applicable
Runs Concurrent Stations	3	Not Applicable		Not Applicable	●		●	●	●	Not Applicable
Number of Programs	6	Not Applicable	Up to 64 cycles	Not Applicable	4	Up to 64 cycles	30	Not Applicable	4	Not Applicable
Percent Irrigation Adjust Feature	●	Not Applicable	●	Not Applicable	●	●		●	●	Not Applicable
Station Distribution Uniformity/Efficiency Setting		Not Applicable		Not Applicable	●					Not Applicable
Syringe Cycle or Program					●					
New Landscape Establishment/Fertilizer Program										
Review of Weather Information	●	●	●	●	●	●	●	●	●	
Review of Irrigation or Water Use Information	●	●	●	●	●	●	●	●	●	
English and Spanish Languages Display	●									
Product Support and Warranty										
Warranty	3 and 5 years	5 Years	5 years	3 Year	5 Years	5 Years	3 Years	3 Years	2 Years	1 Year
Support: On-site Service Technicians	In Southern California							●		●
Support: Telephone Technicians	●	●	●	●	●	●	●	●	●	●
Support: Local Distributors		●	●	●	●	●	●	●	●	
Installation and Maintenance Requirements										
Professional Installation & Programming Recommended	●	●	●	●	Recommended	Recommended	●	Included with purchase		
Ongoing Maintenance Required					Clean Sensors		Clean Sensors	Included with service cost		
Battery Replacement Required		●	●	●		●			●	
Cost										
Suggested Retail Price	$1,800-$2,800[4]	$795	$399-$899	$741	$640-$4,264	$399-$889	$20,150-$23,750	$527-$1,598	$299.90-$816.80	$129.95-$1,295
Annual Service Cost	0	0-$350	$48-$84	0-$350	0-$180	$48-$84	0	$117-$468[6]	0	0

1 - Optional add-on feature not included in controller price(s) shown
2 - Reported water savings documentation is published or publicly available
3 - Scheduling guidelines or assistance provided with purchase
4 - Complete pricing information was not available for this report
5 - Controller back-up schedule based on recent ET good for 21 days without network connectivity which can be modified by user
6 - Includes remote monitoring of irrigation operation and tracks meter usage for savings reports

Soil Moisture Based Irrigation Technologies - Summary of Product Information and Features

Company Name	Acclima	Agrilink	Baseline	Calsense	Dynamax	Irrometer	LawnLogic	Waternomics
Telephone	(866) 887-1470	(714) 966-1975	(866) 294-5847	(951) 352-3891	(800) 896-7108	(951) 689-1701	(925) 286-6185	(760) 591-7344
Contact Person	Kingsley Horton	Drew Gordon	Jon Peters	Rick Capitanio	Gary Woods	Tom Penning	Michael McLaughlin	Dean Cramer
Web Page	www.acclima.com	www.agrilink.net	www.baselinesystems.com	www.calsense.com	www.dynamax.com	www.irrometer.com	www.lawnlogic.com	
Number of Residential Model Types	5	1	2	0	1	1	1	1
Number of Commercial Model Types	3	1	2	1	2	3	1	1
Date Product(s) Entered Market	2003	2006	2002	1986	2006	1985	2004	2001
Method of Operation and Water Savings								
Interrupts Operation of All Stations	●	●	●		●	Residential Models		●
Interrupts Operation of Individual or Groups of Stations	●	Requires Multiple Controllers	●	●	Requires Multiple Controllers	Commercial Models	●	Requires Multiple Controllers
Manufacturer Reported Water Savings	30 to 40[1]	20-50	30 to 50	20 to 40[1]	Not Available	24[1]	44 (one site only)	Not Available
Product Features								
Stand-alone Controller or Add-on to Existing	Both	Add-on	Both	Stand-alone	Both	Add-on	Add-on	Add-on
Type of Soil Moisture Sensor(s)	Digital Time Domain Transmission	Frequency Domain Reflectometry	Time Domain Transmission	Tensiometer	Frequency Domain Reflectometry	Electrical Resistance	Electrical Conductivity	Electrical Conductivity
Multiple Soil Moisture Sensors May Be Used	●	Requires Multiple Controllers	Commercial Models	●	Requires Multiple Controllers	Commercial Models	Multiple Sensors Required	Requires Multiple Controllers
Soil Moisture Sensor Capacity	1-36	1per Controller	6 & 25	48	1 or 2	1 to 8	1-32	1
Sensor(s) or Controller Connects to Existing Valve Wiring	●	●	●	●		Commercial Models	●	●
Number of Soil Moisture Settings	1,000	Unlimited	Unlimited	Unlimited	51 and 0-60%	4, 9 and 11	9	20
Measures and Adjusts for Soil Conductivity	●			●				
Controller Displays Soil Conductivity	●							
Measures and Adjusts for Soil Temperature	●	●	●					
Controller Displays Soil Temperature	●		Commercial Models					
Controller Station Capacity	6,12, 24, 36 & 64	Unlimited	16-200	8-48	Unlimited	Unlimited	1-32	Unlimited
Master Valve or Pump Circuit(s)	Commercial Models	Not Applicable	Commercial Models	2		Not Applicable	Not Applicable	Not Applicable
Internal Power Transformer	Commercial Models		Commercial Models	●			●[2]	
Battery Powered - DC	Commercial Models	●			Option Available	1 Model		
Station Circuit Current Rating (Amperes)	0.7	Not Applicable	Not Reported	1.5	3 & 10	Not Applicable	Not Applicable	Not Applicable
Outdoor Installation	●	●[2]	●[2]	●	●[2]	All Models, Commercial option	●[2]	
Rain Gauge or Sensor Compatible w/ Rain Shutoff/Delay	●		●	●				
Flow Sensor Compatible	Commercial Models		Commercial Models	●	●			
Additional Sensor Terminals	●		Commercial Models	●	●			
Remote Control Device for Controller	Commercial Models[2]		Commercial Models	●[3]	●			
System Testing and Diagnostics	●		●	●				
Surge and/or Lightning Protection	●		●	●[3]			●	
Scheduling Features								
Fully Automatic Schedule (No Base Schedule Required)	Commercial Models		Commercial Models		Commercial Models			
Variable Total Run Times	●		Commercial Models	●	Commercial Models		●	
User May Define Non-Irrigation Days	●	Not Applicable	Commercial Models	●		Not Applicable	Not Applicable	Not Applicable
Operable in Manual Clock Mode	●	Not Applicable	●	●		Not Applicable	Not Applicable	Not Applicable
Manual Operation by Station or Program	●	Not Applicable	Commercial Models	●		Not Applicable	Not Applicable	Not Applicable
Irrigation Schedule Period(s)	Odd/Even, Nth Day & Custom	Not Applicable	All options available	7, 14, 21 or 28 day		Not Applicable	Not Applicable	Not Applicable
Cycle/Soak Manual Input	●	Not Applicable	●	●		Not Applicable	Not Applicable	Not Applicable
Cycle/Soak Periods Automatically Calculated		Not Applicable				Not Applicable	Not Applicable	Not Applicable
Available Start Times	Up to 6 or On Demand	Not Applicable	8	6		Not Applicable	Not Applicable	Not Applicable
Irrigation Pause/Resume	●	Not Applicable	Commercial Models	●		Not Applicable	Not Applicable	Not Applicable
Runs Concurrent Stations	●	Not Applicable	Commercial Models	●	●	Not Applicable	Not Applicable	Not Applicable
Number of Programs	Up to 40	Not Applicable	Up to 10	7	2	Not Applicable	Not Applicable	Not Applicable
Syringe Cycle or Program	●	Not Applicable	Commercial Models	●		Not Applicable	Not Applicable	Not Applicable
Review of Recent Irrigation Information	●		Commercial Models	●				
English and Spanish Languages Display	Commercial Models	Universal Display		●				
Product Support and Warranty								
Warranty	2 Years	2 Years	1 and 3 (sensor only) Years	10 Years	1 Year	1 Year	1 Year	1 Year
Support: On-site Service Technicians	Some Locations			●	Some Locations			
Support: Telephone or Internet Technicians	●	●	●	●	●	●	●	●
Support: Local Distributors	●	Some Locations		●	Some Locations	●	●	
Installation and Maintenance Requirements								
Professional Installation & Programming Recommended	Commercial Models	●	Commercial Models	●	Commercial Models	Commercial Models	Commercial Models	●
Battery Replacement Required	5 to 10 years				Optional			
Cost								
Suggested Retail Prices[3]	$265-$3,078	$139	$149-$10,120	$999-$3,760	$425-$1,242	$100-$3,040	$379.95-$2,149	$199

1 - Reported water savings documentation is published or publicly available
2 - Optional add-on feature not included in controller price(s) shown

For copies of this report contact
Reclamation's Southern California Area Office at 951-695-5310
or download at http://www.usbr.gov/waterconservation/docs/SmartController.pdf