Evaluation of ET Based “Smart” Controllers

Charles Swanson, Extension Program Specialist-Landscape Irrigation
Texas Agrilife Extension Service-Biological & Agricultural Engineering Unit
2117 TAMU
College Station, Texas 77843-2117.

Guy Fipps, Professor & Extension Agricultural Engineer
Director, Irrigation Technology Center, Texas A&M System
Texas Agrilife Extension Service-Biological & Agricultural Engineering Unit
2117 TAMU
College Station, Texas 77843-2117.

Abstract. *A smart controller testing facility was established by the Irrigation Technology Center at Texas A&M University in College Station in 2008. The objectives were to (1) evaluate smart controller testing methodology and to (2) determine their performance and reliability under Texas conditions from an “end-user” point of view. The “end-user” is considered to be the landscape or irrigation professional (such as the Licensed Irrigator in Texas) installing the controller. This report summaries the performance of eight smart controllers over an eight month (238 day) growing season in 2010. Controllers were programmed based on a virtual landscape that evaluated controller performance using multiple plant types (flowers, turf, groundcover, small and large shrubs), soil types (sand, loam and clay), root zone depths (3 to 20 inches) and other site specific characteristics. Controllers were divided into 2 categories, those which utilize on-site sensors to calculate or adjust ET or runtimes; and those which ET values are sent via cellular, radio or the internet. Controller performance was compared to total ETo, plant water requirement (ETc) and the weekly irrigation recommendation of the TexasET Network (http://TexasET.tamu.edu). Results so far indicate that controllers using on-site sensors for calculating irrigation water requirements produced lower water requirements and were more often within the irrigation recommendations of the TexasET Network. Significant seasonal differences in controller performance were also found. Results also indicate problems in quantifying effective rainfall, particularly when using a rain sensor. Continued evaluation of ET based controllers is needed to identify the causes of inconsistency among controllers.*

Keywords. *Landscape Irrigation, Irrigation Scheduling, Smart Controllers, Evapotranspiration, Water Conservation*

INTRODUCTION

The term smart irrigation controller is commonly used to refer to various types of controllers that have the capability to calculate and implement irrigation schedules automatically and without human intervention. Ideally, smart controllers are designed to use site specific information to produce irrigation schedules that closely match the day-to-day water use of plants and landscapes. In recent years, manufacturers have introduced a new generation of smart controllers which are being promoted for use in both residential and commercial landscape applications.

However, many questions exist about the performance, dependability and water savings benefits of smart controllers. Of particular concern in Texas is the complication imposed by rainfall. Average rainfall in the State varies from 56 inches in the southeast to less than eight inches in the western desert. In much of the State, significant rainfall commonly occurs during the primary landscape irrigation seasons. Some Texas cities and water purveyors are now mandating smart controllers. If these controllers are to become requirements across the state, then it is important that they be evaluated formally under Texas conditions.

CLASSIFICATION OF SMART CONTROLLERS

Smart controllers may be defined as irrigation system controllers that determine runtimes for individual stations (or “hydrozones”) based on historic or real-time ETo and/or additional site specific data. We classify smart controllers into four (4) types (see Table 1): Historic ET, Sensor-based, ET, and Central Control.

Many controllers use ETo (potential evapotranspiration) as a basis for computing irrigation schedules in combination with a root-zone water balance. Various methods, climatic data and site factors are used to calculate this water balance. The parameters most commonly used include:

- ET (actual plant evapotranspiration)
- Rainfall
- Site properties (soil texture, root zone depth, water holding capacity)
- MAD (managed allowable depletion)

The IA SWAT committee has proposed an equation for calculating this water balance (SWAT 2011).

Table 1. Classification of smart controllers by the method used to determine plant water requirements in the calculation of runtimes.

Historic ET	Uses historical ET data from data stored in the controller
Sensor-Based	Uses one or more sensors (usually temperature and/or solar radiation) to adjust or to calculate ETo using an approximate method
ET	Real-time ETo (usually determined using a form of the Penman equation) is transmitted to the controller daily. Alternatively, the runtimes are calculated centrally based on ETo and then transmitted to the controller.
On-Site Weather Station (Central Control)	A controller or a computer which is connected to an on-site weather station equipped with sensors that record temperature, relative humidity (or dew point temperature) wind speed and solar radiation for use in calculating ETo with a form of the Penman equation.

MATERIALS AND METHODS

Testing Equipment and Procedures

Two smart controller testing facilities have been established by the ITC at Texas A&M University in College Station: an indoor lab for testing ET-type controllers and an outdoor lab for sensor-based controllers. Basically, the controllers are connected to a data logger which records the start and stop times for each irrigation event and station (or hydrozone). This information is transferred to a database and used to determine total runtime and irrigation volume for each irrigation event.

Smart Controllers

Eight (8) controllers were provided by manufacturers for the Year 2010 evaluations (Table 2). Each controller was assigned an ID for reporting purposes. Table 2 lists each controller's classification, communication method and on-site sensors, as applicable. The controllers were grouped by type for testing purposes. The ET controllers (A & B) were tested indoors, and the sensor-based controllers C-H were tested outdoors.

Table 2. The controller name, type, communication method, and sensors attached of the controllers evaluated in this study. All controllers were connected to a rain shut off device unless equipped with a rain gauge.

Controller ID	Controller Name	Type	Communication Method	Sensors
A	ET Water	ET	Pager	None
B	Rainbird ET Manager	ET	Pager	Tipping Bucket Rain Gauge
C	Accurate WeatherSet	Sensor Based	None	Pyranometer
D	Weathermatic Smartline	Sensor Based	None	Temperature
E	Hunter ET System	Sensor Based	None	Tipping Bucket Rain Gauge, Pyranometer, Temperature/ RH
F	Hunter Solar Sync	Sensor Based	None	Pyranometer
G	Rainbird ESP SMT	Sensor Based	None	Tipping Bucket Rain Gauge, Temperature
H	Toro Intellisense	ET	Pager	None

Definition of Stations (Zones) for Testing

Each controller was assigned six stations, each station representing a virtual landscaped zone (Table 3). These zones are designed to represent the range in site conditions commonly found in Texas, and provide a range in soil conditions designed to evaluate controller performance in shallow and deep root zones (and low/high water holding capacities). Since we do not recommend that schedules be adjusted for the DU (distribution uniformity), the efficiency was set to 100% if allowed by the controller.

Programing the smart controllers according to these virtual landscapes proved to be problematical; as only 2 controllers had programming options to set all the parameters defining the virtual landscape (see Table 4). In addition, it was impossible to see the actual values that two controllers used for each parameter or to determine how closely these followed the values of the virtual landscape.

One example of programming difficulty was entering root zone depth. Only five of the 8 controllers in the study allowed the user to enter the root zone depth (soil depth). Another example is entering landscapes plant information. Three of the controllers did not provide the user the ability to see and adjust the actual coefficient (0.6, 0.8, etc) that corresponds to the selected plant material (i.e., fescue, cool season grass, etc.).

Thus, we programmed the controllers to match the virtual landscape as closely as was possible. Manufacturers were given the opportunity to review the programming, which two did. Four of the remaining manufacturers provided to us written recommendations/instructions for station programming, and one manufacturer trusted our judgment in controller programming.

Table 3. The Virtual Landscape which is representative of conditions commonly found in Texas.

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Plant Type	Flowers	Turf	Turf	Groundcover	Small Shrubs	Large Shrubs
Plant Coefficient (Kc)	0.8	0.6	0.6	0.5	0.5	0.3
Root Zone Depth (in)	3	4	4	6	12	20
Soil Type	Sand	Loam	Clay	Sand	Loam	Clay
MAD (%)	50	50	50	50	50	50
Adjustment Factor (Af)	1.0	0.8	0.6	0.5	0.7	0.5
Precipitation Rate (in/hr)	0.2	0.85	1.40	0.5	0.35	1.25
Slope (%)	0-1	0-1	0-1	0-1	0-1	0-1

Table 4. The parameters which the end user could set in each controller DIRECTLY identified by the letter "x."

Controller	Soil Type	Root Zone Depth	MAD	Plant Type	Adjustment Factor	Precipitation Rate	Zip Code or Location	Runtime
A	X	X	X	X		X	X	
B[1]	-	-	-	X	X	-	X	X
C				X				X
D	X			X	X	X	X	
E	X			X	X	X		
F[2]							X	X
G	X	X		X	X	X		
H	X	X	X	X	X	X	X	

[1] Irrigation amount was set in controller based on runtime using soil type, root zone depth, MAD and precipitation rate.

[2] Controller was programmed for runtime and frequency at peak water demand (July).

Testing Period

The controllers were set up and allowed to run for a 34 week (238 day) period from March 29 to November 22, 2010. Due to the length of the study, controller performance was reported over the entire testing period and on a seasonal basis as well. For the purposes of this study, seasons were defined as follows:

- Spring-March 29 to May 30 (62 Days),
- Summer-May 31 to August 30 (92 Days),
- Fall-August 31-November 22 (84 Days).

ETo and Recommended Irrigation

ETo was computed from weather parameters measured at the Texas A&M University Golf Course in College Station, TX which is a part of the TexasET Network (http://TexasET.tamu.edu). The weather parameters were measured with a standard agricultural weather station which records temperature, solar radiation, wind and relative humidity. ETo was computed using the standardized Penman-Monteith method. During the evaluation period, the total ETo was 41.5 inches with a total of about 18 inches of rainfall (see Table 8).

TexasET and the Plant Water Requirement Calculator

In this report, smart controller irrigation volumes are compared to the recommendations of the TexasET Network and Website generated using the Landscape Plant Water Requirement Calculator (http://TexasET.tamu.edu) based on a weekly water balance. This is the method that is used in the weekly irrigation recommendations generated by TexasET for users that sign-up for automatic emails. The calculation uses the standard equation:

$$ETc = (ETo \times Kc \times Af) - Re \qquad \text{(Equation 1)}$$

where:

- ETc = irrigation requirement
- ETo = reference evapotranspiration
- Kc = crop coefficient
- Af = adjustment factor
- Re = effective rainfall

Recommended Kc for warm season turf is 0.6 and cool season 0.8. Due to the lack of scientifically derived crop coefficients for most landscape plants, we suggest that users classify plants into one of three categories based on their need for or ability to survive with frequent watering, occasional watering and natural rainfall. Suggested crop coefficients for each are shown in Table 5.

In addition to a Plant Coefficient, users have the option of applying an Adjustment Factor. This can be used to adjust the crop coefficient for various site specific factors such as microclimates, allowable stress, or desired plant quality. For most home sites, a Normal Adjustment Factor (0.6) is recommended in order to promote water conservation, while an adjustment factor of 1.0 is recommended for sports athletic turf. Table 6 gives the adjustment factor in terms of a plant quality factor.

A weekly irrigation recommendation was produced using equation (1) following the methodology discussed above. The Af used in this year’s are shown in Table 3. Effective rainfall was calculated using the relationships shown in Table 7.

Table 5. Landscape Plant Water Requirements Calculator Coefficients		
Plant Coefficients		Example Plant Types
Warm Season Turf	0.6	Bermuda, St Augustine, Buffalo, Zoysia, etc.
Cool Season Turf	0.8	Fescue, Rye, etc.
Frequent Watering	0.8	Annual Flowers
Occasional Watering	0.5	Perennial Flowers, Groundcover, Tender Woody Shrubs and Vines
Natural Rainfall	0.3	Tough Woody Shrubs and Vines and non-fruit Trees

Table 6. Adjustment Factors in terms of “Plant Quality Factors.”	
Maximum	1.0
High	0.8
Normal	0.6
Low	0.5
Minimum	0.4

Table 7. TexasET Effective Rainfall Calculator	
Rainfall Increment	**% Effective**
0.0" to 0.1"	0%
0.1" to 1.0"	100%
1.0" to 2.0"	67%
Greater than 2"	0%

RESULTS AND DISCUSSION

Results from the Year 2010 evaluations are summarized in Table 8 which shows the total irrigation volumes for each controller and station (zone). In Tables 9, 10 and 11, irrigation volumes are listed per season. Table 12 shows total irrigation volume over the entire study year in inches and as a percentage of ETo and ETc.

When looking at total irrigation amounts over the entire evaluation period:

- One (1) controller had five stations that were within +/- 20% of the recommendations of the TexasET Network
- One (1) controller had four stations within +/- 20% of the recommendations of the TexasET Network
- One (1) controller did not produce any stations within +/- 20% of the recommendations of the TexasET Network

Controller performance during the Spring evaluation period (March 29-May 30, 62 days) was generally poor.

- Two (2) controllers produced irrigation volumes in excess of ETc
- One (1) controller had irrigation volumes in excess of ETo.
- In total, 54% of the stations had excessive runtimes for the period even though 4.27 inches of rainfall fell, eliminating the need for irrigation for most stations for four of the nine weeks.

Performance during the Summer evaluation period (May 31-August 30, 92 days) showed an improvement.

- One (1) controller had 5 stations within +/- 20% the irrigation recommendations of TexasET.
- Two (2) controllers produced irrigation runtimes in excess of ETc, including one which irrigated in excess of ETo.
- Over nine inches of rainfall fell during this time frame meaning no controllers should have irrigated in excess of ETc.

Controller performance during the Fall evaluation period (August 31-November 22, 84 days) was poor.

- Four controllers produced station runtimes in excess of ETc, including one station in excess of ETo.
- One (1) controller had 4 stations within +/- 20% the irrigation recommendations of TexasET.
- For this time frame, 67% (32 out of 48) of the stations irrigation amounts were between the recommendations of the TexasET Network and that of calculated ETc (excluding rainfall).

Table 8. Total irrigation volumes over the entire testing period: Mar 29 - Nov 22, 2010. Also shown are the total ETo and Rainfall recorded during the evaluation period.

	Station 1	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
Plant Type	Flowers	Turf	Turf	Groundcover	Small Shrubs	Large Shrubs
A	26.93	20.83	14.37	12.48	13.13	9.17
B	35.48	19.61	14.43	10.31	10.92	0
C	16.59	18.37	14.88	5.6	8.97	5.8
D	16.96	7.87	6.26	3.84	5.31	2.9
E	14.07	7.22	4.82	4.07	4.91	1.66
F	20.93	12.69	9.82	6.3	3.58	3
G	27.4	15.8	8.58	5.32	8.04	0
H	46.1	16.29	11.78	7.34	12.47	5.04
TexasET Recommendation	23.61	13.47	9.67	6.33	9.40	3.64
ETc (ETo x Kc)[1]	33.22	24.92	24.92	20.77	20.77	12.46
ETo[2]	41.53					
Rainfall	17.98					

[1] Rainfall is not included in calculation

[2] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Golf Course, College Station, Texas.

Shading denotes values within +/- 20% of TexasET Recommendation

Table 9. Spring irrigation volumes, Mar 29 - May 30, 2010 (62 Days)

Controller ID	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	6.30	6.55	4.10	3.03	3.68	2.50
B	10.0	5.46	4.04	2.89	3.19	0
C	5.93	6.52	5.22	1.72	2.72	1.73
D	4.87	2.25	1.79	0.75	1.52	0.72
E	4.96	2.76	2.20	1.53	1.87	1.12
F	6.61	3.91	3.03	1.80	0.72	0.70
G	7.82	4.15	1.99	1.29	1.47	0
H	12.32	4.64	3.28	2.15	3.62	1.45
Total ETo[1]	11.10					
Total Rainfall[2]	4.27					
TexasET Recommendation	6.14	3.30	2.23	1.31	1.93	0.75
Total ETc[3]	8.88	6.66	6.66	5.55	5.55	3.33

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Golf Course, College Station, Texas.

[2] Total Rainfall collected from TexasET Network Weather Station "TAMU Golf Course"

[3] Rainfall not included in this calculation

Shading denotes values within +/- 20% of TexasET Recommendation

Table 10. Summer irrigation volumes, May 31 - Aug 30, 2010 (92 Days)

Controller ID	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	13.14	10.11	7.28	6.33	6.30	4.17
B	15.90	8.96	6.64	4.74	4.55	0
C	3.35	3.15	2.57	1.15	1.83	1.17
D	4.17	1.70	1.35	0.94	1.15	0.73
E	2.45	1.72	0.76	0.83	1.20	0
F	3.80	2.08	1.66	1.18	0.27	0.13
G	10.66	6.59	3.44	2.32	4.19	0
H	20.87	6.82	4.97	3.01	5.20	2.13
Total ETo[1]	19.18					
Total Rainfall[2]	9.12					
TexasET Recommendation	11.57	6.63	4.78	3.17	4.64	1.78
Total ETc[3]	15.34	11.51	11.51	9.59	9.59	5.75

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Golf Course, College Station, Texas.

[2] Total Rainfall collected from TexasET Network Weather Station "TAMU Golf Course"

[3] Rainfall not included in this calculation

Shading denotes values within +/- 20% of TexasET Recommendation

Table 11. Fall irrigation volumes, Aug 31 - Nov 22, 2010 (84 Days)

Controller ID	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	7.49	4.17	2.99	3.12	3.15	2.50
B	9.58	5.19	3.75	2.68	3.18	0
C	7.31	8.70	7.09	2.73	4.42	2.90
D	7.92	3.92	3.12	2.15	2.64	1.45
E	6.66	2.74	1.86	1.71	1.84	0.54
F	10.52	6.70	5.13	3.32	2.59	2.17
G	8.92	5.06	3.15	1.71	2.38	0
H	12.91	4.83	3.53	2.18	3.65	1.46
Total ETo[1]	11.25					
Total Rainfall[2]	4.59					
TexasET Recommendation	5.90	3.54	2.66	1.85	2.83	1.11
Total ETc[3]	9.00	6.75	6.75	5.63	5.63	3.38

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Golf Course, College Station, Texas.

[2] Total Rainfall collected from TexasET Network Weather Station "TAMU Golf Course"

[3] Rainfall not included in this calculation

Shading denotes values within +/- 20% of TexasET Recommendation

Table 12. Comparison of total volumes (inches) of each controller to plant water requirements and Eto over the entire evaluation period.

Total	A	B	C	D	E	F	G	H
Irrigation Applied, in	96.91	90.75	70.21	43.14	36.75	56.32	65.14	99.02
% ETc	71%	66%	51%	31%	27%	41%	48%	72%
% ETo	39%	37%	28%	17%	15%	23%	26%	40%
TexasET Rec.	66.12							
ETc (ETo x Kc)[1]	137.06							
ETo	249.18							
Rainfall	17.98							

[1] effective rainfall not subtracted

CONCLUSIONS AND FUTURE PLANS

Over the past five years since we started our "end-user" evaluation of smart controllers, we have seen improvement in their performance. The communication and software failures that were evident in our field surveys conducted in San Antonio in 2006 (Fipps, 2008) are no longer a problem. In the past four years of bench tesiting, we have seen some reduction in excessive irrigation charactaristic of a few controllers.

Our emphais continues to be an "end-user" evaluation, how controllers preform as installed in the field. The "end-user" is defined as the landscape or irrigation contractor (such as a licensed irrigator in Texas) who installs and programs the controller.

Although the general performance of the controllers has gradually increased over the last four years, we continue to oberserve controllers irrigating in excess of ETc. Since ETc is defined as the reference plant evapotranspiration (ETo) times a plant coefficient, this should be the greatest amount of water a plant should need over any time frame if no rainfall occurs. However three controllers consistently irrigated in excess of ETc even though over 17 inches of rainfall fell during this typical irrigation season.

The factors that could cause this over irrigation are improper ETo calculation/aquisition and insufficient accounting for rainfall. Of the eight (8) smart controllers in the study, three (3) were equiped with "tipping-bucket" type rain gauges which actually measure rainfall, while the other five (5) controllers were equiped with rainfall shutoff sensors as required by Texas law. Rainfall shutoff sensors only detected the presense of rainfall and interrup the irrigation event. Of the three controllers which used "tipping-bucket" gauges, two were consitently among the top 3 performing smart controllers, especially during the summer period when the greatest amount of rainfall occured.

Generally, controllers with on-site sensors, performed better and more often irrigated closer to the recommendations of the TexasET Network than those controllers which have ET sent to the controller.

While water savings shows promise through the use of some smart irrigation controllers, excessive irrigation is still occuring under some landscape scenerios. Continued evaluation and work with the manufacturers is needed to fine tune these controllers even more to achieve as much water savings as possible.

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