Updates in ET Based Smart Irrigation Controller Performance: Results from 2013

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Abstract. *A smart controller testing facility was established by the Irrigation Technology Program 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. Based on the last 6 years of the ET controller testing program, many ET controllers currently being marketed in Texas remain inconsistent in their performance and continue to apply excessive amounts of irrigation. Some participating manufacturers have used the evaluation results to update and improve sensors and firmware to increase controller performance.This paper provides an update on the performance of 9 commercially available controllers and tries to identify reasons for poor performance of controllers by evaluating controller generated or recieved ET values.*

Keywords. *Landscape Irrigation, Irrigation Scheduling, Evapotranspiration, Smart Controllers, 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. For more information, see the IA's website: http://irrigation.org.

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. The data acquisition and analysis process is illustrated Figure A-1 . Additional information and photographs of the testing facilities are provided in the Appendix.

Smart Controllers

Nine (9) controllers were provided by manufacturers for the Year 2013 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

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	On-Site Sensors[1]	Rain Shutoff
A	ET Water	ET	Pager	None	✓
B	Rainbird ET Manager Cartridge	ET	Pager	Tipping Bucket Rain Gauge	
C	Hunter ET System	Sensor Based	-	Tipping Bucket Rain Gauge, Pyranometer, Temperature/ RH, Anemometer	
D	Hunter Solar Sync	Sensor Based	-	Pyranometer	✓
E	Rainbird ESP SMT	Sensor Based	-	Tipping Bucket Rain Gauge, Temperature	
F	Accurate WeatherSet	Sensor Based	-	Pyranometer	✓
G	Weathermatic Smartline	Sensor Based	-	Temperature	✓
H	Toro Intellisense	ET	Pager	None	✓
I	Irritrol Climate Logic	Sensor Based	-	Temperature, Solar Radiation	✓

[1] Rain shut off sensors are not considered On-Site Sensors for ET Calculation or runtime adjustment

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 (with 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 two controllers (E and H) had programming options to set all the required parameters defining the landscape (see Table 4). 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. Four of the nine controllers did not allow 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, warm season turf, shrubs, 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 three did. Five 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**	**Crop Coefficient**	**Adjustment Factor**	**Precipitation Rate**	**Zip Code or Location**	**Runtime**
A	X	X	X	X		X	X	X	
B[1]	-	-	-		X	-	-	X	X
C	X			X	X	X	X		
D[2]	-	-	-		-	-	-	X	X
E	X	X		X	X	X	X		
F[2]				X					X
G	X			X	X	X	X	X	
H	X	X	X	X	X	X	X	X	
I[2]	-	-	-		-	-	-	X	X

[1] Irrigation amount was set based on plant available water
[2] Controller was programmed for runtime and frequency at peak water demand (July).

Testing Period

The controllers were set up and run from March 4 to May 11 and from July 29 to December 1, 2013. Controller performance is reported over seasonal periods. For the purposes of this report, seasons are defined as follows:

- Spring: March 4 to May 11 (77 Days)
- Summer: July 29 to September 15 (49 Days),
- Fall: September 16 to December 1 (70 Days).

ETo and Required 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 (Campbell Scientific Inc) which records temperature, solar radiation, wind and relative humidity. ETo was computed using the standardized Penman-Monteith method.

Irrigation Requirement

The irrigation requirement was calculated using a daily soil moisture balance model. Irrigation was applied through the model once the managed allowable depletion was reached or exceeded. The model used the following equation:

$SM_D = SM_{PD} – (ETo \times Kc \times Af) + Rain_{Eff}$ (eq.1)

Where:
SM_D = Soil Moisture of the current day, inches
SM_{PD} = Soil Moisture of the previous day, inches
ETo = Daily Evapotranspiration, inches
Kc = Crop Coefficient, %
Af = Adjusment Factor, %
$Rain_{Eff}$ = Effective Rainfall that can be stored in the root zone, inches

Irrigation Adequacy Analysis

The purpose of the irrigation adequacy analysis is to identify controllers which over or under irrigate landscapes. An uncertainty in calculating a water balance is effective rainfall, how much of rainfall is credited for use by the plant. Further complicating rainfall is the use and performance of rain shut off devices.

For this study we broadly define irrigation ***adequacy*** as the range between taking 80% credit for all rainfall (R_e = 0.8) and taking no credit for rainfall (R_e = 0). These limits are defined as:

Extreme Upper Limit = ETo x Kc (eq. 2)
Adequacy Upper Limit = ETo x Kc x Af (eq. 3)
Adequacy Lower Limit = ETo x Kc x Af - Net (80%) Rainfall (eq. 4)
Extreme Lower = ETo x Kc x Af - Total Rainfall (eq. 5)

The adequacy upper limit is defined as the plant water requirement (eq. 3) without rainfall. Irrigation volumes greater than the upper limit are classified as ***excessive***. The adequacy lower limit is defined as the plant water requirements minus Net Rainfall (eq 4). The IA SWAT Protocol defines net rainfall as 80% of rainfall. Irrigation volumes below than the adequacy lower limit are classified as ***inadequate***.

For comparison purposes, extreme limits are defined by taking no credit for rainfall (upper) and total rainfall (lower). These limits are the maximum and minimum possible plant water requirements.

RESULTS

Results from the Year 2013 evaluation periods are summarized in Tables 5-7 by season.

Irrigation Requirement Comparisons

Controller performance during the Spring evaluation period (March 4-May 11, 2013) was good.

Controllers Passing
None

Good Performers
Controller C had four stations that were within irrigation requirement

Poor Performers
Controllers D and I had irrigation applications greater ETo
Controller F had one station in excess of ETc

Controller performance during the Summer evaluation period (July 29-September 15, 2013) was good.

Controllers Passing
None

Good Performers
Controller G had four stations that were within irrigation requirement.

Poor Performers
Controllers D and I produced irrigation volumes in excess of ETo.
Controller D had four stations that were in excess of ETc.

Controller Performance during the Fall evaluation period (September 16-December1, 2013) was generally poor.

Controllers Passing
None

Best Performer
None

Poor Performers
Controllers D and I produced irrigation volumes in excess of ETo.
Controllers F and H produced irrigation volumes in excess of ETc.

Tables 8-10 show the irrigation ***adequacy*** analysis for each station during the three seasonal periods. During the Spring period, four (4) controllers applied excessive amounts of irrigation for one or more stations with one (1) controller applying excessive amounts for all six (6) stations. In the Summer period, four (4) controllers applied inadequate irrigation amounts with two (2) controllers consistently applying inadequate irrigation amounts. Six (6) controllers applied excessive amounts during the summer period with two (2) controllers consistently applying excessive amounts for all six (6) stations. No controllers applied inadequate amounts during the Fall period, however six (6) controllers consistently applied excessive amounts of irrigation with three (3) controller applying excessive amounts for all six (6) station.

Figure 1 and Figure 2 contain daily ET readings from controllers and the TexasET Network graphed with daily rainfall totals during the entire evaluation period (Figure 1) and as a percentage of daily ETo (Figure 2). Controller ET values appeared erratic and inconsistent compared to TexasET throughout the study period; however all controllers consistently show decreases in ETo values during days which rainfall occurred.

Controller Problems

Two controllers experienced problems during the course of the study.

1. Controller B had poor signal accuracy during the study dropping down as low as 17% at some times. The signal provider was notified and adjustments were made in the signal settings and an upgraded antenna was installed. Signal accuracy increased temporarily after adjustments but soon declined again. Signal provider stated controller was in a poor coverage area due to changes in signal/transmission towers. However Controller B does have local historic monthly ET data stored in its settings and continued to operate at low signal accuracy using the historic ET values and onsite rainfall measurements.

2. Controller H experienced communication problems multiple times throughout the study. Controller alerts (beeping) occurred on at least 2 occasions during the evaluation period. The manufacturer was notified of the problem and a signal amplifier was installed on the controller. However, it was later determined that the problem was a result of poor signal service by the signal provider company in the testing area (lack of towers). Controller will not be included in future evaluations at this location due to the continuous communication problems.

Table 5. Spring Performances. Irrigation amount (inches) applied for each controller station. Yellow denotes values within +/- 20 % of the irrigation requirement. Red indicates values in excess of ETc						
Controller	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	8.40	5.14	3.71	2.46	2.62	2.50
B	9.03	5.53	4.10	2.93	3.81	0
C	7.00	3.48	2.66	1.98	2.94	0.51
D	19.76	11.99	9.38	6.43	8.57	3.87
E	9.05	5.17	2.30	1.48	1.61	0
F	9.33	7.51	10.21	3.38	5.55	3.54
G	5.94	2.81	2.10	1.34	2.05	0.83
H	7.94	5.09	3.53	2.68	3.64	1.58
I	16.63	6.30	4.82	2.91	4.66	2.20
Total ETo[1]	14.14					
Total Rain[2]	8.58					
Irrigation Requirement	7.16	4.23	3.19	2.17	1.78	0
Total ET_{MAX}[3]	11.31	8.48	8.48	7.07	7.07	4.24
Effective Rainfall	0.10	0.51	0.65	0.50	1.98	1.64

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Turfgrass Lab, College Station, Texas.
[2] Total Rainfall collected from TexasET Network Weather Station "TAMU Golf Course"
[3] Rainfall and Adjustment Factor not included in this calculation

Table 6. Summer Performances. Irrigation amount (inches) applied for each controller station. Yellow denotes values within +/- 20 % of the irrigation requirement. Red indicates values in excess of ETc

Controller	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	8.32	5.73	4.45	3.74	4.19	3.32
B	5.81	2.96	2.18	1.56	1.50	0
C	5.02	2.39	1.07	1.21	1.21	0
D	18.72	10.97	8.63	5.86	7.82	3.57
E	9.34	5.62	2.88	1.79	2.43	0
F	8.12	6.65	7.28	2.65	4.23	2.70
G	8.50	5.38	4.04	2.78	3.91	1.68
H	10.29	6.59	4.57	3.47	4.71	2.04
I	24.10	8.58	8.86	5.97	6.47	3.95
Total ETo[1]	13.20					
Total Rain[2]	0.86					
Irrigation Requirement	6.37	5.12	3.71	2.54	3.61	0
Total ET_{MAX}[3]	10.56	7.92	7.92	6.60	6.60	3.96
Effective Rainfall	0.17	0.10	0.23	0.19	0.52	0.61

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Turfgrass Lab, College Station, Texas.
[2] Total Rainfall collected from TexasET Network Weather Station "TAMU Golf Course"
[3] Rainfall and Adjustment Factor not included in this calculation

Table 7. Fall Performance. Irrigation amount (inches) applied for each controller station. Yellow denotes denotes values within +/-20% of the irrigation requirement . Red indicates values in excess of ETc.

Table 7. Fall Performance. Irrigation amount (inches) applied for each controller station. Yellow denotes values within +/-20% of the irrigation requirement . Red indicates values in excess of ETc.						
Controller	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	6.13	2.57	1.67	1.46	1.05	0
B	3.84	1.39	1.02	0.73	0	0
C	3.27	0.79	0.19	0.38	0.59	0
D	15.40	10.58	8.26	5.25	7.02	3.40
E	5.97	3.25	1.87	0.49	0.18	0.62
F	6.52	7.01	6.44	2.57	4.09	2.62
G	5.26	3.56	2.66	1.73	2.43	1.13
H	8.53	5.46	3.79	2.88	3.91	1.69
I	22.47	8.52	8.48	6.25	6.62	4.40
Total ETo[1]	10.06					
Total Rain[2]	18.71					
Irrigation Requirement	4.79	2.45	1.52	0.98	0	0
Total ET_{MAX}[3]	8.05	6.04	6.04	5.03	5.03	3.02
Effective Rainfall	0.17	1.26	1.50	1.00	2.85	2.51

[1] Total ETo calculated using the standardized Penmen-Monteith method using weather data collected at the Texas A&M University Turfgrass Lab, College Station, Texas.
[2] Total Rainfall collected from TexasET Network Weather Station "TAMU Golf Course"
[3] Rainfall and Adjustment Factor not included in this calculation

Table 8. Irrigation adequacy during the Spring Period						
Controller	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
A	Adequate	Adequate	Adequate	Adequate	Adequate	Excessive
B	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
C	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
D	Excessive	Excessive	Excessive	Excessive	Excessive	Excessive
E	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
F	Excessive	Excessive	Adequate	Adequate	Excessive	Excessive
G	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
H	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
I	Adequate	Adequate	Adequate	Adequate	Adequate	Excessive

Table 9. Irrigation adequacy during the Summer Period						
Controller	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
A	Adequate	Adequate	Adequate	Excessive	Adequate	Excessive
B	Inadequate	Excessive	Inadequate	Inadequate	Inadequate	Inadequate
C	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate
D	Excessive	Excessive	Excessive	Excessive	Excessive	Excessive
E	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate
F	Inadequate	Excessive	Excessive	Adequate	Adequate	Excessive
G	Inadequate	Inadequate	Inadequate	Adequate	Inadequate	Adequate
H	Adequate	Excessive	Adequate	Excessive	Excessive	Excessive
I	Excessive	Excessive	Excessive	Excessive	Excessive	Excessive

Table 10. Irrigation adequacy during the Fall Period

Controller	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
A	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
B	Adequate	Excessive	Adequate	Adequate	Adequate	Adequate
C	Adequate	Adequate	Excessive	Excessive	Adequate	Adequate
D	Excessive	Excessive	Excessive	Excessive	Excessive	Excessive
E	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
F	Adequate	Excessive	Excessive	Excessive	Excessive	Excessive
G	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
H	Excessive	Excessive	Excessive	Excessive	Excessive	Excessive
I	Excessive	Excessive	Excessive	Excessive	Excessive	Excessive

DISCUSSION AND CONCLUSIONS

Over the past five years since starting our "end-user" evaluation of smart controllers, we have seen improvement in their performance. However, the communication and failures that were evident in our field surveys conducted in San Antonio in 2006 (Fipps, 2008) continue to be a problem for some controllers. In the past five years of bench testing, we have seen some reduction in excessive irrigation characteristics of controllers, however some controllers still have difficulty managing irrigations in some stations, particularly station 1.

Our emphasis 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 five years, we continue to observe controllers irrigating in excess of ETc. Since ETc is defined as the ETo x Kc, it is the largest possible amount of water a plant will need if no rainfall occurs. This year, one controller consistently irrigated in excess of ETc, even though 28.15 inches of rainfall occurred during the study. The causes of such excessive irrigation volumes are likely due to improper ETo values and/or insufficient accounting for rainfall.

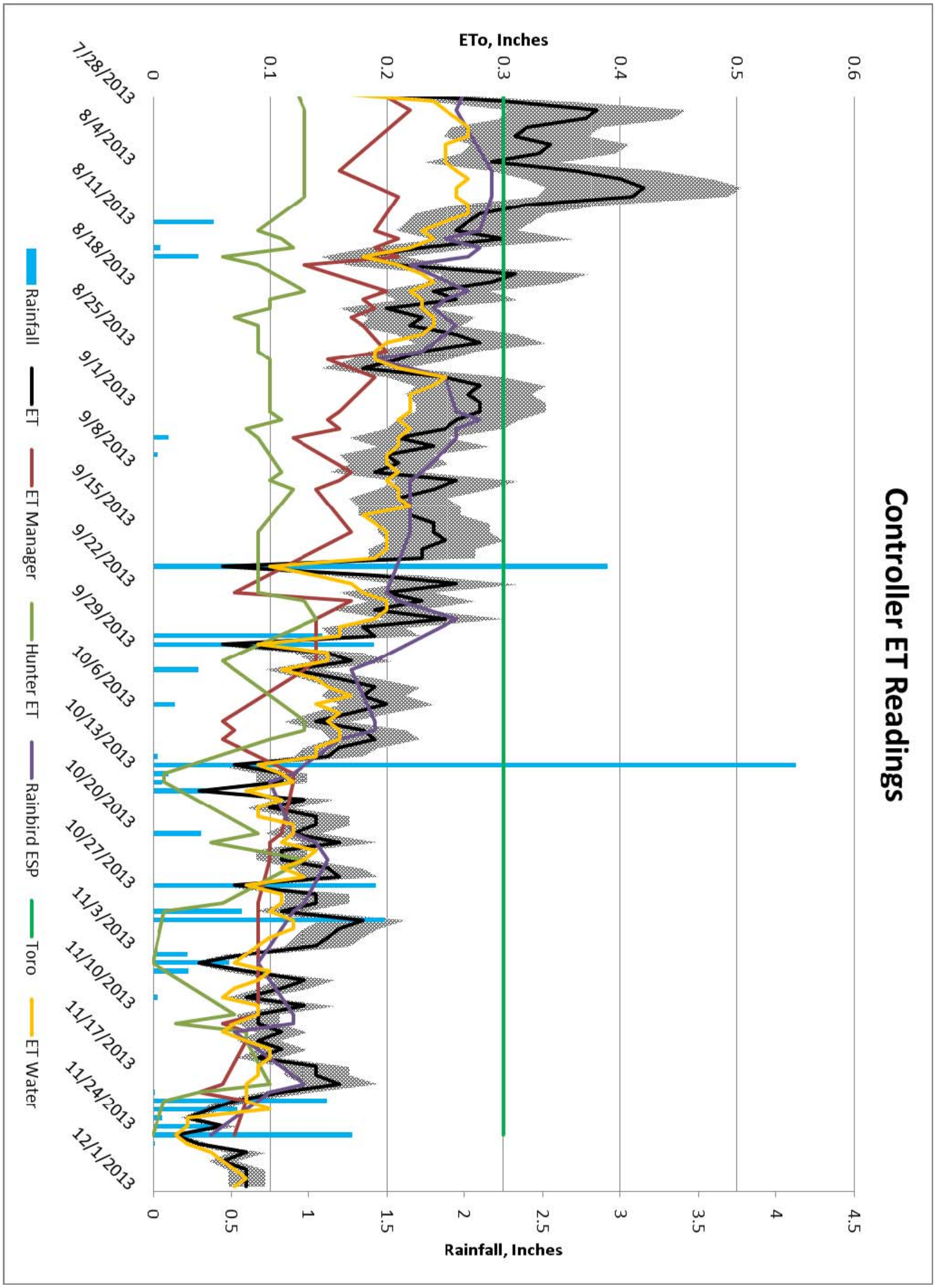
Three (3) controllers were equipped with tipping-bucket rain gauges which measure actual rainfall and six (6) controllers were equipped with rainfall shutoff sensors as required by Texas landscape irrigation regulations. Rainfall shutoff sensors detect the presence of rainfall and interrupt the irrigation event. During the 2013 evaluation period, a variety of rainfall conditions occurred across the three study periods. The fall period had the most rainfall (18.71 inches), and no major differences in performance observed between controllers using rain gauges and those using rainfall shutoff devices. This is in contrast to the 2010 study during which over 17 inches of rainfall occurred; and controllers using rain gauges applied irrigation amounts much closer to the irrigation requirements.

For a controller to pass our test, it would need to meet the irrigation requirements for all six stations. Of the nine (9) controllers tested, none successfully passed the test during the spring, summer or fall season. Results over the last five (5) years have consistently shown that some of the controllers over-irrigate (i.e., apply more water than is reasonably needed). This year, due likely to the variations in rainfall received during the study, four (4) controllers applied an inadequate amount of water compared to 2011 when six (6) controllers failed to meet minimum plant water requirements. Inadequacies appeared most common during periods with the least amount of rainfall while the most excessive amount appeared most common during the period with the highest amount of rainfall.

Generally, there was no difference in performance between controllers with on-site sensors and those controllers which have ET sent to the controller. Previous years evaluations had shown those controllers with on-site sensors to irrigate much closer to the irrigation requirements.

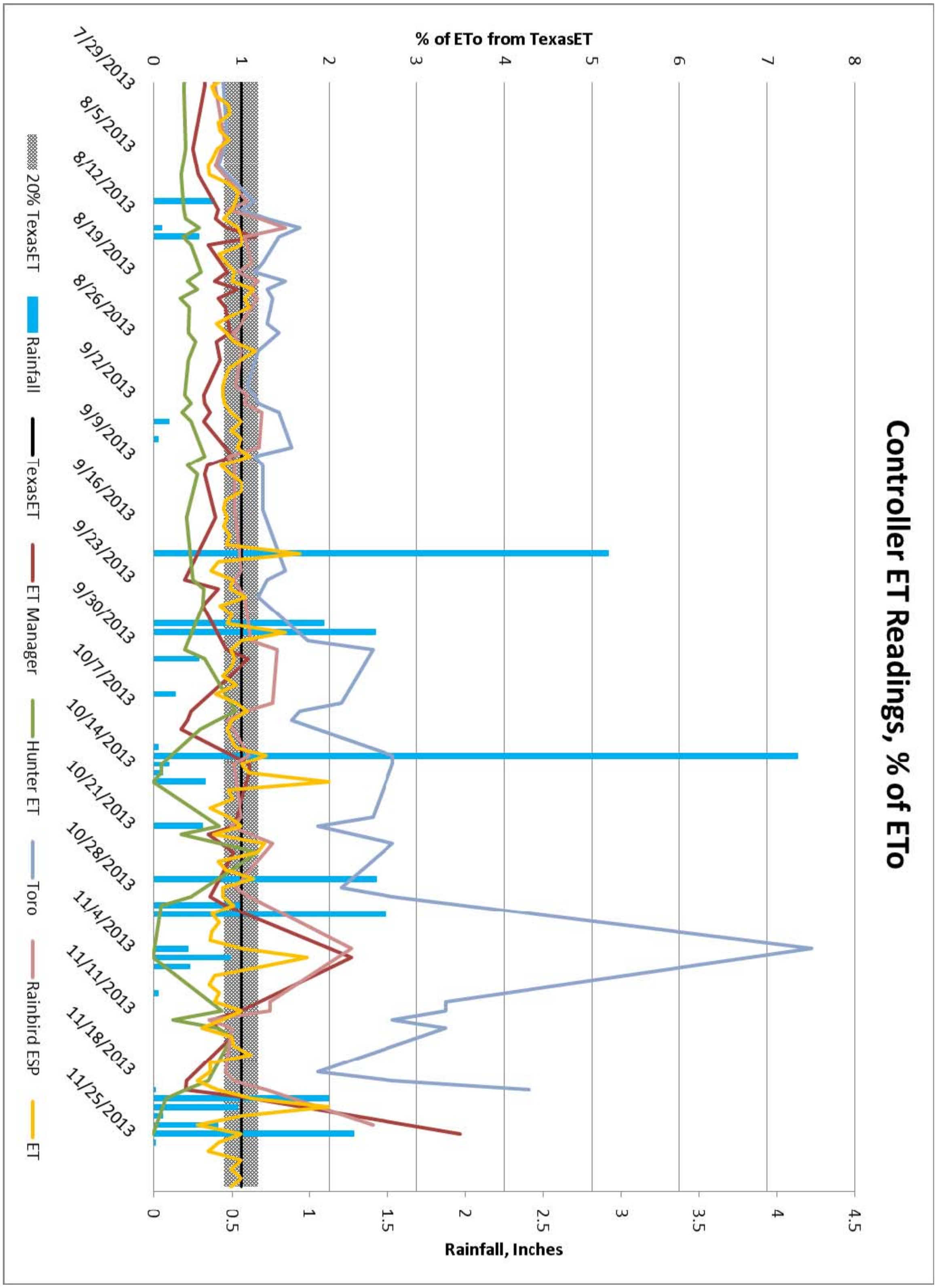
Current plans are to continue evaluation of controllers into the 2014 year and seek funding to expand the evaluation to program other regions in the state. While water savings shows promise through the use of some smart irrigation controllers, excessive irrigation is still occurring under some landscape scenarios. Continued evaluation and work with the manufacturers is needed to fine tune these controllers even more to achieve as much water savings as possible.

Figure 1



Controller ET Readings
ETo, Inches
0
0.1
0.2
0.3
0.4
0.5
0.6
Rainfall, Inches
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
7/28/2013
8/4/2013
8/11/2013
8/18/2013
8/25/2013
9/1/2013
9/8/2013
9/15/2013
9/22/2013
9/29/2013
10/6/2013
10/13/2013
10/20/2013
10/27/2013
11/3/2013
11/10/2013
11/17/2013
11/24/2013
12/1/2013
Rainfall
ET
ET Manager
Hunter ET
Rainbird ESP
Toro
ET Water

Figure 2



Controller ET Readings, % of ETo
% of ETo from TexasET
0
1
2
3
4
5
6
7
8
Rainfall, Inches
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
7/29/2013
8/5/2013
8/12/2013
8/19/2013
8/26/2013
9/2/2013
9/9/2013
9/16/2013
9/23/2013
9/30/2013
10/7/2013
10/14/2013
10/21/2013
10/28/2013
11/4/2013
11/11/2013
11/18/2013
11/25/2013
20% TexasET
Rainfall
TexasET
ET Manager
Hunter ET
Toro
Rainbird ESP
ET