TR-469

EVALUATION OF SMART IRRIGATION CONTROLLERS:

YEAR 2013 RESULTS

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SUMMARY

A smart controller testing facility was established at Texas A&M University in College Station in 2008 in order to evaluate their performance from an "end-user" point of view. The "end-user" is considered to be the landscape or irrigation professional (such as a Licensed Irrigator in Texas) installing the controller. Controllers are tested using the *Texas Virtual Landscape* which is composed of 6 different zones with varying plant materials, soil types and depths, and precipitation rates.

This report summaries the results of the 2013 evaluations. Nine controllers were evaluated over a 196 day period, from March 4 to May 11 and July 29 to December 1, 2013. Controller performance was analyzed for each seasonal period (spring, summer, fall). Controller performance is evaluated by comparison to the irrigation recommendation of the TexasET Network and Website (http://texaset.tamu.edu), as well as for *irrigation adequacy* in order to identify controllers which apply excessive and inadequate amounts of water.

Programing smart controllers for specific site conditions continues to be a problem. Only two (2) of the nine (9) controllers tested could be programmed directly with all the parameters needed to define each zone.

Total Irrigation Amounts

- When looking at seasonal irrigation amounts for the entire landscape, no controller was able to meet the soil water balance requirements for all six (6) zones during any of the Evaluation Periods.
- Two (2) controllers applied more than ETo for one (1) zone during all three seasonal periods
- Two (2) controllers had four (4) zones apply +/-20% of calculated irrigation requirements for the Spring and Summer Periods.

Adequacy Analysis

- Five (5) Controllers were able to (across all 6 zones) to adequately meet the plant water requirements during the spring season
- Six (6) controllers applied excessive amounts of irrigation for one or more zones during a seasonal period.

Factors that could have caused over irrigation of landscape are improper ETo data and ET calculations and insufficient accounting for rainfall. During the 2013 study, 28.15 inches of rainfall occurred compared to historical averages of 22.71 inches for the same time period. ET values recorded off the controllers were inconsistent throughout the study, often calculating ET values greater than 150% of weather station (TexasET Network) ET.

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, some 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

A smart controller testing facility was established by the ITC at Texas A&M University in College Station. Basically, the controllers are connected to a data logger which records the start and stop times for each irrigation event and station (or zone). 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 facility are provided in the Appendix.

Smart Controllers

Nine (9) controllers were provided by manufacturers for the Year 2013 evaluations (Table 2). Each controller is assigned an ID for reporting purposes. Table 2 lists each controller's classification, communication method and on-site sensors, as applicable.

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 as 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 to 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.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 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 Recommended Irrigation

ETo was computed from weather parameters measured at the Texas A&M University Turfgrass Research Facility 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 to refill the root zone. The basic model used the following equation:

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

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 = Adjustment Factor, %
$Rain_{Eff}$ = Effective Rainfall that can be stored in the root zone, inches
I = Irrigation, 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, ie, how much of rainfall is credited for use by the plant.

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 5-8 by season.

Irrigation Requirement Comparisons

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

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 than ETo
Controller F had one station in excess of ETc

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

Controllers Passing
None

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

Poor Performers
Controllers D and I produced irrigation applications 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)

Controllers Passing
None

Good Performer
None

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

Tables 9-12 show the results of the irrigation ***adequacy*** analysis for each zone during the three seasonal periods.

- During the Spring period, four (4) controllers applied excessive amounts of irrigation for one or more zones with one (1) controller applying excessive amounts for all six (6) zones.
- 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) zones.
- 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) zones.

Tables 13-16 summarize the distribution of controller adequacy, inadequacy and excess during the three seasonal period. The greatest percentage of irrigation adequacy occurred during the spring period, whereas the lowest percentage of irrigation adequacy occurred during the summer period which is when typically irrigation requirements are at their highest. The largest percentage of irrigation excess was observed during the fall period.

Appendix B and C show daily ETo readings taken from five controllers and compared to those from the TexasET Network. All five controller ETo values appeared erratic and inconsistent as compared to TexasET throughout the study period; however all five controllers consistently showed 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 times. The signal provider was notified, adjustments were made in the signal settings and an upgraded antenna was installed. Signal accuracy increased temporarily after these adjustments but soon declined again. The signal provider stated that the 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. Controller alerts (beeping) occurred on at least 2 occasions. 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 strength by the signal provider company (lack of towers). The controller will not be included in future evaluations at this location due to the continuous communication problems.

Table 5. Total Irrigation amounts applied by each controller during the entire study. Yellow denotes values within +/- 20 % of the irrigation requirement. Red indicates values in excess of ETc. (All values in inches)

Controller	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
A	22.85	13.44	9.83	7.66	7.86	5.82
B	18.68	9.88	7.3	5.22	5.31	0
C	15.29	6.66	32.75	13.36	4.74	0.51
D	53.88	33.54	26.27	17.54	23.41	10.84
E	24.36	14.04	7.05	3.76	4.22	0.62
F	23.97	21.17	23.93	8.6	13.87	8.87
G	19.7	11.75	8.8	5.85	8.39	3.64
H	26.76	17.14	11.89	9.03	12.26	5.31
I	63.2	23.4	22.16	15.13	17.75	10.55
Total ETo[1]	37.66					
Total Rain[2]	28.15					
Total ET_{MAX}[3]	29.92	22.44	22.44	18.7	18.7	11.22
Irrigation Requirement	18.32	11.80	8.42	5.69	5.39	0

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

Table 6. Spring Performance. Irrigation amount (inches) applied for each controller zone. Yellow denotes values within +/- 20 % of the irrigation requirements. Red indicates values in excess of ETc

Controller	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 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 Turf Lab, College Station, Texas.
[2] Total Rainfall measured at the TexasET Network Weather Station "TAMU Turf Lab"
[3] Rainfall and Adjustment Factor are not included in this calculation

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

Controller	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 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 Turf Lab, College Station, Texas.
[2] Total Rainfall measured at the TexasET Network Weather Station “TAMU Turf Lab”
[3] Rainfall and Adjustment Factor are not included in this calculation

Table 8. Fall Performance. Irrigation amount (inches) applied for each controller station. Yellow denotes values within +/-20% of the irrigation requirements. 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 Turf Lab, College Station, Texas.
[2] Total Rainfall measured at the TexasET Network Weather Station “TAMU Golf Course”
[3] Rainfall and Adjustment Factor are not included in this calculation

Table 9. Irrigation adequacy during the entire testing period						
Controller	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
A	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
B	Adequate	Adequate	Adequate	Adequate	Adequate	Inadequate
C	Adequate	Adequate	Excesive	Excesive	Adequate	Inadequate
D	Excesive	Excesive	Excesive	Excesive	Excesive	Excesive
E	Adequate	Adequate	Adequate	Adequate	Adequate	Inadequate
F	Adequate	Excesive	Excesive	Adequate	Excesive	Excesive
G	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
H	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
I	Excesive	Excesive	Excesive	Excesive	Excesive	Excesive

Table 10. 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 11. 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 12. 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

Table 13. Distribution of Station Adequacy, Inadequacy and Excess during the entire study										
	A	B	C	D	E	F	G	H	I	%
Adequate	6	5	3	0	5	2	6	6	0	61%
Inadequate	0	1	1	0	1	0	0	0	0	6%
Excessive	0	0	2	6	0	4	0	0	6	33%
% Adequate	100%	83%	50%	0%	83%	33%	100%	100%	0%	

Table 14. Distribution of Station Adequacy, Inadequacy and Excess during the Spring Period										
	A	B	C	D	E	F	G	H	I	%
Adequate	5	6	6	0	6	2	6	6	5	78%
Inadequate	0	0	0	0	0	0	0	0	0	0%
Excessive	1	0	0	6	0	4	0	0	1	22%
% Adequate	83%	100%	100%	0%	100%	33%	100%	100%	83%	

Table 15. Distribution of Station Adequacy, Inadequacy and Excess during the Summer Period										
	A	B	C	D	E	F	G	H	I	%
Adequate	4	0	0	0	0	3	2	2	0	20%
Inadequate	0	5	6	0	6	0	4	0	0	39%
Excessive	2	1	0	6	0	3	0	4	6	41%
% Adequate	67%	0%	0%	0%	0%	50%	33%	33%	0%	

Table 16. Distribution of Station Adequacy, Inadequacy and Excess during the Fall Period										
	A	B	C	D	E	F	G	H	I	%
Adequate	6	5	4	0	6	1	6	0	0	52%
Inadequate	0	0	0	0	0	0	0	0	0	0%
Excessive	0	1	2	6	0	5	0	6	6	48%
% Adequate	100%	83%	67%	0%	100%	17%	100%	0%	0%	

DISCUSSION AND CONCLUSIONS

For a controller to pass our test, it would need to meet the irrigation requirements for all six zones. 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.

Over the past six 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 two out of nine controllers. In the past six 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 zone 1.

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 was 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.

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 that controllers with on-site sensors irrigated 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 show promise through the use of some smart irrigation controllers, excessive irrigation is still occurring under some landscape zones such as high water use plants and shallow root zones. Continued evaluation and work with the manufacturers is needed to fine tune these controllers.

Appendix A

Figure A-1. System Set-Up and Data Flow

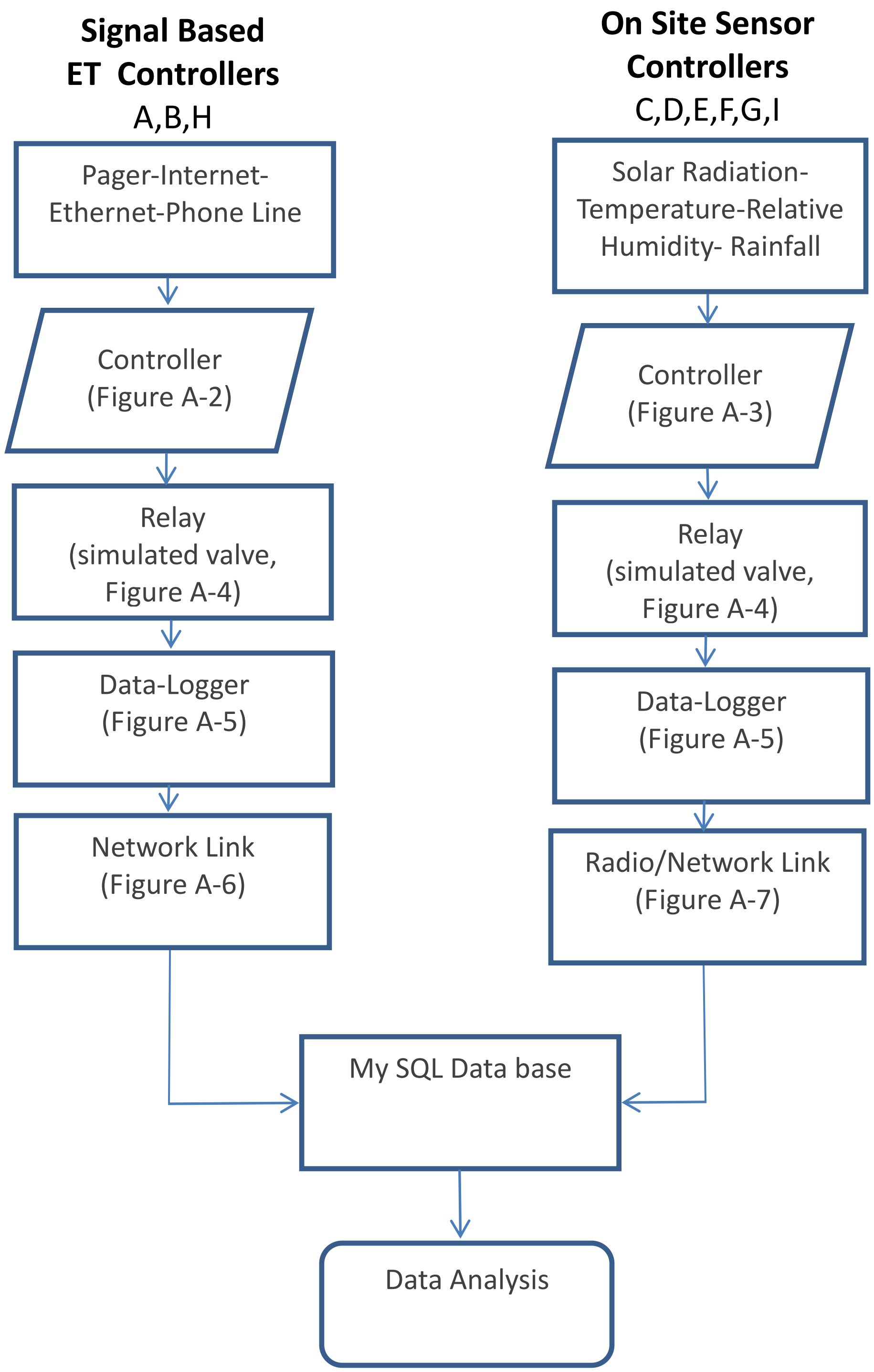

Figure A-2. Outdoor Tested Controllers-Side A

Figure A-3. Outdoor Tested Controllers-Side B

Figure A-4. Relays

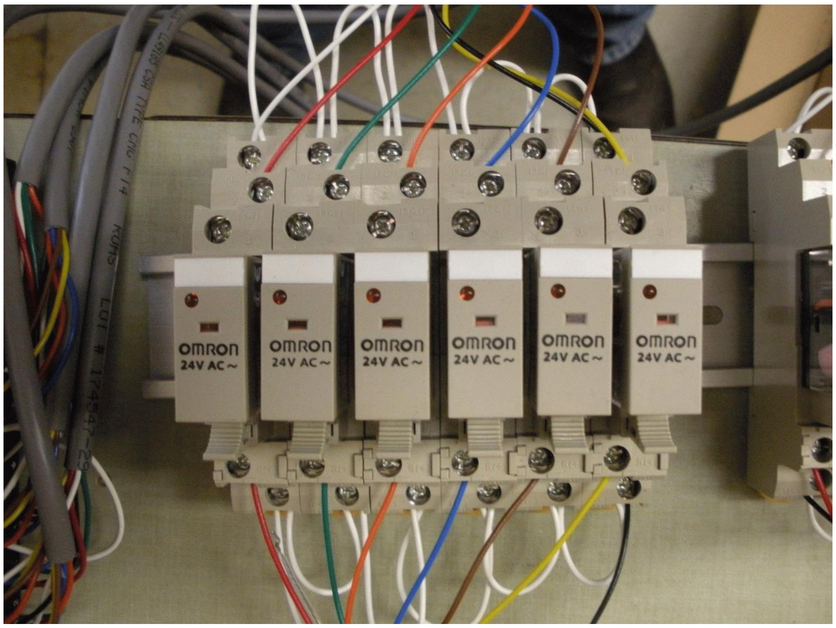

Figure A-5. Datalogger

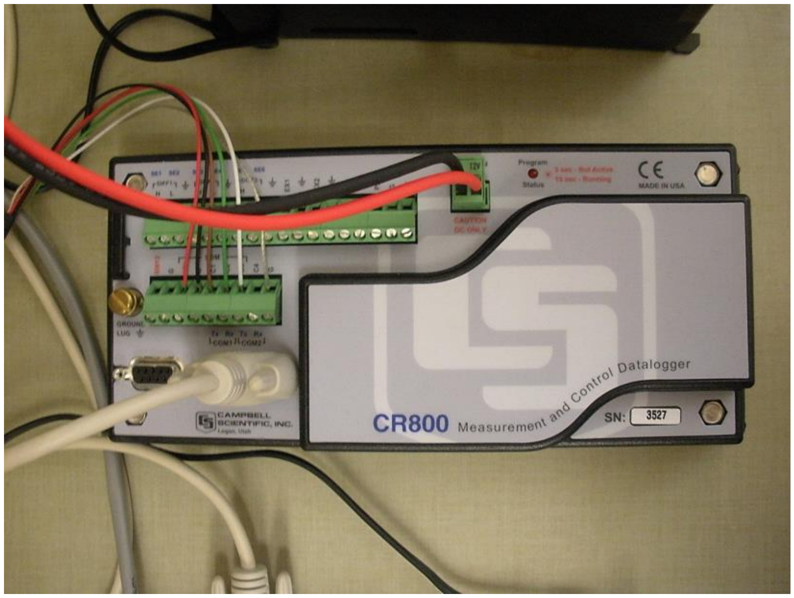

Figure A-6. Network Link

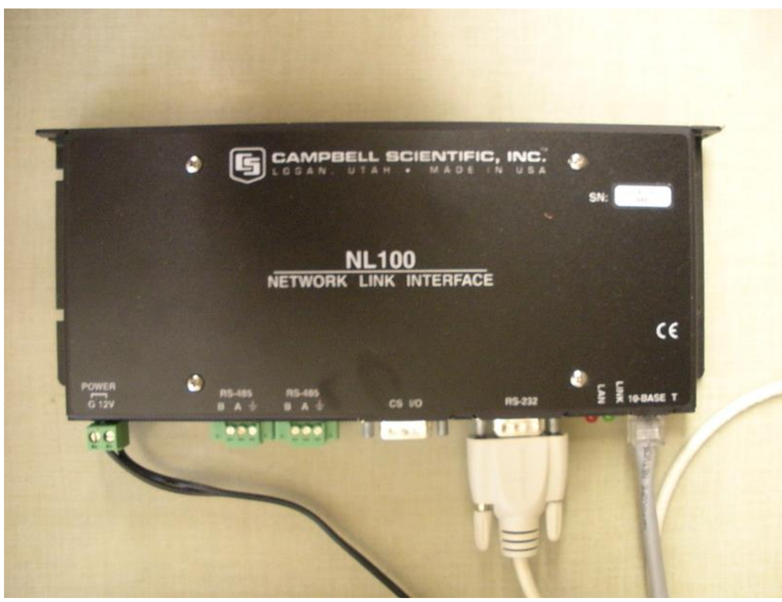

Figure A-7. Radio/Network Link

Appendix B

Table B-1. ETo data from Controllers and TAMU Turf Lab Weather Station

	ET Water	ET Manager	Hunter ET	Rainbird SMT	Toro	TexasET	Rainfall
7/29/2013	0.25	0.22	0.13	0.26	0.3	0.38	0
8/5/2013	0.26	0.16	0.13	0.29	0.3	0.36	0
8/8/2013	0.26	0.21	0.13	0.29	0.3	0.41	0
8/12/2013	0.23	0.19	0.09	0.28	0.3	0.26	0
8/13/2013	0.24	0.21	0.11	0.25	0.3	0.3	0
8/14/2013	0.22	0.19	0.12	0.28	0.3	0.23	0.05
8/15/2013	0.18	0.21	0.06	0.27	0.3	0.18	0.29
8/16/2013	0.21	0.13	0.09	0.22	0.3	0.21	0
8/19/2013	0.22	0.2	0.13	0.27	0.3	0.24	0
8/20/2013	0.23	0.18	0.1	0.25	0.3	0.26	0
8/21/2013	0.23	0.19	0.1	0.24	0.3	0.2	0
8/22/2013	0.24	0.17	0.07	0.25	0.3	0.23	0
8/23/2013	0.24	0.18	0.09	0.26	0.3	0.22	0
8/26/2013	0.19	0.2	0.09	0.23	0.3	0.23	0

8/27/2013	0.19	0.15	0.1	0.19	0.3	0.21	0
8/29/2013	0.25	0.19	0.1	0.25	0.3	0.25	0
9/2/2013	0.22	0.16	0.1	0.26	0.3	0.28	0
9/3/2013	0.21	0.15	0.11	0.28	0.3	0.26	0
9/4/2013	0.22	0.16	0.08	0.26	0.3	0.25	0
9/5/2013	0.21	0.12	0.09	0.26	0.3	0.21	0.1
9/9/2013	0.21	0.17	0.11	0.23	0.3	0.19	0
9/10/2013	0.2	0.16	0.1	0.22	0.3	0.26	0
9/11/2013	0.21	0.14	0.12	0.22	0.3	0.24	0
9/16/2013	0.2	0.17	0.09	0.22	0.3	0.24	0
9/23/2013	0.18	0.07	0.09	0.2	0.3	0.2	0
9/24/2013	0.2	0.17	0.13	0.21	0.3	0.23	0
9/26/2013	0.19	0.14	0.14	0.26	0.3	0.25	0
10/1/2013	0.15	0.14	0.06	0.19	0.3	0.17	0
10/2/2013	0.11	0.13	0.07	0.17	0.3	0.12	0.29
10/8/2013	0.15	0.06	0.13	0.19	0.3	0.14	0
10/9/2013	0.16	0.07	0.13	0.19	0.3	0.18	0
10/10/2013	0.16	0.06	0.1	0.16	0.3	0.19	0
10/14/2013	0.11	0.12	0.01	0.12	0.3	0.11	0.1
10/15/2013	0.12	0.12	0.01	0.1	0.3	0.11	0.06
10/21/2013	0.12	0.11	0.09	0.12	0.3	0.12	0.31
10/22/2013	0.11	0.1	0.05	0.14	0.3	0.16	0
10/24/2013	0.13	0.1	0.13	0.15	0.3	0.11	0
10/29/2013	0.11	0.09	0.06	0.13	0.3	0.14	0
10/30/2013	0.1	0.09	0.01	0.12	0.3	0.11	0.57
11/5/2013	0.07	0.09	0	0.09	0.3	0.04	0.49
11/11/2013	0.09	0.09	0.07	0.12	0.3	0.09	0
11/12/2013	0.07	0.06	0.02	0.12	0.3	0.09	0
11/13/2013	0.06	0.08	0.08	0.07	0.3	0.11	0
11/14/2013	0.08	0.08	0.08	0.08	0.3	0.09	0
11/19/2013	0.08	0.06	0.1	0.13	0.3	0.16	0
11/20/2013	0.08	0.04	0.04	0.1	0.3	0.11	0.01
11/21/2013	0.08	0.08	0.01	0.09	0.3	0.07	1.12
11/25/2013	0.02	0.07	0	0.05	0.3	0.02	1.28

Appendix C

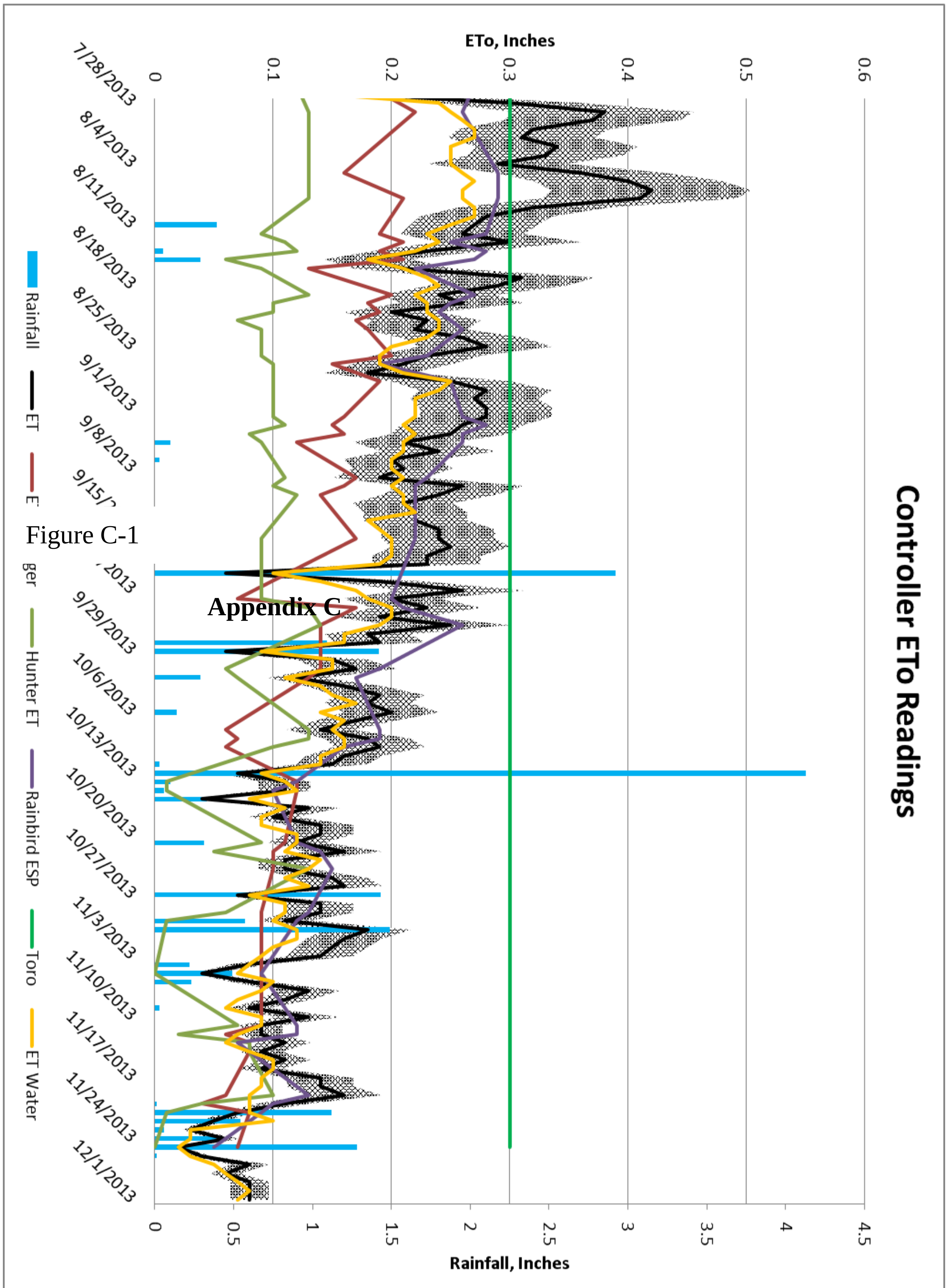

Figure C-1

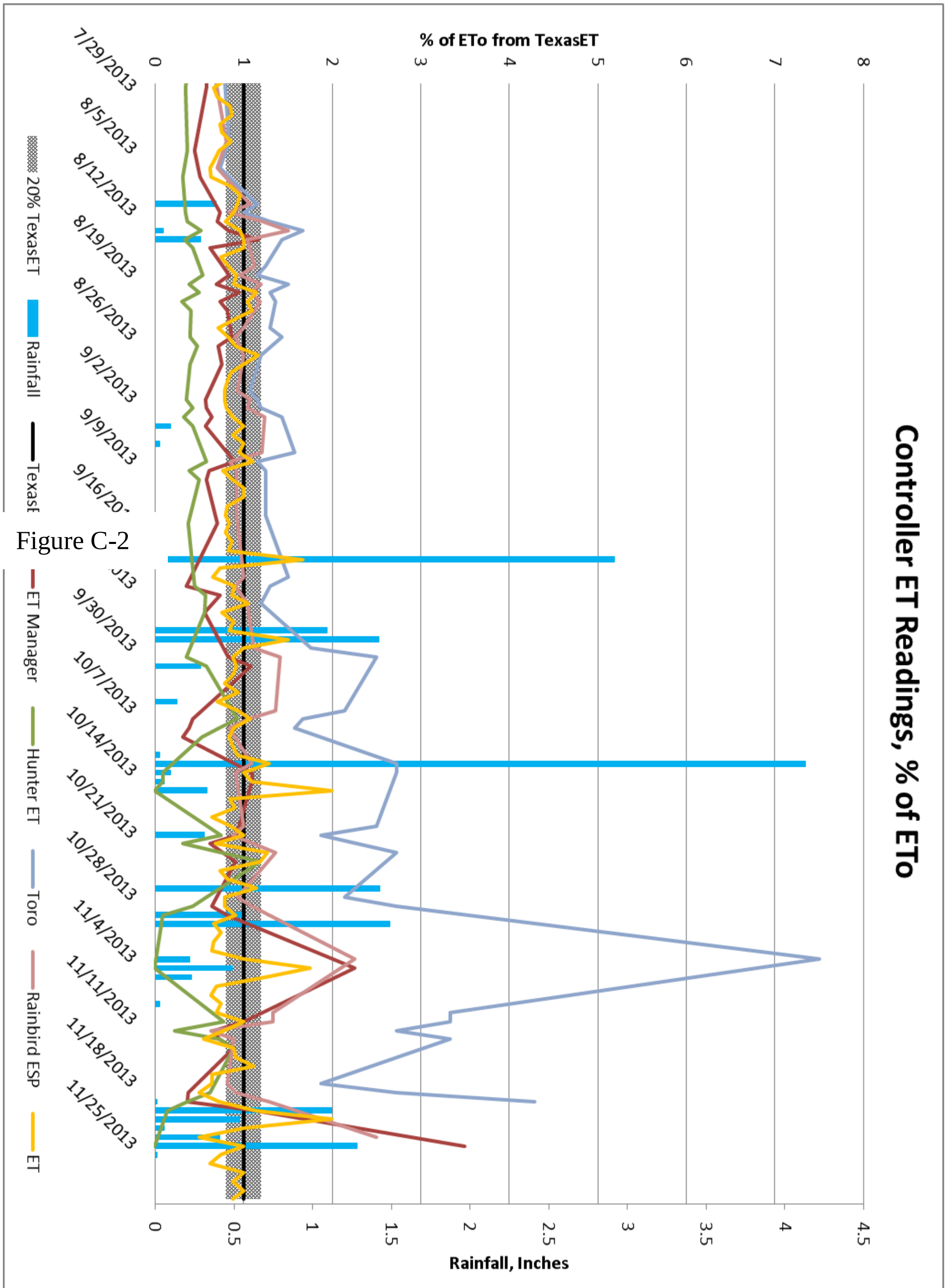
Controller ET Readings, % of ETo
% of ETo from TexasET
Rainfall, Inches
20% TexasET
Rainfall
ET Manager
Hunter ET
Toro
Rainbird ESP
ET
7/29/2013
8/5/2013
8/12/2013
8/19/2013
8/26/2013
9/2/2013
9/9/2013
9/30/2013
10/7/2013
10/14/2013
10/21/2013
10/28/2013
11/4/2013
11/11/2013
11/18/2013
11/25/2013

Figure C-2

Texas Water Resources Institute
make every drop count

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