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Final Report: Agricultural Irrigation System Improvements for the Gulf Coast Water Authority

TWDB Contract Number 1513581822

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August 31, 2020

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Geoscientist and Engineer Seals

The Texas Water Development Board contracted with the Gulf Coast Water Authority (GCWA) to administer this agricultural conservation grant. GCWA subcontracted the reporting portion of the project effort to LRE Water, LLC, a licensed professional geoscientist firm (Texas License No. 50516) and licensed professional engineering firm (Texas License No. 14368). This report documents the work of the following licensed professional geoscientists and licensed professional engineers in the State of Texas:

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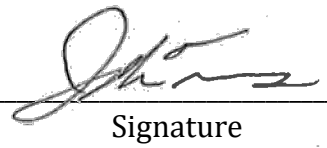
Dr. Furnans was responsible for all completing summary reports for 2017, 2018, and 2019 irrigation years, as well as f completing this final report.



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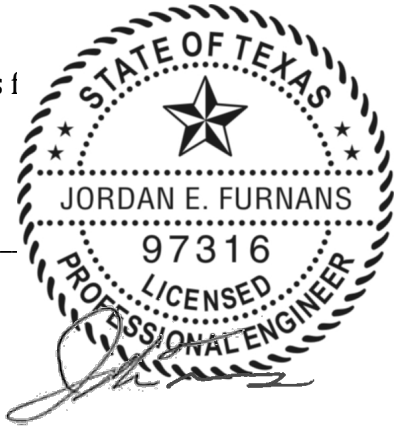

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Abbreviations

Acre-ft.....Acre-Feet
GCWA.....Gulf Coast Water Authority
lb.....Pound
LCRA.....Lower Colorado River Authority
TWDB.....Texas Water Development Board

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1 GCWA Project Summary

1.1 GCWA Introduction

The Gulf Coast Water Authority (GCWA) provides water on a wholesale basis to customers in Galveston, Fort Bend, and Brazoria Counties (TX). GCWA employs a combination of canal conveyance, raw water pipeline infrastructure, and treated water production and conveyance facilities to serve a combination of industrial, municipal, and agricultural demands across these counties. Customers served by GCWA include municipalities (e.g. Galveston, Sugarland, Missouri City) as well as petro-chemical industries (e.g. Dow-UCC, Valero, INEOS, Marathon, Ascend) and rice farmers. A map of GCWA operations is provided in Figure 1-1.

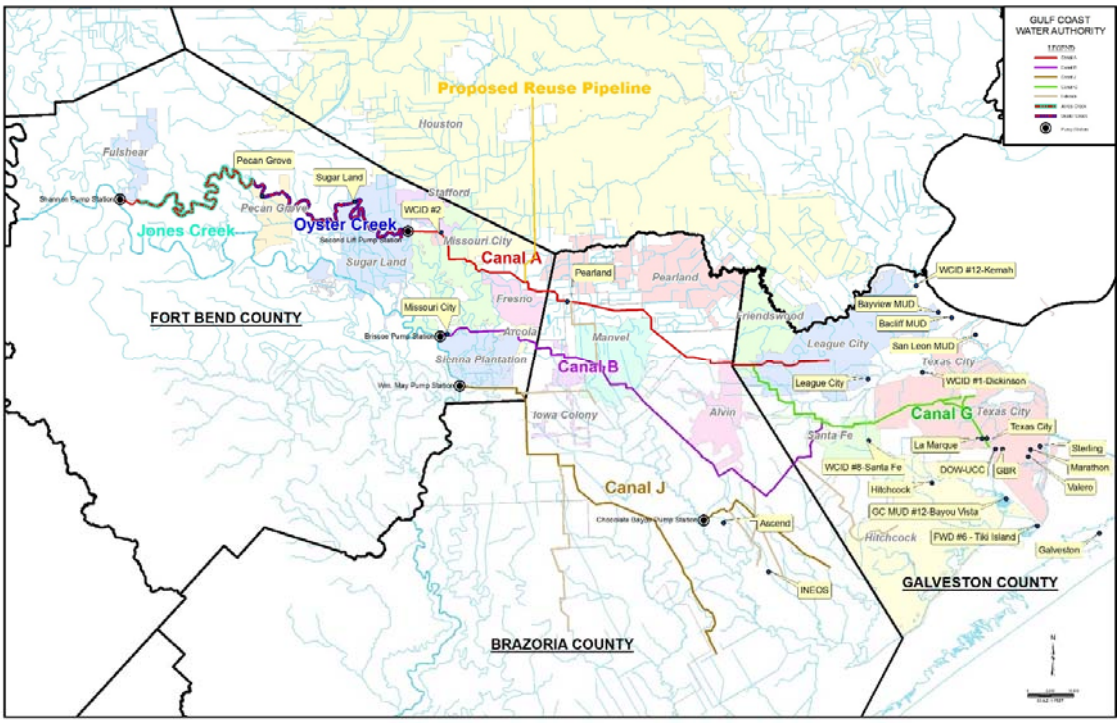

Figure 1-1 – ***Map of GCWA canal infrastructure and Municipal & Industrial water customers.***

The majority of GCWA's water is diverted from the Brazos River, as authorized for diversion by the Texas Commission on Environmental Quality (TCEQ) under certificates of adjudication (CoA) 12-5168, 12-5171, and 12-5322. GCWA also has access to water from Chocolate, Mustang, and Halls Bayou (under CoA 11-5357) and from Jones and Oyster Creek (under CoA 11-5169), although water from these sources is not always reliable and may be of limited utility due to saline-water intrusion. To supplement water available under these certificates, GCWA also maintains long-term water purchase agreements with the Brazos River Authority (BRA), who releases water from upstream reservoirs when requests are made by GCWA.

Within GCWA's service area, rice production typically progresses in the following series of sequential steps:

- Field preparation and planting in late February to early March
- Field flooding approximately 25 days after planting, depending upon the type of rice seed used and climatic conditions
- Continuous flow to fields to replace evaporative losses and keep fields flooded during the growing season prior to harvesting of the rice crop
- Additional field flooding after the first crop harvest, if irrigators intent to harvest a ratoon crop

GCWA typically provides irrigation water from mid-March to mid-October, and coordinates closely with its irrigation customers to ensure timely water deliveries. While all fields typically have a main harvest (or "First Crop") in June or July, some farmers specifically strive for an additional ratoon crop harvested later in the season. The ratoon crop is grown from the roots of the rice plants grown from seed earlier in the growing season. As the ratoon crop does not require seed planting, it is produced at a much lower cost to the farmer, and can therefore result in additional net profits if properly managed.

As shown in Figure 1-2, during the 2020 irrigation season (March-October), GCWA will be providing water for rice field irrigation within Brazoria and Galveston Counties. During this season, GCWA will monitor irrigation water deliveries with 106 active Agriflo Mace Meters that were purchased and installed during the duration of this TWDB contract grant. Irrigation water deliveries are made from GCWA's Juliff Canal system, Chocolate Bayou Canal system, B-Canal system, and A-Canal system. Irrigation water is largely derived from diversions from the Brazos River, yet also from Chocolate Bayou and Mustang Bayou.

GCWA notes that irrigated acreage varies from year-to-year, and that not all fields will be irrigated in any given year. To fully support irrigated agricultural operations within its service area, GCWA has purchased and installed over 160 Agriflo Mace Meters. The purchase and installation of these meters was partially supported by funds received under the TWDB Agricultural Water Conservation Grant for which this document services as the final grant contract report. GCWA does not utilize all meters every year, but provides service to all meters so that meters do not need to be removed-and re-installed as different fields are irrigated during different years.

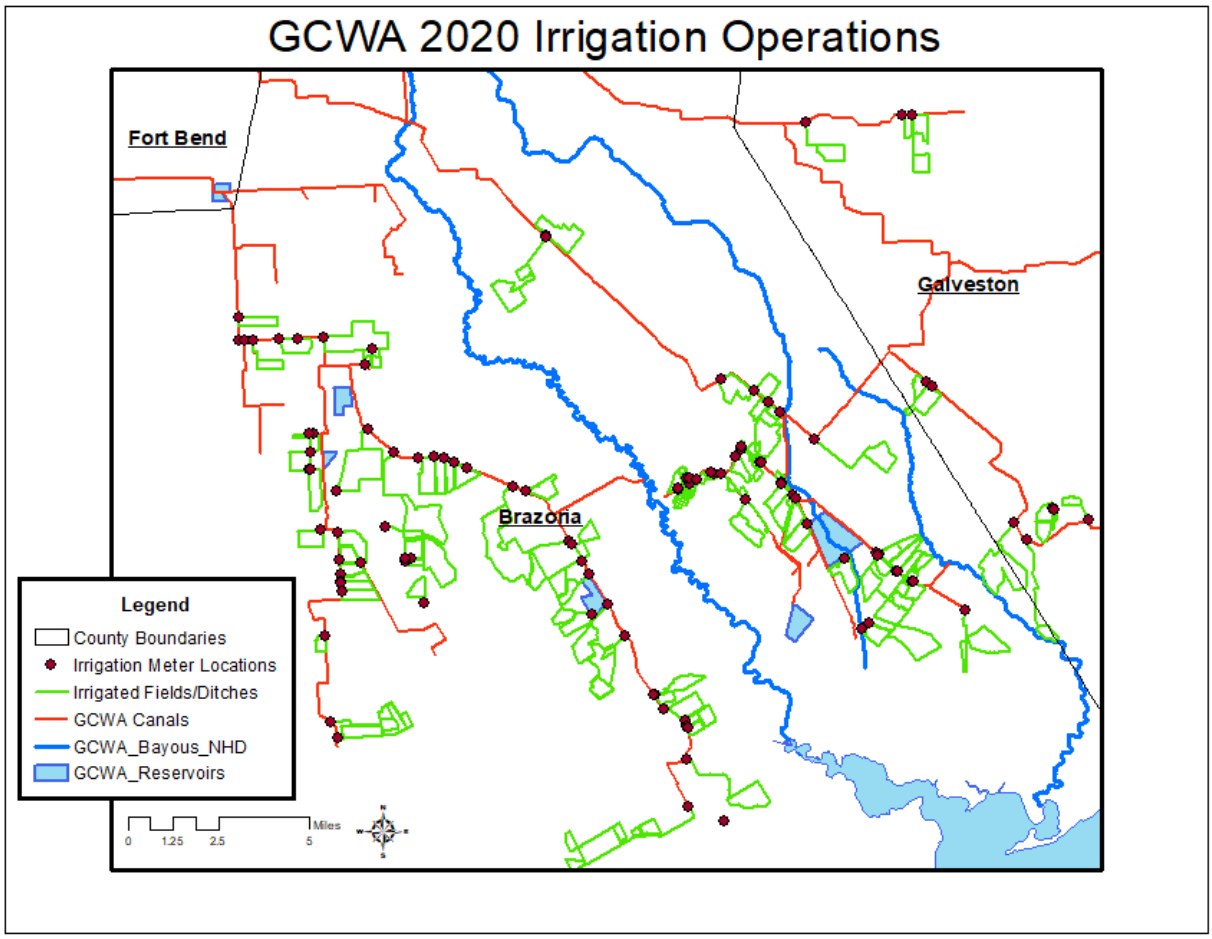

Figure 1-2– ***Map of GCWA's 2020 Irrigation Operations, with 106 active meters servicing irrigation fields.***

1.2 Project Goals & Operation Summary

In 2014, the Gulf Coast Water Authority ("GCWA") was awarded an Agricultural Water Conservation grant from the Texas Water Development Board ("TWDB"). The grant funds were to be utilized to improve GCWA's irrigation delivery efficiency such that a greater proportion of water diverted by GCWA provided tangible benefits to irrigators. GCWA's secondary objective was to reduce irrigation water usage by minimizing on-field water usage by its customers. Through this grant program, the TWDB and GCWA partnered to purchase and install irrigation meters, allowing GCWA to better track irrigation customer water usage. GCWA also implemented per-meter invoicing policies and a tiered water pricing structure to incentivize conservation. Meter installation commenced in 2015 and was completed by 2017.

Through this grant project effort, GCWA purchased and installed over 160 Agriflo Mace Meters, which measure and report water deliveries to specific locations. Each Mace Meter would record cumulative and incremental water volumes passing through the conduit to

which it was installed, and would record data at 15-minute intervals. Data are transmitted automatically to the Mace WebComm Data server, accessible to GCWA via secure internet access. GCWA has developed software to automatically download and process the Mace Meter data, which is stored in comma-separated-value (CSV) files suitable for importation into Microsoft Excel and other similar programs. Total time required to download and process data from all of GCWA's typically active Mace Meters (approximately 120 sites per year, on average) is 3-4 minutes. GCWA also provided farmers with access to the Mace Meter data server, so that farmers could monitor their own water usage over time and make more informed decisions regarding their on-field water use. GCWA also provided farmers with monthly water usage summaries to foster increased awareness of their water usage and to encourage farmers to more efficiently manage water deliveries to their fields.

Figure 1-3 – Example Meter Installation - A) showing housing with easy access port, B) Agriflow meter installed within housing, with solar panel, C) on-pipe acoustic sensor transmits data via cable to the main unit.

Figure 1-3 shows a typical meter installation, with a "housing" installed to secure the Agriflo meter and the sensor installed along the diversion pipe. The finished installation (Figure 1-3A) shows that the sensor on the diversion pipe is typically buried and the land surface re-graded. The installed sensor (Figure 1-3C) transmits data via buried cable (typically loosely enclosed in PVC pipe) to the main unit, which is installed within the concrete pipe housing (Figure 1-3B). The concrete housing is capped with a lid and secured with a padlock. The lid also supports a solar panel which provides power to the Agriflo meter internal battery. The installed main unit is easily accessible to GCWA staff, and is reasonably protected from damage by animals and vehicles/machinery that typical travel around irrigation fields. During the initial stages of this project, GCWA collaborated with professionals at the Texas AgriLife Research Center at Beaumont and faculty and staff from

the Texas A&M Department of Soil and Crop Sciences. This collaboration was voluntary and resulted in the 2016 annual project report (Chapter 6) being jointly written by GCWA staff and Texas A&M researchers. After 2016, however, further collaboration did not occur, and project reports were written by GCWA staff and their project sub-consultant LRE Water, LLC.

1.3 Irrigation Water Savings - Summary

Prior to irrigation meter installation and usage, GCWA would estimate irrigation water needs based on the number of certified acres to be irrigated during the First- and Ratoon Crop seasons. Specifically, GCWA developed a formula relating necessary diversions into GCWA canal systems (from either the Brazos River or GCWA's bayou sources) to the certified acreage. The formula was based on the experience of GCWA water managers using observations and data compiled prior to the commencement of this project. The formula was as follows:

$$V = 4.5\frac{acre-ft}{acre}(CA) + 0.2 \cdot 4.5\frac{acre-ft}{acre}(FA) + 0.35 \cdot 4.5\frac{acre-ft}{acre}(A_2)$$

Where "V" is the volume of water used by an irrigator (in acre-ft), "CA" is the total number of certified acres irrigated (during the first crop season), "FA" is the number of acres to which a 2nd or 3rd flush is applied, and "A_2" is the number of acres used for growing a ratoon crop. GCWA would utilize the formula to plan water diversions from the Brazos River and other GCWA sources, yet would not track actual water deliveries and usage by GCWA irrigation customers.

By metering individual customer deliveries and incentivizing conservation, GCWA was able to quantify actual water usage and obtain better knowledge of actual irrigation diversion requirements. Comparing actual usage/diversions against the historical formula provides a means of estimating water savings resulting from GCWA's metering program (and TWDB's Agricultural Water Conservation grant). Table 1-1 details estimated water savings resulting from the metering program implemented by GCWA, and supported by the TWDB Agricultural Water Conservation grant. As shown, water savings ranged from 23,000 to 32,000 acre-ft/yr (approximately), and totaled over 103,000 acre-ft for the study period.

Table 1-1 – GCWA Irrigation Water Savings Resulting from TWDB Ag Grant Activities

Year	Water Savings (acre-ft)
2019	22,398.12
2018	25,536.88
2017	23,582.10
2016	31,969.17
Total	**103,486.27**

Table 1-2 – First Crop Irrigation Usage By GCWA Customers (acre-ft/acre)

	Juliff	Chocolate Bayou	B-System	A-System	Total
2019	2.23	2.69	2.06	2.66	2.31
2018	2.42	2.15	1.99	<>	2.28
2017	2.66	3.35	2.67	2.67	2.75
2016	2.77	2.71	2.41	2.65	2.68
Ave	2.52	2.73	2.28	2.66	2.51
Formula**	4.50	4.50	4.50	4.50	4.50

**Formula does not include water for a 2nd or 3rd flush

Table 1-2 provides First Crop irrigation water usage data for each year after meter installation, broken down into GCWA's four component canal systems (Juliff, Chocolate Bayou, B-System, and A-System). The units on the provided data are "acre-ft/acre" which refers to the volume of water (acre-ft) applied to each acre of irrigated land. As such, these data represent depths of water applied to the irrigated land over the First Crop irrigation season. As shown, water usage varies between GCWA canal systems and between years – yet in every location and year after the 2015 meter installation, usage was significantly below that predicted by GCWA's historical formula.

Table 1-3 – Ratoon Crop Irrigation Usage By GCWA Customers (acre-ft/acre)

	Juliff	Chocolate Bayou	B-System	A-System	Total
2019	2.18	1.61	2.69	1.76	1.96
2018	1.3	1.18	0.63	<>	1.2
2017	2.18	2.7	2.08	2.08	2.24
2016	2.02	2.24	2.76	2.29	2.22
Ave	1.92	1.93	2.04	2.04	1.91
Formula	1.58	1.58	1.58	1.58	1.58

Table 1-3 presents ratoon crop irrigation water usage data for each year after meter installation, broken down into GCWA's four component canal systems. As shown, ratoon crop water usage is generally more in-line with GCWA's historical water usage formula, compared to the usage for First Crop. Unlike first crop water usage, however, ratoon crop water usage was found to be nearly always greater than estimated by the GCWA historical formula. Ratoon crop water usage in 2018, however, was below the formula-estimated usage for all canal systems. The low water usage for ratoon crops in 2018 may be correlated to the relatively high rainfall recorded in July and September. Rainfall timing and intensity may impact irrigation water usage and adjust crop yield, and therefore may skew the data shown in Table 1-2 and Table 1-3. Monthly rainfall totals for 2015-2019, as recorded at the Bush Intercontinental Airport in Houston, is provided for reference in Table 1-4.

Table 1-4 – Monthly Rainfall Totals for Houston, TX

	Rainfall Totals by Month (inches)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	4.08	1.73	0.5	3.36	7.16	6.88	2.79	2.42	14.95	5.8	1.12	1.14
2018	3.06	5.73	2.97	1.9	3.83	6.64	6.04	0.85	8.6	7.02	1.76	7.62
2017	6.09	2.42	5.63	1.68	2.41	7.19	6.29	**39.11**	1.23	3.42	0.5	3.72
2016	2.16	1.95	3.25	14.39	7.2	13.12	1.09	10.41	1.7	0.14	1.99	3.56
2015	3.17	0.66	6.34	6.1	14.17	11.39	0.61	2.94	2.59	13.05	3.8	5.21

**Hurricane Harvey occurred in August, 2017

Based on the 2016-2019 metering data, GCWA's historical formula for estimating irrigation water delivery requirements should be updated to the following:

$$V = 2.53\frac{acre-ft}{acre}(CA) + 1.95\frac{acre-ft}{acre}(A_2)$$

Where all terms are defined as before. In this updated equation, the usage coefficient "2.53" for first crop was determined as an average of the 2016-2019 usage data (Table 1-2) weighted by the irrigated acreage per GCWA canal system. Similarly the "1.95" usage coefficient for the ratoon crop was determined as an average of the 2016-2019 usage data (Table 1-3). Water used for the 2nd or 3rd flush was incorporated directly into the usage coefficient for the first crop.

GCWA recognizes that water savings estimates based on comparing metered water usage with estimated water usage from a historical formula may be inaccurate, given that GCWA does not have the means to prove the accuracy of its historical formula. It is therefore not possible to quantify whether the water savings reported above is due is actually due to a reduction in water usage, or due to an error in the historical formula used to estimate agricultural usage. GCWA is, however, confident that metering and tiered water pricing have incentivized water conservation amongst its irrigation customers. GCWA believes metering has incentivized on-farm conservation practices in the following manner:

- Irrigators are now actually paying for all of the water they use, with billing based on the metered water usage for each customer. This incentivizes water conservation in that irrigators can see a direct relation between their decisions in field management and the size of bills provided by GCWA. When bills were set based on the historical formula, irrigators were not as likely to manage water effectively as there was not a connection between their bill and the actual volume of water used on the irrigators fields.
- Tiered water prices, with prices and tiers set annually by GCWA, encourage water conservation as greater water use (per acre irrigated) results in a larger increase in water billing and costs to the irrigator. This incentivizes the irrigator to closely monitor water usage to avoid triggering higher rates and to carefully manage field irrigating. The irrigator becomes incentivized to efficiently manage on-field watering.

After GCWA initiated customer billing based on meter readings from the Agriflo Mace meters, many irrigation customers invested in laser-leveling technology to maximize the benefit of each drop of water used to irrigate the rice fields. Irrigators accepted the expense of laser-leveling to increase on-field water efficiency, which ultimately yields to a reduction in irrigation billing while maintaining or increasing the crop yield. GCWA has not required laser-leveling of fields by its customers, and does not know exactly how many fields have been leveled to improve water use efficiency.

The remainder of this report contains the individual annual project reports developed by GCWA for the 2015-2019 irrigation seasons. Reports for 2015-2018 were previously submitted to TWDB per the requirements of the Agricultural Water Conservation grant.

GCWA considers this “Agricultural Irrigation System Improvements Project” to have been a great success. GCWA continues to budget for, purchase, and install Mace meters and has obtained a tremendous wealth of knowledge as a result of this TWDB grant. GCWA certainly appreciated the opportunity to work with the TWDB on this important project.

2 2019 Annual Report – TWDB Grant 1513581822

Prepared by: Jordan Furnans, PhD, PE, PG

Total 2019 Water Savings from Project: **22,398.12 acre-ft**

2.1 INTRODUCTION

This report summarizes the state of the agricultural diversion metering program of the Gulf Coast Water Authority (GCWA), developed through partial support from the Texas Water Development Board via Agricultural Water Conservation Grant #1513581822. GCWA initiated the agricultural diversion metering program in 2015 upon receipt of this TWDB grant. As of 1/1/2018, GCWA had installed 160 Agriflo water meters developed by Mace (currently owned by In-Situ, Inc.). Each meter automatically records water flow data (at 15-minute intervals) and transfers the data to a Mace webserver accessible to GCWA. GCWA has been using metered flow readings to track water usage of its agricultural customers since 2016.

The remainder of this report provides an analysis of metered water usage by GCWA agricultural customers, primarily for the purpose of rice field irrigation. The analysis is limited to 2019. A full project report, detailing water savings resulting from this metering project, will be submitted to TWDB in April, 2020. This full report will quantify water savings resulting from this metering project for the period 2016-2019.

2.2 2019 IRRIGATION WATER USAGE

For 2019, GCWA customers utilized 32,970.47 acre-ft of water for irrigation purposes, as recorded through GCWA meters. Table 2-1presents GCWA irrigation customer usage by crop season and canal location.

Table 2-1– GCWA 2019 Irrigation Water Usage

	Acreage		Usage (acre-ft)		Acre-ft/acre	
System	1st Crop	Ratoon Crop	1st Crop	Ratoon Crop	1st Crop	Ratoon Crop
Juliff	8137.42	1514.31	18153.83	3301.40	2.23	2.18
Chocolate Bayou	3189.47	1291.11	8579.23	2077.97	2.69	1.61
B System	2587.75	276.93	5324.69	745.11	2.06	2.69
A-System	343.49	343.49	912.72	605.63	2.66	1.76
Total	14258.13	3425.84	32970.47	6730.11	2.31	1.96

**Only includes acreage irrigated for entire 1st crop or ratoon crop seasons.

It is notable that GCWA diverted 28,913.82 acre-ft of water from the Brazos River into the Juliff system for use by irrigators. This amounts to 7,458.585 acre-ft more water than was delivered to irrigated acres as measured by Mace meters, which is approximately 26% of the quantity diverted from the Brazos River. This quantity of water was assumed needed to "wet" the canals so that water deliveries could be made to each irrigated field.

2.3 GCWA'S HISTORICAL METHOD FOR ESTIMATING WATER USAGE

Prior to the installation of meters, and at least since 2006, GCWA utilized a mathematical formula to estimate water usage by irrigators. The numerical formula was based on the number of irrigated acres for first and second crop, and also included water attributed to a 2nd or 3rd flush of the rice fields. The formula was as follows:

$$V = 4.5\frac{acre-ft}{acre}(CA) + 0.2 \cdot 4.5\frac{acre-ft}{acre}(FA) + 0.35 \cdot 4.5\frac{acre-ft}{acre}(A_2)$$

Where "V" is the volume of water used by an irrigator (in acre-ft), "CA" is the total number of certified acres irrigated, "FA" is the number of acres to which a 2nd or 3rd flush is applied, and "A_2" is the number of acres used for growing a ratoon crop. GCWA would utilize this formula to compute the total volume attributed to each irrigator, and would then invoice the irrigator based on the volume multiplied by the per-acre-ft water price (which was established annually by GCWA). GCWA decided to utilize the ratio of 4.5 acre-ft/acre and the "0.2" or "0.35" modifiers for the flush and ratoon crop, respectively, based upon years of irrigation data analysis conducted by current GCWA Assistant General Manager David Sauer and others.

Per GCWA's historical formula, given the total acreage irrigated in 2019 (Table 2-1), GCWA customers should have used 69,557.28 acre-ft of water in total, with 39,003.43 acre-ft used on the Juliff system alone. GCWA water managers would have diverted these quantities of water from the Brazos River in order to meet expected irrigation needs. From Table 2-1, the total usage actually was 39,700.58 acre-ft, and the usage on the Juliff system was 21,455.23 acre-ft. Upon adding in the 7,458.585 acre-ft of water used to "wet" the Juliff canal system, 2019 water savings become 22,398.12 acre-ft (32%) of the water quantity based on the GCWA formula. A large portion of this savings is likely due to the use of irrigation meters to record diverted quantities, as provided through this TWDB grant. Canal "wetting" prior to irrigation is only needed on the Juliff system, as the other systems remain wet by conveying water for municipal and industrial users as well as for irrigators.

In comparing the above equation to the irrigation water usage data shown in Table 2-1, a few specific results are notable. For example, if you only consider irrigation for first crop, then per the GCWA formula the acre-ft/acre usage equals 4.5; this value is significantly higher than the metered 1st crop usage per acre shown in Table 2-1 (2.31 acre-ft/acre for the entire GCWA system). For all ratoon crop irrigated fields, the GCWA formula determines that the acre-ft per acre usage is 0.35*4.5 = 1.58; this number is lower than the ratoon crop acre-ft/acre usage data from Table 2-1. This suggests that perhaps irrigators are being less conservative in their water usage during the ratoon season, that the Mace Meter usage has not altered the behavior of ratoon crop irrigators, or that 2019

precipitation and evaporation rates during the ratoon crop season were significantly different than those observed in previous ratoon crop seasons.

Based on the data from the 2019 GCWA meter readings, a more appropriate formula for estimating irrigation water usage would be:

$$V = 2.83\frac{acre-ft}{acre}(CA) + 1.96\frac{acre-ft}{acre}(A_2)$$

Where all terms are as previously defined. GCWA considers the reduction in usage coefficients in the above formula, compared to those in its' historical formula, reflective of water conservation efforts for rice irrigation, including the usage of meters for all diversions. The 2.83 acre-ft/acre coefficient on the first crop term reflects water deliveries to fields as well as water needed to "wet" the Juliff canal.

2.4 CONCLUSIONS & PLANS

In general, analysis of the irrigation data collected during 2019 yields identical conclusions as presented in the 2016, 2017, and 2018 metering reports – namely that meter usage suggests lower water usage per acre than previously computed by GCWA. Reasons for the lower usage could be: 1) generally wetter conditions during the irrigation season, 2) effective measures by irrigators in lowering irrigation water usage, 3) incentivizing water conservation through direct invoicing based on irrigation meter data, and 4) incentivizing water conservation through a tiered pricing structure based on the metered usage per certified acre.

During 2020, GCWA will continue to monitor irrigation water usage through its Mace Meters, and will continue programs to incentivize reducing irrigation water needs through a tiered usage structure.

GCWA continues to budget for, purchase, and install Mace meters and has obtained a tremendous wealth of knowledge as a result of this TWDB grant. GCWA certainly appreciates the opportunity to work with the TWDB on this important project.

3 2018 Annual Report – TWDB Grant 1513581822

Prepared by: Jordan Furnans, PhD, PE, PG

Total 2018 Water Savings from Project: **25,536.88 acre-ft**

3.1 INTRODUCTION

This report summarizes the state of the agricultural diversion metering program of the Gulf Coast Water Authority (GCWA), developed through partial support from the Texas Water Development Board via Agricultural Water Conservation Grant #1513581822. GCWA initiated the agricultural diversion metering program in 2015 upon receipt of this TWDB grant. As of 1/1/2018, GCWA had installed 160 Agriflo water meters developed by Mace (currently owned by In-Situ, Inc.). Each meter automatically records water flow data (at 15-minute intervals) and transfers the data to a Mace webserver accessible to GCWA. GCWA has been using metered flow readings to track water usage of its agricultural customers since 2016.

The remainder of this report provides an analysis of metered water usage by GCWA agricultural customers, primarily for the purpose of rice field irrigation. The analysis is limited to 2018. A full project report, detailing water savings resulting from this metering project, will be submitted to TWDB in April, 2020. This full report will quantify water savings resulting from this metering project for the period 2016-2019.

3.2 2018 IRRIGATION WATER USAGE

For 2018, GCWA customers utilized 41,404.90 acre-ft of water for irrigation purposes, as recorded through GCWA meters. Table 3-1 presents GCWA irrigation customer usage by crop season and canal location. Also the computed "Combined" Usage Per Acre is the total water applied to fields on which first and second crop rice was planted and irrigated.

Table 3-1– GCWA 2018 Irrigation Water Usage

	Acreage		Usage (acre-ft)		Acre-ft/acre	
System	1st Crop	2nd Crop	1st Crop	2nd Crop	1st Crop	2nd Crop
Juliff	8,696.36	3,056.48	21,122.32	3981.51	2.42	1.30
Chocolate Bayou	3,309.87	2,303.75	7,109.23	2715.18	2.15	1.18
B System	2,766.11	508.43	5,502.21	320.17	1.99	0.63
Total	14,772.34	5,868.66	33,733.76	7,016.86	2.28	1.20

It is notable that GCWA diverted 34,535 acre-ft of water from the Brazos River into the Juliff system for use by irrigators. This amounts to 9,431.17 acre-ft more water than was delivered to irrigated acres as measured by Mace meters. This quantity of water was assumed needed to "wet" the canals so that water deliveries could be made to each irrigated field.

3.3 GCWA'S HISTORICAL METHOD FOR ESTIMATING WATER USAGE

Prior to the installation of meters, and at least since 2006, GCWA utilized a mathematical formula to estimate water usage by irrigators. The numerical formula was based on the number of irrigated acres for first and second crop, and also included water attributed to a 2nd or 3rd flush of the rice fields. The formula was as follows:

$$V = 4.5\frac{acre-ft}{acre}(CA) + 0.2 \cdot 4.5\frac{acre-ft}{acre}(FA) + 0.35 \cdot 4.5\frac{acre-ft}{acre}(A_2)$$

Where "V" is the volume of water used by an irrigator (in acre-ft), "CA" is the total number of certified acres irrigated, "FA" is the number of acres to which a 2nd or 3rd flush is applied, and "A_2" is the number of acres used for growing a second crop. GCWA would utilize this formula to compute the total volume attributed to each irrigator, and would then invoice the irrigator based on the volume multiplied by the per-acre-ft water price (which was established annually by GCWA). GCWA decided to utilize the ratio of 4.5 acre-ft/acre and the "0.2" or "0.35" modifiers for the flush and second crop, respectively, based upon years of irrigation data analysis conducted by current GCWA Assistant General Manager David Sauer and others.

Per GCWA's historical formula, given the total acreage irrigated in 2018 (Table 3-1), GCWA customers should have used 75,718.67 acre-ft of water in total, with 43,948.66 acre-ft used on the Juliff system alone. GCWA water managers would have diverted these quantities of water from the Brazos River in order to meet expected irrigation needs. From Table 3-1, the total usage actually was 40,750.62 acre-ft, and the usage on the Juliff system was 25,103.83 acre-ft. Upon adding in the 9,431.17 acre-ft of water used to "wet" the Juliff canal system, 2018 water savings become 25,536.88 acre-ft (34%) of the water quantity based on the GCWA formula. A large portion of this savings is likely due to the use of irrigation meters to record diverted quantities, as provided through this TWDB grant. Canal "wetting" prior to irrigation is only needed on the Juliff system, as the other systems remain wet by conveying water for municipal and industrial users as well as for irrigators.

In comparing the above equation to the irrigation water usage data shown in Table 1, a few specific results are notable. For example, if you only consider irrigation for first crop, then per the GCWA formula the acre-ft/acre usage equals 4.5; this value is significantly higher than the metered 1st crop usage per acre shown in Table 3-1. In addition, for all second-crop irrigated fields, the GCWA formula determines that the acre-ft per acre usage is 0.35*4.5 = 1.58; this number is also higher than the 2nd Crop acre-ft/acre usage data from Table 3-1.

Based on the data from the 2018 GCWA meter readings, a more appropriate formula for estimating irrigation water usage would be:

$$V = 2.9\frac{acre-ft}{acre}(CA) + 0.3 \cdot 0.0\frac{acre-ft}{acre}(FA) + 1.2\frac{acre-ft}{acre}(A_2)$$

Where all terms are as previously defined. GCWA considers the reduction in usage coefficients in the above formula, compared to those in its' historical formula, reflective of water conservation efforts for rice irrigation, including the usage of meters for all diversions. The 2.9 acre-ft/acre coefficient on the first crop term reflects water deliveries to fields as well as water needed to "wet" the Juliff canal.

3.4 CONCLUSIONS & PLANS

In general, analysis of the irrigation data collected during 2018 yields identical conclusions as presented in the 2016 and 2017 metering reports – namely that meter usage suggests lower water usage per acre than previously computed by GCWA. Reasons for the lower usage could be: 1) generally wetter conditions during the irrigation season, 2) effective measures by irrigators in lowering irrigation water usage, 3) incentivizing water conservation through direct invoicing based on irrigation meter data, and 4) incentivizing water conservation through a tiered pricing structure based on the metered usage per certified acre.

During 2019, GCWA continue to monitor irrigation water usage through its Mace Meters, and will continue programs to incentivize reducing irrigation water needs through a tiered usage structure. GCWA will outline its tiered usage structure in the 2020 project completion report.

4 2017 Annual Report – TWDB Grant 1513581822

Prepared by: Jordan Furnans, PhD, PE, PG

Total 2017 Water Savings from Project: **23,582.1 acre-ft**

4.1 INTRODUCTION

This report summarizes the state of the agricultural diversion metering program of the Gulf Coast Water Authority (GCWA), developed through partial support from the Texas Water Development Board via Agricultural Water Conservation Grant #1513581822. GCWA initiated the agricultural diversion metering program in 2015 upon receipt of this TWDB grant. During 2015, GCWA purchased and installed a limited number of meters, and in a report dated 2/5/2016 reported a mean water usage of 2.8 acre-ft/acre irrigated during the first crop of the 2015 irrigation season.

As of 1/1/2018, GCWA has installed and continually monitors 160 Agriflo water meters developed by Mace (currently owned by In-Situ, Inc.). Each meter automatically records the following data (at 15-minute intervals) and transfers the data to a Mace webserver accessible to GCWA:

- Date & Time
- Meter Battery Voltage
- Meter Solar Power Voltage
- Water velocity through the meter
- Flow rate through the meter
- Total gallons through the meter (since last reset)
- Total Acre-ft through the meter (since last reset)

GCWA can continuously monitor (manually) water usage (if needed), and has provided each customer with online access to their individual meter so that the customer may also track meter readings (if desired). GCWA has also developed computer programs and processing techniques to automatically download, archive, and process data into water accounting summaries by meter, farmer, canal system location, and time period. Currently downloaded data is transferred into GCWA's water accounting system, which tracks the movement of water through the GCWA canal system. This potentially allows GCWA to better identify locations within its canal system where water is being either lost or utilized inefficiently. This information will be incorporated into a drought contingency planning process undertaken by GCWA (under a separate contract with the US Bureau of Reclamation), due for completion in 2018.

The remainder of this report provides an analysis of metered water usage by GCWA agricultural customers, primarily for the purpose of rice field irrigation. The analysis is limited to 2017. GCWA is using the data collected during 2017, as well as the "lessons learned" regarding meter installation, placement, and data processing, to improve its metering program during 2018.

4.2 2017 IRRIGATION WATER USAGE

For 2017, GCWA customers utilized 47,407.91 acre-ft of water for irrigation purposes, as recorded through GCWA meters. Table 4-1 presents GCWA irrigation customer usage by crop season and canal location. Usage data shown in Table 4-1 reflects the quantity of water that was billed to irrigators, rather than the exact quantity of water that passed through meters (See Next Section). Also the computed "Combined" Usage Per Acre is the total water applied to fields on which first and second crop rice was planted and irrigated.

Table 4-1– GCWA 2017 Irrigation Water Usage

	Acreage		Usage (acre-ft)		Usage Per Acre (acre-ft/acre)		
System	1st Crop	2nd Crop	1st Crop	2nd Crop	1st Crop	2nd Crop	Combined
Juliff	8386.02	2462.89	22300.36	5364.59	2.66	2.18	4.84
Chocolate Bayou	1745.81	773.57	5844.42	2092.43	3.35	2.70	6.05
A&B System	2755.03	1331.74	7345.19	2768.05	2.67	2.08	4.75
Total	12,886.86	4568.20	35489.97	10225.07	2.75	2.24	4.99

4.3 GCWA'S HISTORICAL METHOD FOR ESTIMATING WATER USAGE

Prior to the installation of meters, and at least since 2006, GCWA utilized a mathematical formula to estimate water usage by irrigators. The numerical formula was based on the number of irrigated acres for first and second crop, and also included water attributed to a 2nd or 3rd flush of the rice fields. The formula was as follows:

$$V = 4.5\frac{acre-ft}{acre}(CA) + 0.2 \cdot 4.5\frac{acre-ft}{acre}(FA) + 0.35 \cdot 4.5\frac{acre-ft}{acre}(A_2)$$

Where "V" is the volume of water used by an irrigator (in acre-ft), "CA" is the total number of certified acres irrigated, "FA" is the number of acres to which a 2nd or 3rd flush is applied, and "A_2" is the number of acres used for growing a second crop. GCWA would utilize this formula to compute the total volume attributed to each irrigator, and would then invoice the irrigator based on the volume multiplied by the per-acre-ft water price (which was established annually by GCWA). GCWA decided to utilize the ratio of 4.5 acre-ft/acre and

the "0.2" or "0.35" modifiers for the flush and second crop, respectively, based upon years of irrigation data analysis conducted by current GCWA Assistant General Manager David Sauer and others.

Per GCWA's historical formula, given the total acreage irrigated in 2017 (Table 4-1), GCWA customers should have used 69,297 acre-ft of water. From Table 1, the total usage actually was 45,715.04 acre-ft, or a savings of 23,582.1 acre-ft of water. A large portion of this savings is likely due to the use of irrigation meters to record diverted quantities, as provided through this TWDB grant.

In comparing the above equation to the irrigation water usage data shown in Table 4-1, a few specific results are notable. For example, if you only consider irrigation for first crop, then per the GCWA formula the acre-ft/acre usage equals 4.5; this value is significantly higher than the metered 1st crop usage per acre shown in Table 4-1. In addition, if all irrigated fields were used with a 1st crop, 2nd flush, and for 2nd crop planting, the GCWA formula determines that the acre-ft per acre usage is 6.975; this number is also significantly higher than the "Combined" usage data from Table 4-1 (which only considers those fields on which 2nd crop rice were grown). It is interesting to note, however, that the metered usage for 2nd crop (2.08 to 2.70 in Table 1) agrees well with the 2.475 acre-ft/acre usage from the GCWA formula when combining the 2nd flush and 2nd crop terms. This suggests that GCWA's formula was more accurate in assessing 2nd crop usage, yet less accurate in assessing water usage for first crop irrigation. This finding for 2017 data may be the result of Hurricane Harvey, which largely wiped-out fields, which then required flushing prior to planting the 2nd crop. GCWA expects that 2nd crop watering demands would have been lower had Hurricane Harvey not occurred in August 2017.

Based on the data from the 2017 GCWA meter readings, a more appropriate formula for estimating irrigation water usage would be:

$$V = 2.9\frac{acre-ft}{acre}(CA) + 0.3 \cdot 2.9\frac{acre-ft}{acre}(FA) + 0.5 \cdot 2.9\frac{acre-ft}{acre}(A_2)$$

Where all terms are as previously defined. GCWA considers the reduction in usage coefficients in the above formula, compared to those in its' historical formula, reflective of water conservation efforts for rice irrigation, including the usage of meters for all diversions.

4.4 IRRIGATION FORECASTING & BILLING FOR 2017

2017 was the first year in which GCWA has invoiced customers based on meter readings. GCWA also implemented an irrigation rate structure that incentivizes conservation, using a tiered pricing based on the average acre-ft/certified acre usage from each meter. GCWA is implementing a similarly incentivizing rate structure for 2018, and providing customers with either discounts or increases from the base rate depending upon metered usage per certified acre. 2017 also resulted in improved water usage forecasting by GCWA, based on the need to request permission to divert from the Brazos Watermaster. Specifically, GCWA developed a system where irrigators had to report to GCWA by noon Monday there

expected water needs for the following week, so that GCWA could determine the appropriate diversion quantity to request from the Watermaster.

It was GCWA's intention to use Mace meter data to generate automatic invoices for individual irrigation customers during 2017. GCWA developed such capabilities, however refrained from generating invoices in this manner after noticing that many meters were recording a small amount of water movement at times when customers were not actively irrigating. GCWA is investigating the cause of such errant meter readings, assuming that either the meter installation/piping is leaking (which would necessitate repairs to minimize water waste) or that meter hardware and software are faulty (which could necessitate warranty repairs or software updates). As a result of these errant meter readings, GCWA in 2017 only billed customers based on the differences in meter readings as determined by GCWA staff who manually read meters upon initiating and terminating water deliveries to irrigators. The difference between metered usage (47,407.91 acre-ft) and billed usage (45,751.04 acre-ft) amounts to 1,692.87 acre-ft of unbilled water, or 3.6% of the total metered quantity.

Figure 4-1 presents the daily diversion history of water through meter J-DH#1 from December 2016 through March 2018. In focusing on 2017, there were two periods during which the irrigator using this meter was actively diverting water. However there were also periods in January when the meter recorded a small amount of diversion (0.3 to 0.5 acre-ft/day – Figure 4-1B). GCWA decided these small diversion readings were not to be included in billing for this customer. The meter also recorded a negative reading after ceasing diversions on 4/11/2017, and recorded a slightly positive reading on 4/13/2017 (after irrigation diversions had ceased). These readings were also not included in billings made to this irrigator.

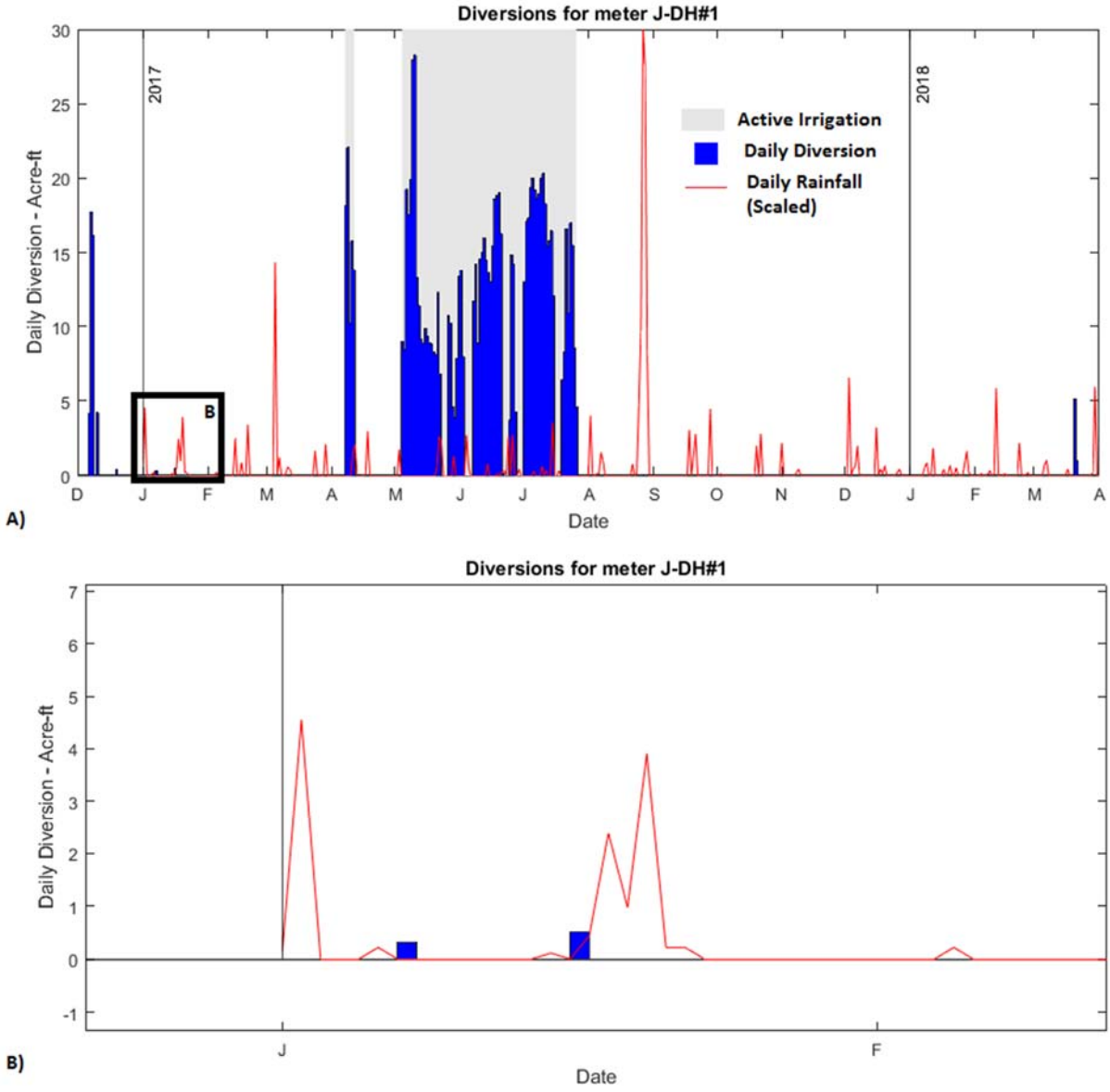

Figure 4-1– Daily Diversions for meter J-DH#1 with scaled local rainfall data A) December 2016-March 2018, B) Close-up of January 2017 showing small daily diversions outside of active irrigation periods. Rainfall data obtained from Station #190 on the Harris County Flood Control District Flood Warning System. The Station is located along Clear Creek at US 288 along the Harris-County and Brazoria County border.

Figure 4-1 is also interesting in that it demonstrates how diversions may be altered by local rainfall events. For example, during the main irrigation period for 2017 (May through July), diversions ceased for typically 1-2 days after most moderate rain events. This result is as expected as rainfall limits the need for irrigation water.

Whereas Figure 4-1 demonstrated how meter readings outside of active irrigation periods may be relatively small, Figure 4-2 shows that this is not always the case. For meter

P.O._CC#2, there were significant meter readings during periods when fields were not being actively irrigated. Specifically, over the course of 2017, the meter recorded 56.61 acre-ft of diversions during times when GCWA considered irrigation to be in-active. This results in nearly 14.5% of the total annual metered water being un-billed by GCWA.

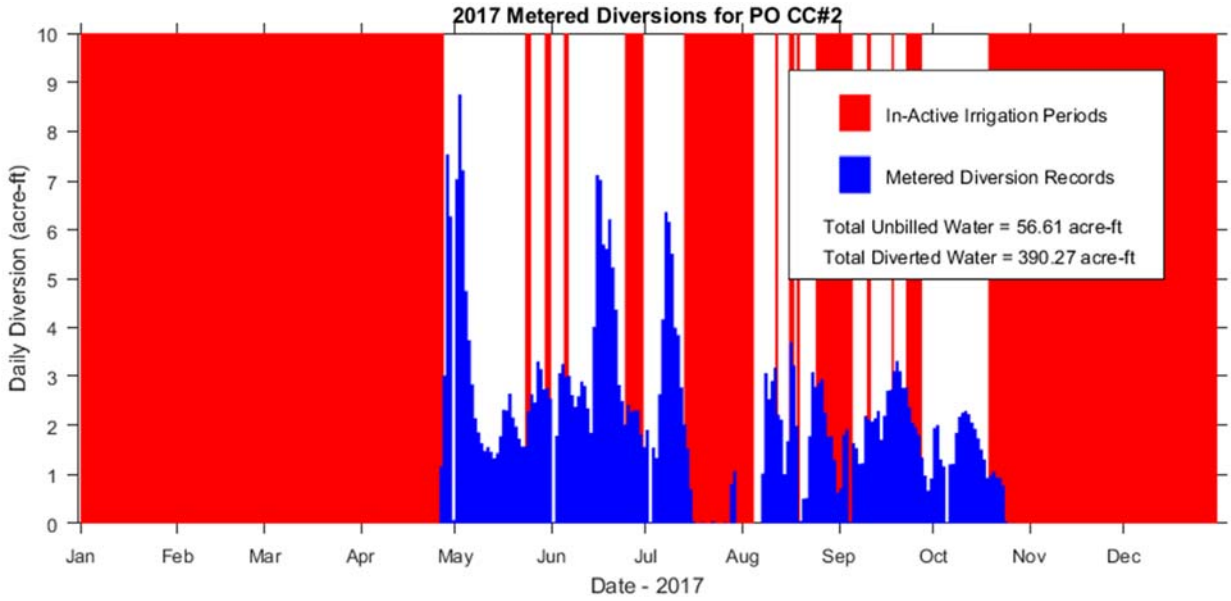

Figure 4-2 – Daily diversions for meter PO CC#2 with times of in-active irrigation. Significant diversions were recorded with this meter during times when irrigation was reportedly in-active.

To determine times of irrigation activity, GCWA staff would physically record the time and meter reading when irrigators requested diversion to commence and cease. In the case of PO CC#2, GCWA staff made 13 sets of such measurements, requiring expenditure of staff time and resources. GCWA is investigating the discrepancies between staff and meter records, and will develop revised invoicing policies for 2018 based on these investigations.

Another difficulty regarding the use of the above equation to estimate agricultural water usage is that GCWA has no way of monitoring water delivery efficiency, defined as a comparison of the amount of water pumped into its canal system versus the amount of water used in irrigation of rice fields. GCWA's historical practice has been to divert water from the Brazos River to the extent that the water is needed to fill canals and transport water down to customers. The decisions regarding how much to divert and when were typically made based on the experience of the GCWA canal division staff and not based on the quantity of water diverted. Through the installation of the meters, and better tracking of water diversions through the Brazos Watermaster Program, GCWA should be able to better quantify water consumption and therefore water diversion demands. Doing so is one of the GCWA staff efforts to be undertaken during the 2018 GCWA irrigation season.

4.5 CONCLUSIONS & PLANS

In general, analysis of the irrigation data collected during 2017 yields identical conclusions as presented in the 2016 metering report – namely that meter usage suggests lower water usage per acre than previously computed by GCWA. Reasons for the lower usage could be: 1) generally wetter conditions during the irrigation season, 2) effective measures by irrigators in lowering irrigation water usage, 3) incentivizing water conservation through direct invoicing based on irrigation meter data, and 4) incentivizing water conservation through a tiered pricing structure based on the metered usage per certified acre.

As shown in this report, analysis of meter data indicates that meters are recording water passage at times when irrigation is not supposed to be active. For 2017, GCWA invoiced irrigators for nearly 97% of all water recorded by its irrigation meters. The invoicing process, however, is necessarily more manually-intensive in that GCWA staff have to record the times of manual meter readings in order to exclude from invoices any recorded flows that occurred outside of those times. GCWA will continue to use meter data to educate irrigators on their water usage and possible further conservation best practices.

During 2018, GCWA will continue to investigate the discrepancies between recorded and invoiced water usage by meter, and will strive to increase the percentage of metered water invoiced to irrigators. GCWA may also adjust its computer programs for processing meter data so as to “filter-out” insignificant meter readings recorded during times outside of the typical irrigation season. Lastly, GCWA will analyze meter data in conjunction with diversion data from its Brazos River pump stations in order to increase irrigation efficiency.

5 2016 Annual Report – TWDB Grant 1513581822

Prepared by: Jordan Furnans, PhD, PE, PG

Total 2016 Water Savings from Project: **31,969.17 acre-ft**

5.1 INTRODUCTION

This report summarizes the state of the agricultural diversion metering program of the Gulf Coast Water Authority (GCWA), developed through partial support from the Texas Water Development Board via Agricultural Water Conservation Grant #1513581822. GCWA initiated the agricultural diversion metering program in 2015 upon receipt of this TWDB grant. During 2015, GCWA purchased and installed a limited number of meters, and in a report dated 2/5/2016 reported a mean water usage of 2.8 acre-ft/acre irrigated during the first crop of the 2015 irrigation season.

As of 1/1/2017, GCWA has installed and continually monitors 137 Agriflo water meters developed by Mace (currently owned by In-Situ, Inc.). Each meter automatically records the following data (at 15-minute intervals) and transfers the data to a Mace webserver accessible to GCWA:

- Date & Time
- Meter Battery Voltage
- Meter Solar Power Voltage
- Water velocity through the meter
- Flow rate through the meter
- Total gallons through the meter (since last reset)
- Total Acre-ft through the meter (since last reset)

GCWA can continuously monitor (manually) water usage (if needed), and has developed computer programs and processing techniques to automatically download, archive, and process data into water accounting summaries by meter, farmer, canal system location, and time period. Currently downloaded data is transferred into GCWA's water accounting system, which tracks the movement of water through the GCWA canal system. This allows GCWA to better identify locations within its canal system where water is being either lost or utilized inefficiently. This information will be incorporated into a drought contingency planning process undertaken by GCWA (under a separate contract with the US Bureau of Reclamation), due for completion in 2018.

The remainder of this report provides an analysis of metered water usage by GCWA agricultural customers, primarily for the purpose of rice field irrigation. The analysis is limited to 2016. GCWA is using the data collected during 2016, as well as the "lessons learned" regarding meter installation, placement, and data processing, to improve its metering program during 2017. Within 2017, GCWA intends to use the data from the irrigation meters in its process of formulating water-usage invoices for each customer. GCWA has developed a tiered water pricing structure for use during 2017, designed to further encourage water conservation amongst irrigators.

5.2 IRRIGATOR COMMENTS

While GCWA has not conducted a formal interview with each irrigation customer regarding the usage of water meters, GCWA has received positive feedback from some rice farmers. Long-time GCWA customers Cliff & Wade Mock were interviewed on March 20, 2017 in preparation for the compilation of this report. They expressed gratitude to GCWA regarding the meters, and attributed their installation and usage to the more efficient water usage on their irrigated lands. Wade Mock commented that prior to meter installation, farmers had no incentives to regulate their water usage, or even to concern themselves with how much water they would deliver to fields. Their gratitude stemmed from their ability to monitor and better regulate their water usage and requests from GCWA, and thus their gained ability to control their personal water costs based on usage. GCWA's previous method for computing irrigation water costs (see below) did not financially encourage conservation or other related activities (such as field leveling to minimize water usage).

5.3 GCWA'S HISTORICAL METHOD FOR ESTIMATING WATER USAGE

Prior to the installation of meters, and at least since 2006, GCWA utilized a mathematical formula to estimate water usage by irrigators. The numerical formula was based on the number of irrigated acres for first and second crop, and also included water attributed to a 2nd or 3rd flush of the rice fields. The formula was as follows:

$$V = 4.5\frac{acre-ft}{acre}(CA) + 0.2 \cdot 4.5\frac{acre-ft}{acre}(FA) + 0.35 \cdot 4.5\frac{acre-ft}{acre}(A_2)$$

Where "V" is the volume of water used by an irrigator (in acre-ft), "CA" is the total number of certified acres irrigated, "FA" is the number of acres to which a 2nd or 3rd flush is applied, and "A_2" is the number of acres used for growing a second crop. GCWA would utilize this formula to compute the total volume attributed to each irrigator, and would then invoice the irrigator based on the volume multiplied by the per-acre-ft water price (which was established annually by GCWA). GCWA decided to utilize the ratio of 4.5 acre-ft/acre and the "0.2" or "0.35" modifiers for the flush and second crop, respectively, based upon years of irrigation data analysis conducted by current GCWA Assistant General Manager David Sauer and others.

The above equation, as it is based only on certified acreage and past knowledge of rice irrigation usage, does not in any way incentivize water conservation among GCWA

customers. The customers were charged identically whether they utilized more or less water than that dictated by the above formula. Therefore, if additional water usage were indicative of a greater crop yield, farmers would have been actually incentivized to use more water. Also the use of the above equation does not incentivize laser leveling of fields, which is commonly known to minimize water usage.

Another difficulty regarding the use of the above equation to estimate agricultural water usage is that GCWA has no way of monitoring water delivery efficiency, defined as a comparison of the amount of water pumped into its canal system versus the amount of water used in irrigation of rice fields. GCWA's historical practice has been to divert water from the Brazos River to the extent that the water is needed to fill canals and transport water down to customers. The decisions regarding how much to divert and when were typically made based on the experience of the GCWA canal division staff and not based on the quantity of water diverted. Through the installation of the meters, and better tracking of water diversions through the Brazos Watermaster Program, GCWA has been able to better quantify water consumption and therefore water diversion demands. This has led to the reduction of diversions from the Brazos River for irrigation purposes.

5.4 GCWA'S 2016 AGRICULTURAL WATER USAGE – METERED

Of the 137 Agriflo meters installed by GCWA, 102 were used in 2016 to measure the volume of water transported onto individual irrigated fields. Meters not used to track deliveries to individual fields may have been installed at strategic places within the GCWA canal system so as to track water losses/gains in between specific canal locations. Alternatively, gauges may be located at the mouth of canal sections upstream of additional meters; such gauges would be used to track delivery efficiency between gauges.

Table 5-1 provides the 2016 water usage recorded by each of the 102 meters, along with the certified acreage of the field(s) irrigated from each meter. Also shown are the depths of water applied to each field (acre-ft/acre) based on the meter readings, as well as the computation of water usage based on GCWA's historical formula. In calculating the applied water depths for fields for which a 2nd crop was grown, the total irrigated acreage for that field was computed as the SUM of the certified First Crop acreage and the acreage utilized during Second Crop. Table 5-2 provides 2016 water usage, limited only to First Crop. Table 5-3 provides water usage by meter for fields utilized during Second Crop. The following paragraphs detail observations of interest that were made upon reviewing this data compiled from the irrigation meters.

Per GCWA records, the total certified acres irrigated in 2016 was 15,791.20 acres. Combined with the total recorded water usage (62,484.00 acre-ft), this yields an average depth of water used of 3.96 ft (or acre-ft/acre, combined over both First and Second Crop). Through application of GCWA's historical formula, irrigating 15,791.20 acres (and accounting for those acres requiring 2nd flushes or used for 2nd crop production) would require 94,453.13 acre-ft of water. Thus by switching to meter usage, GCWA can now show that they needed 31,969.13 acre-ft **LESS** water than they would have previously thought,

based on their historical formula. Assuming the GCWA historical formula is approximately accurate of past GCWA customer usage for rice irrigation, this amount represents the quantity of water saved by GCWA customers as compared to previous years.

As reported in GCWA's 2015 Annual Report to TWDB regarding this Agricultural Water Conservation Grant, during the 2015 first-crop irrigation season GCWA customers utilized 2.8 acre-ft/acre. Based on data utilized to compute data shown in Table 5-2, GCWA's average water use for the 2016 first-crop irrigation season was 2.68 acre-ft/acre. This indicates a slight savings in applied water depth, which may be indicative of the metering program's effect on overall water usage.

Based on the data shown in Table 5-1, there is a large range in water usage amongst GCWA irrigation customers. For example, fields irrigated through meter "J-MF#1" used 10.14 acre-ft/acre in 2016, whereas fields irrigated through meter "J-RD#2" used only 0.6 acre-ft/acre. The cause for this wide variation in usage was not investigated by GCWA until the end of the 2016 irrigation season. Based on lessons learned by GCWA during those investigations, GCWA decided to undertake monthly investigations of individual fields exhibiting either high or low water usage rates during 2017. Eighteen (18, or 18%) of the meters suggested greater water use than implicit using GCWA's historical formula.

5.5 CONCLUSIONS & PLANS

The data presented in Table 5-1, Table 5-2, and Table 5-3 demonstrate the in-suitability of approximating irrigation water usage through the use of a historical formula, now that actual metered data is available. Comments from selected irrigators also suggest that the use of meters has better allowed them to control their own water usage, and to incentivize conservation. In general, GCWA is pleased with the metering program it has developed, and feels they have a better understanding of their customer water needs (and the timing of needs) as a result.

The large range of irrigated depths (acre-ft/acre) amongst GCWA's customers and fields warrants future scrutiny. During 2017, GCWA expects to investigate (monthly) the cause of this range, and to try and lower the irrigated depths for customers who may not yet be implementing best management practices with regard to water usage. GCWA has also developed an irrigation water rate structure that will monetarily incentivize conservation amongst irrigators. Implementation of this rate structure may further reduce irrigation demands and force irrigators to better monitor water usage. Comparing 2017 data with the 2016 data shown in Table 5-1, Table 5-2, and Table 5-3, in combination with an analysis of rainfall patterns for each year, will also provide further insight into the efficacy of a metering program in reducing water usage in rice irrigation operations.

Table 5-1 – 2016 Water usage by GCWA's Rice Irrigation Customers as recorded by Agriflo Mace Meters.

			Meter Readings		GCWA Historical Formula	
Rank	Meter	Certified Acreage	Usage (acre-ft)	Usage (acre-ft/acre)	Usage (acre-ft)	Usage (acre-ft/acre)
1	J-MF#1	63.00	639.08	**10.14**	283.50	4.50
2	J-CC#2	41.03	693.19	**8.45**	286.17	3.49
3	J-MT#6	24.62	372.85	**7.58**	149.54	3.04
4	CB-RTR#8	8.00	50.87	**6.36**	36.00	4.50
5	B-CS#1	27.86	347.95	**6.24**	169.25	3.04
6	A-WADE#2	38.67	475.71	**6.15**	234.98	3.04
7	J-MT#3	100.00	1,227.03	**6.14**	607.43	3.04
8	J-JO#2	34.31	412.19	**6.01**	239.26	3.49
9	CB-RTR#5	8.00	45.84	**5.73**	36.00	4.50
10	J-MH#1	31.37	158.73	**5.06**	169.40	5.40
11	J-TJ#5	28.40	142.79	**5.03**	127.80	4.50
12	J-CC#1	245.46	2,302.05	**4.69**	1712.15	3.49
13	J-MF#2	23.00	106.54	**4.63**	103.50	4.50
14	J-TJ#4	56.25	258.10	**4.59**	303.75	5.40
15	B-ST#1	76.10	652.69	**4.29**	530.78	3.49
16	J-TJ#6	46.95	192.05	**4.09**	211.28	4.50
17	J-SH#1	125.00	498.99	**3.99**	675.00	5.40
18	J-ST#2	63.00	495.58	**3.93**	382.81	3.04
19	CB-RTF#3	12.00	46.58	**3.88**	54.00	4.50
20	J-MT#2	115.00	888.29	**3.86**	802.27	3.49
21	CB-MW#1	57.50	426.52	**3.71**	401.15	3.49
22	J-MH#2	60.00	220.48	**3.67**	324.00	5.40
23	A-WADE#6	76.50	552.37	**3.61**	464.63	3.04
24	CB-RTF#4	15.00	53.04	**3.54**	67.50	4.50
25	J-JO#1	327.66	2,154.37	**3.29**	2285.43	3.49
26	B-WADE#1	218.28	1,395.89	**3.20**	1326.32	3.04
27	J-TJ#3	41.49	130.27	**3.14**	224.05	5.40
28	B-CP#1	192.22	587.30	**3.06**	864.99	4.50
29	CB-MW#5	195.98	1,194.08	**3.04**	1367.39	3.49
30	J-TJ#2	88.65	267.89	**3.02**	478.71	5.40
31	CB-HF#1	464.85	1,400.77	**3.01**	2091.83	4.50
32	J-NB#2	110.00	331.04	**3.01**	495.00	4.50
33	J-CF#3	65.76	193.72	**2.95**	355.10	5.40
34	J-JO#3	36.05	206.23	**2.86**	251.56	3.49
35	B-HF#1	413.95	1,170.92	**2.83**	1862.78	4.50
36	CB-CS#1	564.52	3,127.00	**2.77**	3939.50	3.49
37	B-DH#1	139.08	765.07	**2.75**	844.75	3.04
38	B-DJ#2	182.51	762.74	**2.75**	970.83	3.50
39	B-CS#2	109.41	585.44	**2.68**	664.70	3.04
40	B-CF#2	75.21	200.91	**2.67**	338.45	4.50
41	J-RD#1	167.86	890.26	**2.65**	1171.27	3.49
42	A-WADE#4	90.20	474.27	**2.63**	629.06	3.49
43	J-TJ#1	50.24	263.68	**2.61**	305.78	3.03
44	J-JO#4	392.66	2,049.53	**2.61**	2737.93	3.49
45	B-ST#2	121.60	620.44	**2.57**	845.85	3.50
46	J-RM#2	130.48	664.07	**2.55**	792.21	3.04
47	J-RD#4	30.47	154.67	**2.54**	212.54	3.49
48	J-CF#2	115.53	292.59	**2.53**	623.86	5.40
49	J-JB#1	266.97	675.04	**2.53**	1201.37	4.50
50	A-WADE#5	81.73	405.69	**2.48**	496.57	3.04
51	J-RM#1	271.02	1,329.77	**2.45**	1647.17	3.04

Table 5-1 – 2016 Water usage by GCWA's Rice Irrigation Customers as recorded by Agriflo Mace Meters, Continued

			Meter Readings		GCWA Historical Formula	
Rank	Meter	Certified Acreage	Usage (acre-ft)	Usage (acre-ft/acre)	Usage (acre-ft)	Usage (acre-ft/acre)
52	B-DL#1	121.80	297.53	**2.44**	548.10	4.50
53	J-GFR#3	884.88	2,160.17	**2.44**	4778.35	5.40
54	J-CF#4	65.76	157.53	**2.40**	355.10	5.40
55	DL-MW#1	197.28	940.69	**2.38**	1198.35	3.04
56	J-CF#1	162.26	385.26	**2.37**	876.20	5.40
57	B-CF#1	454.11	1,704.18	**2.37**	2867.99	3.99
58	J-N-DB#1	56.29	131.43	**2.33**	253.31	4.50
59	CB-C-H#1	147.00	686.45	**2.33**	893.03	3.04
60	J-MT#1	194.08	906.70	**2.33**	1354.26	3.49
61	B-MF#1	496.00	1,751.83	**2.32**	3084.21	4.09
62	A-WADE#3	66.39	308.06	**2.32**	403.32	3.04
63	J-A-DB#1	631.94	1,446.87	**2.29**	3412.48	5.40
64	DL-RTF#1	67.80	152.49	**2.25**	366.12	5.40
65	B-MF#2	80.00	178.55	**2.23**	360.00	4.50
66	J-NB#1	106.11	234.25	**2.21**	572.99	5.40
67	CB-MW#4	141.80	617.32	**2.18**	988.93	3.49
68	CB-MW#2	190.80	825.53	**2.16**	1330.60	3.49
69	J-VP#2	178.14	766.77	**2.15**	1241.96	3.49
70	B-DJ#1	90.90	384.48	**2.12**	551.92	3.04
71	J-GFR#1	480.58	1,013.85	**2.11**	2595.13	5.40
72	J-ST#1	164.54	584.05	**2.09**	920.52	3.30
73	B-DJ#3	108.36	451.64	**2.08**	658.43	3.04
74	J-DB#1	249.09	515.34	**2.07**	1120.91	4.50
75	J-ST#3	271.00	1,024.72	**2.07**	1817.03	3.67
76	CB-RTR#9	25.00	51.02	**2.04**	112.50	4.50
77	A-WADE#1	249.79	996.81	**2.00**	1741.38	3.49
78	J-N-TJ#1	784.09	2,699.96	**1.97**	5158.87	3.76
79	J-RD#3	70.61	277.63	**1.96**	492.77	3.49
80	J-VP#1	142.11	541.56	**1.91**	990.89	3.49
81	J-DB#2	248	932.01	**1.88**	1507.32	3.04
82	A-JR#2	59.00	211.87	**1.80**	411.43	3.49
83	J-MT#4	153.11	512.94	**1.67**	930.38	3.04
84	J-JM#1	180.96	481.15	**1.60**	1165.94	3.88
85	J-MT#5	38.94	123.51	**1.58**	236.78	3.03
86	B-DJ#4	193.98	612.77	**1.58**	1179.08	3.04
87	J-JM#2	159.36	496.71	**1.56**	1111.54	3.49
88	J-DH#1	409.74	1,264.24	**1.54**	2856.31	3.49
89	J-CF#5	66.27	101.35	**1.53**	298.22	4.50
90	A-JR#1	80.00	241.32	**1.51**	557.53	3.49
91	CB-CK#1	60.00	177.64	**1.48**	364.55	3.04
92	J-JS#1	176.00	510.06	**1.45**	1227.50	3.49
93	CB-RTR#4	22.60	30.18	**1.34**	101.70	4.50
94	B-MF#3	232.19	308.05	**1.33**	1044.86	4.50
95	CB-MW#3	160.40	416.81	**1.30**	1118.75	3.49
96	CB-RTR#1	26.10	32.98	**1.26**	117.45	4.50
97	CB-RTF#2	46.00	56.39	**1.23**	207.00	4.50
98	B-RTR#1	34.30	40.00	**1.17**	154.35	4.50
99	CB-RTR#7	41.70	25.61	**0.61**	187.65	4.50
100	J-RD#2	106.38	127.40	**0.60**	740.13	3.50
101	J-CF#6	65.26	25.66	**0.39**	352.40	5.40
102	CB-RTF#1	31.00	9.52	**0.31**	139.50	4.50

Table 5-2 – 2016 Water usage by GCWA's Rice Irrigation Customers – As recorded by Agriflo Mace Meters. FIRST CROP ONLY

			Meter Readings		GCWA Historical Formula	
Rank	Meter	Certified Acreage	Usage (acre-ft)	Usage (acre-ft/acre)	Usage (acre-ft)	Usage (acre-ft/acre)
1	J-MF#1	63.00	639.08	10.14	283.50	4.50
2	J-MT#6	24.62	247.88	10.07	110.79	4.50
3	J-CC#2	41.03	326.87	7.97	221.56	5.40
4	J-JO#2	34.31	264.80	7.72	185.27	5.40
5	B-CS#1	27.86	213.67	7.67	125.37	4.50
6	A-WADE#2	38.67	277.54	7.18	174.02	4.50
7	B-ST#1	76.10	498.99	6.56	410.94	5.40
8	CB-RTR#8	8.00	50.87	6.36	36.00	4.50
9	CB-RTR#5	8.00	45.84	5.73	36.00	4.50
10	J-MT#3	100.00	535.32	5.35	450.00	4.50
11	J-TJ#5	28.40	142.79	5.03	127.80	4.50
12	J-TJ#1	50.24	248.50	4.95	226.08	4.50
13	J-MH#1	31.37	151.14	4.82	169.40	5.40
14	J-CC#1	245.46	1158.01	4.72	1325.48	5.40
15	J-MF#2	23.00	106.54	4.63	103.50	4.50
16	J-ST#2	63.00	289.39	4.59	283.50	4.50
17	J-TJ#4	56.25	258.10	4.59	303.75	5.40
18	J-JO#1	327.66	1400.75	4.28	1769.36	5.40
19	J-MT#2	115.00	475.12	4.13	621.00	5.40
20	J-TJ#6	46.95	192.05	4.09	211.28	4.50
21	J-SH#1	125.00	498.99	3.99	675.00	5.40
22	CB-CS#1	564.52	2224.68	3.94	3048.41	5.40
23	CB-RTF#3	12.00	46.58	3.88	54.00	4.50
24	CB-MW#1	57.50	218.75	3.80	310.50	5.40
25	CB-RTF#4	15.00	53.04	3.54	67.50	4.50
26	J-RD#1	167.86	592.65	3.53	906.44	5.40
27	J-RD#4	30.47	105.91	3.48	164.54	5.40
28	J-MH#2	60.00	205.96	3.43	324.00	5.40
29	A-WADE#6	76.50	251.22	3.28	344.25	4.50
30	B-DJ#2	182.51	585.20	3.21	821.30	4.50
31	J-JO#3	36.05	114.85	3.19	194.67	5.40
32	B-DH#1	139.08	441.25	3.17	625.86	4.50
33	J-JO#4	392.66	1233.95	3.14	2120.36	5.40
34	J-TJ#3	41.49	130.27	3.14	224.05	5.40
35	B-ST#2	121.60	377.77	3.11	656.64	5.40
36	J-MT#1	194.08	595.61	3.07	1048.03	5.40
37	B-CP#1	192.22	587.30	3.06	864.99	4.50
38	J-TJ#2	88.65	267.89	3.02	478.71	5.40
39	CB-HF#1	464.85	1400.77	3.01	2091.83	4.50
40	J-NB#2	110.00	331.04	3.01	495.00	4.50
41	J-CF#3	65.76	193.72	2.95	355.10	5.40
42	J-RM#1	271.02	797.67	2.94	1219.59	4.50
43	CB-CK#1	60.00	175.11	2.92	270.00	4.50
44	J-RM#2	130.48	378.95	2.90	587.16	4.50
45	A-WADE#4	90.20	261.53	2.90	487.08	5.40
46	J-JS#1	176.00	500.54	2.84	950.40	5.40
47	B-WADE#1	218.28	618.21	2.83	982.26	4.50
48	B-HF#1	413.95	1170.92	2.83	1862.78	4.50
49	B-CF#2	75.21	200.91	2.67	338.45	4.50
50	J-N-TJ#1	784.09	2083.44	2.66	4234.09	5.40
51	CB-MW#5	195.98	517.00	2.64	1058.29	5.40

Table 5-2 – 2016 Water usage by GCWA's Rice Irrigation Customers – As recorded by Agriflo Mace Meters., FIRST CROP ONLY, Continued

			Meter Readings		GCWA Historical Formula	
Rank	Meter	Certified Acreage	Usage (acre-ft)	Usage (acre-ft/acre)	Usage (acre-ft)	Usage (acre-ft/acre)
52	B-CS#2	109.41	279.03	2.55	492.35	4.50
53	J-CF#2	115.53	292.59	2.53	623.86	5.40
54	J-JB#1	266.97	675.04	2.53	1201.37	4.50
55	DL-MW#1	197.28	493.04	2.50	887.76	4.50
56	CB-MW#4	141.80	350.88	2.47	765.72	5.40
57	B-DL#1	121.80	297.53	2.44	548.10	4.50
58	J-GFR#3	884.88	2160.17	2.44	4778.35	5.40
59	B-DJ#1	90.90	220.29	2.42	409.05	4.50
60	J-VP#1	142.11	340.06	2.39	767.39	5.40
61	J-CF#4	65.76	157.00	2.39	355.10	5.40
62	J-CF#1	162.26	385.26	2.37	876.20	5.40
63	J-N-DB#1	56.29	131.43	2.33	253.31	4.50
64	A-WADE#3	66.39	154.70	2.33	298.76	4.50
65	J-RD#3	70.61	163.68	2.32	381.29	5.40
66	J-A-DB#1	631.94	1446.87	2.29	3412.48	5.40
67	J-MT#5	38.94	88.73	2.28	175.23	4.50
68	J-VP#2	178.14	405.88	2.28	961.96	5.40
69	A-WADE#1	249.79	565.67	2.26	1348.87	5.40
70	DL-RTF#1	67.80	152.49	2.25	366.12	5.40
71	J-ST#3	271.00	604.85	2.23	1463.40	5.40
72	B-MF#2	80.00	178.55	2.23	360.00	4.50
73	J-NB#1	106.11	234.25	2.21	572.99	5.40
74	J-ST#1	164.54	355.37	2.16	740.43	4.50
75	CB-MW#2	190.80	411.81	2.16	1030.32	5.40
76	A-JR#1	80.00	171.18	2.14	432.00	5.40
77	J-GFR#1	480.58	1013.85	2.11	2595.13	5.40
78	J-DB#1	249.09	515.34	2.07	1120.91	4.50
79	A-WADE#5	81.73	168.57	2.06	367.79	4.50
80	CB-RTR#9	25.00	51.02	2.04	112.50	4.50
81	A-JR#2	59.00	119.33	2.02	318.60	5.40
82	J-JM#1	180.96	346.92	1.92	977.18	5.40
83	B-MF#1	496.00	950.51	1.92	2678.40	5.40
84	J-MT#4	153.11	279.98	1.83	689.00	4.50
85	B-CF#1	454.11	774.91	1.71	2452.19	5.40
86	J-JM#2	159.36	270.11	1.69	860.54	5.40
87	J-DH#1	409.74	667.53	1.63	2212.60	5.40
88	J-CF#5	66.27	101.35	1.53	298.22	4.50
89	B-DJ#3	108.36	152.31	1.41	487.62	4.50
90	J-DB#2	248	345.65	1.39	1116.00	4.50
91	CB-RTR#4	22.60	30.18	1.34	101.70	4.50
92	B-MF#3	232.19	308.05	1.33	1044.86	4.50
93	CB-RTR#1	26.10	32.98	1.26	117.45	4.50
94	CB-RTF#2	46.00	56.39	1.23	207.00	4.50
95	B-DJ#4	193.98	229.81	1.18	872.91	4.50
96	CB-C-H#1	147.00	173.41	1.18	661.50	4.50
97	B-RTR#1	34.30	40.00	1.17	154.35	4.50
98	J-RD#2	106.38	100.05	0.94	574.45	5.40
99	CB-MW#3	160.40	146.81	0.92	866.16	5.40
100	CB-RTR#7	41.70	25.61	0.61	187.65	4.50
101	J-CF#6	65.26	25.66	0.39	352.40	5.40
102	CB-RTF#1	31.00	9.52	0.31	139.50	4.50

Table 5-3 – 2016 Water usage by GCWA's Rice Irrigation Customers – As recorded by Agriflo Mace Meters. SECOND CROP ONLY

			Meter Readings		GCWA Historical Formula	
Rank	Meter	Certified Acreage	Usage (acre-ft)	Usage (acre-ft/acre)	Usage (acre-ft)	Usage (acre-ft/acre)
1	J-CC#2	41.02	366.32	8.93	41.02	64.61
2	J-MT#3	99.96	691.71	6.92	99.96	157.43
3	A-WADE#2	38.71	198.17	5.12	38.71	60.96
4	J-MT#6	24.60	124.97	5.08	24.60	38.75
5	B-CS#1	27.86	134.28	4.82	27.86	43.88
6	J-CC#1	245.50	1144.04	4.66	245.50	386.67
7	J-JO#2	34.28	147.39	4.30	34.28	53.99
8	A-WADE#6	76.43	301.15	3.94	76.43	120.38
9	CB-MW#1	57.55	207.77	3.61	57.55	90.65
10	J-MT#2	115.09	413.17	3.59	115.09	181.27
11	B-WADE#1	218.45	777.68	3.56	218.45	344.06
12	B-CF#1	264.00	929.27	3.52	264.00	415.80
13	CB-C-H#1	147.00	513.04	3.49	147.00	231.53
14	CB-MW#5	196.26	677.08	3.45	196.26	309.10
15	J-ST#2	63.06	206.19	3.27	63.06	99.31
16	B-MF#1	257.66	801.32	3.11	257.66	405.81
17	A-WADE#5	81.77	237.12	2.90	81.77	128.78
18	B-CS#2	109.43	306.41	2.80	109.43	172.36
19	B-DJ#3	108.45	299.33	2.76	108.45	170.81
20	CB-MW#3	160.38	421.79	2.63	160.38	252.59
21	J-JO#3	36.12	91.38	2.53	36.12	56.89
22	A-WADE#4	90.14	212.74	2.36	90.14	141.98
23	J-DB#2	248.46	586.36	2.36	248.46	391.32
24	B-DH#1	138.98	323.82	2.33	138.98	218.89
25	A-WADE#3	66.39	153.36	2.31	66.39	104.56
26	J-JO#1	327.66	753.62	2.30	327.66	516.07
27	DL-MW#1	197.20	447.65	2.27	197.20	310.59
28	J-RM#2	130.19	285.12	2.19	130.19	205.05
29	CB-MW#2	190.65	413.72	2.17	190.65	300.28
30	J-JO#4	392.11	815.58	2.08	392.11	617.57
31	J-VP#2	177.78	360.89	2.03	177.78	280.00
32	B-ST#1	76.09	153.70	2.02	76.09	119.84
33	B-ST#2	120.13	242.67	2.02	120.13	189.21
34	J-ST#1	114.34	228.68	2.00	114.34	180.09
35	B-DJ#4	194.40	382.96	1.97	194.40	306.17
36	J-RM#1	271.48	532.10	1.96	271.48	427.58
37	CB-CS#1	565.77	902.32	1.89	565.77	891.09
38	CB-MW#4	141.72	266.44	1.88	141.72	223.21
39	B-DJ#2	94.94	177.54	1.87	94.94	149.53
40	J-ST#3	224.53	419.87	1.87	224.53	353.63
41	B-DJ#1	90.71	164.19	1.81	90.71	142.87
42	J-RD#1	168.14	297.61	1.77	168.14	264.82
43	A-WADE#1	249.21	431.14	1.73	249.21	392.51
44	J-RD#3	70.78	113.95	1.61	70.78	111.47
45	J-RD#4	30.48	48.76	1.60	30.48	48.00
46	J-MT#1	194.43	311.09	1.60	194.43	306.23
47	A-JR#2	58.94	92.54	1.57	58.94	92.83
48	J-MT#4	153.26	232.96	1.52	153.26	241.39
49	J-DH#1	408.71	596.71	1.46	408.71	643.71
50	J-JM#2	159.36	226.60	1.42	159.36	251.00
51	J-VP#1	141.90	201.50	1.42	141.90	223.49

Table 5-3 – 2016 Water usage by GCWA's Rice Irrigation Customers – As recorded by Agriflo Mace Meters., SECOND CROP ONLY, Continued

			Meter Readings		GCWA Historical Formula	
Rank	Meter	Certified Acreage	Usage (acre-ft)	Usage (acre-ft/acre)	Usage (acre-ft)	Usage (acre-ft/acre)
52	J-JM#1	119.85	134.23	1.12	119.85	188.76
53	J-N-TJ#1	587.16	616.52	1.05	587.16	924.78
54	J-MT#5	39.08	34.78	0.89	39.08	61.55
55	A-JR#1	79.70	70.14	0.88	79.70	125.53
56	J-TJ#1	50.60	15.18	0.30	50.60	79.70
57	J-RD#2	105.19	27.35	0.26	105.19	165.68
58	J-JS#1	175.93	9.52	0.05	175.93	277.10
59	CB-CK#1	60.03	2.53	0.04	60.03	94.55

6 2016 Annual Report – TWDB Grant 1513581822

Prepared by: L.T. Wilson, PhD
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Total 2015 Water Savings from Project: **Unknown**

**Note: This report was re-formatted from a PDF file submitted to TWDB on 2/5/2016.

6.1 INTRODUCTION

This report summarizes water use and rice yields for first and second crop rice grown in Brazoria County as part of a Gulf Coast Water Authority project funded by TWDB to study the use of remotely accessed water meters in 2015. Nine (9) water meters were used to monitor water applied to nineteen (19) fields distributed on five (5) farms. Seventeen of the 19 fields were planted to the variety Presidio and two to the variety Cheniere. Rice was drill-seeded in late March to early April for 17 fields, with two additional fields planted in early-May. The March and April planted fields were ratoon cropped, while the two May planted fields were not. The amount of water applied for the first crop ranged from 1.10 to 4.56 acre-ft per acre with a mean of 2.80 acre-ft per acre. However, the 1.10 acre-ft /acre of water recorded as received by Field #16 and #17 appears to be in error possible due to one field instead of two fields receiving water from that particular meter. The amount of water applied to the second crop averaged 2.10 acre- ft/acre. Grain yield (at 12% moisture content) for the first crop ranged from 5,832 lb/acre to 9,100 lb/acre, while yield for the second crops were 3,888 lb/acre to 4,536 lb/acre (Table 6-1 and Table 6-2).

6.2 ANALYSIS & DATA

The amount of irrigation water applied during a rice-cropping season is a function of several variables, most noticeable of these being annual precipitation and temperature conditions occurring during the growing season. Normally, approximately 30 to 40 inches of rainfall is received for this area of Texas during a typical year. However, rarely is a year average. The amount of rainfall received in the Alvin area from 2011 through 2015 ranged from 21" to 58",averaging 37" (Figure 6-1). The amount of rain received in 2015 (57.9") is in the upper 10 percentile, while the amount received in 2011 (21.0") is very likely in the lower 10 percentile. An analysis by Wilson et al. (2007) for the Lower Colorado River Authority (LCRA) reported 37" to 40" (3.08-3.33 acre-ft/acre) of irrigation was on average required to grow the first (main) rice crop, as contrasted with the 2.8 acre-ft/acre estimated for 2015 by the Gulf Coast Water Authority project. Had the project been conducted during a typical rainfall year, irrigated water use would have been closer to that reported in the LCRA study. As a further contrast, had rainfall been in the 21" range as occurred during 2011, the amount of irrigation water needed to produce a crop would have been considerably greater.

Table 6-1 – Water meters and associated farms, fields, and field acreage

		Field	
Water Meter (#)	Farm	#	Acreage (acres)
1	FM 517	1	74
		2	134
2	Dump	3	117
		4	106
3	Alvin	5	49
		6	86
4	Alvin	7	98
5	Alvin	8	77
		9	82
6	Home	10	41
		11	56
		12	106
		13	115
		14	43
		15	123
7	Home	16	106
		17	109
8	Freeway	18	32
9		19	70

Figure 2 summarizes irrigation water received for the first and second rice crops and for both crops combined. The nearly two-fold difference comparing combined water used for different growers suggests the potential for major water savings. Equally important, Fig. 3A suggests the presence of a significant relationship between grain yield and amount of irrigation water applied (prob. A review of Table 6-2 illustrates two problems that occurred in the 2015 study. Firstly, a single meter serviced anywhere from 1 to 6 fields. If each field serviced by a single meter had the same soil characteristics, was planted to the same variety, seeded at nearly the same date, and received the same agronomic and pest management, then it would be appropriate to use a single meter for the combined fields. However, such a situation rarely occurs. Similarly, a single harvest for the main crop and for the ratoon crop incorporated the yield of as few as 1 field and as many as 7 fields. Combining both the aggregation of fields within a meter and the aggregation of harvests across fields resulted in 5 sets of main crop yields and water records, and only 4 sets for the ratoon crop. As a consequence, the ability to detect significance differences was greatly reduced.

Table 6-2 – Rice field seeding date, variety planted, first and second grain yield (lbs/acre) and water use (acre-ft/acre)

Field (#)	Seeding Date	Rice Variety	First crop yield (lbs/acre)**	First crop Irrigation (acre-ft/acre)	Second crop yield (lbs/acre)**	Second crop Irrigation (acre-ft/acre)
1	3/28/2015	Presidio	8,136	2.07	4,300	3.49
2	3/28/2015	Presidio				
3	5/8/2015	Presidio	8,100	2,79	NA*	NA*
4	5/8/2015	Presidio				
5	4/1/2015	Presidio	5,832	3.24	4,001	1.92
6	4/1/2015	Presidio				
7	4/2/2015	Presidio		4.56		3.36
8	4/2/2015	Presidio		3.57		2.36
9	4/2/2015	Presidio				
10	4/1/2015	Cheniere	9,100	2.03	4,536	1.65
11	4/1/2015	Presidio	8,300		3,888	
12	3/31/2015	Presidio				
13	4/1/2015	Presidio				
14	3/30/2015	Presidio				
15	4/1/2015	Presidio				
16	3/30/2015	Presidio		1.10		1.58
17	3/30/2015	Presidio				
18	4/1/2015	Presidio	7,639	3.05	4,260	1.10
19	4/1/2015	Presidio		2.80		1.82

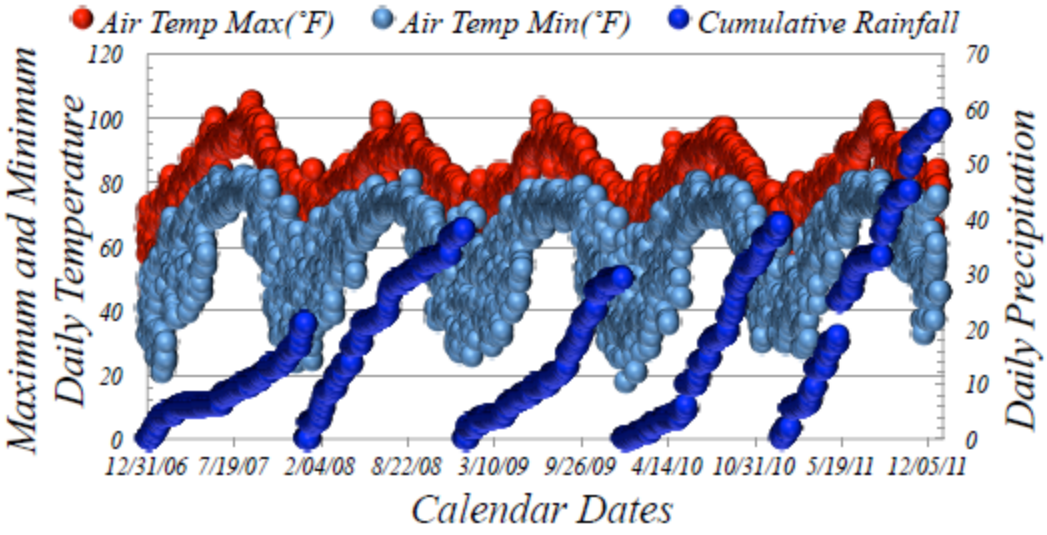

Figure 6-1 – 2011-2015 daily maximum and minumum temperatures and cumulative rainfall for Alvin, Texas

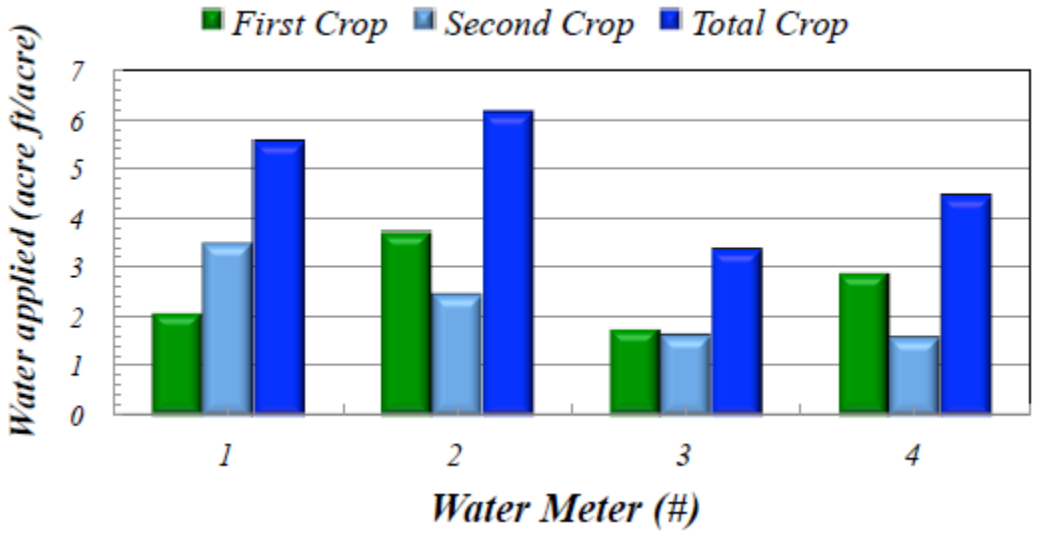

Figure 6-2 – Irrigation water applied to rice during the first and second crops, and combined for both crops.

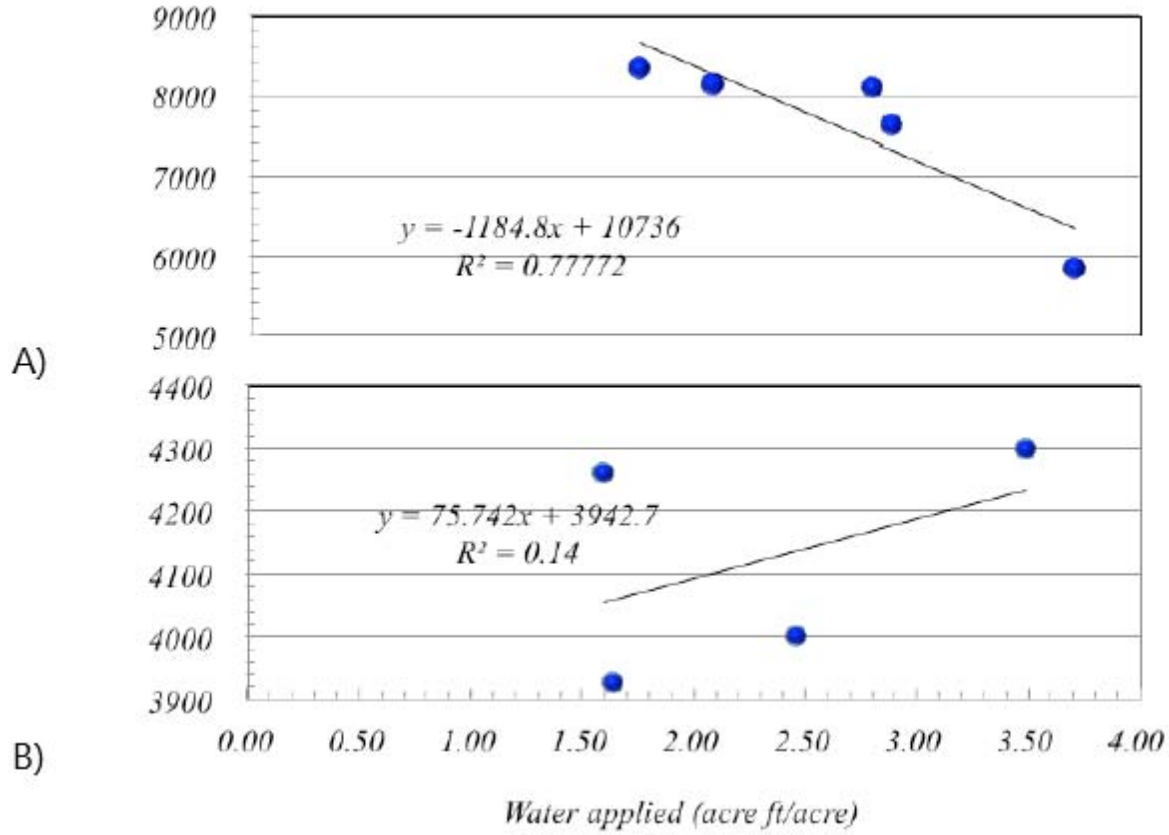

Figure 6-3 – Relationship between irrigation water applied for A) first and B) second crop grain yield.

6.3 RECOMMENDATIONS

Our recommendation for 2016 is for funding to be provide to locate separate meters for as many fields as possible at both the inlet and outlet of fields to generate data to estimate water uptake by the rice crop and lost through percolation, and the amount lost through the outlet. We also recommend meters be placed in association with rice fields that differ in terms of grade (bench, constant grade, and contour leveling), soil texture (degrees of sand/silt/clay content and possibly depth to hardpan), varietal type (inbred vs hybrid), and nutrient management. If the study is structure as proposed, the quality of information produced will help to set a new standard of water system and delivery management, and improved field- and farm-level water use management.

Optimally used water-meters offers several advantages to growers, consultants, and water providers alike. From a grower/consultant perspective, accurate estimates of water delivery rates combined with detailed information on how the rice plant responses to water depth and water stress can be used to optimize crop yield. From a water provider perspective, having ready and simultaneous access to water use information along the

length and breadth of the delivery system and the ability to manage delivery from a centralized facility can help to optimize the water delivery particularly during critical growth stages such as immediately prior to peak tillering and during panicle formation and heading. A logical endpoint for such a system will likely be SCADA controls that allows for balanced delivery of water up and down the system.

6.4 REFERENCES CITED

Wilson, L. T., Y. Yang, J. W. Stansel, J. Wang, P. Lu, and M. Gallegos. 2007. Rice Water Conservation Analyzer: Model Documentation. Texas A&M University System, Texas Agricultural Experiment Station, Agricultural Research and Extension Center at Beaumont, 1/5/07, 50 pp.

7 Response to TWDB Comments

GCWA submitted the Draft Final Report for this contract to TWDB on April 3, 2020. On June 29, 2020 TWDB provided GCWA and its subcontractor for this project (LRE Water) with comments on the Draft Final Report. The comments are listed below, and were addressed by expanding Chapter 1 and including more project summary material. Along with each comment, GCWA has provided the section of this Final Report which addresses the comment.

Comments & Responses:

- Consider providing a clear and detailed discussion on the total number of meters installed, overall water savings, and other impacts seen throughout study in the Summary section of the report.

  GCWA Response: Comment addressed in Chapter 1

- Consider mentioning any relevant coordination efforts with the AgriLife Research Center at Beaumont or the David R. Wintermann Research Station in Eagle Lake, if applicable.

  GCWA Response: Comment addressed in Chapter 1.2

- Elaborate on how the difference between estimated water usage and metered water usage can be described as water savings. How much of the difference is the error in the estimation formula versus the reduction of water diverted due to per-meter invoicing and tiered water pricing structure?

  GCWA Response: Comment addressed in Chapter 1.3

- Explain how metering allowed GCWA to incentivize on-farm conservation practices.

  GCWA Response: Comment addressed in Chapter 1.3

- Include an explanation of rice production practices such as the differences in the “first crop” and “ratoon crop.”

  GCWA Response: Comment addressed in Chapter 1.1

- Consider adding images of the technology installments and maps of the region.

  GCWA Response: Comment addressed in Chapter 1.2 and Chapter 1.3

- Check consistency of font format throughout report text and tables.

  GCWA Response: Comment addressed throughout the report, although adjustments to graphics within Chapter 6 were not possible.