GARWOOD IRRIGATION DIVISION WATER USE, 2012-2016:

Quantifying the Effects of Time, Field Characteristics, and Farmers on Purchased Water

The Meadows Center for Water and the Environment

October 2017

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Texas State University

MEMBER THE TEXAS STATE UNIVERSITY SYSTEM

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Submitted to:

Dr. Valerie Miller and Ms. Stacy Pandey
Lower Colorado River Authority, Austin, Texas

In Fulfillment of an

Interlocal Cooperation Agreement
January 3, 2017 – October 31, 2017

Performing Agency:

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31 October 2017

Amended on 22 January 2018

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ACKNOWLEDGMENTS

The Texas State University project team is grateful for the opportunity and associated funding support provided by the Lower Colorado River Authority to conduct this work. We wish to thank Dr. Valerie Miller for her invitation to submit a proposal and Ms. Stacy Pandey for her guidance and patience throughout the project. The project team is also appreciative of the contributions by Dr. Nathaniel Dede-Bamfo, GIS Services Specialist, Albert B. Alkek Library. Lastly, we are thankful for the rice farmers who volunteered to visit with us and participate in our survey questionnaire.

INTRODUCTION

Texas State University was approached by the Lower Colorado River Authority (LCRA) during the summer of 2016 to conduct an analysis of water savings that might be attributed to volumetric measurement and pricing, a conservation strategy that was newly implemented in the Garwood Irrigation Division in 2012. Five years of data were expected to become available at the end of 2016 and plans to collect these data were made in order to develop a statistical model using an approach that had been used in a previous study conducted with data from the Lakeside Irrigation Division.[1] Preparations got underway beginning in the Fall of 2016, a project proposal was submitted to LCRA in November, and an Interlocal Cooperation Agreement (ICA) was executed in January 2017. While the original ICA was scheduled to end August 31, 2017, the timing of water price data delivery and challenges related to data integration necessitated a two-month, no-cost extension.

Data collected for this project came from a variety of sources. Survey questionnaire data were collected from farmers via in-person interviews, water-use billing data and GIS-based shapefiles were provided by LCRA, and climate data were sourced from LCRA's Hydromet system of weather stations (temperature and rainfall) and Texas A&M University's Eagle Lake Research Station (evapotranspiration.) Historical data, such as pre-2012 billed water use and on-farm data such as we collected via the survey, were not available and thus, estimating the independent effects of volumetric measurement and pricing on water use is not possible.[2] Analyses that were conducted with the dataset created by the Texas State project team yielded considerable insight into the relationship between annual water use by rice farmers and a variety of explanatory factors, nonetheless. It is the purpose of this report to provide those results and an interpretation of their meaning where possible.

BACKGROUND

The 76th Texas Legislature (1999) passed House Bill 1437 relating to the powers of the Lower Colorado River Authority (LCRA) to provide water services to Williamson County. Since Williamson County lies within the Brazos River Basin, HB1437 authorizes the LCRA to do an interbasin water transfer if there is "no-net-loss" of water to the Colorado River Basin. Among the other conditions placed on such an interbasin transfer are: 1) payment for water by the recipient entity of an amount sufficient to pay both LCRA's applicable water rate and the costs of mitigating any adverse effects from the transfer, and 2) a 25,000 acre-feet maximum annual volume of transferable water.[3]

House Bill 1437 also created the Agricultural Water Conservation Fund to cover the aforementioned mitigation costs and can be used only for water resources development and to implement the strategies (i.e., conservation best management practices or BMPs) necessary for making water available for interbasin transfer while meeting associated conditions.

The "no-net-loss" provision[4] is expected to be met in part, at least, by implementation of new agricultural water-use conservation measures in LCRA's irrigation divisions located in Matagorda, Colorado, and Wharton counties: Gulf Coast, Lakeside, and Garwood. Volumetric measurement of water delivery and related pricing and land leveling are a couple of examples of conservation BMPs. But many other factors involved in rice farming can influence water use as well.

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[1] Ana Ramirez and D.J. Eaton, 2012. Statistical Testing for Precision Graded Verification: Does Precision Leveling Save Water? A report from the University of Texas at Austin to the Lower Colorado River Authority, Austin, TX, September, 2012.

[2] This is the reason for the difference between the proposal and final report titles.

[3] For context, the City of Round Rock, Texas, used 21,005.6 acre feet of water for the 12 months of Dec. 2015 through November 2016. 25,000 ac. ft. of water is approximately 68% of the capacity of Lake Georgetown, City of Round Rock's (and others) primary supply of water.

[4] Per LCRA staff member, Stacy Pandey, LCRA defines "no net loss" as the three-year average of water savings or development meant to offset water transfers.

METHODOLOGY

Study Area

The Garwood Irrigation Division (GID) is one of three rice-farming areas where farmers purchase water from the LCRA (Figure 1). The GID lies in Colorado and Wharton County and within the Western Gulf Coastal Plain Ecoregion (U.S. EPA, 2013). Rice farm fields receive water from the Colorado River via a network of canals and associated water delivery structures. Some farmers supplement their purchased water with private well water. Those farm fields that did such could not be included in the analyses.

The climate of the area is subtropical humid (Larkin and Bomar, 1983 as cited in Estaville and Earl, 2008). Average annual precipitation is approximately 39-47 inches[5] (Narasimhan et al. 2005). Annual potential evapotranspiration (Priestly Taylor Method) ranges from 67 to 71 inches (Dugas and Ainsworth, 1983 as cited in Estaville and Earl, 2008). Nearby Columbus, Texas has an annual average high temperature of 80.3 °F, an average low temperature of 58 °F, and an annual average temp. of 69.15 °F[6] (U.S. Climate Data, 2017).

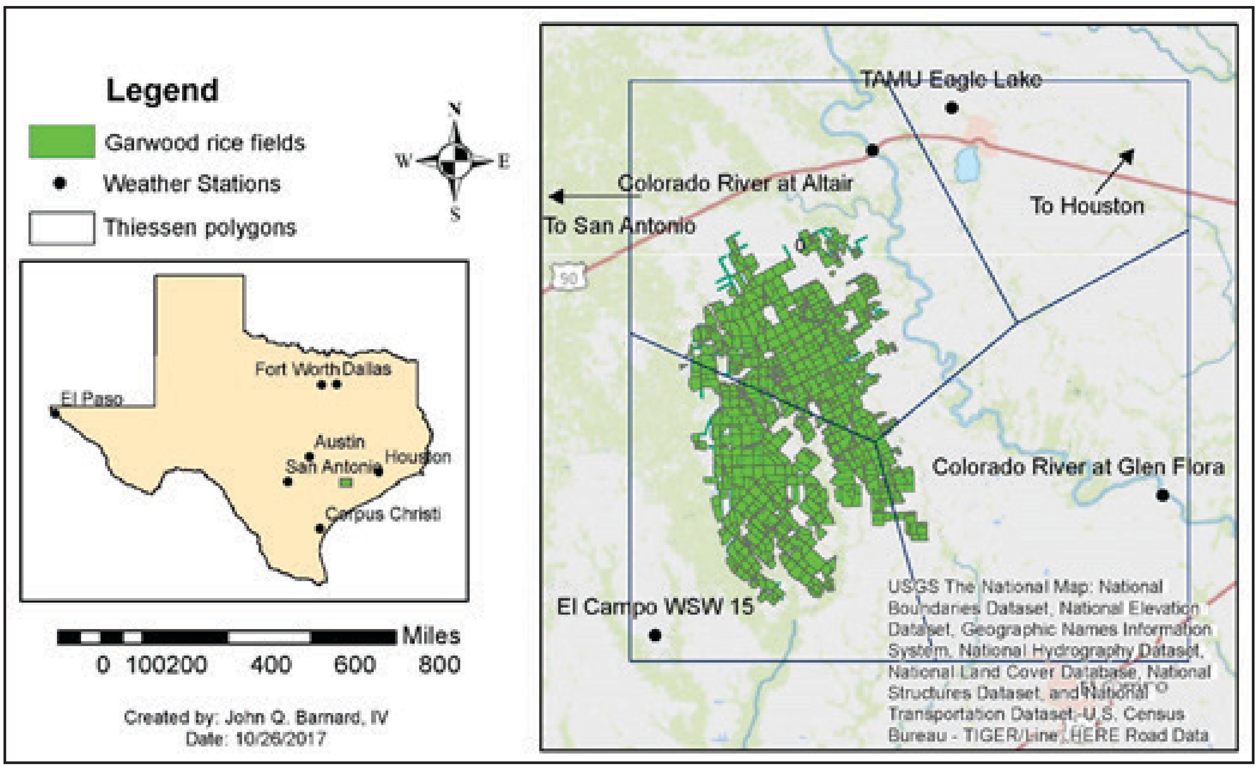

Figure 1. Location of Garwood Irrigation Division rice fields.

[5] Isohyets generally run north/south and are relatively tightly packed in the eastern third of Texas. Thus, there can be considerable variation in year-to-year rainfall even exceeding that which is indicated.

[6] Climate data for Columbus, Longitude: -96.573, Latitude: 29.699. Average weather Columbus, TX 78934, 1981-2010 normals.

Data Collection

The project team traveled to Garwood, Texas and conducted in-person survey interviews with fourteen rice farmers at the LCRA Garwood Irrigation Division field office during the week of March 6, 2017. Survey data were collected from those farmers that had appointments to sign contracts in the Garwood field office during the week that had been arranged for the project team to travel and conduct interviews.

The survey instrument used (Appendix A) is a slightly modified version of the survey used in the Lakeside Irrigation Division where results are presented in an unpublished report by Ramirez and Eaton (2012). The survey sought to collect data for each field farmed by an interviewee over the course of five years: 2012-2016. The LCRA's Umap system was utilized on-site during interviews to facilitate the connection between fields farmed during the study period and farmers interviewed.

Climate data were collected from nearby weather stations: LCRA Hydromet stations, Altair, El Campo, and Glen Flora for rainfall and temperature, and Texas A&M University's Eagle Lake Research Station for evapotranspiration. Monthly values were tabulated for the five years under study and are available as a worksheet in the MS-Excel-based spreadsheet file that accompanies submission of this report. Since the water use/billing data are annual rather than monthly, monthly climate data were either summed to produce a total (e.g., rainfall (in.), evapotranspiration (in.)), or an average (e.g., temperature (°F) for the eight-month growing season (i.e., March – October inclusive.))

The LCRA provided ten billing data files to the project team: one for each of two crop seasons per year. Both the volume of water sold (acre-feet) and the total charge ($) for that water were provided. Acreage values for each record in the project team dataset were first obtained from LCRA's Umap system that led to the identification of fields farmed each year just prior to conducting survey interviews. Billing files also included acreage, however, and these values were used because they are tied to water use and thus, are the official billing record.

The GIS-derived shapefiles provided by LCRA were used to locate the fields for which the project team collected survey data. Field acreage was among the variables included in the attribute table. Since LCRA often billed a farmer for a collection of fields for which the project team collected individual field data, the shapefiles helped inform the project team as to which fields were grouped and billed as one field. In such cases, project dataset records had to be combined in order to match the billing data files. One outcome of this process was a dataset reduced in size in both the original dataset and in the modeled dataset.

The task of combining/dropping records presented an unexpected challenge. For example, some record variable values are additive in nature (e.g., field acreage, number of levees[7], etc.), but others (e.g., slope percentage, several categorical variables) are not additive and thus, resulted in the loss of records when such data were in conflict. In the case of levee type, the need to aggregate records resulted in the need to create a new levee-type choice: "combination" when levee type among such records was variable. Approximately 82 records from the original dataset were aggregated into 36 records after combining their variable values with the related record that was referenced in the billing data. While we equate a record in our original dataset to a data-point collected, most records requiring aggregation were in agreement when considering variable values that were either nonadditive or, in the case of levee type, recoded as "combination." Record aggregation, therefore, resulted in the complete loss of 12 records from the 82 records that required aggregation, but just 4 records from the 36 records after

[7] Levee count and type were not verified via a separate review of corresponding-year aerial imagery. While suggested in the project proposal, data management challenges prevented the team from executing this verification task prior to the start of data analysis.

aggregation. This is because "null" values (i.e., conflicting, nonadditive values) were forced upon one or more of the variables that the model found to be statistically significant.[8] Additionally, 35 records[9] had to be dropped because a farmer answered "yes" to the survey question, "Did you supplement this field's water use with private-well water?"

The shapefiles also allowed the project team to execute a Thiessen Polygon routine in order to assign climate data (i.e., temperature and precipitation) to each record from the closest of three LCRA weather stations. The shapefile used by the project team also provided the object ID that was included in the project team dataset in order that the dataset should have a unique identifier associated with each record (i.e., unique combination of year/farmer/field name.) On this last point, it is important to note that the shapefile attribute table features a unique entry and object ID for each time a physical field was cropped during the study period. Thus, a physical field could have one or more object IDs in the shapefile attribute table irrespective of the field name in a given year (i.e., regardless if the field name was consistent or varied across years.) The project team selected the object ID associated with the year, farmer, and field name for which survey data were collected.

Dataset Basics

The project team assembled a dataset that originally featured 365 records or unique combinations of a farmer/year/field[10]. After culling 81 records as noted above, and nine other records (e.g., due to error or redundancy), the final-full dataset features:

275 records[11] or unique combinations of year/farmer/field name, 246 records without null values in final-model variables, 153 unique field names, 14 farmers interviewed, and 5 years of data: 2012-2016 inclusive. Table 1 illustrates number of records by year.

2012		2013		2014		2015		2016	
Full Dataset	Model Dataset	Full Dataset	Model Dataset	Full Dataset	Model Dataset	Full Dataset	Model Dataset	Full Dataset	Model Dataset
52	49	53	51	66	56	47	40	57	50

Table 1. Number of records per year/growing season.

[8]One of the four data-points in the final-full dataset of 275 records featured a null value in the precision-leveled column. This means that this data-point could not be included in the modeled dataset as explained in the text. This datapoint resulted from the aggregation of four records from the original set of 356. At least one of these four records, but less than all four, featured a "yes" value in the categorical variable "precision-leveled.

[9]Three records in 2012, seven records for each of the years 2013-2015, and 11 records in 2016.

[10]Since LCRA field names do not remain consistent across the years and no other unique identifier is associated with each field, the same field was not tracked through time separate from its association with a given year and farmer for that year.

[11]The full dataset of 275 records equals 275 data-points in the LCRA billing file.

Sample Representativeness

Depending on the year, data collected on fields ranged from 22.7 to 31.5 percent of the fields farmed during the corresponding year for an average of 27.5 percent across the five-year study. Furthermore, a standard technique was applied to the data to test whether the sample collected is representative of the larger population of rice fields in the GID. The data tested came from an LCRA shapefile (IRRIGATION_HISTORICAL_FIELDS_FROM_REPOSITORY_1_31_2017.prj) containing 1,204 records in the polygon attribute table and from a subset of this shapefile that was created to represent the fields for which the project team collected survey data (365 records). The shapefile and subset created from it represent the only data that were both readily available and comparable and thus, appropriate for the test of representativeness.

The technique applied to test for a statistically significant sample, involved t-tests: one for each year and another test applied to the combined datasets (i.e., all years lumped together or 365 vs. 1,204 records.) The t-tests centered on two variables: GIS acres and contract acreage, to test the null hypothesis that the average (mean) field size (acres) between surveyed farmers and nonsurveyed farmers is different. In all six tests the null hypothesis is rejected as there is no statistically significant difference in field size between the sample and population (Appendix B) Accordingly, results found in this study are representative of the population of fields farmed each year in GID.

Approach to Data Analysis

The project team had intended to use Stata/IC 14 (StataCorp LP) for statistical analysis, but an unexpected change in project personnel combined with a relatively late completion of a quality-checked dataset, necessitated the need to use R for model development. The end results would be the same, of course, as the stats package applied here is simply the vehicle used to get from "point A to point B." R is a free software environment for statistical computing and graphics output.[12] Like many stats packages, R imports an Excel file, converts it to a text file, and proceeds to compute as directed.

Drawing on a recent, similar study,[13] we explored the possibility of estimating a multi-level model in which water use acts as a dependent variable, with observations grouped at three levels of analysis: (1) time, (2) field, (3) farmer.[14] To understand whether such a modeling structure was warranted, we first estimated the intra-class correlation coefficient (ICC) for a two-level model with observations by time grouped by field. The ICC measures the proportion of variance in our outcome variable—Total Water Use (acre-feet)—that occurs between groups (fields) relative to the total variation present.[15] The ICC ranges from 0 (no variance among fields) to 1 (variation among fields, but not within fields). Higher values of ICC indicate that a large share of total variation in Total Water Use is associated with field assignments. In our case, the ICC associated with field groups was equal to 0.552, as estimated in a null model of Total Water Use that used no explanatory variables. This value means that the correlation of Total Water Use among temporal observations on the same fields is roughly 0.55, which is quite high. As such, we moved forward with including field as a level of analysis.

Next, we investigated the possibility of longitudinal multilevel modeling structure, which is often appropriate when repeated measurements at level 1 (time) are nested within a particular field (level 2). To evaluate the suitability of such a modeling design, we updated our prior unconditional model (no explanatory variables) to include a time predictor on the right-hand side of the equation.[16] A likelihood ratio test that compared

[12] The R Foundation. The R Project for Statistical Computing. https://www.r-project.org/ (last accessed on 9/20/17).

[13] Ibid. 1

[14] For additional information on this technique, also see: Andrew Gelman and Jennifer Hill, 2007. Data Analysis Using Regression and Multilevel/Hierarchical Models. New York, NY: Cambridge University Press. 625 p.

[15] Finch, W. Holmes, Jocelyn E. Bolin, and Ken Kelley. Multilevel modeling using R. CRC Press, 2014.

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the unconditional model to the longitudinal model suggested that the longitudinal model (with time as an explanatory variable) was better suited to our data (p<<0.001). The longitudinal model has value in modeling both intra-field change over time and differences in temporal change across the levels of the analysis.[17]

Third, we estimated a three-level, longitudinal model that grouped observations by time (level 1), field (level 2), and farmer (level 3), to account for the possibility that farmers make similar decisions for all of the fields that they manage. A likelihood ratio test that compared this specification to the working two level longitudinal model suggested that the three-level specification was more appropriate for our data (p<<0.001). Thus, our approach employs a longitudinal-type, hierarchical linear model.[18]

Fourth, we set up a log-level model[19] to include 15 major explanatory variables plus two interaction terms (Table 2). The log-level model structure is valuable here in that coefficient estimates on the explanatory variables represent roughly the percent change in Total Water Use (outcome variable) associated with a single unit increase in a given explanatory variable. Such models are popular in econometric analyses of demand.[20]

List of variables evaluated by model	Is the variable retained by model?
Time (relative to 2012)	Yes
Cost per unit ($, mean-centered)	Yes
Field size (acres, mean-centered)	Yes
Growing season (days, mean-centered)	Yes
Temperature (average annual, mean-centered)	Yes
Levee density	Yes
Hybrid rice (all other rice types considered "nonhybrid")	Yes
Interaction: hybrid rice * growing season	No
Farmed by owner (all other relationships considered "not farmed by owner")	Yes
Precipitation (total for growing season)	No
Evapotranspiration (total for growing season)	No
Precision level (Yes, No)	No
Interaction: precision level * levee density	No
Permanent perimeter levee (Yes, No)	No
Conservation Tillage	No
Number of inlets	No
Levee type	No

Table 2. Explanatory variables evaluated by model.

[17] Ibid. 15 p. 100

[18] By comparison, the Ramirez and Eaton (2012) study employed a hierarchical linear model, but there is no evidence found in their final report that it was also set up as a longitudinal model.

[19] The dependent or outcome variable only is natural log-transformed. This is another difference with the HLM model employed in the Ramirez and Eaton (2012) study as best as we can tell.

[20] Wooldridge, Jeffrey M. Introductory Econometrics: A Modern Approach. Nelson Education, 2015.

Finally, a backwards stepwise selection process resulted in a parsing out of the statistically significant variables from those with no explanatory power to arrive at a "final" model. The stepwise-selected model is a longitudinal, multi-level model with yearly observations (i.e., time as the first level) that are nested in fields (the second level) that are nested in farmers (the third level.) A longitudinal multi-level model allows the project team to capture any temporal trend that might emerge with the outcome variable.

It was determined that the outcome variable to be used throughout the analysis is "Total Growing Season Water Use" (i.e., combining both crop 1 and crop 2 season's water use rather than modeling each season independently. The variable "growing season" fully accounts for those farmers who didn't plant a second crop as the season is determined by the first and last dates of water delivery.) Using Total Growing Season Water Use, or Total Water Use, as the outcome variable allowed the project team to move field size to the right-hand side of the model as an explanatory variable. Doing so allowed for testing the hypothesis that larger fields use more water than smaller fields. This would not have been possible had the team chosen "water demand," a normalized value in the dataset (i.e., total growing season water use divided by field size, resulting in a water use per acre value), to be the outcome variable. Furthermore, using Total Water Use rather than Water Demand as the outcome variable resulted in the model with the greatest explanatory power possible.

As a final technical matter, note that a majority of the explanatory variables in the final model (Table 2) were grand mean-centered, which is a common practice to avoid issues of multicollinearity—and add to the interpretability—of multilevel models.[21]

[21] Ibid. 15

RESULTS AND DISCUSSION

Table 3 presents the full model output. The model's "Marginal R^2" value of 0.77 captures the fixed effects of the significant explanatory variables only. In other words, the model's eight explanatory variables explain 77 percent of the variability found in water use during the five-year study period. Unobserved farmer behavior is captured in the random effects that are included in the "Conditional R^2," a measure of full model performance that includes both fixed and random effects. Here, the model explains about 88 percent of the variability found in total water use across the modeled dataset of 246 records. This is a particularly strong performing model of the data. The R^2 values found here, however, are normal for economic studies where there is a longstanding history of strong linear relationships found between price and quantity of a commodity demanded, in this case water.[22]

Fixed Effects	Coef.	Std. Err.	Lower 95%†	Upper 95%†	t	VIF
Intercept	5.720	0.095	5.525	5.913	60.32***	--
Year2012	-0.076	0.018	-0.116	-0.040	-4.14***	1.69
CostUnitTotal	-0.014	0.002	-0.018	-0.010	-6.74***	1.32
FieldSize	0.009	<0.001	0.008	0.010	19.30***	1.22
GSDayC	0.003	<0.001	0.001	0.004	3.70***	1.08
Temp	0.004	0.001	<0.001	0.068	2.043*	1.40
LeveeDensity	-0.576	0.210	-1.037	-0.133	-2.746**	1.20
Hybrid	0.185	0.071	0.024	0.333	2.602**	1.03
Farmed_by_Owner	-0.288	0.008	-0.442	-0.128	-3.70***	1.05
n=246	Field_Name =153				Farmer_Name=14	

Table 3. Full model output.
***p<0.001 **p<0.010 *p<0.050 VIF=variance inflation factor †bootstrap confidence intervals (500 simulations)

Random Effects	Variance
Field_Name:Farmer_Name	0.049
Farmer_Name	0.021
Residual	0.072

Model Performance[23]	Measure
Marginal R^2 (fixed effects)	0.77
Conditional R^2 (full model)	0.88

[22] See, for example, Howe and Linaweaver (1967)

[23] See Nakagawa et al. 2013

Table 4 provides an interpretative summary of model output consistent with the explanation provided above for employing log-level models. And the model equation can be found in Appendix C.

A one-unit increase in the explanatory variable below:	Is associated with the following percent change in Total Water Use:	Interpretation, holding all else constant:
Time (relative to 2012)	-7.6%	Water use has trended downward since 2012
Cost per unit ($, mean-centered)	-1.4%	Price increases reduce water usage
Field Size (acres, mean-centered)	+0.9%	The larger the field, the more water used
Growing Season (days, mean-centered)	+0.3%	The longer the growing season, the more water used
Temperature (°F, mean-centered)	+3.5%	The higher the growing season temperature, the more water used
Levee Density (not mean-centered)	-57.6% (consider that the average levee density is 0.17/unit area, where the max is 0.97; so a one unit increase for this variable is a very substantial increase)	The higher the levee density, the less water used
Hybrid Rice (all other responses considered "non-Hybrid)	+18.5%	Hybrid rice is linked to higher use than other rice types
Farmed by Owner (all other arrangements considered "Not Farmed by Owner")	-28.8%	Owners use significantly less water than farmers who do not own their land

Table 4. Summary of model output.

"Time" as a predictor is the only temporal variable in the model and output indicates that there was a 7.6% decline in water use each year from 2012 to 2016. Since this trend in the data is independent of other variables, we have no readily available explanation for it. Unlike the other variables, there is no rationale behind an associated hypothesis stated one way or the other. Thus, this finding is simply a temporal trend of interest that is documented by the model. For context, Table 5 shows the mean water use per year from the dataset—these are simply the arithmetic means, and were not drawn from the multilevel model.

Year	Mean Total Water Use (ac. ft.)
2012	460.86 (n=49)
2013	417.42 (n=51)
2014	249.55 (n=56)
2015	294.65 (n=40)
2016	248.56 (n=50)

Table 5. Annual average water use per field during study period.

A reasonable hypothesis concerning the cost of anything is that as cost increases, one can expect lower demand as a result. Such a hypothesis proves true here as the modeled data indicate that for every (one) dollar increase in the per unit cost of water sold by LCRA, 1.4% less water was used by GID rice farmers in response.

As might be expected, bigger fields use more water than smaller fields. For every acre increase in field size, 0.9% more water was used during the study period. Table 6 shows average (arithmetic mean) size field for each of the five years studied. Similarly, the longer the growing season, the more water is used: 0.3% more water used for each day the growing season exceeded the average length growing season.

Year	Average (mean) size field (acres)
2012	103.5 (n=52)
2013	110.6 (n=53)
2014	93.8 (n=66)
2015	103.4 (n=47)
2016	86.4 (n=57)

Table 6. Average aggregated field size during study period from full dataset.

Not surprisingly, higher growing season temperatures are associated with greater water demand. Specifically, the model shows that for every (one) degree Fahrenheit increase in temperature, water use increased 3.5%. The other two climate variables – evapotranspiration and precipitation – were not found to be statistically significant. It's possible their effects were masked by the temperature variable.

Levee density, by definition, is a value between 0.01 and 1. We see a considerable percentage effect, therefore, between a one-unit increase in levee density and water use. The results of this study show that the higher the levee density, the less water is used. Model results here are different from those found in the Lakeside Irrigation Division (LID) insofar as "levee density" did not prove to be a statistically significant independent variable in the LID study. In the LID, the variable only became significant as an interaction term with the variable "precision leveling." In this study, we found no significant interaction effect between levee density and precision leveling

(Table 2). To be sure that the result found here was not an artifact of the model—in which all coefficients indicate a relationship between water use and a given explanatory variable holding all else constant—Figure 2 presents a smoothed scatterplot which depicts the inverse relationship that exists between water use and levee density in the project team's dataset.

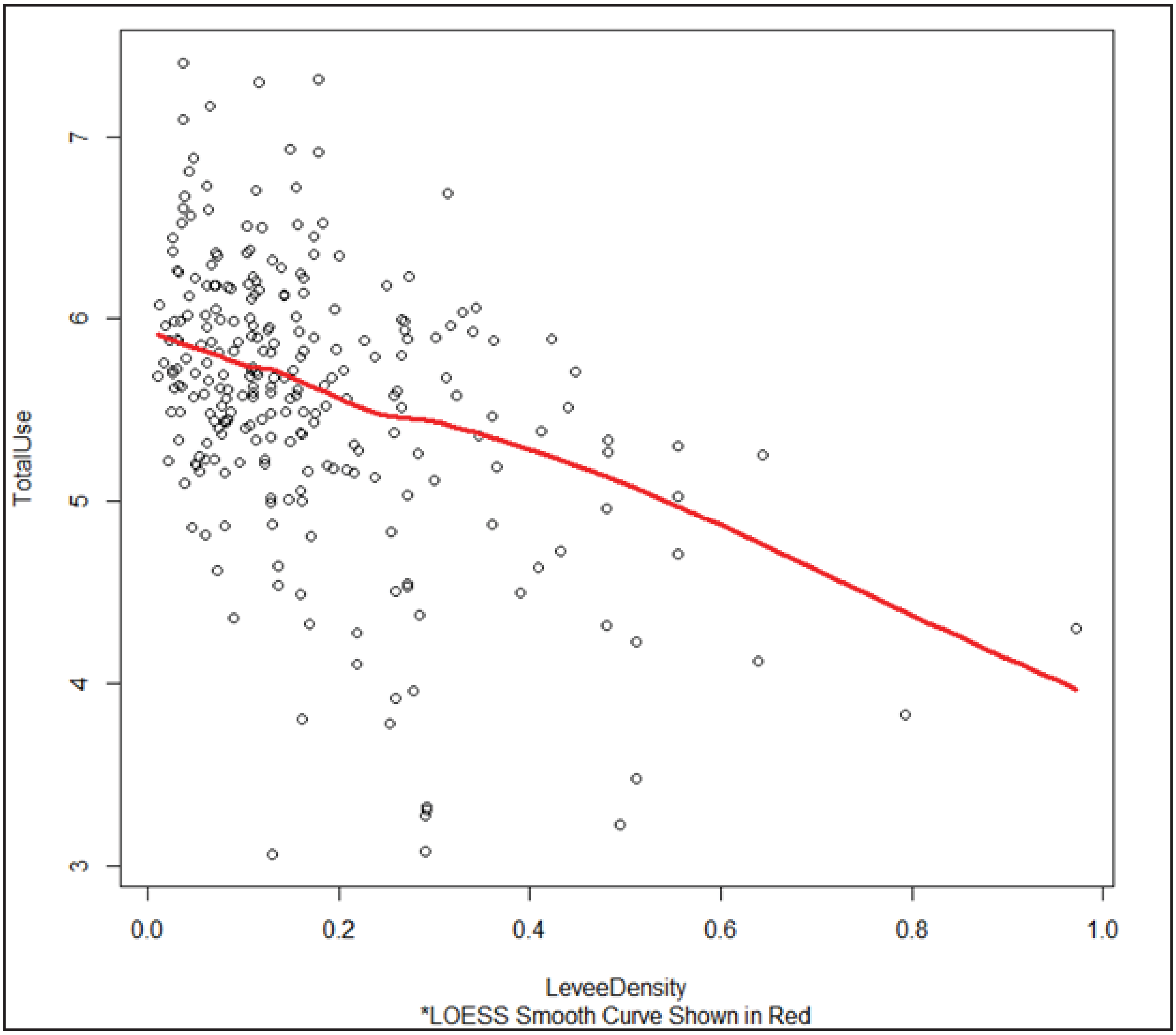

Figure 2. Log of total water use vs. levee density.

Data representing the last two explanatory variables found to be significant, "hybrid rice" and "farmer by owner," were organized to become dichotomous categorical variables. Hybrid rice, for example, is a rice-type choice among three other choices that accounts for 80% of the modeled observations. Thus, all other rice choices – seed, traditional, other – were grouped together in a nonhybrid category. Farmers who used hybrid rice used 18.5% greater water that farmers who chose other rice types for cultivation. This is a slightly different finding than the study in LID where hybrid rice was combined with seed rice versus conventional and other rice varieties and found to not affect water use in and of itself. In the LID, farmers who planted hybrid or seed rice were found to use more water, but only when rice type was entered in that study's model as an interaction term with length of growing season. Here, we found no such significant interaction effect (Table 2). Rice type data collected in this study is shown in Table 7.

Rice Types				
	traditional	***hybrid***	***seed***	***other***
# of cases	15	213	20	24
avg GS days	140	126	79	113
min GS days	73	50	52	50
max GS days	174	194	125	173

Table 7. Rice-type metrics across five-year study.

Notes:

- *Growing season (GS) days is for both crops if a second crop was planted.*
- *When seed was planted, there was no 2nd crop planted across all 20 cases.*

Regarding the relationship between the farmer and the fields farmed, four choices were available to interviewees: farmed by owner, rented for cash, share rented, or other. Since renting for cash or a share of the crop are similar, and there were very few "other" observations, data were organized into a categorical variable: "farmed by owner" and "not farmed by owner." The model indicates that farmers who work the land they own, use 28.8% less water than farmers who are renting the land. This finding is not consistent with the relationship found in the LID study, but results found here may not be comparable to that study as relationships were grouped differently in the LID study.[24]

Regardless of comparability, the finding here that those who own the land they farm also use less water does not come as a surprise. First, there is a fundamental difference between farming land that one owns versus renting a field for a season or more whether it be for cash or a share of the crop production. Ownership is tantamount to investment and an investment over time leads to experience and familiarity. Greater knowledge of how a field performs in response to an input should lead to more informed decisions over time about the timing and quantity of inputs necessary. Furthermore, other research (Loftus, 1999; Esseks and Kraft, 1989) suggests that rented land does not benefit from the same conservation ethic that is more likely applied to a field that is both owned and operated by the same famer. Thus, we're inclined to think that owner-operators are more conservative with inputs and more willing to make long-term investments in the land despite bearing similar financial risks as those who otherwise rent the land they farm.

[24] In the LID study, share renters were grouped with owner-operators based on the argument that cash renters bear a much greater financial risk than those who either pay their rent with a share of the crop or those who own the land they farm. This is a questionable premise and was posited without support from any reference(s) to the literature.

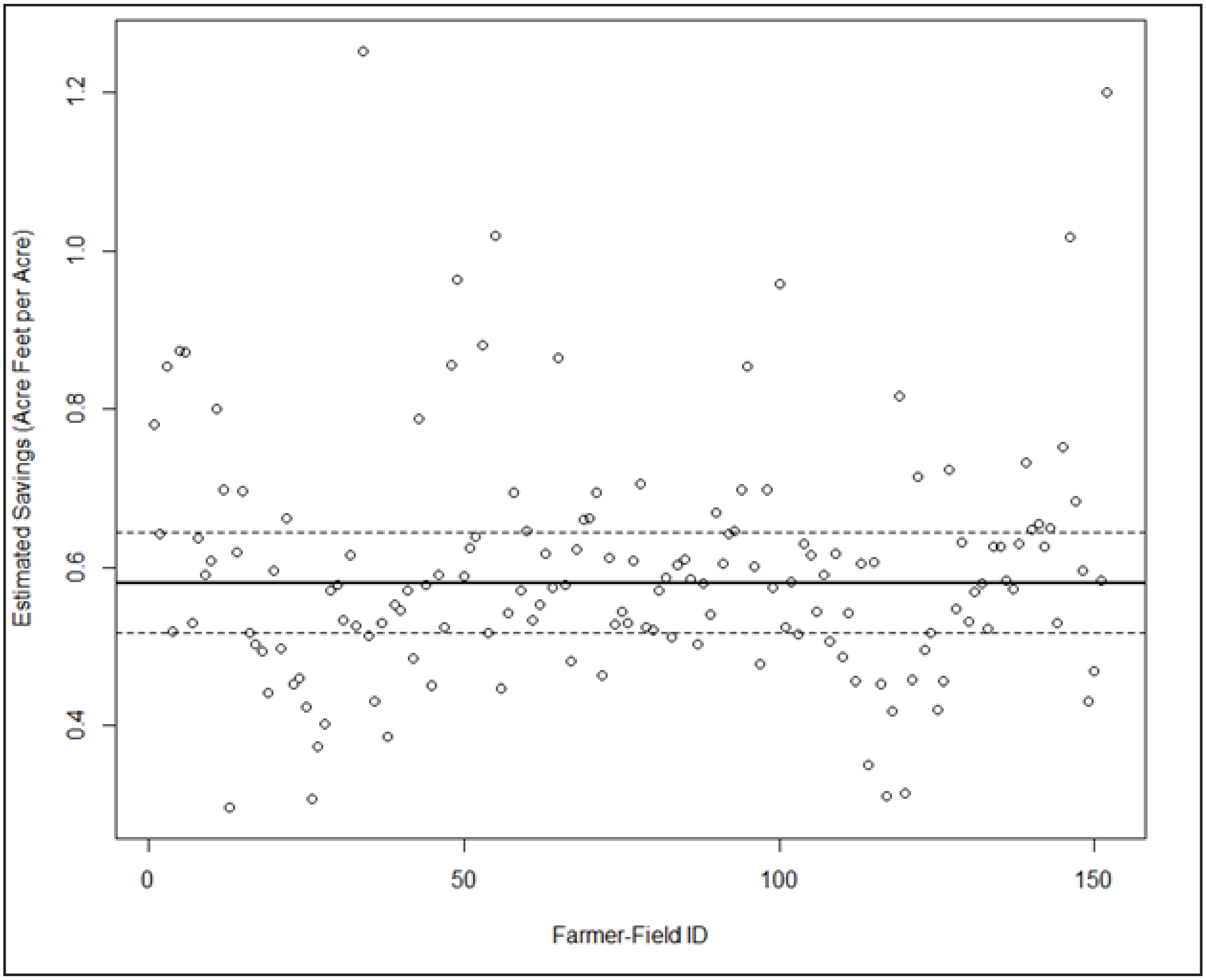

Figure 3. Simulated water savings (acre-feet per acre) by field in response to price Increase.

Figure 3 above illustrates a model simulation that considers the effect of water price change from 2012 to 2016 average levels on water use for each of the fields modeled. Each dot represents estimated water savings for an individual combination of farmer-field. Estimated savings are calculated by simulating the following scenarios and computing the difference in water use between them:

1. All independent variables are held at their 2012 (or earliest observed (e.g., 2013 if that was the first time for a particular farmer-field combination)) levels except for (1) price, which is set to the average 2012 cost per unit ($30.54 / ac. ft.) and (2) year, which is set to 2016. Thus, the scenario estimates water use for each farmer-field combination in 2016 under prior conditions (i.e., 2012 or whenever the combination first appears in the dataset.) The estimates, therefore, incorporate the temporal trend observed in the data which shows that average water use has been declining each year since 2012. These specifications were chosen to imagine the case that all of the circumstances that existed in 2012 continue to exist today.

2. All independent variables are held at their 2012 (or earliest observed) levels except for (1) price, which is increased to the average 2016 cost per unit ($45.01 / ac. ft.) and (2) year, which is again set to 2016, as in the scenario described above. In this way, we estimate water use for each farmer-field combination in 2016 under prior conditions, but current (increased) price. Because all of the independent variables in this scenario are set to the same values that they were in the above-described scenario, any difference in estimated water use is due exclusively to the modeled change in average price (i.e., from average 2012 cost per unit to average 2016 cost per unit). In other words, if the average price per unit of water in 2016 were exactly equal to the average price per unit of water in 2012, then the scenarios described in bullets (1) and (2) would produce the exact same estimates. However, because price per unit of water in 2016 was higher in 2016 than it was in 2012, the estimates in scenario (2) should be different from those in scenario (1). The magnitude of this difference, for each farmer-field, is therefore a proxy measure of the estimated water savings for each farmer-field due to the price increases that occurred from 2012 to 2016. These estimates thus represent expected levels of water conservation in response to price changes.

Recall from above that Figure 3 shows the simulated effect of price change only - an increase of 47.4 percent from 2012 to 2016 - on the water usage of 153 fields that were farmed/modeled during the study period. This price increase equals a median expected water savings of 0.58 acre-feet per acre, or 52.95 acre-feet per field on average.[25] This makes clear that increasing the price per unit of water is associated with meaningful water savings. The magnitude of the savings, as shown in Figure 3, will vary from farmer-field to farmer-field; but the overall tendency is net positive water savings. In an overall sense, based on the findings of the regression model, a $1 increase in price per acre-foot. of water is associated with approximately a 1.4% reduction in water demand (Table 4). Put another way, 100 acre-feet of water used under current per unit prices is expected to decrease to 98.6 acre-feet if per unit cost increases by $1.

[25] The average price of water in 2016 is $45.01 per acre foot.

[26] Except for temperature, which is held constant at 2012 levels given that it is not a variable under our control.

To comment on the relationships between total water use and two remaining explanatory variables,[26] Tables 8 and 9 summarize expected water use by: (1) rice type [hybrid v. other]; and (2) tenure [owner v. other]. Note that the expected water use figures are drawn from the multilevel model by setting the explanatory variables for each farmer-field combination at their most recent observed values (e.g., if Ownership was observed in 2016, then the value for 2016 is used; otherwise, the most recent observed value is used in its place). Temperature is held constant (at its grand mean) for all farmer-fields, as is time (2016) and cost per unit (2016 average = $45.01 per acre-foot). Fields farmed by owners use 0.46 acre-feet of water less per acre than farmers with a different relationship to the fields they farm. And growing hybrid rice uses 0.59 acrc-feet of water more per acre than other types of rice planted.

	Farmed by Owner	Other
Minimum	1.06	1.76
1st Quartile	1.63	2.02
Median	2.43	2.83
Mean	2.48	2.96
Standard Deviation	0.67	0.77
3rd Quartile	3.02	3.40
Maximum	4.01	5.59

Table 8. Predicted values of water use in acre-feet per acre from multilevel model, by ownership.

	Hybrid Rice	Other
Minimum	1.67	1.06
1st Quartile	2.16	1.61
Median	2.86	2.07
Mean	2.96	2.37
Standard Deviation	0.72	0.91
3rd Quartile	3.39	2.49
Maximum	5.59	4.63

Table 9. Predicted values of water use in acre-feet per acre from multilevel model, by type of rice planted.

[26] Except for temperature, which is held constant at 2012 levels given that it is not a variable under our control.

A Word About Precision Leveling

As noted above, the variable "precision-leveled" did not indicate a statistically significant contribution to the final model either as an independent variable or as an interaction term with levee density. A separate analysis was conducted on the presence/absence of precision leveling on a field relative to water demand, a normalized value of water use (i.e., water use / field size = water use per acre.) T-tests performed separately for each of the five years revealed no significant difference in water use for the first four years (2012-2015), but a statistically significant difference emerged in 2016.[27] Tables 10 and 11 show that the majority of fields sampled are precision-leveled.

Total Fields in production 2012-2016 during the first crop					
Year	Total Fields	Nonleveled fields		Leveled Fields	
		# Fields	Percentage	# Fields	Percentage
2012	52	15	28.85%	33	63.46%
2013	53	17	32.69%	32	60.38%
2014	66	23	44.23%	37	56.06%
2015	47	14	26.92%	30	63.83%
2016	57	22	42.31%	33	57.89%

Table 10. Fields in production of first crop: 2012-2016.

Note: Nineteen null values are distributed as follows: 4 in 2012, 4 in 2013, 6 in 2014, 3 in 2015, and 2 in 2016.

Year	Total Fields	Nonleveled fields		Leveled Fields	
		# Fields	Percentage	# Fields	Percentage
2012	47	13	27.66%	31	65.96%
2013	39	12	30.77%	24	61.54%
2014	21	1	4.76%	18	85.71%
2015	27	7	25.93%	19	70.37%
2016	46	18	39.13%	26	56.52%

Table 11. Fields in production of second crop: 2012-2016.

[27] Results are displayed in the MS-Excel file, "PLevel_vs_nonlevel_ttests_Nov2017".

CONCLUSIONS AND RECOMMENDATIONS

The model developed for this project explains most – 88 percent – of the variability found in water use among rice farmers in the GID. Among the seven nontemporal predictors, however, just one appears to be policy relevant: cost of water per unit sold. In other words, there are no policy levers for influencing field size or length of growing season. And temperature, much like rainfall, cannot be influenced to increase or decrease as a short-term response to a policy decision.[28]

Levee density might be managed to meet a minimum standard, but farmers must each make a decision of how many levees to install based on a number of factors: field characteristics, cost, advantages to be gained (e.g., less water use), and disadvantages of additional levees (e.g., natural slope contours and the practical matter of using farm equipment, etc.) Here it will be useful to explore the extent to which the local USDA NRCS field office is providing technical advice and if staff have the sense that levee density is about right or if it can be adjusted and/or improved for the purpose of minimizing water use further.

Similarly, the variety of rice chosen for planting is a matter of farmer preference. This study did not seek to understand why one type of rice was chosen over the other types available and much work would need to be done on rice variety cost, potential crop production, value of harvest relative to market forces, and other factors before one might consider, for example, a tax imposed on higher water using rice varieties during a water shortage. But water price is another way to address the matter without overtly favoring one variety over another by implementing an unpopular tax. In any event, rice variety appears to matter when it comes to water use and findings here are in general agreement with the LID study as noted above.

Lastly, the relationship between the farmer and land ownership will vary over time in response to demographics, market forces, and the history of land ownership, none of which lends itself well to influence by policy makers.

If LCRA wishes to reduce water use in the GID or any of their other rice-growing irrigation divisions, then using the price of water as a regulator of the volume purchased (and thus, volume saved for transfer) is proven to be effective. Of course, this has not been the intent to date. Yet farmers have nonetheless become increasingly more conservative with water purchases in response to rising price. In that vein, implementation of volumetric measurement and pricing has been instrumental in enabling LCRA to manage demand. It should be noted, however, that rising price also appears to be incentivizing conjunctive use among some farmers. A number of farmers interviewed, indicated that they are supplementing purchased water with private-well water applied to their fields. As long as this alternative supply is unmetered, it will be impossible to know the full extent of overall water use in the GID.

Finally, rising price during the five-year study period may also be responsible for precision leveling, eventually (i.e., only in year five) showing a noticeable relationship to water demand. This relationship will be important to follow over time regardless of whether significance is maintained or not.

We believe that water use and any measured savings from reduced use, to the extent that water use changes relative to a baseline, need to be quantified annually to provide a defensible foundation for a future interbasin water transfer. Furthermore, a baseline of water use needs to be determined for GID and other irrigation

[28] This statement is aside from the fact that Earth is warming and some policymakers are making decisions to reduce greenhouse gas emissions that are driving the warming trend.

divisions along with an accounting period (e.g., 20 or 30 years rolling) during which time annual surpluses/deficits can be tallied in order to arrive at an annual status of water availability for transfer whenever a request for such is made.

The recommendations made for LCRA in the 2012 study conducted in the LID can be echoed here as they remain relevant. Here, we'll highlight the recommendation to include many of the questions that were asked of farmers during the on-site survey interviews, in the annual contracting process. Doing so will have three advantages: 1) data will be collected annually for all farmers under contract, 2) the burden of lengthy survey interviews that was placed on farmers in this study will be greatly reduced should survey interviews be conducted in the future, and 3) more accurate data is likely to result when questions are posed annually versus every three to five years.

Data analysis conducted here in the GID and five years ago in LID, concerns an administrative mismatch between fields that are physically farmed and fields as they are represented in the billing files. While the mismatch concerns a minority of fields, the loss of data resolution and potential for reduced data quality that results when fields are aggregated to compensate for the mismatch, are matters that seek rectification if possible.

Since field names can change over time, LCRA should also include the USDA FSA farm and tract numbers that are associated with each of the rice fields of interest. Doing so will create a unique identifier for each field that currently does not exist and will allow for efficient tracking of a field over time in the event that there is value associated with such tracking.

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APPENDIX A

Volumetric Measurement and Pricing as a Conservation Practice

RICE PRODUCTION FARM PRACTICES SURVEY 2012-2016

INTRODUCTION: The purpose of this survey is to investigate how volumetric measurement and pricing of water, and other water conservation practices, as currently applied by farmers in LCRA's Garwood Irrigation Division influence on-farm water use. A research team from Texas State University will analyze data collected by this survey.

Your voluntary response to the survey is important to understanding the effects of certain conservation practices on water use. The information you share will be compiled into a report that has aggregated data for the entire division, and LCRA will not release your individual information unless required to do so by law.

If you do not wish to answer a question, you are not required to do so. The survey consists of three parts: general information, farming practices and field characteristics. We greatly appreciate your time and effort.

PART 1: GENERAL INFORMATION - In the general information section you will be asked to provide information about yourself to help LCRA and the research team better understand the factors most related to conservation and water use.

PART 2: FARMING PRACTICES - These questions refer to water conservation measures and management practices.

PART 3: FIELD CHARACTERISTICS - These questions are central to verifying the benefits of the program to pay for farm land improvements. You will be asked about ALL fields planted from 2012 to 2016 (one row per field per year). Please bring farm records you consider necessary to ensure the information is as accurate as possible. If you do not have records for some fields or years, please let us know. If you have questions about the terminology in the survey, refer to the glossary attached to this survey.

The project team will use LCRA's uMap tool to verify your fields. If there are fields incorrectly marked, not part of your farming operation or missing, please let us know. If you have questions about completing this survey, contact Stacy Pandey at 800-776-5272, ext. 7471 or by email at stacy.pandey@lcra.org. We look forward to completing the survey with you.

Survey respondent name: ____

LCRA contract holder name: ____

Date: ____________________

Part 1 – General Information

Name: ___________________________

Role in farm operation: ___________________________

Gender: _____ Male _____ Female

Total area of your farm operation: _____ acres

Years you actively have farmed: _____

Please circle your age (optional).

- Less than 30
- 31-40
- 41-50
- 51-60
- More than 60

Please circle your level of formal education (optional):

a. Completed grade school

b. Completed high school

c. Attended a four-year or junior college

d. Graduated from a four-year college

e. Attended graduate or professional school

f. Completed graduate or professional degree

Part 2 – Farming Practice

1. What percentage of your total working time (i.e., time spent generating income) do you spend working on:

a. Farms you own _____

b. Farms rented for cash _____

c. Farms share rented _____

d. Off-farm activities _____

Total 100 percent

2. In your farming practice, please circle who makes the management decisions for crop variety, pesticide use, labor and water orders when land is:

Farmed by owner	Rented for cash	Share rented
Landowner	Landowner	Landowner
Tenant	Tenant	Tenant
Manager	Manager	Manager
Field hand	Field hand	Field hand
Ag/crop consultant	Ag/crop consultant	Ag/crop consultant
Other_________________	Other_________________	Other_________________

3. Which of the following conservation practices do you practice to reduce water use? Circle all that apply.

a. Precision land leveling

b. Multiple inlets

c. Permanent levees

d. Other: ___________________

4. Please rank the reasons below for adopting conservation practices such as precision land leveling, multiple inlets or permanent perimeter levees (1 being most important, 5 being least important).

a. Increase yield. _____

b. Land topography _____

c. Reduce labor costs _____

d. Water savings _____

e. Financial support _____

f. Other, please specify: ______________________

5. Please estimate the percentage of your farmland that has been precision leveled (i.e., land graded to a slope of less than 2 percent).

_____ percent

6. How often do you perform land-grading maintenance on your precision-leveled fields?

a. Each year they are in production.

b. Every other year they are in production.

c. Every _____ years.

d. As needed based on visual inspection.

e. Other:___________________________

7. What circumstances lead you to perform land-grading maintenance on your precision-leveled fields?

a. Weather

b. Fallow-field flooding

c. Livestock damage

d. Other: ____________________________

8. Please rank the following sources of farming knowledge (1 being most important, 5 being least important).

a. My own practice and experience _____

b. Parents/relatives _____

c. Other farmers _____

d. University Extension/USDA _____

e. School/professional training _____

f. Ag/crop consultant _____

g. Other, please specify: _______________________________

9. How has volumetric measurement and pricing of water affected your water usage (choose one answer)?

a. I use about the same amount of water as I always have.

b. I use less water than I did prior to implementation of this pricing mechanism.

c. I use more water than I did prior to implementation of this pricing mechanism.

10. Since volumetric measurement and pricing were introduced, are you managing water in your fields differently with greater investment in labor or some other management technique?

a. Investing in more labor to increase efficiency of water use.

b. Other technique (please describe): ______________________________________

11. Do you manage/maintain your private lateral canals on a regular basis and if so, what is the primary reason(s) for doing so?

- No
- Yes, because____

12. On your farm fields, do you collect rainfall or other weather data?

- Yes
- No

13. Do you flush your field(s) as a standard practice before holding a permanent flood?

- Yes
- No

14. Do you flush to start a herbicide?

- Yes
- No

15. Are there any other things that you can tell us about your farming practice that influence your water use?

____
____
____
____
____

PART 2: FIELD CHARACTERISTICS *Please list the fields you farmed in 2012 and place a check in the appropriate box to describe each field*

Survey ID:

2012	2nd crop	Management		Conservation Measures								
Field name	**Abandoned harvest of 2nd crop**	**Rice Variety**	**Ownership stake**	**Conservation Measures**	**In-field lateral**	**Multiple Inlets**	**Levees**		**Slope**	**Multiple Inlets Funding**	**Precision Leveling Funding**	**Water by wells**
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other____	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other____	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other____	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other____	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other____	Yes if Yes, %water ____ No

PART 2: FIELD CHARACTERISTICS *Please list the fields you farmed in 2013 and place a check in the appropriate box to describe each field* Survey ID:

2013 Field name	2nd crop Abandoned harvest of 2nd crop	Management Rice Variety	Ownership stake	Conservation Measures Conservation Measures	In-field lateral	Multiple Inlets	Levees		Slope	Multiple Inlets Funding	Precision Leveling Funding	Water by wells
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ________	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ________	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ________	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ________	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ________	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ________	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ________	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ________	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ____	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ________	Precision Leveled ____yr % of field leveled ____ Multiple Inlets ____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ________	Yes No	Number of water inlets controlled by farmer ____	Permanent Straight Contour None Other (specify) ____	Number of Levees ____	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ____ No

PART 2: FIELD CHARACTERISTICS *Please list the fields you farmed in 2014 and place a check in the appropriate box to describe each field* Survey ID:

2014 Field name	2nd crop	Management		Conservation Measures								Water by wells
	Abandoned harvest of 2nd	Rice Variety	Ownership stake	Conservation Measures	In-field lateral	Multiple Inlets	Levees		Slope	Multiple Inlets Funding	Precision Leveling Funding	
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____________	Precision Leveled _______yr % of field leveled _______ Multiple Inlets _______yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____________	Yes No	Number of water inlets controlled by farmer _______	Permanent Straight Contour None Other (specify) ________	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other_________	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____________	Precision Leveled _____yr % of field leveled _____ Multiple Inlets _____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____________	Yes No	Number of water inlets controlled by farmer _______	Permanent Straight Contour None Other (specify) ________	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other_________	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____________	Precision Leveled _____yr % of field leveled _____ Multiple Inlets _____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____________	Yes No	Number of water inlets controlled by farmer _______	Permanent Straight Contour None Other (specify) ________	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other_________	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____________	Precision Leveled _____yr % of field leveled _____ Multiple Inlets _____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____________	Yes No	Number of water inlets controlled by farmer _______	Permanent Straight Contour None Other (specify) ________	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other_________	Yes if Yes, %water ____ No
LCRA: **Owner:** FSA number Description: Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ____________	Precision Leveled _____yr % of field leveled _____ Multiple Inlets _____yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ____________	Yes No	Number of water inlets controlled by farmer _______	Permanent Straight Contour None Other (specify) ________	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ____________	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other_________	Yes if Yes, %water ____ No

PART 2: FIELD CHARACTERISTICS *Please list the fields you farmed in 2015 and place a check in the appropriate box to describe each field* Survey ID:

2015	2nd crop	Management		Conservation Measures								
Field name	Abandoned harvest of 2nd crop	Rice Variety	Ownership stake	Conservation Measures	In-field lateral	Multiple Inlets	Levees		Slope	Multiple Inlets Funding	Precision Leveling Funding	Water by wells
LCRA: **Owner:** FSA number Description: / Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ______	Precision Leveled ______yr % of field leveled ______ Multiple Inlets ______yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ______	Yes No	Number of water inlets controlled by farmer ______	Permanent Straight Contour None Other (specify) ______	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ______	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ______ No
LCRA: **Owner:** FSA number Description: / Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ______	Precision Leveled ______yr % of field leveled ______ Multiple Inlets ______yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ______	Yes No	Number of water inlets controlled by farmer ______	Permanent Straight Contour None Other (specify) ______	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ______	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ______ No
LCRA: **Owner:** FSA number Description: / Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ______	Precision Leveled ______yr % of field leveled ______ Multiple Inlets ______yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ______	Yes No	Number of water inlets controlled by farmer ______	Permanent Straight Contour None Other (specify) ______	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ______	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ______ No
LCRA: **Owner:** FSA number Description: / Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ______	Precision Leveled ______yr % of field leveled ______ Multiple Inlets ______yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ______	Yes No	Number of water inlets controlled by farmer ______	Permanent Straight Contour None Other (specify) ______	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ______	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ______ No
LCRA: **Owner:** FSA number Description: / Acres:	Yes No	Traditional Seed Hybrid Other ______	Farmed by owner Rented for cash Share rented 50/50 Other (specify) ______	Precision Leveled ______yr % of field leveled ______ Multiple Inlets ______yr Permanent Perimeter Levees Conservation Tillage Other (please specify) ______	Yes No	Number of water inlets controlled by farmer ______	Permanent Straight Contour None Other (specify) ______	Number of Levees ______	Slope = 0.2% 0.2% > Slope > 0.1% Slope = 0.1% Slope = 0.05% Zero grade Other (specify) ______	NRCS funding Yes No	Cost-share with NRCS Yes No All Private funding Yes No Other______	Yes if Yes, %water ______ No

PART 2: FIELD CHARACTERISTICS *Please list the fields you farmed in 2016 and place a check in the appropriate box to describe each field*

Survey ID:

2016	2nd crop	Management		Conservation Measures								
Field name	Abandoned harvest of 2nd crop	Rice Variety	Ownership stake	Conservation Measures	In-field lateral	Multiple Inlets	Levees		Slope	Multiple Inlets Funding	Precision Leveling Funding	Water by wells
LCRA: Owner: FSA number Description: Acres:	☐Yes ☐ No	☐Traditional ☐ Seed ☐ Hybrid ☐ Other _____	☐Farmed by owner ☐ Rented for cash ☐ Share rented 50/50 ☐ Other (specify) __________	☐Precision Leveled _____yr % of field leveled _____ ☐ Multiple Inlets _____yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ Yes ☐ No	Number of water inlets controlled by farmer _____	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) _____	Number of Levees _____	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Slope = 0.05% ☐ Zero grade ☐ Other (specify) __________	NRCS funding ☐ Yes ☐ No	Cost-share with NRCS ☐ Yes ☐ No All Private funding ☐ Yes ☐ No ☐ Other_______	☐Yes if Yes, %water ___ ☐ No
LCRA: Owner: FSA number Description: Acres:	☐Yes ☐ No	☐Traditional ☐ Seed ☐ Hybrid ☐ Other _____	☐Farmed by owner ☐ Rented for cash ☐ Share rented 50/50 ☐ Other (specify) __________	☐Precision Leveled _____yr % of field leveled _____ ☐ Multiple Inlets _____yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ Yes ☐ No	Number of water inlets controlled by farmer _____	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) _____	Number of Levees _____	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Slope = 0.05% ☐ Zero grade ☐ Other (specify) __________	NRCS funding ☐ Yes ☐ No	Cost-share with NRCS ☐ Yes ☐ No All Private funding ☐ Yes ☐ No ☐ Other_______	☐Yes if Yes, %water ___ ☐ No
LCRA: Owner: FSA number Description: Acres:	☐Yes ☐ No	☐Traditional ☐ Seed ☐ Hybrid ☐ Other _____	☐Farmed by owner ☐ Rented for cash ☐ Share rented 50/50 ☐ Other (specify) __________	☐Precision Leveled _____yr % of field leveled _____ ☐ Multiple Inlets _____yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ Yes ☐ No	Number of water inlets controlled by farmer _____	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) _____	Number of Levees _____	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Slope = 0.05% ☐ Zero grade ☐ Other (specify) __________	NRCS funding ☐ Yes ☐ No	Cost-share with NRCS ☐ Yes ☐ No All Private funding ☐ Yes ☐ No ☐ Other_______	☐Yes if Yes, %water ___ ☐ No
LCRA: Owner: FSA number Description: Acres:	☐Yes ☐ No	☐Traditional ☐ Seed ☐ Hybrid ☐ Other _____	☐Farmed by owner ☐ Rented for cash ☐ Share rented 50/50 ☐ Other (specify) __________	☐Precision Leveled _____yr % of field leveled _____ ☐ Multiple Inlets _____yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ Yes ☐ No	Number of water inlets controlled by farmer _____	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) _____	Number of Levees _____	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Slope = 0.05% ☐ Zero grade ☐ Other (specify) __________	NRCS funding ☐ Yes ☐ No	Cost-share with NRCS ☐ Yes ☐ No All Private funding ☐ Yes ☐ No ☐ Other_______	☐Yes if Yes, %water ___ ☐ No
LCRA: Owner: FSA number Description: Acres:	☐Yes ☐ No	☐Traditional ☐ Seed ☐ Hybrid ☐ Other _____	☐Farmed by owner ☐ Rented for cash ☐ Share rented 50/50 ☐ Other (specify) __________	☐Precision Leveled _____yr % of field leveled _____ ☐ Multiple Inlets _____yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ Yes ☐ No	Number of water inlets controlled by farmer _____	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) _____	Number of Levees _____	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Slope = 0.05% ☐ Zero grade ☐ Other (specify) __________	NRCS funding ☐ Yes ☐ No	Cost-share with NRCS ☐ Yes ☐ No All Private funding ☐ Yes ☐ No ☐ Other_______	☐Yes if Yes, %water ___ ☐ No

Name	Description
CONSERVATION TILLAGE	Any practice where a field is not tilled in the spring before planting (including minimum tillage, stale seedbed planting, and limited tillage)
CONTOUR LEVEE	Unmodified slopes; levees are usually serpentine and irregularly spaced
CROP CONSULTANT	Whether or not management decisions (such as amount of water applied to a field, application of herbicides, pest control, rice variety etc.) about rice production are influenced by an independent crop consultant
CONVENTIONAL RICE VARIETY	A rice variety such as Cocodrie or Cypress or Presidio
EXTENSION AGENT	Government sponsored agent who disseminate agricultural technical information by talking to farmers, sponsoring demonstrations, field days and meetings
FAILED 2ND CROP	Whether harvest of the rice field was completed or the rice field was abandoned
FARM GAUGE	Sensors installed on fields to transmit rainfall or other weather data to the farmer
FARMED BY OWNER	When the person who farms the land is the landowner
FIELD HAND	Paid labor used on the field to produce the rice crop
FLUSH	Number times irrigation water is applied to the field prior to holding a permanent flood
FUNDING	Whether or not a farmer received cost-sharing or incentive payments for installing/using conservation practices on this field
HYBRID RICE VARIETY	A hybrid rice variety such as rice tech varieties
IN-FIELD LATERAL	Presence of an open canal with a series on inlets controlled by the farmer to release water at multiple points on a field
LEVEE DENSITY	Number of levees used in the field as part of the irrigation system to cascade water from one level to the next; number of levees divided by the size of the field
MANAGEMENT DECISIONS	Decisions on farming practices such as crop variety, pesticides, water use, labor and infrastructure investments
MANAGER	Also called operator; paid worker who makes management decisions regarding rice production
MULTIPLE INLETS	Presence of unmetered multiple inlets on a field; multiple-inlet distribution is the practice of releasing water at multiple points along the side of a field utilizing a field lateral and multiple control structures instead of feeding all water through the highest cut of a rice field and cascading it down through each lower cut.
OWNERSHIP	Ownership stake: does the farmer own, rent, or only work the field
PERIMETER PERMANENT LEVEE	A field that contains permanent levees surrounding the field that are not plowed between growing seasons
PERMANENT FLOOD DATE	When floodwaters are maintained over the entire rice field throughout much of the growing season
PERMANENT LEVEE	Type of system used to apply water to a field; where the field contains permanent levees (e.g., in bench grading) that are not plowed between growing seasons
PLANTING DATE	Date the field was planted
PRECISION LEVEL	Whether or not a field was graded using laser-guided excavation equipment to a uniform slope equal to or less than 2 percent (conforming to minimum NRCS standards)
RENTED FOR CASH	When the person who farms the land is not the landowner and he/she pays cash to rent the field
SEED RICE VARIETY	Rice that is grown for the purpose of seed production
SHARE RENTED	When the person who farms the land is the not the landowner, but shares crop production from this field with the landowner
STRAIGHT LEVEE	Fields with 0.1 percent grade, where levees are usually straight or have a slight bending
VOLUMETRIC MEASUREMENT AND PRICING	The practice of measuring water use once a day at each farm turnout, equipped with a standardized aluminum slide gate, by determining flow rate with a portable velocity probe flow meter.
WELL	Whether or not wells were used to supplement water to irrigate a field
YEAR	Year when a field was in production (i.e., crop year)
ZERO GRADE	All slopes are removed; the fields are devoid of internal levees

APPENDIX B

t-tests applied to determine sample representativeness

T-Test

Group Statistics					
	Sample_Code	N	Mean	Std. Deviation	Std. Error Mean
contr_acre	Non-Surveyed Fields	839	83.4498093000000	52.8056311200000 0	1.82305284200000
	Surveyed Fields	365	78.4393698600000	50.7432007000000 0	2.65602051500000

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
contr_acre	Equal variances assumed	6.751	.009	1.531	1202	.126	5.0104394 3400000	3.2724302 7700000	- 1.4098709 2900000	11.430749 80000000
	Equal variances not assumed			1.555	718.500	.120	5.0104394 3400000	3.2214851 6100000	- 1.3142094 7400000	11.335088 34000000

T-Test

Group Statistics					
	Sample_Code	*N*	*Mean*	*Std. Deviation*	*Std. Error Mean*
gisacres	*Non-Surveyed Fields*	*839*	*78.7366127000000*	*45.3359191400000 0*	*1.56516974600000*
	Surveyed Fields	*365*	*75.0134529500000*	*39.2314973000000 0*	*2.05347042100000*

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
gisacres	Equal variances assumed	12.579	.000	1.363	1202	.173	3.72315975 300000	2.7324360 2700000	- 1.6377145 3700000	9.0840340 4400000
	Equal variances not assumed			1.442	793.46 7	.150	3.72315975 300000	2.5819560 6200000	- 1.3451121 3600000	8.7914316 4200000

COMPUTE filter_$=(year = 2012).
VARIABLE LABELS filter_$ 'year = 2012 (FILTER)'.

T-Test

Group Statistics

	Sample_Code	N	Mean	Std. Deviation	Std. Error Mean
gisacres	Non-Surveyed Fields	147	78.2078816800000	44.45538353000000	3.66661823500000
	Surveyed Fields	69	85.9086101300000	38.94391515000000	4.68829644800000
contr_acre	Non-Surveyed Fields	147	106.6748299000000	74.15253361000000	6.11599789100000
	Surveyed Fields	69	104.9115942000000	80.99695754000000	9.75088783100000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
gisacres	Equal variances assumed	1.424	.234	-1.233	214	.219	-7.70072844300000	6.24303402100000	-20.00644308000000	4.60498619800000
	Equal variances not assumed			-1.294	150.415	.198	-7.70072844300000	5.95182433100000	-19.46070613000000	4.05924924200000
contr_acre	Equal variances assumed	.032	.858	.158	214	.874	1.76323572900000	11.14813753000000	-20.21098366000000	23.73745511000000
	Equal variances not assumed			.153	123.151	.879	1.76323572900000	11.51022344000000	-21.02026838000000	24.54673984000000

COMPUTE filter_$=(year = 2013).
VARIABLE LABELS filter_$ 'year = 2013 (FILTER)'.

T-Test

	Group Statistics				
	Sample_Code	N	Mean	Std. Deviation	Std. Error Mean
gisacres	Non-Surveyed Fields	181	74.1726690300000	45.02305519000000	3.34653733700000
	Surveyed Fields	75	71.9874591800000	36.52012098000000	4.21698033600000
contr_acre	Non-Surveyed Fields	181	73.5207182300000	44.99804548000000	3.34467838000000
	Surveyed Fields	75	72.0309333300000	36.85239144000000	4.25534762300000

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
gisacres	Equal variances assumed	5.882	.016	.372	254	.710	2.18520985500000	5.86665177500000	-9.36826638800000	13.73868610000000
	Equal variances not assumed			.406	169.001	.685	2.18520985500000	5.38351514300000	-8.44238944400000	12.81280915000000
contr_acre	Equal variances assumed	5.057	.025	.254	254	.800	1.48978489900000	5.87549650100000	-10.08110968000000	13.06067948000000
	Equal variances not assumed			.275	167.408	.783	1.48978489900000	5.41247234200000	-9.19571190300000	12.17528170000000

COMPUTE filter_$=(year = 2014).

T-Test

Group Statistics						
	Sample_Code	N	Mean	Std. Deviation	Std. Error Mean
gisacres	Non-Surveyed Fields	167	82.4603993600000	46.30815434000000	3.58343256800000
	Surveyed Fields	71	73.0616421700000	40.14752537000000	4.76463467300000
contr_acre	Non-Surveyed Fields	167	82.6549700600000	46.32133979000000	3.58445288900000
	Surveyed Fields	71	73.1588732400000	40.16938780000000	4.76722926600000

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
gisacres	Equal variances assumed	4.247	.040	1.488	236	.138	9.39875718500000	6.31453601800000	-3.04130091700000	21.83881529000000
	Equal variances not assumed			1.577	151.188	.117	9.39875718500000	5.96177260000000	-2.38038847200000	21.17790284000000
contr_acre	Equal variances assumed	4.329	.039	1.503	236	.134	9.49609682000000	6.31672886700000	-2.94828134000000	21.94047498000000
	Equal variances not assumed			1.592	151.150	.113	9.49609682000000	5.96445952200000	-2.28838154400000	21.28057518000000

COMPUTE filter_$=(year = 2015).
VARIABLE LABELS filter_$ 'year = 2015 (FILTER)'.

T-Test

Group Statistics					
	Sample_Code	N	Mean	Std. Deviation	Std. Error Mean
gisacres	Non-Surveyed Fields	166	79.5930299500000	44.15132935000000	3.42680774800000
	Surveyed Fields	72	72.2013483400000	39.13160662000000	4.61170406700000
contr_acre	Non-Surveyed Fields	166	78.1546385500000	43.85813102000000	3.40405114500000
	Surveyed Fields	72	71.4054166700000	36.39595090000000	4.28930394800000

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
gisacres	Equal variances assumed	.868	.352	1.227	236	.221	7.39168161700000	6.02600125800000	-4.47994371800000	19.26330695000000
	Equal variances not assumed			1.287	151.214	.200	7.39168161700000	5.74550482900000	-3.96015100300000	18.74351424000000
contr_acre	Equal variances assumed	2.203	.139	1.145	236	.253	6.74922188800000	5.89199810700000	-4.85840828200000	18.35685206000000
	Equal variances not assumed			1.233	161.100	.220	6.74922188800000	5.47591933500000	-4.06461685000000	17.56306063000000

COMPUTE filter_$=(year = 2016).
VARIABLE LABELS filter_$ 'year = 2016 (FILTER)'.

T-Test

Group Statistics

	Sample_Code	N	Mean	Std. Deviation	Std. Error Mean
gisacres	Non-Surveyed Fields	178	79.5217791600000	46.6378956300000 0	3.49565806900000
	Surveyed Fields	78	72.6574758400000	40.5660161600000 0	4.59319684600000
contr_acre	Non-Surveyed Fields	178	80.0499438200000	47.0560929900000 0	3.52700328600000
	Surveyed Fields	78	72.4830769200000	40.1126396000000 0	4.54186205900000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
gisacres	Equal variances assumed	2.736	.099	1.126	254	.261	6.8643033 2500000	6.0947337 3800000	- 5.138345 57000000	18.866952 22000000
	Equal variances not assumed			1.189	167.57 2	.236	6.8643033 2500000	5.7720951 6500000	- 4.531092 38400000	18.259699 03000000
contr_acre	Equal variances assumed	3.251	.073	1.237	254	.217	7.5668668 9700000	6.1192135 9800000	- 4.483991 35000000	19.617725 14000000
	Equal variances not assumed			1.316	170.84 2	.190	7.5668668 9700000	5.7505011 2100000	- 3.784317 38800000	18.918051 18000000

APPENDIX C

Longitudinal multi-level model equation

Notation: t = level-1 time, i = level-2 field, j = level-3 farmer

Level 1: $Y_{tij} = \beta_{0ij} + \beta_{1ij}(T_{tij}) + \beta_{kij}(\boldsymbol{X_{tij}}) + \varepsilon_{tij}$

Level 2: $\beta_{0ij} = \delta_{00j} + u_{0ij}$

Level 3: $\delta_{00j} = \gamma_{000} + v_{00j}$

Y_{tij} = log of total water use at time t for field i, managed by farmer j
β_{0ij} = intercept for field i, managed by farmer j
β_{1ij} = regression coefficient on the time predictor for field i, managed by farmer j
β_{kij} = regression coefficients on the k time-varying predictors for field i, managed by farmer j (k=7)
ε_{tij} = level 1 error term
T_{tij} = dedicated time predictor (centered on first year of observation (2012))
$\boldsymbol{X_{tij}}$ = {Cost per Unit*, Field Size*, Growing Season*, Temperature*, Levee Density, Hybrid Rice, Farmed by Owner}
*Indicates variable mean-centered during regression analysis
δ_{00j} = level 2 intercepts
u_{0ij} = field random effects
γ_{000} = level 3 intercepts
v_{00j} = farmer random effects

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