VERIFYING CONSERVATION ESTIMATES FOR ON-FARM AGRICULTURAL WATER CONSERVATION PROGRAMS

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ABSTRACT

This paper presents a statistical analysis of water use practices for precision leveled rice fields irrigated by the Lower Colorado River Authority (LCRA) Lakeside irrigation division. Results from this analysis indicate there is a statistically significant difference in water use between leveled and non-leveled fields. The study also evaluated the effects of other water use factors such as other on-farm conservation measures, farmer management practices, and environmental factors. The analysis used a Hierarchical Linear Model (HLM) technique to statistically model water use and farm practice data over a 4-year period. This study is a conservation verification component of LCRA's HB 1437 Agriculture Water Conservation Program.

The House Bill 1437 (HB 1437) Agriculture Water Conservation Program is an innovative way to meet rising municipal demands in Williamson County (located in the Colorado River Basin of Texas), conserve river water used for irrigation, and maintain agriculture productivity. The grant program began in 2006, and from 2006-2009 has funded up to a 30% cost share to precision level 18,869 acres of farm land irrigated with surface water from LCRA. To date an estimated 5,567 acre-feet of water has been conserved as a result of these precision land leveling grants.

LCRA partnered with the LBJ School of Public Affairs at the University of Texas to develop the statistical model and analysis presented in this paper.

INTRODUCTION

The HB 1437 Agricultural Water Conservation Program began in 2006 and has funded up to a 30% cost share to precision level 18,869 acres of farm land irrigated with surface water from the Lower Colorado River Authority (LCRA). To date an estimated 5,567 acre-feet of water has been conserved as a result of these precision land leveling projects. The purpose of this paper is to report the results of a statistical evaluation of water conservation estimates between precision leveled and non-leveled rice fields in the LCRA's Lakeside irrigation division (Figure 1).

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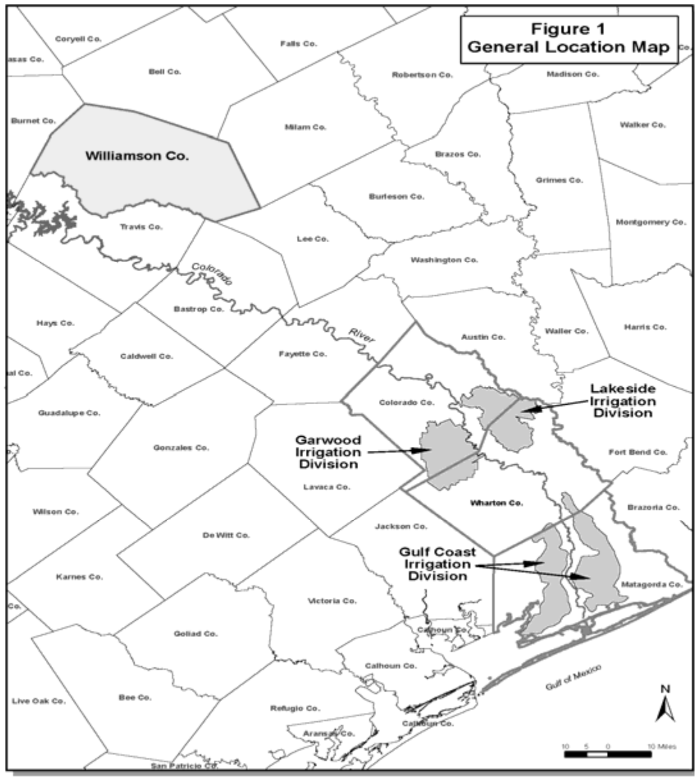


Figure 1. General Location Map

The LCRA is a conservation and reclamation district created by the Texas Legislature in 1934. LCRA supplies electricity for Central Texas, manages water supplies and floods in the lower Colorado River basin through the operation of six dams, manages three irrigation divisions (Lakeside, Garwood, and Gulf Coast), develops water and wastewater utilities, provides public parks, and supports community and economic development in 58 Texas counties.

PROGRAM OVERVIEW

The House Bill (HB) 1437 Agriculture Water Conservation Program is an innovative way to conserve agricultural water, meet rising municipal demands, and maintain agricultural productivity. A bill, HB1437, passed by the Texas Legislature in 1999, authorized the LCRA to transfer up to 25,000 acre-feet of water annually to Williamson County, if the transfer results in "no net loss" of water to the lower Colorado River basin. "No Net Loss" is generally defined as the hydrologic condition where the volume of water transferred is equivalent to the volume of water conserved within the LCRA irrigation divisions.

The bill also established a conservation surcharge on the transferred water to fund on-farm and in division agricultural conservation projects within the LCRA irrigation divisions. Additional details of the program history and legislation are available at www.hb1437.com

This program is a major part of the LCRA's water conservation program for agricultural uses. The program joins individual producers, local soil and water conservation districts, and the NRCS in a collaborative effort to conserve water. The goals of the HB 1437 program are to: 1) Reduce agricultural use of surface water; 2) Plan and implement conservation projects to fulfill obligations of the HB 1437 water sales contract and interbasin transfer permit; 3) Provide grants from the Agricultural Water Conservation Fund to implement water conservation projects; and 4) Provide program performance and conservation metrics to the LCRA Board, water customers, and the public.

Demand Projections for HB 1437 Water

The water demand projections were developed by the Brazos River Authority (BRA) and its customers and are reviewed and updated annually. Figure 2 compares the HB 1437 water demands used to develop the current HB 1437 implementation plan with the updated demand projections recently provided by BRA and their customers. The updated projections indicate an initial delay in demand, relative to the previous projections, followed by a more uniform growth.

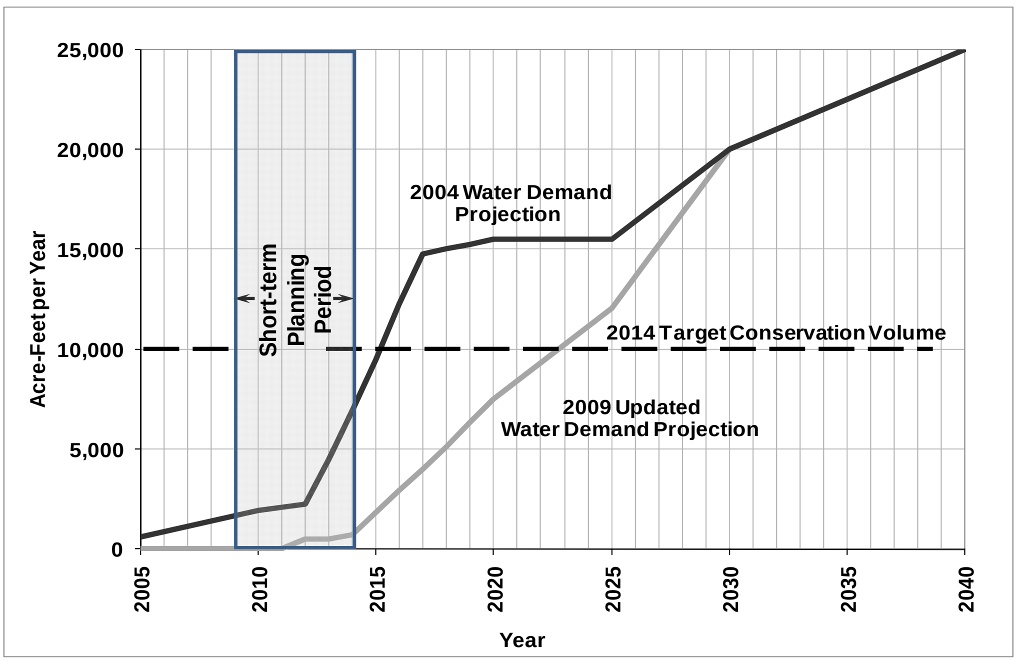


Figure 2. Water Demand Projections for HB 1437 Water

Program Plan

The current program plan includes a series of on-farm and in division conservation projects and studies to be completed during the period 2009 to 2014. The goal of this short-term plan is to conserve 10,000 acre-feet of HB 1437 water per year for transfer to Williamson County by 2014. This target provides for development of conservation improvements 4 to 6 years ahead of their need while accounting for other uncertainties, such as reliability of conservation during drought. A summary of the HB 1437 program plan is presented in Table 1.

Table 1. 2010-2014 Conservation Projects and Program Costs

On-Farm Projects	In-Division Projects	Studies and Management
Precision level 12,500 acres of farmland (2,500 acres per year)	Implement volumetric measurement in the Garwood Irrigation division Retrofit to automate eleven canal check structures with centralized control in the Gulf Coast Irrigation Division	Conservation verification and monitoring
Construction Cost - $1.2 million	Construction Cost - $1.6 million	Oversight and customer communication Program administration
Total cost: $8.0 million **Funding sources:** Ag Fund - $3.1 million, EQIP, USBR Grant, and TWDB Grant - $3.1 million, Farmer - $2.1 million **HB 1437 Water Available for Transfer**: 10,000 acre-feet per year		

Program Funding

The program is funded through the income stream generated from a conservation surcharge applied to the HB 1437 water sales contract. The conservation surcharge is applied to both reserved water and transferred water. Income to the Ag Fund is based on the following rates:

- Conservation Surcharge 25%
- Normal Raw Water Cost: $151/ac-ft
- Max Available Water: 25,000 ac-ft/yr
- Reserved Water Cost: $75/ac-ft

CONSERVATION VERIFICATION STUDY

Verification of the water savings from the HB 1437 program is essential to comply with the "no net loss" provision of the law, and to accurately judge the cost effectiveness of water conservation projects.

Estimating Volume of Conserved Water

Water conserved through precision leveling is estimated by multiplying the number of acres leveled times the Conservation Factor (C_f) for precision leveling.

- For example: In 2009, approximately 10,652 acres were in production saving an estimated 7,989 acre-feet of water – (10,652 acres * 0.75 acre-ft/acre leveled).
- The 0.75 acre-ft/acre conservation factor was developed based on results from field studies at the Texas A&M's Texas Agricultural Experiment Station (TAES) in Eagle Lake, Texas.

Previous Work

Studies by others have examined the role of precision leveled fields in agricultural water conservation (Goel et al. 1981, Anderson et al. 1999, Bjornlund et al. 2009, Smith et al. 2007) and have identified several factors affecting conservation estimates including: farmer's age and education, dependence on off-farm work, acres farmed, a field's ownership, the quality of land leveling work and water costs.

Current Work

In August 2009, LCRA partnered with the University of Texas at Austin LBJ School of Public Affairs to conduct a statistical analysis of water use factors for the HB 1437 water conservation program. The study evaluated four years (2006 - 2009) of water use data and other farming practices in the LCRA's Lakeside irrigation division. The goals of this study included:

- Determine the extent to which precision land leveling explains on-farm water use;
- Identify other factors that affect water use such as temperature, rainfall, duration of crop season, and other water conservation measures; and
- Examine how these water use factors operate at the field level as well as among groups of fields managed by the same farmer.

Initial Analysis. An initial look at comparing water use between leveled and non-leveled fields within one crop season indicated that the data is normally distributed, and that there is a statistically significant difference in water use between leveled versus non-leveled fields using Student t-tests statistics. Findings from this initial analysis also identified the need to:

- Consider multiple years in the analysis;
- Incorporate other variables to extend the statistical analysis to a complete model, reducing or eliminating the effects of confounding factors (other conservation or management practices) measured along with the variable of interest (precision land leveling); and
- Account for the lack of independence between observations, which is an assumption required when using Student t-test statistics, by specifying a model that incorporates clusters of fields at the farmer/ownership level.

HLM Model. The LBJ School developed a series of Hierarchical Linear Models (HLM) to sort out the effects of factors contributing to water use. HLM analysis allows for both correlation between observations and correlation through time.

HLM models have several advantages: They allow comparisons across multiple years, incorporate all field data even when a rice field is not in production every year, and provides a robust data structure suitable for small sample sizes. Additional details of the model development are presented in the final report: “Statistical Testing for Precision Graded Verification” (http://www.lcra.org/library/media/public/docs/water/hb1437/LBJ_Final_Interim_Report_12-2010.pdf)

A graphical representation of the model is presented in Figure3. The initial model consisted of three levels and 17 factors: Level 1 – The Crop Season (TIME) to test the predictive relationship between year-to-year variation and field water use; Level 2 - FIELD tests the predictive relationship between specific field characteristics and water use; and finally, Level 3 - FARMER which tests the predictive relationship between farmer characteristics and water use. Table 2 presents the general form of the regression equations used in the analysis.

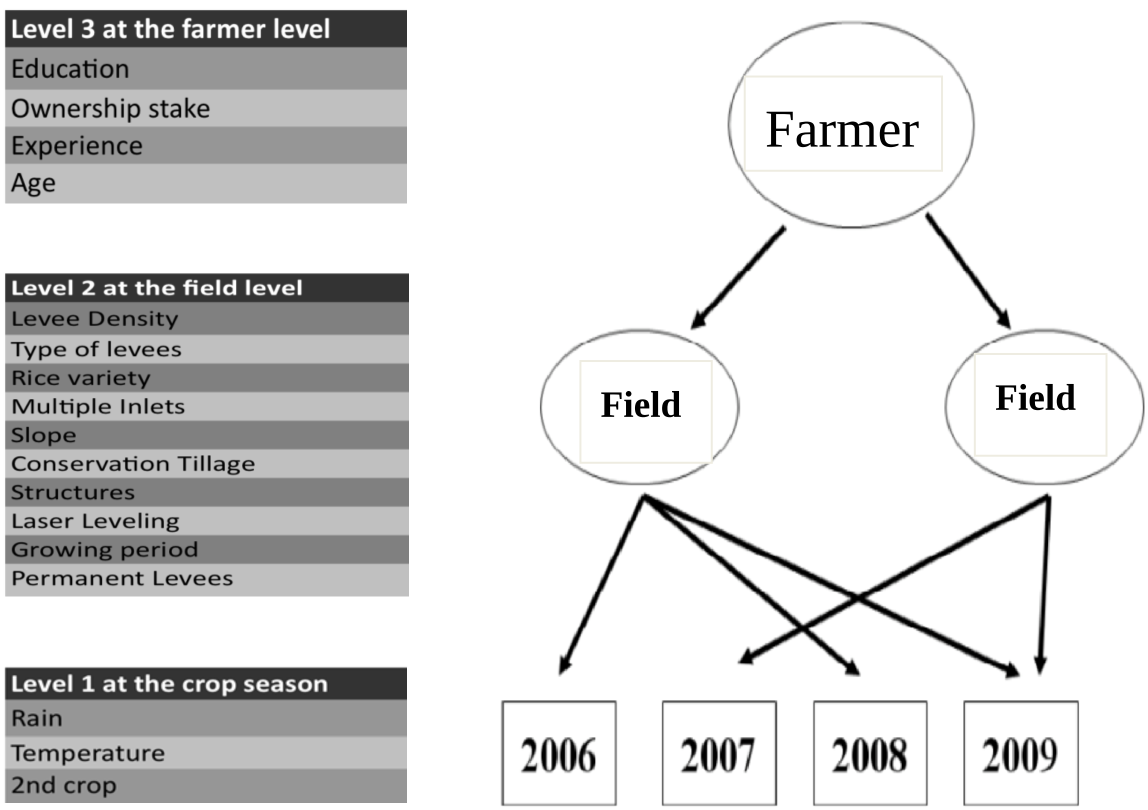


Figure 3. Graphical Depiction of the HLM Analytical Approach

Table 2. General HLM Linear Regression Equations [1]

Level 1:

$$WATER\_DEMAND_{tik} = \pi_{0ik} + \pi_1 RAIN_t + \pi_2 TEMP_t + \pi_3 SCROP_t + \varepsilon_{tik}$$

Level 2:

$$\pi_{1t} = \beta_{10t}$$
$$\pi_{2t} = \beta_{20t}$$
$$\pi_{3t} = \beta_{30t}$$

Level 3:

$$\beta_{04k} = \gamma_{010} + u_{01k}$$

$$\beta_{06k} = \gamma_{020} + u_{02k}$$

[1] (http://www.lcra.org/library/media/public/docs/water/hb1437/LBJ_Final_Interim_Report_12-2010.pdf)

Model Hypothesis

Table 3 summarized the research questions and model hypotheses for this statistical study to explore the effect of precision leveling on field water use, and the complex interaction between the contributing factors including weather conditions, fields characteristics and farming practices.

Table 3. Hypotheses: What Factors Affect On-farm Water Use?

Research Questions	Factors	Hypothesis
How do annual characteristics affect on-farm water use?	**Rain**	A relatively distinct wet crop season will reduce the water usage of fields.
	Temperature	A relatively hot crop season will increase the water usage of fields.
	Second Crop	During the second crop, fields have lower water usage than during the first crop.
How do the characteristics of fields affect on-farm water use?	**Precision Leveling**	Precision-leveled fields have lower water usage than non-precision leveled fields.
		The effect of precision leveling differs according to the levee system present in a field.
	Levee-System	When fields have a straight-levee system, the water usage of fields decrease.
	Multiple Inlet	The effect of a straight-levee system on the water use of fields differs according to the levee density in each field.
	Structures	The effect of a straight-levee system on the water use of fields differs according to the number of multiple inlets present in a field.
		Fields with four or more multiple inlets have lower water usage than fields with three or less multiple inlets.

Research Questions	Factors	Hypothesis
		As the number of measured structures in a field increases the water usage of that field decrease.
How do the characteristics of farmers affect on-farm water use?	**Growing Period**	An extended growing season leads to higher levels of water use while a shorter growing season results in lower on-farm water use.
	Ownership	The water usage of contract holders who farm their land is lower than the water usage of contract holders who rent their land.
	Rice Variety	The water usage of farmers cultivating hybrid rice is higher than those planting conventional cultivars.

Data Sources

This study uses three data sources: 1) LCRA contract and billing data from LCRA's WAMS (Water Application Management System), 2) Farmer Survey Data - information collected from the farmer survey developed for this study; and 3) Weather data. A description of each is presented below.

Water Application Management System (WAMS) Database. LCRA staff collects information about field characteristics through its annual water contracting process. Data collected in this system include: information for first and second crop, contract name, field name, year the field was in production, whether the field was in production during the 2nd crop, field acreage, field water use (ac-ft) and delivery structure information.

Table 4 presents a summary of the fields included in the study and includes approximately 195 fields each year over four years of data. The number of precision-leveled fields funded through the HB1437 program increased from 6 (2006), to 13 (2007), to 32 (2008), to 28 (2009).

Table 4. Total Fields in Production 2006-2009 during the First Crop

Year	Total fields	Non-Leveled fields		Leveled fields	
		Fields	Percentage	Fields	Percentage
2006	178	135	76%	43	24%
2007	174	120	69%	54	31%
2008	201	122	61%	79	39%
2009	227	143	63%	84	37%

Source: Survey and WAMS database 2010

Farmer Survey Data. A farmer survey instrument was developed and mailed to existing irrigation customers in the Lakeside irrigation division to collect information about conservation measures in place, water usage, and management decisions that affect water use. It focused on fields in production from 2006 to 2009.

The survey was divided into three main sections. Part 1, General Information, elicited information about the respondent including years of farming, age and education. Part 2, Farming Practices, asked for information about the entire farming operation including off-farm work, upgrades on irrigation equipment and farmers rationale for investing on water-conserving technology. In Part 3, Field Characteristics, detailed questions were asked on farming practices and upgrades implemented by field and year.

The surveys were mailed in mid-February 2010. Follow-up phone calls were made to all non-respondents about a month after the initial mailing and an additional mail survey was sent again as needed. Reminder post-cards were sent the third week of May 2010.

Over a period of seven months, 36 surveys were completed and returned, which accounted for 59 percent of the surveys mailed, 61 percent of rice fields in production and 62 percent of the annual planted acreage. Table 5 compares field information from contract holders and survey respondents and indicates that the field survey data are representative of most rice fields when considering field size and water use.

Table 5. Representative Sample: Field Size and Water Use

	WAMS DATA				SURVEY DATA			
	ACRES		WATER USE		ACRES		WATER USE	
YEAR	MEAN (ac-ft/ac)	STD DEV	MEAN (ac-ft/ac)	STD DEV	MEAN (ac-ft/ac)	STD DEV	MEAN (ac-ft/ac)	STD DEV
2006	118.960	78.754	2.494	0.666	119.239	79.378	2.472	0.581
2007	131.564	97.233	1.492	0.593	134.334	91.998	1.510	0.525
2008	143.006	115.190	2.956	0.885	146.049	120.685	2.912	0.806
2009	127.527	82.763	3.007	1.051	126.413	80.044	2.954	0.990

Some data collected in the survey was not sufficiently complete to be used in the HLN analysis of water use characteristics. Some data on conservation measures was available from a previous study, but it was necessary to expand and validate this data due to substantial changes in field characteristics. A summary of the Field Characteristics factors included in the analysis is presented in Table 6.

Table 6. Survey Information: Field Characteristics by Year

Part of HLM analysis		Not part of HLM analysis
EXPAND & VALIDATE	NEW INFORMATION	UNRELIABLE INFORMATION
Multiple inlets	Type of levees	Failed 2nd crop
Conservation tillage	Rice variety	Row crop
Historical leveled fields	Slope	Number of flushes
	Ownership	
	Permanent perimeter levees	

<u>Weather data.</u> Weather data were collected from 3 stations: Eagle Lake 7 NE station, Colorado River at Altair, and Wharton station from the LCRA's Hydromet System. Weather data were averaged during the average growing season for each station. Growing season refers to the average time between the first and last water delivery of the set of fields within each weather station polygon.

RESULTS AND CONCLUSIONS

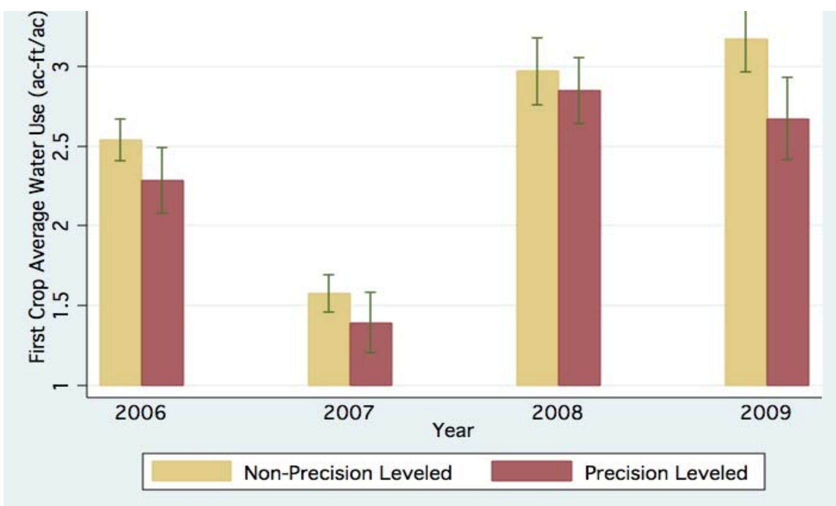
Due to the relative small sample size, some factors and hypotheses could not be tested with the HLM model. Table 7 summarizes those factors included in the HLM analysis as well as those factors excluded. A complete discussion of the results and conclusions are presented in the final report from the LBJ School and can be viewed at http://www.lcra.org/library/media/public/docs/water/hb1437/LBJ_Final_Interim_Report_12-2010.pdf

Table 7. Factors in the HLM Analysis

Part of HLM analysis		Not part of HLM analysis
FACTORS		FACTORS
Average Temperature	Multiple inlets	Permanent perimeter levees
Average Rain	Straight-levee system	Conservation Tillage
Second Crop	Levee Density	Age
Growing period	Rice Variety	Education
Precision leveling	Ownership	Experience
Structures		

The statistical analysis of the HLM modeling results show that precision leveling has both a direct and indirect effect on field water use. Figure 5 compares 1st crop water use between precision and non-precision leveled fields.

Figure 5. Comparison of Water Use in Precision and Non-Precision Leveled Fields



The results show that within a 95% confidence interval, precision leveling directly accounts for a 0.31 ac-ft/ac reduction in on-farm water use for the first crop compared to unleveled fields. The upper and lower bounds on the water saving suggest precision leveling reduces the water usage of fields by no less than 0.16 ac-ft/ac and no more than 0.46 ac-ft/ac.

The results also show that straight levees have both a direct and indirect effect on water use. The indirect effect is through the variable “precision leveling” - primarily due to the fact that fields with straight levees are more likely to be precision leveled. Results also showed that fields with straight levees exhibit lower overall water usage than fields with contour levees or a mixed-levee type system.

The results also indicate precision-leveled fields in combination with straight levees can save approximately 0.606 ac-ft/ac of water during the first crop. Using a 95% confidence interval, the upper and lower bounds of these results suggest that during the first crop water savings range from, 0.20 to 1 acre-feet less water, on precision-leveled fields with a straight levees system.

Recommendations for Future Work

The HLM statistical analysis of water use data from the Lakeside irrigation division has demonstrated it to be a suitable tool for estimating the conservation factor for precision leveling, as well as predicting the interaction with other variable contributing to water use. While much of the data is available from the LCRA contracting process, additional process refinements will be necessary to collect the necessary data to build upon the data set developed in this study.

This analysis also found that refinements to the model are necessary to improve the accuracy of these water savings. Recommendations include:

- Expand the model to include information from a fifth year of data (2010) which will allow 1st crop data to be evaluated separately from 2nd crop data,
- Include a evapotranspiration factor in the model,
- Evaluate the need for additional rain gauges, and
- Revaluate those factors considered to have unreliable data, including multiple inlets and levee density.

This research may be used to develop future guidelines for evaluating water conservation policies for the HB 1437 program and may influence the direction of implementing water-conserving technology. Additionally, water use data from the other districts will be evaluated to determine if a similar methodology can be used for LCRA's other divisions, Gulf Coast and Garwood.

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