VERIFYING CONSERVATION ESTIMATES FOR ON-FARM AGRICULTURAL WATER CONSERVATION PROGRAMS

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ABSTRACT

This paper presents an update on the statistical analysis of water use practices on precision leveled rice fields irrigated by the Lower Colorado River Authority (LCRA) Lakeside Irrigation Division. Results from the 2011 analysis confirms again that there is a statistically significant difference in water use between leveled and non-leveled fields (0.33 acre feet of water savings per acre farmed for the first rice crop only). The updated study incorporated and/or refined several additional variables that affect field water use such as other on-farm conservation measures and management practices of individual producers, added a year of data, and will include a separate analysis of the effect of system-wide savings on river diversions. The analysis used a statistical model that incorporated 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. 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.

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. For more information on this program please visit http://www.hb1437.com.

A 2005 implementation study identified land leveling as the first strategy that should be pursued using the funds from this program. The land leveling grant program began in 2006 and from 2006-2010 has funded up to a 30% cost share to precision level 22,086 acres of farm land irrigated with surface water from LCRA. To date an estimated 7,100 acre-feet of water has been conserved as a result of these precision land leveling grants. This study is essential to confirm the accuracy of the water savings estimates, which are being used to calculate the water available for transfer to meet municipal demands. The updated HB1437 short-term plan established a goal of conserving 10,000 acre feet per year by 2014.

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INTRODUCTION

Increasing the effectiveness of water-conserving verification programs has important implications particularly since "most United States legislation focus[es] on encouraging individual farmers to increase irrigation efficiency (Henning et al. 2009, Huffaker 2003)." A consequence of this policy perspective has been the significant amount of public and private funds invested in infrastructure, technology and incentives to reduce irrigated agricultural water use without reducing yields or productivity. Verification programs must be in place to judge the efficacy of numerous policies and resources invested in water-conserving programs. It is in the interest of water regulators and farmers to verify whether and how on-farm and on-district conservations measures save water in the fields and reduce the volume of water pumped from the river. This is an important step in making the case for ongoing investment of federal, regional and state funding to increase irrigation efficiency by improving the irrigation system as well as encouraging individual farmers to improve their farms.

The effectiveness of water conservation programs matter because policy makers, water regulators and utilities are looking at options to transfer water from agricultural-to-urban usage as a way to respond to the increasing water demands of fast growing populations that have limited water resources. It is hard to advocate for water changes from agricultural to municipal uses if reduced amount of water withdrawals from irrigation harm farm productivity significantly. As water becomes scarcer, precipitation patterns more uncertain and pressure for rural-to-urban transfers occur more frequently, legal and institutional mechanisms have to be in place to render water transfers politically, environmentally, socially and economically feasible. Reducing farmers' consumptive use of irrigation water by implementing conservation measures is one way to justify water transfers that can meet the needs of both municipal and agricultural water users

PROGRAM OVERVIEW

The Agricultural Water Conservation Program (HB1437 program) is a central component of the Lower Colorado River Authority's (LCRA) water conservation programs for agricultural uses. The HB1437 program is tied to a bill passed by the Texas Legislature in 1999 to authorize the LCRA to transfer up to 25,000 acre-feet of water annually to the Brazos River Basin 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. To account accurately for the conserved water developed through this program, the LCRA depends upon its ability to explain the difference in water use between many potential sources of water savings and the HB1437 conservation programs LCRA implements, such as precision leveling of farmland. The LCRA monitors and evaluates to ensure that sufficient water savings targets are achieved so water can be transferred to the Brazos River Basin with no adverse impact on the Colorado River Basin, as required in the HB1437 legislation.

The LCRA has significantly invested in cost-share programs (HB1437 program) to encourage farmers to implement precision laser-land leveling in an effort to conserve water. According to the LCRA, from 2006 to 2010, it has invested $1.41 million in precision land-leveling 271 fields, totaling 22,086 acres. A major goal of the HB1437 program is to continue to fund precision leveling 2,400 acres per year from 2010 to 2014. This program is run collaboratively with the Natural Resource Conservation Service's Environmental Quality Incentive Program (EQIP) through an interlocal agreement so most HB1437 grant recipients begin by entering into a EQIP contract to receive NRCS cost-share funds to precision level a particular piece of land. When a field is precision graded, the field's natural slopes are reduced or removed; this so-called "uniforming" of land evens out the distribution of water, lowering the required flood depth for a productive rice crop. Eligibility criteria for HB1437 Funds require meeting the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) standards.

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.

This paper reports on the Statistical Testing for Precision Graded Verification, based on a reliable and rigorous water conservation savings verification program for precision leveling in Lakeside Irrigation Division, an irrigation division is situated in Colorado and Wharton County in Texas. This verification study takes on a statistical approach, which is useful to illustrate relationships among the driving factors that influence fields' water usage. To tease-out precision leveling water savings, one needs to separate the effects of factors that can reasonably be expected to influence water usage of fields. Different fields managed by the same farmer may display some similarities in water use. Farmers may differ from one another on the judgments and choices they make about how, when and what amount of water to apply to their fields among other farming decisions they make. Hierarchical Linear Models (HLM) are particularly useful to deal with groupings of fields that share management style as well as when the same data points (fields in this case) do not occur at a regular interval (yearly).

CONSERVATION VERIFICATION STUDY

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.

The LCRA partnered with the University of Texas at Austin to develop and implement a rigorous statistical methodology to verify water savings from the on-farm conservation practice of precision land leveling while taking into account other water conservation

measures and management practices, as currently applied by the farmers, that influence water use.

A first step is to evaluate whether different types of fields have different patterns of water use. To tease-out precision leveling water savings, one needs to separate the effects of factors that can reasonably be expected to influence the water usage of fields. Different fields managed by the same farmer may display some similarities in water use. Farmers may differ from one another on the judgments and choices they make about how, when and what amount of water to apply to their fields among other farming decisions they make.

This analysis separates the 'precision leveling effect' from 'management skills' related to on-farm water usage. To separate the effects of precision leveling in light of farmers' skills and practices, it is important to recognize that a single farmer manages groupings of fields. Although it is plausible that a single farmer may manage one field, information from Lakeside from 2006 to 2010 shows that this one-to-one relationship is unlikely. Table 1 shows that, each year of the study, on average one farmer manages at least four fields. Grouping of fields by farmers supports the idea that different fields managed by the same farmer may display some similarities in their water usage.

Table 1. Number of Fields per Farmer

Year	Average	Maximum
2006	4	10
2007	4	14
2008	4	14
2009	5	14
2010	4	11

Source: Survey and WAMS database 2011

This verification study uses Hierarchical Linear Models (HLM) to quantify the separate effects that a range of factors have on farmers' use of irrigation water. HLM is particularly useful to deal with groupings of fields that share management style as well as when the same data points (fields in this case) do not occur at a regular interval (yearly due to crop rotation).

Data Sources

This study uses three data sources: LCRA data collected for billing purposes from WAMS (Water Application Management System), information collected through a survey of farmers and weather data. This study uses a sample set of approximately 180 fields each year over a five-year period (N=727). The number of precision-leveled fields in the sample funded through the HB1437 program has increased from 5 (2006), to 12 (2007), to 34 (2008), to 43 (2009), to 43 (2010). The three data sources are described below.

Water Application Management System (WAMS) Database. LCRA staff collects information about field characteristics through its annual water contracting process. The LCRA's water customer billing system collects the following information for first and second crop: contract name, field name, year the field was in production, whether the field was in production during the second crop, field acreage (ac), field water use (ac-ft) and number of delivery structures.

Survey data**.** The survey, which elicited information from farmers about fields in production from 2006 to 2010, provides data not otherwise available to LCRA. The survey asks farmers about conservation measures in place, water usage and management decisions that affect water use. The survey was implemented in 2010 and 2011. To increase the accuracy of the conservation verification analysis, during the 2011 survey effort, project staff collected new data (2010) as well as information from farmers who did not respond to the 2010 survey or who submitted an incomplete response. The data collected in the survey represents farmers' self-reported information; field verification of this information was outside of the scope of the study.

The response rate in 2011 was 20 percent higher than that of 2010. A high response rate was achieved as a result of in-person surveys and follow-up phone calls. In 2011, 64 of 73 surveys were completed, which represents 86 percent of the surveys mailed. Over 80 percent of both rice fields in production and planted acreage per year were represented in completed surveys. More than half (62 percent) of all completed surveys were face-to-face questionnaires; the remaining surveys were received via return mail.

Weather data. Weather data were collected from Eagle Lake 7 NE station, Colorado River at Altair and Wharton station from the Lower Colorado River Authority's (LCRA) Hydromet System.[4] Windspeed, solar radiation and humidity were collected from the Eagle Lake Research Center from the Texas A&M AgriLIFE Research Center due to the unreliability of these data collected by LCRA's Hydromet System. Daily weather data was 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 polygon.

Factors. This study takes a statistical approach to quantify the factors that influence water usage and to illustrate the relationship between factors. The effectiveness of the statistical verification program depends on which factors are included in the analysis. The choice of factors used in evaluating the effect of the quality of leveled land on farm water usage was informed by literature review, local producers, representatives of Lakeside, Garwood and Gulf Coast Irrigation Districts and the LCRA staff. Table 2 shows the factors included in the HLM analysis.

[4] LCRA's website http://hydromet.lcra.org/

Table 2. Factors Included in the HLM Analysis

WHAT ARE THE FACTORS?	
FACTORS	**DESCRIPTION**
PRECISION LEVELING	Whether a field has been precision leveled or not
MULTIPLE INLETS	Number of unmetered water inlets in a field.
RAIN	Average daily precipitation during the average growing season.
EVAPOTRANSPIRA-TION	Average daily evapotranspiration during the average growing season.
CASH	When the person who farms the land pays cash to rent the field from the landowner.
HYBRID*GROWING	Number of days between the first and last water delivery to a field planted with hybrid rice.
NUMBER OF LEVEES	Number of internal levees in a field as part of the irrigation system.
STRAIGHT LEVEES	When internal levees in a field are straight or have a slight bending.

RESULTS

Data from both WAMS and the Survey were used in modeling water usage and savings. When reviewing the results it is important to note that water demand is measured in acre-feet of water used per each acre farmed. An acre-foot is the amount of water required to cover an area of one acre to a depth of one foot.

Factors that influence water use

The 2011 results suggest that farmers who precision leveled a field use on average 0.33 acre-feet per acre less irrigation water than a farmer who does not precision level a field. The 95 percent confidence interval indicates that precision leveling reduces the water usage of a field by no less than 0.14 acre-feet per acre and no more than 0.54 acre feet per acre. The 2011 result is consistent with the 2010 first crop water savings (0.31 acre feet per acre) attributable to precision leveling (see Table 3). The 2011 confidence intervals increase slightly after 116 observations were removed from 2010 to 2011 to achieve a high reliability to all data points (see Figure 1), in that data were verified in the face-to-face survey. Some levee (n=54) and multiple inlet (n=62) observations were dropped to maintain the quality of the data. The results indicate that the water saving estimate for precision leveling is robust, as the values are essentially the same even with an additional year of data and the removal of second crop.

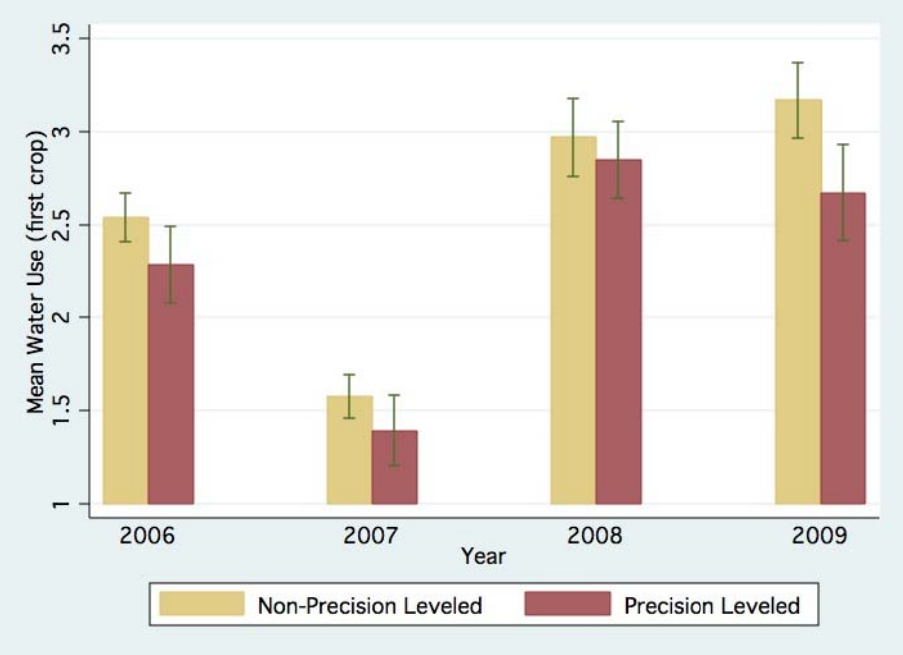

Figure 3. Average Water Use per Year
Source: Ramirez, A.K., Eaton, D. J. "Statistical Testing for Precision Graded Verification"

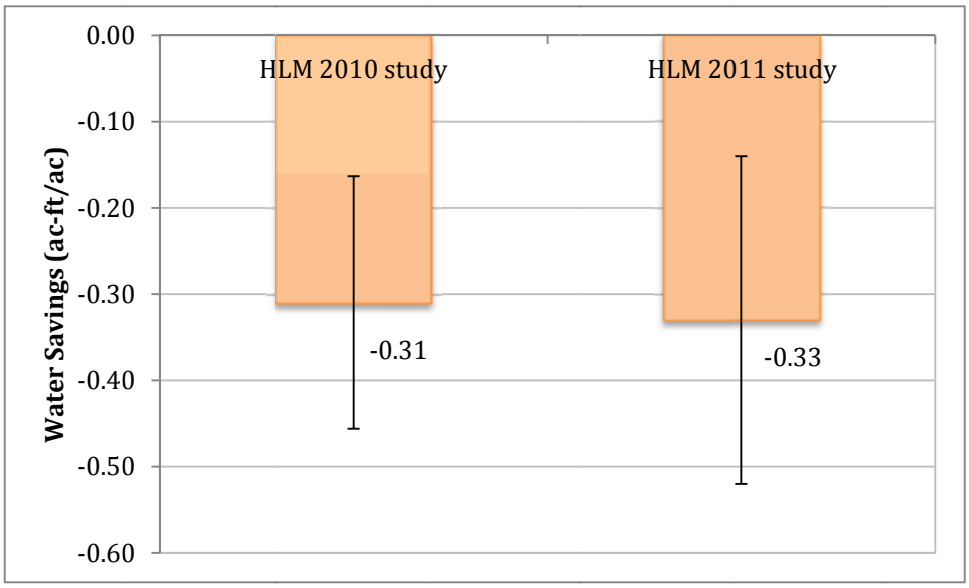

Figure 4. Precision Leveling Water Saving Estimates
Source: Ramirez, A.K., Eaton, D. J. "Statistical Testing for Precision Graded Verification"

These results also suggest that if a field is precision leveled, the type of levee (straight or contour) does not affect fields' water usage (see Table 3). In previous research based on agricultural extension experiments, straight levees were associated with lower water usage. This report of 'real' water usage differs because of the 91 precision-leveled fields with a contour levee-system in Lakeside Irrigation Division, almost half (43 percent) are managed by two farmers with superb management practices. These result contrast with

2010 data, which appeared to indicate an interaction between precision leveling and levee type. In 2010 the Interim Report on the "Statistical Testing for Precision Leveling Verification" recommended that the number and type of levees of fields be checked to improve unreliable data and ensure accurate estimates. After the levee type verification and levee count verification, (which improved greatly the accuracy of the levee data), ten percent of the fields were found to have been mis-categorized in terms of their levee type.

Multiple inlets, another conservation farm investment, reduce on-farm water use. The first survey in 2009 gathered multiple inlet data in intervals. To improve the accuracy of the results, the 2010 study collected the exact number of multiple inlets in each LCRA field. Results show that if a field that has one multiple inlet, the use of irrigation water will be reduced by 0.035 acre-feet per acre farmed (see Table 3). Multiple inlets have a statistically significant effect on the water usage of fields. The data from the study indicate a lower rate of water saving than estimates reported by some experimental field studies. One reason is that prior studies evaluate the performance of multiple inlets using a small sample of experimental plots, as field experiments occur in controlled research environments. Researchers seek to control all other influences except for the one technology (variable) tested that could cause a reduction in farmers' water usage. This controlled research approach isolates the effect of the factor that scientists wish to examine. Field experiments are likely to provide high (upper boundary) estimates of water savings.

The quality of the multiple inlet and levee data probably could be improved if data were collected by physical field and not by LCRA aggregate field. LCRA's field boundaries sometimes aggregate a number of different "physical" fields for billing purposes. Water savings attributable to multiple inlets and number of levees is dependent on the quality of these data. Every effort should be made in the 2012 survey (based on 2011 data) to collect multiple inlets and levees at the physical field. This is an important step for LCRA to verify the water savings associated with other conservations measures. This is an additional benefit from this verification study which not only verifies the water savings associated with precision leveling but also from other conservation measures.

The data indicates that, in each year of the study (2006-2010), farmers who cash-rent use less irrigation water per acre farmed than do farmers who share-rent or farm their own land. Results from this verification study show that farmers who cash-rent on average use 0.20 acre-feet per acre less water. When the person who farms the land cash-rents a field, the effect of costs (such as labor and water costs) and profit are tangible and immediate. A farmer who cash-rents bears all the financial risk in the rice production of any given field. Due to the increased financial risk, they are likely to pay more attention to the amount and management of the water they order. This finding is consistent with opinions that farmers who participated in The HB1437 Agricultural Fund Advisory Committee voiced in reaction to what the 2010 data indicated, which seemed contrary to their experience. The improved data (2006-2010) of the 2011 study has results that are consistent with what farmers would expect.

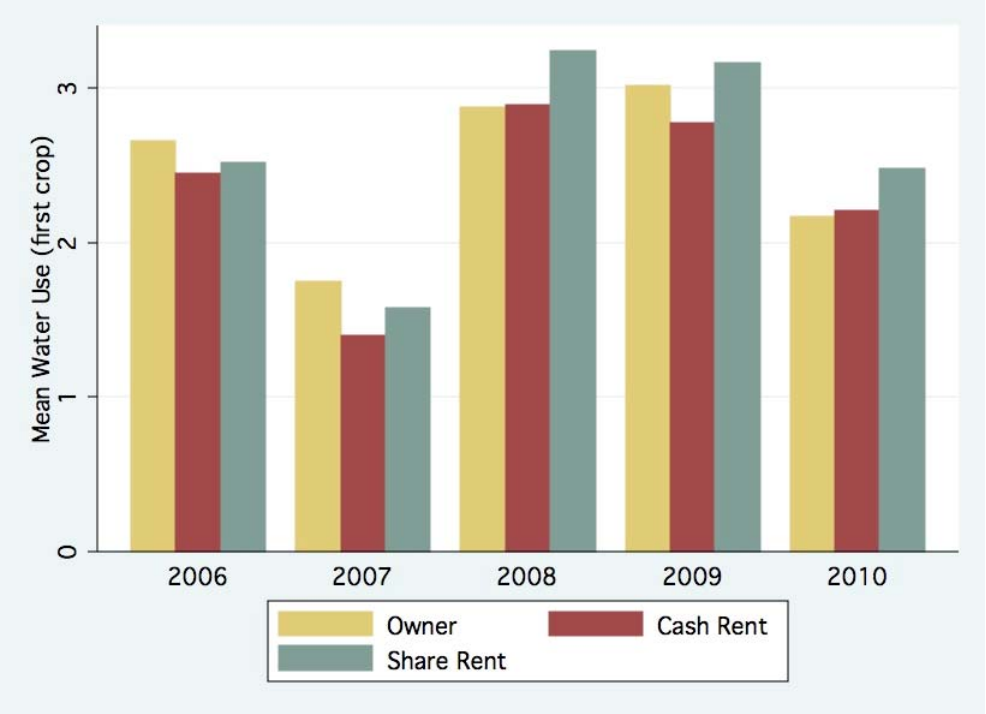

Figure 5. Average Field Water Use by Year and Ownership Stake
Source: Ramirez, A.K., Eaton, D. J. "Statistical Testing for Precision Graded Verification"

In 2011, results also show that farmers that plant hybrid rice uses 0.03 ac-ft/ac more irrigation water for each additional day water is delivered to a field (see Table 3). Hybrid rice in itself does not affect the water usage of a field, but hybrid rice in relation to the growing period does. When farmers plant hybrid rice, this cultivar's longer growing periods lead to higher levels of water usage.

The factors of rainfall and evapotranspiration were included to isolate the effect of precision leveling and other conservation measures from the effect of year-to-year variation in weather. While the previous study in 2009 included temperature, the 2010 study has improved this variable by including the evapotranspiration in the place of temperature. Including evapotranspiration as a factor in the analysis provides more accurate estimates of the marginal effect of year-to-year variation on the water usage of rice fields because higher farm water consumption is not only associated high temperatures but it also influenced by other weather factors (humidity, radiation, wind).

As expected, a one-inch per month increase in rain on average decreases the irrigation water usage of a field by 0.18 acre-feet per acre (see Table 3). This result indicates that farmers reduce the use of irrigation in years with high rainfall, as it contributes to the supply of water. Results also show that in a 'hot' year, with a one-inch per month increase in evapotranspiration, water usage in a field would increase on average by 0.13 acre-feet per acre (see Table 3). Higher farm water usage is associated with high evaporation, which in turn corresponds to noticeable high temperatures and low humidity in a given year. Including evapotranspiration in the verification study accounts for

changes in maximum and minimum temperature, humidity, wind speed, and sunshine hours because these factors are used to estimate evapotranspiration.

Table 3. Influence of Factors on the Water Usage of Fields

STATISTICALLY SIGNIFICANT VARIABLES		
FACTORS	**SIGN**	**DESCRIPTION**
PRECISION LEVELING	Negative	Precision land leveling, on average, reduces farmers' water usage by 0.33 acre-feet per acre during the 1st crop.
MULTIPLE INLETS	Negative	Having one multiple inlet reduces the water usage of a field by 0.03 acre-feet per acre during the first crop.
RAIN	Negative	A one-inch per month increases in rain, on average decreases the water usage of a field by 0.18 acre-feet per acre.
EVAPOTRANSPIRA-TION	Positive	A one-inch per month increase in evapotranspiration, on average increases the water usage of a field by 0.13 acre-feet per acre.
CASH	Negative	Farmers who cash-rent their land, from planting to harvest during the first crop, use 0.20 acre-feet of water less than farmers who share-rent or farm land they own.
HYBRID*DIFF_GROW2	Positive	Farmers that plant hybrid rice uses 0.03 acre-feet per acre more irrigation water for each additional day water is delivered to a field.
NOT STATISTICALLY SIGNIFICANT VARIABLES		
FACTORS	**SIGN**	**DESCRIPTION**
NUMBER OF LEVEES	Positive	A one levee increase in the number of internal levees in a field, on average increases the water usage of a field by 0.001 acre-feet per acre
STRAIGHT LEVEES	Positive	A straight-levee irrigation system increases the water use of a field by 0.12 acre-feet per acre.

RECOMMENDATIONS

Second Crop Water Savings

An HLM analysis of only the second crop is an important next step to estimate precision leveling water savings only during the second crop. If the LCRA can gather water use and farm practices information for a sixth year (2011) it will be possible to compute for the first time a water savings coefficient for precision leveling for the second crop using the methodology delineated in “Statistical Testing for Precision Graded Verification.” Estimating the total effects of precision leveling that include savings during the second crop, in addition to the water savings coefficient for the first crop is an important step to revise LCRA’s current coefficient of 0.75 acre-feet of water saved per acre leveled for both crops.

Survey 2011

A new and more complete data set (2006-2011) will not only improve the quality, accuracy and reliability of precision leveling water savings, but also increase the sample size necessary to separate precision-leveling water savings during the second crop. Because the accuracy of the results of this conservation verification analysis depends on the information collected, this study involves the revision of the survey instrument and the implementation of face-to-face interviews to cross check and to expand existing

information with an additional year of data (2011). The 2011 survey data is necessary to estimate the second crop water savings from precision-leveled fields.

Multiple Inlets

This verification study has the added benefit of estimating water savings for other conservation such as multiple inlets. Multiple inlets are a less costly conservation measure than precision leveling and may have comparable water savings. LCRA's field boundaries sometimes aggregate a number of different "physical" fields for billing purposes. If the data were to be collected at the individual field level, instead of at the aggregated billing field level, the LCRA could develop two conservations measures (precision leveling and multiple inlets) with verified water savings to better plan and invest in conservation programs.

Multiple inlets is a conservation measure LCRA can invest on to further reduce the volume of water used by agricultural customers. Multiple inlets could eventually complement precision leveling if and when precision-leveled acreage reaches a saturation point and remains steady over time.

Water savings attributable to multiple inlets and number of levees is dependent on the quality of these data. Collecting multiple inlets and levee data at the physical field level is necessary to achieve an accurate water savings associated with multiple inlets. This is an additional benefit from this verification study which not only verifies the water savings associated with precision leveling but also from other conservation measures.

CONCLUSION

LCRA is delivering on its promise to evaluate its precision-leveling conservation program in Lakeside Irrigation Division. So far, the verification study provides a water saving estimate for precision leveling that is robust, as the values are essentially the same in the 2010 study as in the 2011 study. The sample changed between the 2010 to the 2011 study with an additional year of data (2010), the removal of second crop and an overall increase in fields surveyed each year (2006-2009).

Progress in estimating the relationship between precision leveling and the water usage of fields should be directed to estimate water savings during the second crop. With better data, LCRA will have precision leveling water savings coefficients for both the first and second crop to compare with the current 0.75 ac-ft/ac coefficient. Absence of adequate data on multiple inlets and levees by physical field also hampers LCRA's ability to capitalize on the added benefit of this verification study to estimate water savings attributable to other conservation measures besides precision leveling. With additional data on multiple inlets LCRA will be in a stronger position to evaluate the feasibility of funding additional water conservation measures through the HB1437 grant program. With verified water savings from precision leveling, LCRA can ensure that sufficient water savings targets are achieved so water can be transferred to the Brazos River Basin

with no adverse impact on the Colorado River Basin, as required in the HB1437 legislation.

REFERENCES

Agarwal, MC, and Goel AC. (1981). "Effect of field leveling quality on irrigation efficiency." Agricultural Water Management 4(4): 457-464.

Anderson, David P., and Thompson, Gary D. (1999). "Adoption and Diffusion of Level Fields and Basins." Journal of Agricultural and Resource Economics 24(1): 186-203.

Bjornlund H, Nicol L, and Klein KK. (2009). "The adoption of improved irrigation technology and management practices-A study of two irrigation districts in Alberta, Canada." Agricultural Water Management 96(1): 121-131.

Huffaker R, Whittlesey N. (2003). "A theoreti cal analysis of economic incentive policies encouraging agricultural wate r conservation." International Journal of Water Resources 19(1): 37-53.