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Saving Water in Farming: Methodology for Water Conservation Verification Efforts in the Agricultural Sector

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Saving Water in Farming: Methodology for Water Conservation Verification Efforts in the Agricultural Sector

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Dedication

This dissertation is dedicated to my loving mother, the memory of my father and my family who always stood behind me.

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Saving Water in Farming: Methodology for Water Conservation Verification Efforts in the Agricultural Sector

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This dissertation develops, tests and validates statistical methods for verifying the amount of water conserved as a result of investments in precision leveling, other on-farm conservation measures in place, weather variation and farmer behavior. This evaluation uses a sample of 328 unique fields from Lakeside Irrigation Division in Texas over a six-year period, totaling 966 observations. Results show that precision leveling accounts for a 0.30 acre-feet reduction of irrigation water per acre leveled. There are additional indirect affects to precision leveling that, with the proper verification of levee densities, could potentially double the amount of water savings attributable to precision leveling. This Mixed-Level Model (MLM) estimate for precision leveling water savings is more precise than the estimates either from an Ordinary Least Square Model or a Fixed Effect Model. A meta-analysis combines the results from this model with other similar studies. Although the mean estimate of the meta-analysis is similar to the MLM estimate, the meta-analysis further reduces the standard error of the mean precision leveling estimate by 2 percent. A better approximation of the acre-feet water savings per acre farmed translates into less uncertainty for water regulators, managers and policymakers regarding the volume of conserved water that is available for transfer.

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Chapter 1: Introduction

This dissertation develops, validates and compares methods for verifying the amount of water conserved as a result of investments in irrigation technology. Since the 1960's farmers have increased crop yields, production and planting acreage with the use of improved irrigation technology and high-yield crop varieties.[1] One challenge for future agricultural production is whether farmers will face decreased water supplies for irrigation due to higher-paying, growing urban domestic and industrial water users or environmental water demands.[2] Uncertain precipitation patterns from droughts or irregular rains[3] could hamper planting operations. It may be difficult to maintain current irrigated acreage or farm productivity under declining future water supplies.

Water scarcity is particularly challenging for agriculture;[4,5] as irrigation water allocation may have a lower priority than the water needs of municipal users. Population growth and the consequent increased demand for food production as well as uncertain precipitation patterns strain water availability.[6] Shortages in irrigation water are likely to become more frequent if climate change further reduces water supply. For example, as a result of shortages in water supply due to a severe drought in 2011 and 2012, many Texas rice farmers received no surface water to irrigate their crops in 2012 and 2013.[7]

The pressure for rural-to-urban water transfers is likely to increase as policy makers, water regulators and utilities look to transfers as a means to respond to the increasing water demands of fast growing urban populations that have limited water resources. Within Texas' Lower Colorado River Basin, for example, water savings from conservation measures in rice farming may be used as water for transfer to the fast growing urban area of Round Rock in Williamson County in the neighboring Brazos River Basin. Other examples of rural-to-urban water transfer agreements are found in California, between the Imperial Irrigation District with both the Metropolitan District of Southern California and San Diego County.[8]

Chapter One of this dissertation examines conservation efforts and investments for irrigated rice agriculture. The second chapter reviews published literature on water conservation measures, such as precision leveling. Chapter Three describes this study's verification approach. Chapter Four covers the sources and types of data used in the analysis. Chapter Five and Six discuss the four statistical analyses and the resulting water savings estimates from precision leveling and other related conservation investments. Chapter Seven presents the findings, lists recommendations to improve the quality, accuracy and reliability of water savings attributable to conservation programs and describes the policy implications.

WATER CONSERVATION

Water conservation programs focus on reducing water usage by implementing technological innovations, improving farmers' management skills or improving the water conveyance and delivery of irrigation systems. 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. It is hard to advocate for water changes from agricultural to municipal uses if reduced amount of water withdrawals from irrigation harm farm productivity. As water becomes scarcer and pressure for rural-to-urban transfers occur more frequently, monitoring and verification programs ought to be in place to document the mass balances, shifts among users, and the nature and source of any water conservation savings.

Some water analysts argue that irrigation technology can further reduce water use while maintaining or increasing farm yields, a concept of 'efficiency gains as a source of new water.' If water conservation could save water while increasing yields and productivity, saved water could be shifted to domestic, commercial, industrial, in-stream, or estuarine uses or made available to increase farm acreage.[9] However, a shift of water to alternative uses usually assumes that a water conservation investment can actually save water. One problem for documenting water savings is that many factors affect field water use, such as the weather, farmers' practices as well as agricultural technology.

Increasing the effectiveness of water conservation programs in agriculture has important implications for policy-making as water conservation in "most United States legislation focus[es] on encouraging individual farmers to increase irrigation efficiency."[10,11] Water conservation programs for agricultural uses has become a national priority, as it now involves individual producers, state and local agencies, water conservation districts, and the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) in a collaborative effort to conserve water. State and regional management plans encourage these demand-reduction strategies by investing resources to support technology-based conservation programs in the agricultural industry by providing state, local agencies and farmers with funds to implement more efficient water-use practices.

Agricultural water conservation programs can save water either on a farm (on-farm) or within an irrigation division (on-district). Irrigation districts can make diverse investments to save water, including; volumetric measurement and pricing; improvements to the canal and conveyance system; rehabilitation and maintenance of the canal network. Farmers can make investments in on-farm technological improvements, such as precision leveling and multiple inlets. On-farm volumetric measurement refers to volumetrically measuring the water delivered to individual fields. When a farmer pays for the amount of water used, he or she may improve water management practices to reduce the water bill. One would expect a reduction in usage when farmers pay for the volume of water used, instead of paying a flat rate per acre irrigated. The underlying rationale is that when farmers act in their own self-interest they can reduce costs if they can sustain or increase yields with lower per acre water use. If water costs drop, farmers can increase the per acre profit. Another component of agricultural conservation programs is investment to improve irrigation districts' water conveyance systems. Rehabilitating a canal and conveyance network, for example by improving the lining material or repairing leaks, reduces seepage. The irrigation water that no longer leaks out contributes to the supply of water for crops, which translates into a reduction in the total volume of water diverted from the river. Management of vegetation can also reduce the volume of water conveyed and delivered by removing flow reductions and/or restrictions, preventing canal spills and decreasing the volume of water taken up and transpired by the vegetation in the canal. Structures clogged with limbs, sticks, or aquatic weeds increase the likelihood of canal spills.

As farmers invest and switch to more efficient irrigation methods they can reduce field water use. One conservation program analyzed in this dissertation is precision leveling. Table 1.1 shows that flood irrigation (also known as gravity irrigation) is the most common irrigation method for rice production in the U.S. Precision leveling is a conservation technology that has made flood-irrigation more water efficient. When a field is precision leveled, the field's natural slopes are reduced or removed, evening out the distribution of water, thus lowering the required flood depth and reducing the volume of water farmers require to irrigate a field. Currently, Farmers are more likely to voluntarily precision grade rice fields with cost-share incentives. Alternative irrigation methods for rice production that reduce water use, such as sprinkle irrigation, resulted in yield reductions.[12]

Table 1.1: Rice Farming by Type of Irrigation Method

Irrigation Method	**1994**	**1998**	**2003**	**2008**
Pressure	15,185	6,310	47,838	48,154
Gravity	3,138,610	3,205,148	2,946,919	2,635,209

Cultivated rice acreage in the U.S. by type of irrigation system for four years in Arkansas, California, Louisiana, Mississippi and Texas. Pressure indicates rice irrigated with sprinkler or pivot irrigation systems while gravity indicates rice under flooded conditions.

Source: United States Department of Agriculture, Census of Agriculture, Farm and Ranch Irrigation Survey, (2007) http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/fris08_1_04.pdf

(1997) http://www.agcensus.usda.gov/Publications/1997/Farm_and_Ranch_Irrigation_Survey/tbl04.pdf

This dissertation develops, tests and validates qualitative and statistical methods to evaluate the effectiveness of on-farm water conservation practices. The motivation for this study is the question as to whether precision leveling of farmland reduces irrigation water use per acre farmed. This study quantifies the water savings associated with the implementation of precision leveling and examines how on-farm water use varied in Lakeside Irrigation Division among fields and farmers during the period of 2006 to 2012. It also identifies other factors that affect water consumption, such as other water-conservation measures in place, weather variation and farmer behavior. Finally, it also examines how these conservation factors operate at the field level as well as among groups of fields managed by the same farmer.

This dissertation address the following research questions:

- Do precision-leveled fields use less irrigation water than non-precision leveled fields?
- Does on-farm water use change through time and can we predict these differences?
- Do fields managed by different farmers experience a different pattern of water use?

This study focuses on water savings from precision leveling, as distinguished from other factors that influence water use, because such leveling has been the subject of significant financial farm incentives. This study evaluates how much data should be collected and implements new methods for collecting data. This study also develops quantitative methods to assess how technology-based water conservation measures and management practices, as currently applied by farmers, influence on-farm water use.

IRRIGATED AGRICULTURE AND RICE FARMING

Water use in irrigated agriculture plays an important role in global food production as forty percent of the world food crops are produced with irrigated agriculture,[13,14] with this food production representing approximately seventy percent of all global water withdrawals.[15,16,17,18] Water use in irrigated agriculture plays a large role for the United States, the country with the third largest irrigated area in the world.[19] Policy makers and researchers agree that irrigated agriculture will play an increasingly important role as water becomes more scarce. For example, the Food and Agricultural Organization of the United Nations (FAO) estimates that 15 percent of all investments in the water sector will be allocated to improve irrigation efficiency. [20]

As this dissertation addresses water conservation in rice farming, it is worthwhile to discuss the cultivation of rice and its significance for water conservation. Rice, a dietary staple and food source, accounts for one-fifth of the caloric intake of the world's population. As a result, rice production has important implications for a country's food security. Shortages in rice have implications for the lowest-income citizens of developing nations for whom rice is the main food and accounts for one third of their caloric intake. Rice shortages have been linked to malnutrition, starvation and in some cases deaths within vulnerable populations. Nations within Africa, the Middle East, South and South-East Asia, among the largest consumers of rice, are especially vulnerable. For some rice-dependent countries, domestic rice production is insufficient to cover their domestic consumption of rice. These countries must depend on imports for their supply of rice, leaving them vulnerable to fluctuations in the market. For example Haiti must import four-fifths of its national rice consumption and Egypt must import one-third of its national rice consumption.

Rice is the most water-intensive food grain staple. The water use to irrigate rice (12.3 ML/hectare) is at least double the volume per acre required to irrigate cotton (6.4 ML/hectare), another water-intensive crop. Most rice in the US is cultivated under flood irrigation, which means that a field may maintain a continuous flood of approximately 1 meter throughout most of the growing season. When water is applied to rice, the depth of flood irrigation ranges from 610 to 1220 mm.[21]

According to FAO, due to the 2008 global shortage of rice, rice prices increased by 70 percent.[22] As rice prices increased dramatically and the largest rice exporters restricted exports, violent protests occurred around the world in rice-dependent countries such as: Cameroon, Egypt, Ethiopia, Haiti, Indonesia, Italy, Ivory Coast, Mauritania, the Philippines, Thailand, Uzbekistan, Yemen and Senegal.[23] Food shortages of staple crops like rice also have serious implications for growers, as rice farming directly impacts the income and consequently the livelihoods of the poorest strata of the population.

Because some countries aim to be self-sufficient in grains, rice trade is modest; commerce in rice represents only 17 percent of the global trade of other cereals. The largest rice producers are China, India and Indonesia[24] while the largest rice exporters are Thailand, Vietnam, Pakistan, India and the United States.[25] China is not among the world's major rice exporters due to its larger domestic consumption. Although, the United States produces approximately 1 percent of the world's rice,[26] it is the fifth most important rice exporter[27] due to its low domestic rice consumption of 27 pounds per capita per year.[28] According to the U.S. Department of Agriculture (USDA), rice was a $1.8 billion dollar industry in 1997, the eighth most valued U.S. crop.[29] A decade, later the value of this industry increased to $200 billion dollars.

During the last century, US rice has been farmed primarily in Arkansas, California, Louisiana, Mississippi, Missouri, and Texas(Table 1.2 and Figure 1.1). The rice industry was established in California by 1920.[30] Although rice production in Texas started during the 1800's[31] it was not until 1940, twenty years after California, that Texas rice production expanded, dominating crop production near the Gulf of Mexico. Since the 1940's, rice acreage in Texas has increased. Texas, part of the Gulf Coast region, is one of the main regions in the United States where rice is produced.

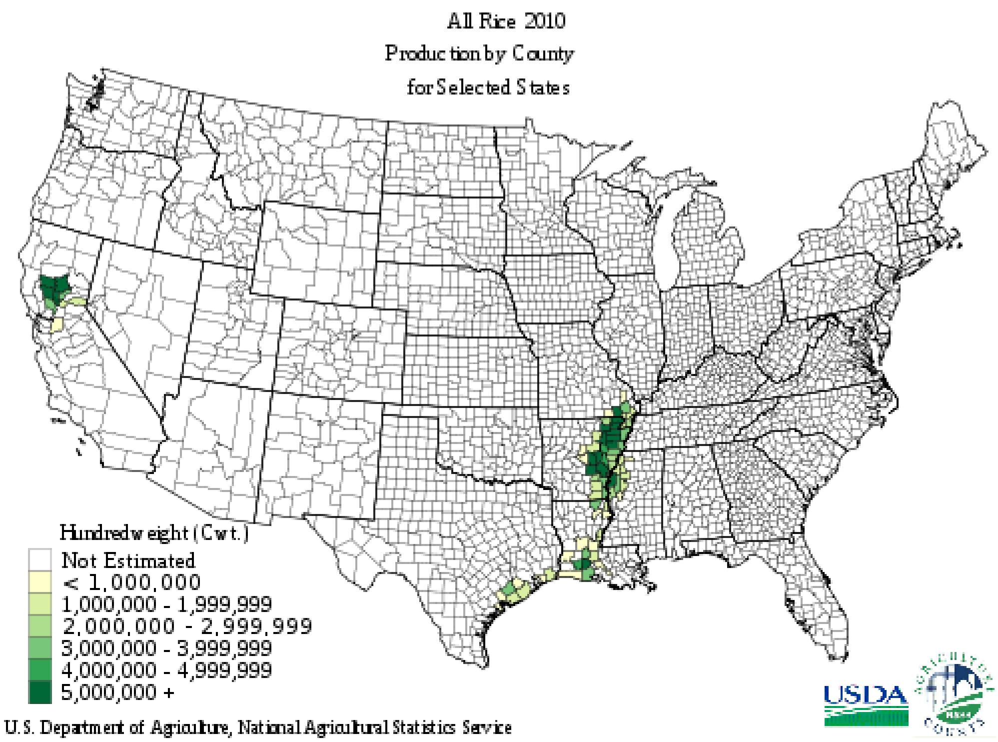
Table 1.2: Rice Area Harvested in the U.S. by State 2007 Crop

State	Area Harvested (1000 acres)
Arkansas	1,325
California	533
Louisiana	378
Mississippi	189
Missouri	178
Texas	145

Rice acreage harvested during 2007 in the U.S. divided by the six main rice producing states.

Source: USA Rice Federation, "Rice Notes," http://www.usarice.com/doclib/188/217/3892.pdf.

Figure 1.1: Rice Production in the U.S. by County in 2010



Location of rice production in the U.S by county. Darker color represents more rice production.

Source: U.S. Department of Agriculture, National Agricultural Statistics Service. "Rice County Maps, Production Acreage by County." http://www.nass.usda.gov/Charts_and_Maps/Crops_County/pdf/AR-PR10-RGBChor.pdf

The Texas rice industry was valued at $137.6 million during 2008.[32] In arid regions like Texas, rice production is feasible only when there is access to irrigation, which occurs in a 100 km wide 90 to 140 cm rainfall belt[33] along the Gulf of Mexico in eight counties, Brazoria, Calhoun, Chambers, Colorado, Fort Bend, Jackson, Jefferson, Matagorda, and Wharton,.

CASE STUDY

The Lower Colorado River Authority (LCRA), a quasi-governmental regional agency established in 1934 by the Texas Legislature,[34] coordinates water use within Texas' Lower Colorado River Basin by managing five dams along the Lower Colorado River that provide water supply, flood control and other water services in a region of 25,900 square kilometers. The LCRA delivers water and electric power to more than 1 million people in 11 counties in Texas.[35] It provides water to three irrigation Divisions (Lakeside, Gulf Coast and Garwood) along the Texas Coast. Irrigation water makes up 80 percent of all water withdrawals from the Lower Colorado River.[36]

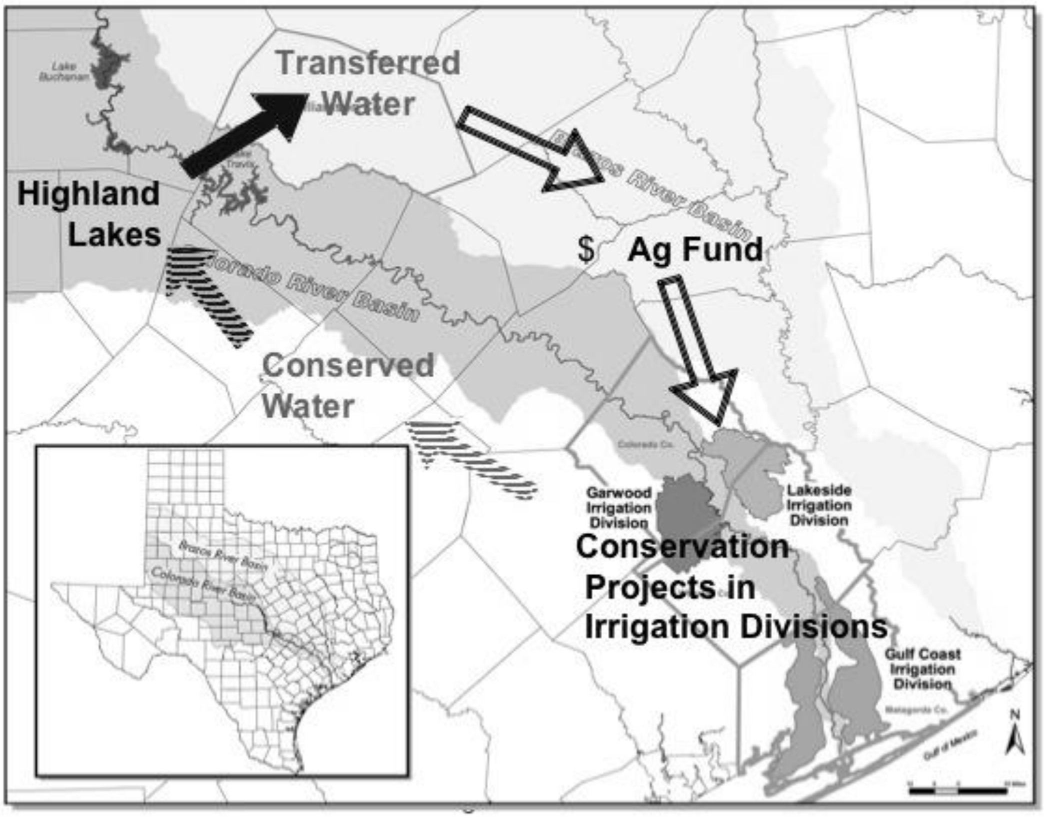
In 1999, the Texas Legislature passed a bill (HB1437) that authorizes the LCRA to transfer water to the Brazos River Basin for the growing urban population in Williamson County near Austin, Texas.[37] The following year, the LCRA and the Brazos River Authority (BRA) signed a 50-year sales agreement to transfer 25,000 ac-ft of surface water per year.[38] LCRA was granted a permit to transfer surface water a year after the water sales agreement was signed. Although the inter-basin water transfer permit has been granted, as of 2013 no water transfer has occurred. The goal before 2014, the date at which the water saved will be transferred to Williamson County, has been to develop and implement a sound methodology to save water and document those quantify water savings.

The HB1437 requires that LCRA develop “new” sources of water to make up for the volume of surface water to be transferred through a concept of “no net loss,” which requires no reduction of water supplies within the Colorado River Basin. The LCRA conducted a public consultation process and decided to focus part of its strategy to achieve "no net loss" on reducing the volume of irrigation water through water conservation programs to comply with its water transfer responsibility.

The components of LCRA’s water transfer strategy are depicted in Figure 1.2. The black arrow represents water transfers from the Highland Lakes within the Colorado River Basin to the Brazos River Basin water users. The white arrows denote money transactions from Brazos River Basin water users to LCRA. The hatched arrows indicate water saved to be used for transfer. The LCRA agreed to transfer water to the Brazos River Basin based on the quantity of water saved from conservation projects in the irrigation Divisions. Water transfers include a 25 percent surcharge to fund conservation programs in agriculture and reduce irrigation water use. One of the first strategies in the HB1437 water conservation program to be implemented was precision leveling. Since, 2006 the LCRA has invested $1.61 million on precision leveling 301 fields, totaling 25,275 acres.[39] A major goal of the HB1437 program is to continue to fund precision leveling at least 2,500 acres per year until 2014.[40]

The LCRA decided to use Lakeside Irrigation Division for a study area to test the methodology for future conservation verification efforts in different farming regions. Lakeside Irrigation Division is one of three irrigation divisions LCRA operates that relies on water from the Colorado River for the production of rice. Lakeside Irrigation Division is located in Texas' Colorado, Matagorda and Wharton Counties within the Lower Colorado River Basin (Figure 1.2).

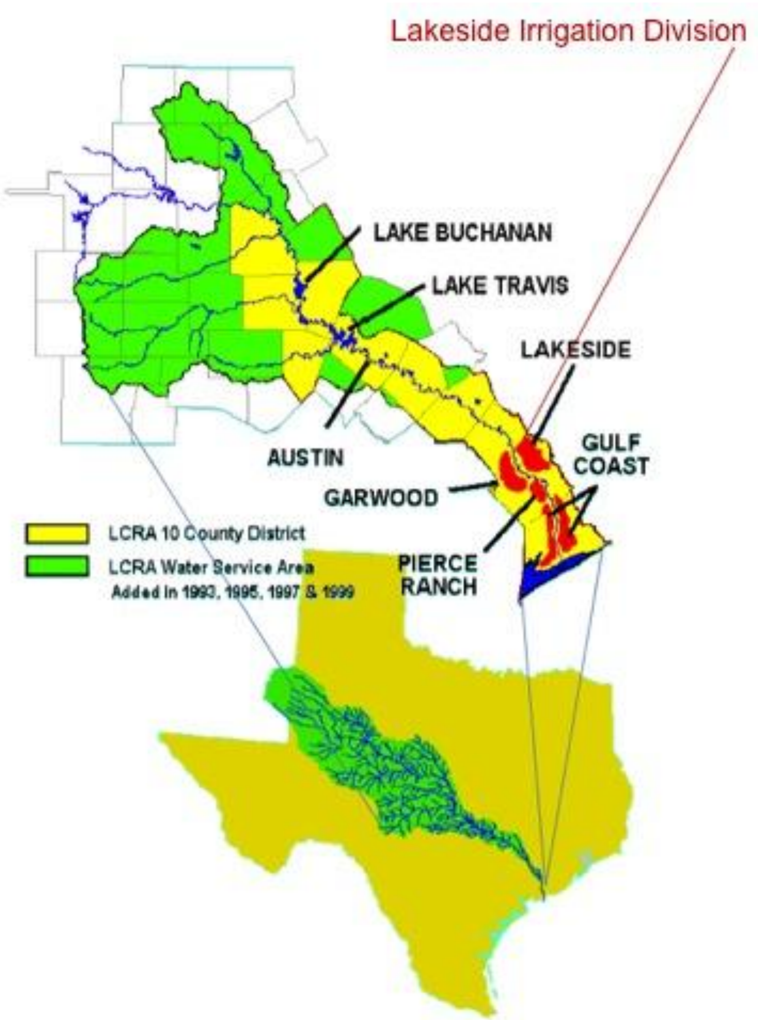
Figure 1.2: LCRA Water Transfer Strategy



Flow of physical water, conservation investments and conserved water under water transfer strategy between the Lower Colorado River Basin and the Brazos River Basin. Black arrows indicate physical water transfers from the Lower Colorado River Basin to the Brazos River Basin. White arrows indicate money transferred from a water surcharge used to finance conservation investments. Hatched arrows represent the water savings attributable to conservation investments in rice agriculture.

Source: Lower Colorado River Authority, 2010 Report: HB 1437 Agricultural Water Conservation Program, (Austin, Texas: LCRA 2011), 5, http://www.lcra.org/library/media/public/docs/water_utilities/HB1437_2010_Annual_Rpt.pdf.

Figure 1.3: Location of Lakeside Irrigation Case Study



Below: the green outline indicates the Colorado River Basin within the state of Texas. Above: the Colorado River Basin subdivided by county. The four irrigations districts are in red. Lakeside Irrigation Division, one of the four, is the case study in this dissertation.

Source: David R. Kracman, "Estimating Water Demands for Irrigation Districts on the Lower Colorado River," 2000, http://www.crwr.utexas.edu/gis/gishydro01/Class/trmproj/Kracman/termproject.html.

Figure 1.4 shows an aerial photograph of Lakeside Irrigation Division, where farmed fields are marked as white boxes. From 2006 to 2011 in Lakeside, on average 200 fields were in production during the first crop season for an average of 25,752 acres each year (Table 1.3). Within Lakeside Irrigation Division of Texas most fields use flood irrigation as rice is the prominent crop.

Figure 1.4: Fields in Production in Lakeside Irrigation Division

Aerial photograph of Lakeside Irrigation Division; white boxes represent rice fields in production during case study.
Source: Ana Ramirez

Table 1.3: Summary Statistics for Lakeside Irrigation Division, First Crop

Year	Acreage	No. Fields	Average Field Size (ac)
2006	21,451	178	119
2007	22,758	175	132
2008	27,973	198	143
2009	27,786	220	128
2010	26,951	204	129
2011	27,554	215	128

Total acreage, fields in production, and the average field size in Lakeside Irrigation Division from 2006 to 2011.

Source: Statistics estimated using WAMS database (2006-2011)

Garwood Irrigation Division is where the greatest percentage of land has been precision leveled. The reason for choosing Lakeside Irrigation Division over Garwood Irrigation Division is that measurement of water use by field was not available for Garwood during the study period (2006-2011). Also, one field had been precision leveled in Gulf Coast Irrigation Division.[41]

Federal Funding

The government can influence a farmer's adoption of water conservation technology through policymaking and the regulatory process. The Texas state government regulates surface water withdrawals and water quality. Federal and state governments enable and constrain information and financial flows as well as provide technical assistance that may influence a farmer's decisions to adopt irrigation technology. From this perspective, a farmer's adoption decisions may be conditioned by how government formulates and implements agricultural policy, sponsors subsidies and provides information through dissemination programs.

Some precision-leveled fields are funded by a combination of federal, state and private funds. The U.S. Department of Agriculture's Natural Resources Conservation

Service (NRCS) has invested in cost-share programs to encourage farmers to implement precision leveling in an effort to conserve irrigation water. Through the Natural Resource Conservation Service's Environmental Quality Incentive Program (EQIP), NRCS provides grants to individual farmers to implement agricultural water conservation projects. Both EQUIP and HB1437 precision-leveling programs could be described as demand-side policy interventions, programs that are aimed at decreasing the use of irrigation water by farmers.

HB1437 standards require that any field that will be precision leveled meet NRCS criteria. The HB1437 precision leveling guidelines integrated the NRCS technical specifications and payment certification processes into the requirements, so that any HB1437 recipients would have received NRCS cost-share funds to precision level. A typical HB1437 grant receipt is made conditional on successful completion of the precision leveling project and project certification by the local NRCS office. Upon successful completion of the project and project certification by the local NRCS office, the grant recipient is reimbursed for up to 30 percent of the cost of precision leveling from the HB1437 funds. The HB1437 cost share percentage has been reduced from the initial 30 percent using a new pro rata adjustment rule.[42] LCRA customers accepted this method as an equitable way to distribute grant funds.

Differentials in the quality of precision leveling implementation may exist that could explain variability in the water use of precision-leveled fields. All fields leveled to NRCS standards through the EQIP program regardless of year are likely to be leveled to a comparable quality because NRCS leveling standards in the rice area have not changed substantially from the late 1990s to 2013.[43] Not all precision leveled fields were funded by NRCS, as some are privately funded. For Lakeside Irrigation Division, no records exist on the quality of privately funded precision leveling practices during and before 2006.

In the United States, during the past three decades, there has been a trend to precision-level rice fields (Table 1.4). Comparatively across rice-producing states, there is variation in the amount of rice acreage that has been precision leveled. Arkansas has the largest precision-leveled rice acreage with an increasing amount of acreage being precision leveled. During the same period of time, the implementation of precision leveling remained practically constant over time in California and Louisiana. In recent year n Texas, there has been a decline in precision leveling of rice acreage.

Table 1.4: Precision Leveled Acreage in the U.S. by State

	2008	**2003**	**1998**	**1994**	**1988**	**1984**	**1979**
Arkansas	1,262,140	1,316,011	1,484,631	1,251,000	1,083,196	942,002	992,480
California	432,208	588,600	502,424	619,556	418,294	452,673	553,800
Louisiana	410,331	428,619	612,747	491,892	460,647	449,471	571,377
Texas	174,565	286,522	264,968	440,821	333,988	282,816	623,148

Source: United States Department of Agriculture, Census of Agriculture, *Farm and Ranch Irrigation Survey* (2007)
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CONCLUSION

Improving water use in irrigated agriculture will help to address water scarcity , a consequence of both climate change and population growth. Pathways to address water scarcity are diverse and may include conservation programs. These demand-based programs focus on reducing the consumptive use of water through strategies designed to promote more efficient use of irrigation water. Federal, state and regional policy encourage these demand-reduction strategies by investing resources to provide incentives to farmers in the form of cost-share programs.

This chapter has given an overview of rice irrigation, conservation investments, and the case study in Lakeside Irrigation Division for which the conservation verification methodology in this dissertation is developed. Chapter 2 will provide a literature review of similar verification studies of water conservation technology in agriculture. Chapter 3 will develop the specific methodology used in this study. Chapter 4 will describe the data collected. Chapter 5 will explain the survey methodology for the data collection. Chapter 6 will explain the multi-level modeling methodology implemented for the analysis. Chapter 7 will describe the validation of the analytical procedures conducted as part of this dissertation, and Chapter 8 will review the conclusions and recommendations from this study.

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Chapter 2: Literature Review

It is a challenge to detect and credit reductions in irrigation water use achieved through water conservation technologies because it is hard to identify the marginal savings attributable to specific improvement from the many factors that influence field water use. Conservation programs can reduce water use by improving an irrigation district's water conveyance and delivery system, on-farm irrigation technology[1] or farmers' management skills. This study looks at the direct and indirect effects of precision leveling and interrelated on-farm technology. It is beyond the scope of this dissertation to document in-depth the published literature on other water conservation programs in agriculture such as on-district conservation. However, this literature review will briefly touch on other water conservation programs in agriculture.

One component of agricultural conservation programs is improvement to the irrigation district's water conveyance system. In order to improve the canal and conveyance network,[2] irrigation districts may implement rehabilitation programs such as canal lining[3] and leak repairs to reduce seepage[4] and canal spills[5] or maintenance[6] programs that include vegetation control of "weed, grasses and trees along canals and drainage,"[7] to prevents canal spills and decrease water loss due to transpiration of the vegetation in the canal. Both rehabilitation and maintenance of the canal and conveyance network conserve water by reducing water losses, which decreases the volume of water diverted for irrigation.

Volumetric measurement is another conservation investments at the district-level to save irrigation water. Volumetric measurement refers to measuring the water delivered to each individual field, which includes the installation of water delivery structures. According to Small and Svendsen, the installation of these and other measuring and recording devices are evaluation factors to assess irrigation performance.[8] However, not only the installation but also the performance of structures matters in terms of water conservation. Clemens and Bos identify the "ability of structure[s] to deliver water" as a factor to be included in the performance evaluation of irrigation systems.[9] Another district-level evaluation factor are canal spills,[10] which may occur due to malfunctioning structures clogged with limbs, sticks, or aquatic weeds.

Shah indicated that farmers might pump more irrigation water under a flat rate pricing system, while a pro-rate pricing system may encourage farmers to use water more efficiently.[11] If a farmer's water costs are directly related to the volume of water used, then there is an incentive to use the minimum amount of water possible without affecting yields. However, if farmers are charged a flat rate, independent of the amount of water they use, there is less incentive to be discriminating in how water is used.

This study addresses only the on-farm water savings resulting from precision leveling. Precision leveling is an agricultural technology for reducing water use in flood irrigation.[12,13,14,15] Thus, this chapter reviews available literature regarding precision leveling and the associated water conserved to inform the development of a verification methodology. Evaluation ought to be guided by as much knowledge as possible about past approaches to verification and evaluation of irrigation water conservation. This information can also be useful for selecting the factors that may influence field water use. Documenting knowledge from past evaluations will yield a better methodology to assess field water use.

A field is precision-leveled by GPS-controlled laser equipment that cuts the slope of the land to a specific level based on topographical and hydrological information. When a field is precision leveled, the highs and lows of the field's natural topography are flattened. By flattening the topography, water evenly distributes itself across the field, thus lowering the required flood depth and reducing the water needed to uniformly irrigate the field. The estimated life of a precision-leveled field ranges from 10 years[16] to 15 years,[17] as long as the farmer maintains the field level over time through post-leveling touch ups.

For the past three decades, precision leveling has been widely used as a water conservation practice in flood-irrigated farming; it has become a so-called 'mature technology.'[18] Beginning 1983 in Arkansas and Mississippi, farmers have implemented a series of precision leveling and multiple-inlet recommendations in rice producing fields through federal and state-funded cost-share programs.[19] Arizona's Groundwater Management Act of 1980 established a cost-share program for farmers investing in precision leveling fields.[20]

As a mature technology, the diffusion of precision leveling relies on second-hand, publicly disseminated information from either government-sponsored extension services or from the hands-on learning experience of neighbors and colleagues who have already implemented this technology. For innovative technology first-hand information from the manufacturer can be helpful for adoption.[21] Regardless of whether the technology is innovative or mature, Feder and Slade,[22] and Smith et al.[23] contend that farmers who invest in more efficient irrigation technology do so prompted by word-of-mouth testimonials.

MEASUREMENT OF EFFECT

Not all precision-leveled fields are identical and the quality of precision leveling affects field water use. One issue is how to define and measure precision leveling. There are a number of measures to assess the impact of precision leveling programs. Precision leveling can be defined based on the slope of the land and measured as a binary (yes/no) variable, based on a maximum slope threshold. The current NRCS standard threshold for precision leveling fields is set to a maximum slope of 0.2 percent, in other words a grade of two-tenths percent. In the United States, Smith et al.[24] use a 0.1 percent slope as the threshold to classify precision and non-precision leveled fields. Smith et al.[25] move beyond dichotomizing precision leveling and incorporate an additional category, fields that have been zero-graded (no slope) as the benchmark. Zero-grade also serves as a benchmark for NRCS, although Rege contends that some slope is better for water drainage.[26] Making precision leveling a binary variable (precision leveled versus non-precision leveled) eliminates variability in the data about the degree of the leveling work in a field. With a 'yes/no' variable it is difficult to differentiate the quality of precision leveling implementation or the acreage leveled.

Some studies measure the amount of land a farmer allocates for technology implementation, such as precision leveling, by calculating the ratio of acres allocated for a given technology divided by all acres involved in the farm operation.[27,28] Continuous measures based on acreage are useful to examine the rate of adoption. Recent studies have examined the quality of the precision leveling implementation,[29,30,31] and how differentials in implementation of precision leveling influence field water use. Higher quality precision leveling appears to yield greater on-farm water savings than lower quality leveling.[32] Johnson III et al. investigate the quality of implementation by categorizing precision leveling based on 18 slopes between the high and low areas in a field and stated that 4 cm between a field's high and low spot ought to be the precision leveling benchmark.[33] In India, Agarwal and Goel[34] investigate the difference between precision leveling as is designed and as it is implemented. Both Agarwal and Goel[35] and Johnson III et al.[36] show that only few precision-leveled fields meet the precision leveling benchmark.

Other precision-level performance measures are the cost of leveling or the skill of the machinist, the person who operates the precision leveling machine, to examine the quality of implementation.[37] The movement of soil is the most costly element of precision leveling.[38,39] Depending on the volume of soil to be moved, precision leveling can be more or less costly. Precision leveling work requires soil movement to relatively uniformly grade land that would otherwise be uneven. If a farmer has to move more soil, precision leveling costs more. One could reasonably expect that higher quality precision leveling would require greater volume of soil moved, resulting in higher precision leveling costs. However, precision leveling cost also is a function of field topography. If precision graded to the same slope, a relatively flat field may be less costly to precision-level than a steeper field. One problem with 'cost' as a variable for analysis is that farmers are not likely to disclose what they paid a private contractor to level a field. Government agencies that provide precision leveling cost-share funds, like the NRCS, does not report information on what a farmer paid for the leveling work and the LCRA does not collect this information.[40]

Precision leveling quality ought to be of interest to financing agencies such as the NRCS and LCRA, because analyzing current precision leveling implementation could help identify practices that either improve or have limited effect on field water use. It is not easy to measure the 'quality of leveled land,' taking into consideration farmers' actual precision-leveling practices without posing excessive burden of data collection. When a field is precision-leveled, field measurements are needed to determine the slope of the land between levees. This detailed on-site surveying is costly and may limit the sustainability of long-term monitoring and verification of precision leveling programs.

RESEARCH DESIGN

Previous studies document that precision leveling does reduce on-farm water use (Table 2.1). Table 2.1 lists six studies that estimate water savings from precision leveling, where water savings range from 0.26 to 0.85 acre-feet per acre farmed.[41,42,43] Not all precision leveling studies are directly comparable because there are differences among studies regarding the metrics, instruments and procedures to measure field water use. Studies also vary with level of intrusiveness of the research, the type of agriculture (subsistence and commercial farming), and the origin of the farming community (U.S. or international).

Table 2.1: Previous Precision Leveling Studies

Reference	Location	Sample	Water Savings (ac-ft/ac)
Smith et al. 2007	MS (USA)	28 fields	0.58
Smith et al. 2007	AR (USA)	48 fields	0.45
Cook et al. 1996	MS (USA)	96 fields	0.26
McCauley et al. 1986	TX (USA)	8 fields	0.75
Johnson et al. 1978	(Pakistan)	48 fields	0.35
Jat et al. 2006	(India)	8 plots	0.85

Previous estimates of the water savings attributable to precision leveling, with sample size and location.

Source: Compiled by Ana Ramirez

Precision leveling studies can be categorized either as experimental research or as measurements of farm practice (non-experimental research). In experimental trials scientists design, direct and manage field research. Experimental trials can take place either on a research station (on-station) or on a farmer's field (on-farm). On-farm experiments are designed and directed by a scientist but managed by a farmer, as the experimental trial occurs in a farmer's field. In on-farm experiments, the scientist dictates the management practices farmer ought to follow. On-station experiments intensively study plots in controlled research environments to test how water conservation technology reduces water use and are designed, directed, managed and implemented by a scientist at a research station. In non-experimental research farmers' actual operations are at the center of the evaluation. In non-experimental evaluations, researchers collect data un-obtrusively under farmers' actual production systems and day-to-day management operations.

Experimental trials have estimated precision leveling savings from 0.35 to 0.85 acre-feet per acre farmed. On-farm experimental evaluations have estimated precision leveling savings from 0.45 to 0.75 acre-feet per acre farmed (Table 2.2), while non-experimental research estimates a reduction of 0.35 to 0.58 acre-feet per acre farmed.

The volume of irrigation water saved depends on how the technology is implemented. In the Arkansas on-farm experiment, researchers controlled inputs and management.[44] Under such conditions the estimated water savings from conservation technology is likely to be as close as possible to the ideal saving rates. In the same paper, the Mississippi study focuses on evaluating the effects of water conservation practices under producers' actual field operations with non-obtrusive data collection.[45]

Table 2.2: Previous Precision Leveling Studies by Research Design

Reference	Location	On-station Trial Experiment	On-farm Trial Experiment	Non-experimental	Sample	Water Savings (ac-ft/ac)
Smith et al. 2007	MS (USA)			X	28 fields	0.58
Smith et al. 2007	AR (USA)		X		48 fields	0.45
Cook et al. 1996	MS (USA)			X	96 fields	0.26
McCauley et al. 1986	TX (USA)		X		8 fields	0.75
Johnson et al. 1978	(Pakistan)			X	48 fields	0.35
Jat et al. 2006	(India)	X			8 plots	0.85

Previous precision leveling estimates, designated based on the type of study conducted. On-station trial experiment represents an experimental study performed at a research facility, on-farm trial experiment represents a quasi-controlled experimental study on a farm, and non-experimental represents a study using actual rice production operations.

Source: Compiled by Ana Ramirez

On-station and on-farm trials may not capture the multiple factors that affect water use in farmers' actual production systems. Farmers' irrigation systems are a combination of technological improvements[46,47,48] that vary from one plot to another. It is the interrelated performance of these irrigation technologies along with farmers' management practices that determine the use of irrigation water at each field.

SOURCES AND MEASUREMENT OF FIELD WATER USE

The precision leveling studies use either flow meters or timing devices to measure the water use within an individual field (Table 2.3). Some studies use flow meters to measure the water use for each individual field. Smith et al.[49] estimate ground water use for fields in Mississippi and Arkansas using a flow meter. Others precision leveling studies assume water flow rates and compute water use based on the estimates of the length of time allowed for irrigation. These studies use timing devises to track the duration of irrigation and multiply hours pumped for the month by the pump rate. This more indirect measure, as compared to real-time flow measurement devices, may result in measurement bias from imprecisely measuring the program outcome, the field water use. These differences in the level of control of input variables and the different systems of water measurement limit the comparability of published literature studies.

Sources of irrigation water (surface or groundwater) may also affect water use (Table 2.3). Pumps move and distribute water for farming, at an irrigation division or at an individual field. Some empirical evidence[50,51] suggests that pumping is the single most costly input in irrigated agriculture. One could expect energy savings and lower costs when an irrigation district pumps water to all the farmers, as compared to each farmer pumping water from his own well. On the other hand, a farmer who individually pumps water from a well may make more efficient use of irrigation water to reduce electricity costs.

Table 2.3: Previous Precision Leveling Studies by Measure of the Outcome

Reference	Location	Measure of Outcome	Source of Water
Smith et al. 2007	MS (USA)	Flow meter	Groundwater
Smith et al. 2007	AR (USA)	Flow meter	Groundwater
Cook et al. 1996	MS (USA)	Flow meter	Groundwater
McCauley et al. 1986	TX (USA)	Timing device	Ground and Surface water
Johnson et al. 1978	(Pakistan)	Timing device	Surface water
Jat et al. 2006	(India)	Timing device	Groundwater

Previous precision leveling studies listed by the type of measurement and the source of water. Flow meter represents an actual measurement of the total flow and timing device represents an estimate of the flow based on the pump size and time of pump operation. Groundwater and surface water represent the source of the water used for irrigation.

Source: Compiled by Ana Ramírez

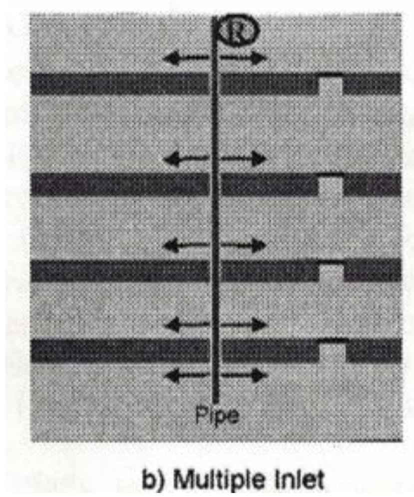
OTHER FACTORS

Empirical evidence suggests that precision leveling improves farmers' management of fields.[52] Farmers can ride on levees 'straightened' after precision leveling and 'widened' from installing permanent levees, increasing the efficiency of supervision of hired hands. There is also evidence that precision leveling decreases flooding times,[53,54] as less volume of water is required to over-fill paddies and for water to cascade down to the lower cuts. Precision leveling may reduce labor.[55,56,57,58] Reduction in the time it takes to irrigate an entire field may reduce the time to supervise tail-water runoff from the field.

Precision leveling increases yields.[59,60] Using regression analysis, Johnson III et al. found that precision-leveled fields have 26 percent more wheat grain yields than non-precision leveled fields.[61] There is also empirical research on the effects of precision leveling on the quality of the top-most soil. Brye shows that precision leveling affects soil properties and these biological and physical changes may reduce productivity.[62,63]

Multiple inlets are another conservation farm investment that reduces field water use. Multiple inlet distribution is the practice of releasing water at multiple points along the side or center of a field using either a field lateral or polypipe and multiple control structures instead of feeding all water through the highest cut of the field and cascading it down through each lower cut. Smith et al.[64] shows an 11 to 28 percent reduction in irrigation water use with multiple inlets, and Vories et al.[65] indicate a 24 percent reduction in field water use. Figure 2.1 shows the best inlet-to-bay configuration, where one inlet (depicted as arrows) release water in each of the bays (light gray shaded area) simultaneously in a field. The configuration of multiple inlets under farmers' actual irrigation systems vary and may not correspond to this one multiple-inlet to one bay benchmark.

Figure 2.1: Multiple-inlet Configuration



Plan representation of multiple inlets installation in field. The black thick lines indicate levees, the gray shaded areas are the land between the levees (also known as cuts), the multiple inlets system is represented by the poly-pipe in the center (thin black line) and the water inlets (arrows). This multiple inlet configuration shows one water inlet per cut.

Source: Figure drawn from Earl. D. Vories, Phil. L. Tacker, and Robert Hogan, "Multiple Inlet Approach to Reduce Water Requirements for Rice Production," *Applied Engineering in Agriculture* 21, no.4 (2005): 611-616, 612.

The type of rice variety is an important farming management decision.[66,67] Rice varieties can be categorized as short, medium and long duration by the number of days to maturity. The days to maturation leads to higher or lower levels of water use. Short duration rice varieties use less irrigation water.[68] Rice can also be broadly categorized as conventional or hybrid varieties, depending on the rice breeding method. Hybrid rice, engineered by crossbreeding more than one variety, increases yields.[69] With the development of high-yield rice crop varieties, the cultivation of only a first crop may be profitable without requiring a second crop.[70]

CONCLUSIONS

It may be difficult to assess the quality of precision leveling given that precision leveling work has occurred since the 1980's and few records may exist on post-leveling maintenance that would preserve the quality of leveled land in fields that have been precision-leveled years ago. Site-surveying may impose both time and money costs that may render ex-post evaluations impractical.

The location of on-farm trial experiments may not always be random and may lead to selection bias. In on-farm trials many researchers depend on a farmer's voluntary participation. In the Arkansas study, Smith et al. indicate that farmers who voluntarily participated "may be less representative of the practices of most rice growers."[71] Cooperating farmers involved in non-randomized on-farm trials may differ systematically from farmers who opt not to participate. If selection bias is present in some on-farm trials, water savings results may not be replicable in other farms.

Field water use is publicly available at the county-level. Due to the aggregate nature of the available water-use data, some studies rely on estimates of duration of irrigation to quantify field water use. Few empirical studies use the volumetrically measured water delivered to each individual field. All six studies cited above have a smaller sample size than the number of observations used in the analyses for this dissertation, which covers 328 unique fields over a six-year period (totaling 966 observations) in an irrigation district in Texas. While many studies provide estimates of water savings from a smaller sample of fields, this dissertation fills a gap in existing research by estimating water savings for an entire irrigation district.

Comparability across all studies may be challenging due to a lack of systematic measurement of water use, different meanings to the term precision leveling, diversity of reporting in the published literature and heterogeneity of research design. This chapter has reviewed previous published literature regarding conservation technology, particularly precision leveling. The following chapter will describe the methodology that will be used in this paper to evaluate the water savings attributable to precision leveling and other conservation investments in agriculture.

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[68] E.J.Wailes, J.Popp, K.B. Young, and J. Smartt, “Economics of On-Farm Reservoirs and Other Water Conservation Improvements on Arkansas Rice Farms” B.R. Wells Rice Research Studies, Research Series 517, 2001, 309-315, 311.
[69] Texas AgriLife Extension, “Breeding for high-yielding water-efficient varieties,” *Texas Riceti Special Section* 101, (College Station, Texas: Texas A&M, 2010): 1-24, 4.
[70] Ibid.
[71] M.C. Smith and others, “Water use estimates for rice production in Mississippi and Arkansas,” 146.

Chapter 3: Methodology

The effectiveness of a water conservation verification study depends upon its ability to explain the difference in water use between many potential sources of water savings and the conservation programs implemented. The purpose of this chapter is to develop a water savings evaluation method that yield valid and reliable water conservation estimates that can provide practical guidance to environmental regulators, river authorities, water utilities and irrigation districts seeking to quantify water savings from conservation programs in agriculture. This chapter describes the verification framework, presents the analytical approach, and establishes research questions and hypotheses for this dissertation. The final section presents the main assumptions of the case study.

VERIFICATION FRAMEWORK

How can a water utility or an irrigation division prove that an investment in irrigation saves water in a field? Verification programs compare actual on-farm water use with the water use in the absence of conservation investment. The purpose of this section is to develop a verification framework for testing hypotheses about factors that may influence field water use. This evaluation framework includes seven main components that influence field water use. These seven components can be classified relative to the farming operation, as either internal (endogenous) or external (exogenous) factors. Table 3.1 lists these factors.

Table 3.1: Factors that Influence Field Water Use

Exogenous Factors	**Endogenous Factors**
Climate	Farmer
Policy	Management
	Technology
	Field Characteristics

Categorization of the types of factors that affect field water use. Exogenous factors are external factors to the field operations and endogenous factors are internal factors to the field operations

Source: Ana Ramírez

There are internal and external factors to the farming operation that affect the water use of fields. Field water use can be affected by year-to-year weather variation,[1] farmer behavior or diverse irrigation technologies.[2,3] Figure 3.1 depicts the interconnections between climate, irrigation technology and farmers' management practices. Factors internal to the farming operation are shown inside of the dotted box; external factors are shown outside of the box. One of the exogenous factors to the farming operation is climate, which influences farmers' decision-making on when and what amount of water to apply to fields. Policy is an exogenous factor. Through policy, the government enables and constraints information and financial flows that may influence a farmer's behavior and decision-making. One way the government can influence farming is through farmers' access to publicly disseminated information, such as sponsored demonstrations and field days, which may inform farmers' irrigation management decisions or encourage farmers to investment in water conservation technology. Other government policies such as cost-share programs and subsidies also encourage farmers to adopt water conservation technology. In turn, farmers can influence policy through lobbying.

Figure 3.1: Verification Framework

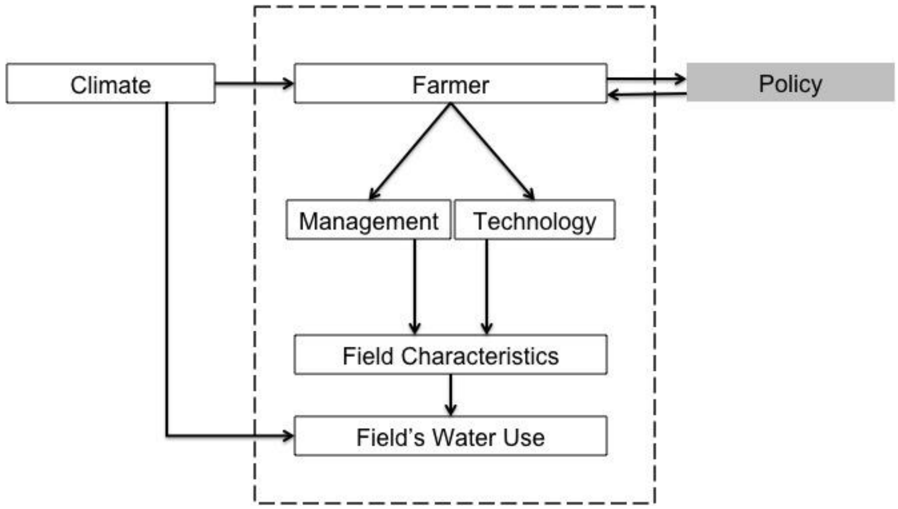


Figure 3.1 shows the seven main components that influence a field water use. Exogenous factors to the farming operation are outside the dotted box while endogenous factors can be found inside the dotted box.

Source: Modified diagram by Ana Ramirez from Rowan,T., Maier, H., Conner. J., and Dandy, G. "An integrated dynamic modeling framework for investigating the impact of climate change and variability on irrigated agriculture," *Water Resources Research* (2011): 47, 117.

The farmer is central to the farming operation as he manages field water use by investing in technology, land improvements and irrigation practices. Farm practices vary with the type of crop variety cultivated[4] and farmers' investments in other irrigation technology and land improvements.

Farmers' investments in conservation technology can also reduce irrigation water. Farmers who invest in technology and land improvements (such as precision leveling or multiple inlets) can reduce the volume of water used to irrigate fields[5,6] while maintaining or increasing yields. Fields with more improvements on infrastructure or land may have lower on-farm water use, while fields without these investments may have higher on-farm water usage. Differences in the type and extent of investments in either irrigation technology or land improvements can be expected to affect field water use. Investments in conservation technology are influenced by external factors, such as available financing or policy. For instance cost-share programs, subsidies and other government policies that can encourage farmers to adopt water conservation technology.

Over and above farmers' investment in technology and management skills, climate directly influences field water use. Field water use will decrease in a wet year and increase in a dry year as high evapotranspiration is likely to lead to higher on-farm water use.

Rice, a water-intensive food staple, is commonly farmed under flood conditions, with a permanent flood of 610 to 1220 mm through most of the rice-growing season.[7] Precision leveling is one conservation technology used in rice production to reduce field water use[8,9] by reducing the required depth of the water. When a field is precision leveled, the field's natural slopes are reduced or removed, evening out the distribution of water, thus lowering the required flood depth and reducing the volume of water farmers require to uniformly irrigate the entire field.

ANALYTICAL APPROACH

There are many factors that influence the amount of irrigation water used in agriculture. It is difficult to separate the marginal improvements in field water use from a single conservation program. To estimate the water savings associated with precision leveling one first needs to isolate the reduction in water use from precision leveling versus other factors that can also affect field water use, such as a farmer's management or weather variation.

Differences in farmer skills and practices are one of the many factors that could affect field water use. If farmers' management skills can be accounted for, water savings can be better related to the underlying effects of precision leveling. While some preceding analyses assume constant management skills across all fields, the proposed analytical approach acknowledges similar management skills among groups of fields that are managed by the same farmer.

In farming, one farmer can manage more than one field and a field can be in production in more than one year, as illustrated in Figure 3.2. Table 3.2 shows that field clustering occurs at the farmer level. For example, the maximum numbers of fields managed by a single farmer was 11, 16, 18, 18, 11 and 17 fields from 2006 to 2011, respectively. In all these years, farmers managed five fields on average.

Table 3.2: Number of Fields per Farmer in Lakeside Irrigation Division

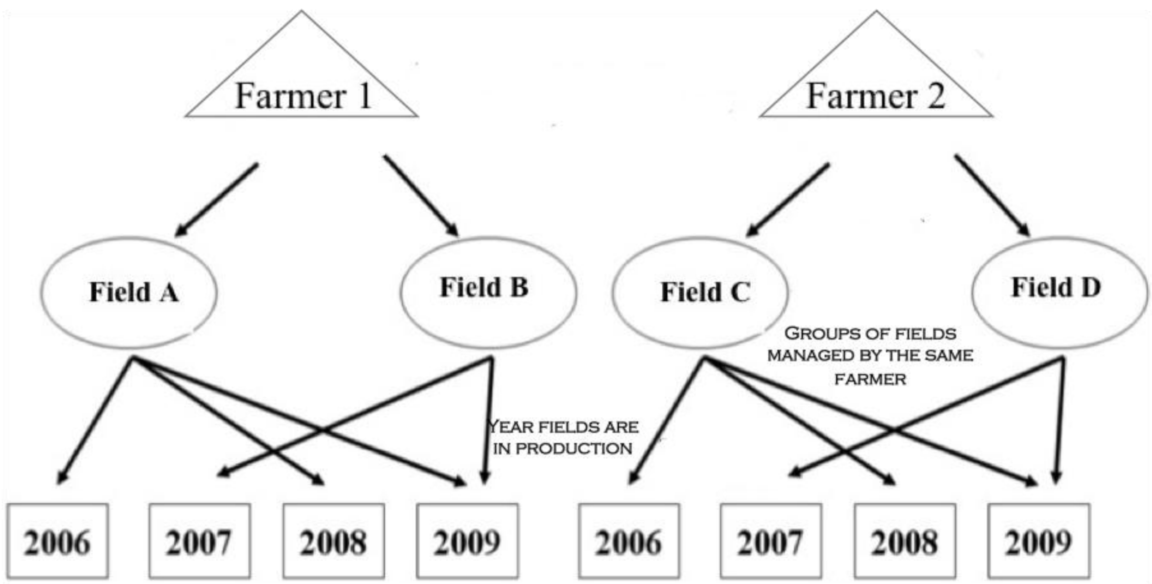
Year	Average Fields	Maximum Fields
2006	5	11
2007	5	16
2008	5	18
2009	5	18
2010	5	11
2011	5	17

The range of fields that an individual farmer may manage, broken up by each year of the study.

Source: Survey and WAMS database 2012

Figure 3.2 depicts the type of nested data common in farming, where field observations are unlikely to be independent from one another. In Figure 3.2, each triangle represents a farmer, each circle represents a field (Field A, Field B, Field C and Field D) and each square represents a year when a field is in production. The arrows indicate connections among entities. For example, Farmer 1 manages Field A in 2006. If the same farmer (Farmer 1) manages Field A and Field B but not Field C, the water use of Field A may be more similar to the water use of Field B versus that of Field C (Figure 3.2). The expectation is that grouping of fields managed by the farmer share similar management, technology investments or cropping patterns because of clustering. For example, 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.

Figure 3.2: Nested Analytical Approach



The nested analytical approach used in this study represents the relationship between farmers, fields, and years of production. There is no one-to-one relationship of farmers to fields; a given farmer operates more than one field, and each field is in and out of production in different years due to crop rotation.

Source: Ana Ramirez

Crop rotation is a common practice in farming. Rice fields transition in and out of production across crop seasons and years. For example, two to three years may elapse before a given field is in production again. A set of rice fields may be in production in only two years during the six-year study period. For example, Figure 3.2 shows Field B in production only in the years of 2007 and 2009. Thus, one can also anticipate, in a multiple year analysis, correlation across multiple measurements of a given field. The same field measured on different occasions creates a correlation across occasions; in other words autocorrelation in the residuals of each field measured in the different non-sequential years it is in production. Correlation among observations is likely with this kind of nested data, where a farmer manages more than one field and a field is in production in more than one year.

HYPOTHESES

This dissertation address three questions by investigating longitudinal irrigation patterns over six years of data from 2006 to 2011:

- Does on-farm water use change through time and can we predict these differences?
- Do precision-leveled fields use less irrigation water than non-precision leveled fields?
- Do fields managed by different farmers experience a different pattern of water use?

Table 3.3 lists a set of questions and related hypotheses that explore how factors affect on-farm water use and the complex interaction between the varying characteristics of weather conditions, fields and farmers.

Table 3.3: Hypotheses

	Factors	Hypothesis
How does 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.
	Ratoon crop	During the ratoon crop, fields have lower water usage than during the first crop.
How do the characteristics of fields affect on-farm water use?		Precision-leveled fields have lower water usage than non-precision leveled fields.
	Precision Leveling	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.
		The effect of a straight-levee system on the water use of fields differs according to the levee density in each field.
	Multiple Inlets	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.
	Structures	Fields with four or more multiple inlets have lower water usage than fields with three or less multiple inlets.
		As the number of measured structures in a field increases the water usage of that field decreases.
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.

The hypotheses of this study developed prior to conducting the analysis.

Source: Ana Ramirez

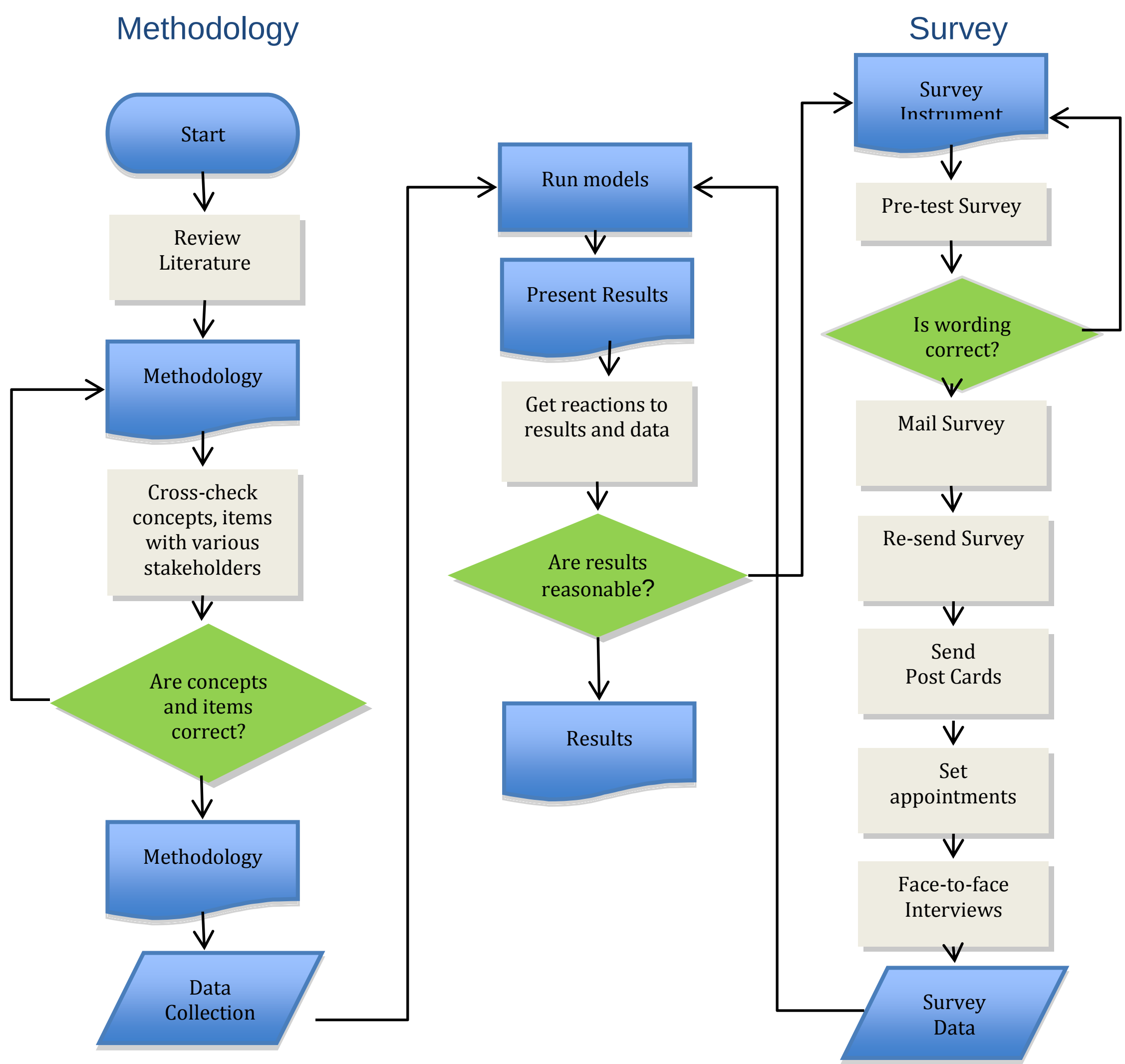
PARTICIPATION

The conservation verification program has been a cooperative effort with a high level of participation from local producers, representatives of Lakeside, and Garwood Irrigation Divisions, LCRA staff and The University of Texas at Austin. One element of the data collection has been establishing effective two-way communication with stakeholder groups. The HB1437 Agricultural Fund Advisory Committee was consulted through the development and implementation of the methodology and survey instrument.

For example, during several meetings, different stakeholders suggested that new factors be included to the original proposed research. Farmers' insights were crucial, as they reflect the experience of the intended conservation program participants.

As the accuracy of the verification depends on the quality of the information collected, this study includes three rounds of data collection through a survey instrument. Figure 3.3 illustrates the process of participation during the development of the methodology and data collection. Each round of data collection involved the revision of the survey instrument, the implementation of face-to-face interviews, as well as contacting farmers who did not participate in previous survey efforts to expand existing information. Three rounds of analysis with different sub-samples were used to cross check the robustness of the verification results. The flow chart below shows the interaction with stakeholders at different stages of the research.

Figure 3.3: Flow Chart Depicting Methodology Development and Data Collection



Flow chart showing the feedback loops with stakeholder input for developing the methodology, the survey, and verifying the results of the model.

Source: Ana Ramirez

ASSUMPTIONS

Table 3.4 lists five assumptions to implement the statistical approach to Lakeside Irrigation Division, as listed below.

Table 3.4: Assumptions to Implement the Methodology in Lakeside Irrigation Division

No.	Assumptions
1	All fields classified as leveled fields have the same quality of leveling.
2	For a field to be classified as "leveled," the minimum proportion of leveled land is fifty percent in relation to total acreage.
3	The soil type is constant.
4	Only factors during the irrigation period influence field water use.
5	Only surface water was used for irrigation.

These assumptions could be verified with further data collection, but they were necessary to make for the implementation of the model given the available amount of data.

Source: Ana Ramirez

One step is to assume that all leveled fields (HB1437 and other leveled fields) have the same quality of leveling as the NRCS standards. This is a reasonable assumption because the EQIP program requires land to be leveled to a comparable quality regardless of year; NRCS leveling standards in the rice area have not changed substantially from the late 1990's to 2013. Survey respondents were asked to identify whether precision leveling funding was provided by NRCS. If funding was provided, one would expect fields to be precision leveled to NRCS standards, which requires a maximum 0.2 percent slope.[10] The NRCS did not fund all field leveling in Lakeside Irrigation Division, according to survey participants. As a result, the slope of leveling cannot be confirmed to NRCS standards, although every effort was made, with LCRA's irrigation division staff and farmers, to verify that privately funded fields were leveled to NRCS standards. Of the precision-leveled fields, 77 percent were reported leveled to NRCS standards, 9 percent were not leveled to NRCS standards and 14 percent had missing information regarding

NRCS standards. Fields precision-leveled that did not conform to NRCS standards or with missing information were evaluated and verified by the Lakeside Irrigation coordinator to have been precision leveled to comparable quality.[11] No records exist on the quality of privately funded land leveling practices from 199 to 2005.

Table 3.5 and 3.6 lists number and type of leveled fields in production by year from 2006 to 2011, respectively. Over time the sample size increases. For example, in 2006 only 6 level fields funded through the HB1437 program were in production. Once these 6 fields from the HB1437 program are grouped with the other 24 leveled fields, the number of precision-leveled fields in the sample increases to 28 fields.

Table 3.5: Total Fields in Production 2006-2011, First Crop

Year	Total fields	Non-Leveled fields		Leveled fields	
		Fields	Percentage	Fields	Percentage
2006	146	118	81%	28	19%
2007	159	123	77%	36	23%
2008	168	95	57%	73	43%
2009	201	106	53%	95	47%
2010	176	93	53%	83	47%
2011	196	101	52%	95	48%

Breakdown of the number of non-precision leveled fields and precision leveled fieldss during each year of the study.

Source: Survey and WAMS database 2012

Table 3.6: Total Precision Leveled Fields in Production 2006-2011, First Crop

Year	Total Leveled Fields	HB1437 Fields		Leveled Fields 1999-2005	
		Fields	Percentage	Fields	Percentage
2006	28	6	14%	24	86%
2007	36	13	24%	24	67%
2008	73	42	53%	35	48%
2009	95	50	53%	45	47%
2010	83	47	57%	36	43%
2011	95	52	55%	43	45%

Breakdown of the precision leveled fields in each year of the study between whether the fields were precision leveled through funding from the HB 1437 program or if they were precision leveled before the program was implemented (1999-2005).

Source: Survey and WAMS database 2012

This study classifies as “leveled” any LCRA field with at least half of the land leveled. The second assumption made was that fields with less than 50 percent leveled acreage remain in the sample as “non-leveled” fields. This criterion established a minimum proportion of leveled land (50%) in relation to total acreage for a field to be classified as “leveled.” This cut-off point is a way to segment data, given that the field boundaries used for LCRA’s billing system sometimes aggregate a number of different ‘physical’ fields. The LCRA billing system may at times combine non-precision leveled and precision-leveled fields. The water use of combining precision-leveled and non-precision leveled ‘physical’ fields in one LCRA field is likely to be higher than the water use of a unique precision-leveled physical field that corresponds to one LCRA field. The inclusion of non-precision leveled fields increases the average water use that would otherwise be recorded if all fields were precision-leveled. As a result, it is a conservative assumption to estimate that partially leveled fields may be similar to non-leveled fields because both types of fields are more likely to have higher water use as compared to precision-leveled fields.

The third assumption is that the soil type is constant. A soil variable was not included in the statistical analysis because the soil type (Crowley fine sandy loam: Hydro soil group D) has low infiltration rates and high runoff potential was similar throughout fields in Lakeside Irrigation Division. If there would be variation in the soil type among fields located in the same or different irrigation divisions, soil type ought be included as a predictor.

The dissertation also assumes that only factors that have impacts during the irrigation period influence field water use, even though weather conditions before a farmer starts taking water influence soil moisture, which affects field water use. Given the retrospective nature of the data collected, the use of irrigation period factors only was appropriate because farmers did not remember the exact planting dates for each field every year during the six-year study period. The first and last water delivery to a field is information readily available to irrigation districts and water utilities like the LCRA and their data is consistent over time and space.

Finally, the last assumption has to do with the type of irrigation water source. To the best of the researcher's knowledge no supplemental water from wells was used for irrigation. This is a reasonable assumption that was corroborated during the survey; which asked farmers for each field in each year whether they water by wells and if so, which percentage of their irrigation water was provided by groundwater. This chapter has explained the methodology developed, and Chapter 4 will describe the data collected for this analysis.

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[1] David H. Laughlin and Robert K. Mehrle, "Straight Versus Contour Levee Rice Production Practices in Mississippi," *Mississippi Agricultural and Forestry Experimental Station* Bull.1063, (1996): 1-16, 15.
[2] Earl. D. Vories, Phil. L. Tacker, and Robert Hogan, "Multiple Inlet Approach to Reduce Water Requirements for Rice Production," *Applied Engineering in Agriculture* 21, no.4 (2005): 611-616, 613.
[3] M.C. Smith and others, "Water use estimates for various rice production systems in Mississippi and Arkansas," *Irrigation Science* 25, (2007): 141-147, 141.
[4] Ibid., 142.
[5] M.C. Smith and others, "Water use estimates for various rice production systems in Mississippi and Arkansas," 141.
[6] Fred T. Cooke Jr., DeWitt. F. Caillavet and James C. Walker III, "Rice Water Use and Cost in the Mississippi Delta," 2.
[7] Earl. D. Vories, Phil. L. Tacker, and Robert Hogan, "Multiple Inlet Approach to Reduce Water Requirements for Rice Production," 611.
[8] Fred T. Cooke Jr., DeWitt. F. Caillavet and James C. Walker III, "Rice Water Use and Cost in the Mississippi Delta," 2.
[9] M.C. Smith and others, "Water use estimates for various rice production systems in Mississippi and Arkansas," 141.
[10] National Resources Conservation Service, Precision Land Forming Code 462 (Washington D.C., NRCS, 2002). http://efotg.sc.egov.usda.gov/references/public/NE/NE464.pdf
[11] Unpublished emails and communication provided by Larry Harbers, Operations Analyst Sr, Lakeside Irrigation District, LCRA.

Chapter 4: Data

This evaluation uses three data sources: weather data from the LCRA Hydromet System; field-level data LCRA collects for billing purposes through their Water Application Management System (WAMS); and farmer and field level information collected through a survey. This evaluation uses a sample of 328 unique fields from Lakeside Irrigation Division in Texas over a six-year period, totaling 966 observations. Eleven factors were used to isolate the effect of precision leveling from other factors such as variations in climate, farmers' management skills and other investments in irrigation improvements, as discussed below. The choice of factors was informed both by previous research as well as in consultation with a variety of stakeholders, including local producers, irrigation coordinators, and professionals at LCRA and the University of Texas at Austin. This chapter presents the sources and type of climate data used in the analysis, followed by a description of the various factors that need to be taken into account at the field level. This chapter closes with a discussion of relevance of incorporating farmer characteristics to ensure reliable results.

CLIMATE DATA

Weather conditions are likely to influence year-to-year on-farm water use. In essence, when using longitudinal data an analyst ought to include temporal measures to differentiate the impact of weather conditions from the estimated effects of water conservation programs, such as precision leveling.

The first step in the analysis was to separate the effect of precision leveling from the effects of year-to-year weather variation on field water use. In this multi-year analysis, rain, evapotranspiration and year 2011 (as a proxy variable for extreme drought) were included in the model to account for the effect of variation in climate on field water use. The rain variable is a relevant exogenous control, because farmers will have to irrigate more in years that have less rainfall. This exogenous variable measures the average rainfall over the average irrigation period in Lakeside Irrigation Division. At this time, measurement of rainfall is available at three rain gauge stations in the proximity of the irrigation division area. Daily rainfall data were collected from Eagle Lake 7 NE station, Colorado River at Altair and Wharton station (Figure 4.1, with stations indicated by red circles). Using the Thiessen interpolation methodology, three polygons represent the variation in rainfall across Lakeside Irrigation Division. Thiessen polygons are one way to look at weather variability within an irrigation division by allocating rainfall and evapotranspiration data from different weather stations to fields. Using an interpolation methodology, the irrigation division is divided into three polygons, so that fields within each polygon are allocated the same volume of rainfall as its corresponding weather station (see Figure 4.1).

Figure 4.1:   Thiessen Polygons

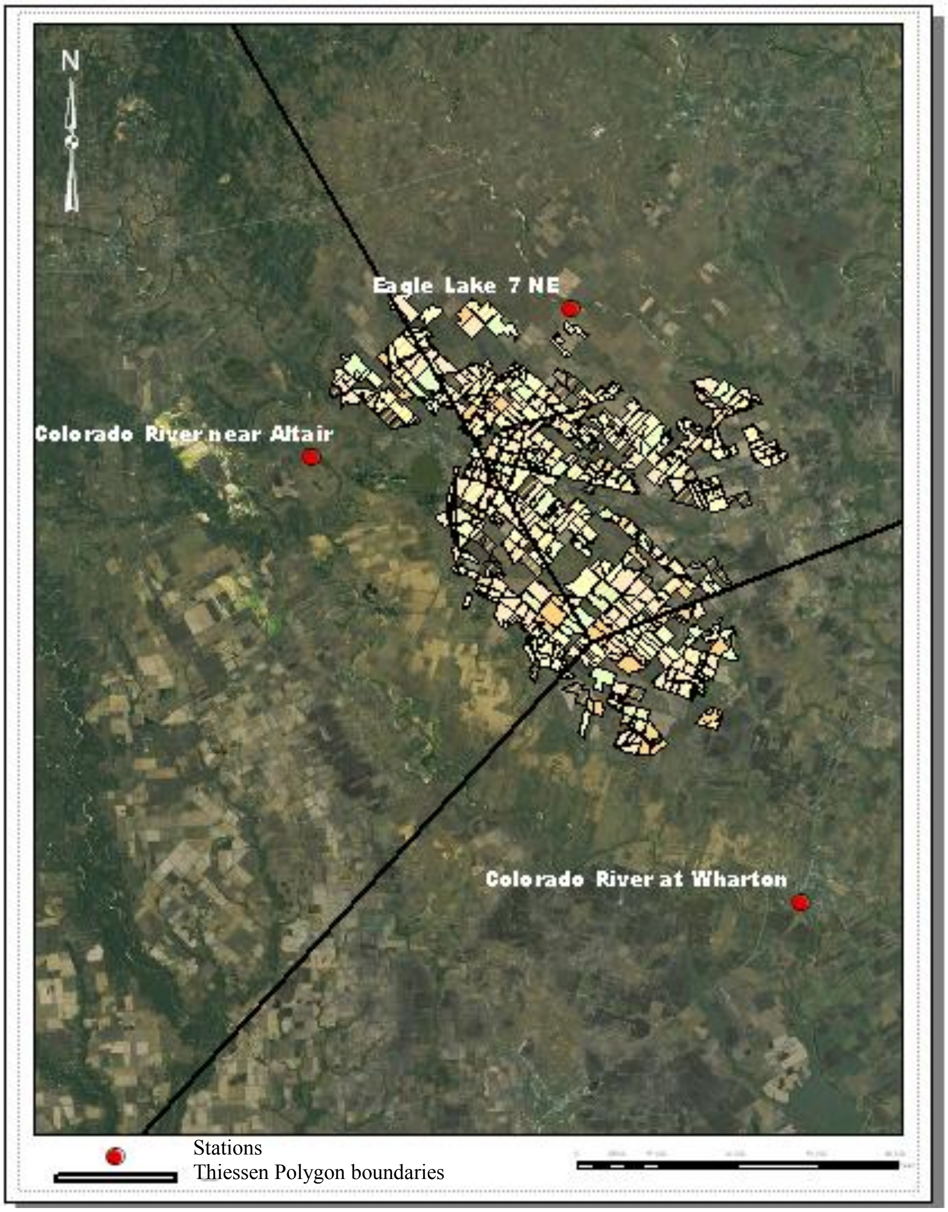

Figure 4.1 shows an aerial photograph of Lakeside Irrigation Division where the black lines delineate the three Thiessen Polygons, the red dots indicates the weather stations used for this analysis. The yellow and orange squares represent fields in rice production. Fields inside of the same polygon receive the same amount of rain as that recorded by the nearest weather station.

Source: Ana Ramirez

Within each of the three polygons, fields were assumed to receive the same volume of rainfall as that of the corresponding gauge. Daily rainfall data were averaged during the average irrigation period, which refers to the average number of days between the first and last water delivery to the set of fields within each polygon. Values for evapotranspiration were calculated using the Penman-Monteith method recommended by the Food and Agriculture Organization of the United Nations (FAO). The FAO Penman-Monteith combination method, in the absence of radiation data,[1] includes a range of climate factors (maximum and minimum temperature, humidity, wind speed and radiation) in the calculation of evapotoranspiration (Equation 1 and Table 4.1).[2]

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

(Equation 1)

Table 4.1: Variables in Penman-Monteith Combination Method

Variable	Description	Units
ETo	Reference evapotranspiration	mm day-1
Rn	Net radiation at the crop surface	MJ m-2 day-1
G	Soil heat flux density	MJ m-2 day-1
T	Mean daily air temperature at 2 m height	°C
u2	Wind speed at 2 m height	m s-1
Es	Saturation vapor pressure	kPa
Ea	Actual vapor pressure	kPa
es – ea	Saturation vapor pressure deficit	kPa
D	Slope vapor pressure curve	kPa °C-1
G	Psychrometric constant	kPa °C-1

Source: Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements (FAO, 1998)

FIELD LEVEL DATA

Field level data can help an analysis to evaluate how specific field predictors influence water use, by separating precision leveling water savings from the influence of other infrastructure, land and crop variety improvements. Field-level data were collected from LCRA's billing system (WAMS) and through a farmer survey. LCRA staff collects information about field characteristics through its annual water contracting process. For example, the LCRA's water customer billing system collects the following information for first and ratoon (second) crop: contract name, field name, year the field was in production, whether the field was in production during the ratoon crop, field acreage (ac), field water use (ac-ft) and number of structures used to deliver water to a field.

The farmer survey asked respondents about conservation measures in place and management decisions that affect field water use. This survey was conducted in 3 phases. Data from the 2006-2009 planting years were collected in early 2010. In early 2011 and 2012 data were collected for the 2010 and 2011 planting years, respectively. The data collected in the survey represents farmers' self-reported information based on farmers' experience and records. The survey gathered information about farmers' age, experience, and education; asked farmers about their farm operation including off-farm work, irrigation system upgrades and water conservation technology investment decisions; and included detailed questions about farming practices, field characteristics and upgrades, collected by field and year during the six-year period of the analysis from 2006 to 2011. Field verification of farmers' information was outside of the scope of the study.

Irrigation period refers to the number of days between the date of initial water delivery to a field and the field's final water delivery date. The variable 'irrigation period' is the number of days beyond the average irrigation period that a field took water. An extended irrigation period is likely to lead to higher water use, while a shorter irrigation period may lead to lower field water use. To calculate the additional number of days that a field took water, a mean-centered irrigation period was calculated for each field. To calculate the mean-centered irrigation period, it was necessary to first calculate the average irrigation period for each Theissen polygon. The equation for the average irrigation period can be found below (Equation 4.2), where the average irrigation period for each Theissen polygon(*j*) is the date of the last water delivery to a field (d_{lti}) , minus the date of the first water delivery to a field (d_{fti}), for each field (i) , averaged over all fields in Theissen polygon (N_j) .

$$\bar{g}_{tj} = \frac{\sum_{j_i=1}^{N_j}(d_{lti-}d_{fti})}{N_j}$$

(Equation 4.2)

The irrigation period of each field was group mean centered among all the fields within each Theissen polygon (Equation 4.3), where $\bar{g}_{cti}$ is the mean-centered irrigation jl of a given field i, g_{ti} is the irrigation period for a given field, and $\bar{g}_{tj}$ is the average irrigation period in Theissen polygon *j*.

$$\bar{g}_{cti} = |g_i - \bar{g}_{tj}|$$

(Equation 4.3)

Investments in infrastructure or land improvements other than precision leveling can influence field water use, such as levee density, multiple inlets[34], rice variety,[5] and ownership. A soil variable was not included in the statistical analysis because the soil type (Crowley fine sandy loam: Hydro soil group D) with low infiltration rates and high runoff potential was similar throughout fields in Lakeside Irrigation Division.

FARMER LEVEL DATA

Differences in farmers' skills and practices are factors that could affect field water use. If the management practices of a farmer play a role in the amount of water conserved, farmer practices ought to be accounted for in the model. Because farmers precision-level fields voluntarily, a farmer who precision levels may have management skills that differ from another farmer who does not precision level. For example, farmers with better management practices may be more likely to implement precision leveling. Or, farmers who implement precision leveling may improve the management of their fields[6] in part because of reduced labor[7] and flooding times.[8] It is useful to include a 'farmer effect' to separate the water savings attributable to the implementation of precision leveling from water savings due to farmers' management skills. The 'farmer effect' accounts for factors not readily observable or measurable, such as skills, abilities, practices and personality of famers that may affect field water use. These farmer skills may account for differences in the pattern of water use across groups of fields managed by different farmers within an irrigation Division.

This chapter has reviewed the data used for this analysis, and Chapter 5 will explain the survey methodology developed for the data collection.

[1] Food and Agricultural Organization, *Crop evapotranspiration – Guidelines for computing crop water requirements* (FAO, 1998), http://www.fao.org/docrep/X0490E/x0490e07.htm#solar%20radiation/, Chapter 3 Example 16.

[2] Food and Agricultural Organization, *Crop evapotranspiration – Guidelines for computing crop water requirements* (FAO, 1998), http://www.fao.org/docrep/X0490E/x0490e06.htm#fao%20penman%20monteith%20equation, Chapter 2.

[3] Earl. D. Vories, Phil. L. Tacker, and Robert Hogan, "Multiple Inlet Approach to Reduce Water Requirements for Rice Production," *Applied Engineering in Agriculture* 21, no.4 (2005): 611-616, 613.

[4] M.C. Smith and others, "Water use estimates for various rice production systems in Mississippi and Arkansas," *Irrigation Science* 25, (2007): 141-147, 142

[5] Ibid.

[6] Arshad Ali, Wayne Clyma and Alan C. Early, "Improved Water and Land Use Management through Precision Land Leveling," *In: Proceedings Conference on Waterlogging and Salinity,* Department of Civil Engineering, University of Engineering and Technology, Lahore, October 13-17, (1995): 209-216, 211.

[7] David H. Laughlin and Robert K. Mehrle, "Straight Versus Contour Levee Rice Production Practices in Mississippi," *Mississippi Agricultural and Forestry Experimental Station,* Bull.1063 (1996): 1-16, 5.

[8] Sam H. Johnson III, Zahid. Saeed Khan and Ch. Muhammad Hussain, "The Economics of Precision Leveling: a Case Study from Pakistan," *Agricultural Water Management*, no.1 (1978): 319-331, 325.

Chapter 5: Survey

The survey validates and expands on information that LCRA already collects through its water contracting process. To validate and expand information, each phase of data collection involved revising the survey instrument, implementing face-to-face interviews and contacting farmers who did not participate in previous survey efforts. This survey was conducted in three phases: 2006-2009 data was collected in early 2010; 2010 data was collected in early 2011; and 2011 data was collected in early 2012. Cooperating farmers from the HB1437 Agricultural Fund Advisory Committee assisted in pre-testing the survey. The data collected in the survey are farmers' self-reported information; field verification of this information was outside of the scope of the study.

Potential survey respondents included the approximately 70 contract holders who purchase surface water from the LCRA for rice farming in Lakeside Irrigation Division. The contract holders and farmers received a letter of explanation and the questionnaire by mail. The introductory letter commented about the nature of the research project. It informed the respondent that in two weeks a project staff member would contact them by telephone to ask them whether they are willing to participate in the survey. During the call, project staff described the study and asked farmers whether they were willing to participate in the survey. If the farmer decided to participate, the investigator created a time period to fill out the survey with the farmers. Appointments were held at LCRA's Wharton office.

The survey asks farmers about conservation measures in place, water usage and management decisions that affect water use. It obtained information from farmers about fields in production from 2006 to 2011. The survey (Appendix A) was divided into three main sections. Part 1, General Information, gathered 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 conservation technology. This section of the survey was only collected once for each farmer. In Part 3, Field Characteristics, detailed questions were asked on farming practices and upgrades implemented by field and year from 2006 to 2011.

The survey strategy focused on farmers who agreed to participate and answer the survey. As it is possible that these participants may be more conscientious farmers or their landholdings may differ from other farmers, it may be useful to test whether such an assumption is true. Table 5.1 indicates that the fields surveyed are representative of most rice fields when considering field size and water use. There was broad participation from farmers in Lakeside Irrigation Division, as indicated by the 87 percent survey response rate. Table 5.1 illustrates the 'representativeness' of the sample by irrigated field acreage and water usage. The tables below show that the fields surveyed are representative of most rice fields (WAMS Data) when considering water use and field size. The mean total water use is similar in all fields, based on a comparison between survey data and the WAMS data for each year. Note that the average water use differs by year, as farmers' consumptive use of irrigation water is influenced by precipitation in wet and dry years. Farmers reduce the use of irrigation water in years with high rainfall. For example, the average field water usage in 2009 and 2008, both dry years, is almost twice that of 2007, a wet year.

The average annual field acreage in the survey is close to that of the WAMS data, which includes all the fields in production by year. Variation in average field size by year is modest. The average field acreage for all survey respondents ranges from 121 to 139 acres. However, these mean acreages can be deceptive because several fields used in the study are a grouping of separate individual physical fields. LCRA groups these fields together for billing purposes; these large grouped-fields are outliers that are likely to inflate the overall average per-field-acreage.

Table 5.1: WAMS data by Field Size and Water Use First Crop

Year	Acres		Water Use	
	Mean	Std Dev	Mean	Std Dev
2006	120.73	77.99	2.47	0.65
2007	129.96	96.17	1.46	0.60
2008	141.28	114.59	2.98	0.92
2009	126.30	84.30	3.23	0.95
2010	132.11	129.35	2.29	0.70
2011	128.16	80.84	3.48	0.94

Table 5.3 presents the mean acreage of fields and the mean water use for the entire population of fields in Lakeside Irrigation Division.

Source: Statistic calculated by Ana Ramírez using WAMS and the Survey database.

Table 5.2: Representative Sample by Field Size and Water Use First Crop

Year	Acres		Water Use	
	Mean	Std Dev	Mean	Std Dev
2006	117.68	78.43	2.49	0.68
2007	123.89	83.83	1.51	0.60
2008	137.21	114.63	3.00	0.92
2009	124.77	79.89	2.99	1.02
2010	125.15	119.07	2.29	0.67
2011	127.94	78.59	3.45	0.90

Table 5.4 presents the mean acreage of fields and the mean water use for fields included in the study.

Source: Statistic calculated by Ana Ramírez using WAMS and the Survey database.

Demographic Profile

The survey shows that that the majority of irrigators are 41 years or older (Table 5.3). According to the USDA, countrywide, approximately 75 percent of rice farmers are 45 years or older. The survey indicates that 39 percent of the farmers are older than 60 years old. Over one-quarter of the farmers fall within 41-50 or 51-60 age cohorts. Few farmers (5 percent) are younger than 40 years of age and none are younger than 30 years old.

Table 5.3: Age of Farmers in Lakeside Irrigation Division

Age Range	Number	Percentage
31-40	2	5%
41-50	9	24%
51-60	12	32%
Over 60	15	39%

Source: Survey 2012

Anecdotal information from face-to-face questionnaires suggests that older farmers are less likely to go in-debt to finance cost share/match resources, as they may be more likely to retire soon. This is consistent with research on adoption behavior[1] documenting how a farmer's age influences their investment preferences in conservation technology.

Survey results show that almost half of the respondents (45 percent) are tenants (Table 5.4). The term 'tenant' refers to a person who farms the land but does not own the land. He/she either pays cash to rent the field or shares the crop production with the landowner. One-quarter of the farmers indicated they both own and rent land for farming. About 22 percent reported that they only farm land they own. This is consistent with 1997 Agricultural Census (Table 5.5), which also indicates that farmers usually do not own all the land they farm.

Table 5.4: Percent of Fields by Ownership Stake and Year

Year	Owner	Cash	Share
2006	13%	35%	52%
2007	16%	39%	45%
2008	21%	35%	44%
2009	18%	42%	40%
2010	17%	43%	40%
2011	21%	40%	39%

The ownership stake by year of each field, whether the farmer owns the field, cash-rents the field, or share-rents the field.

Source: Survey (2006-2012)

Table 5.5: Percent of Fields by Ownership Stake, Agricultural Census

Study	1997 Ag Census
Tenant	37%
Own/Share	42%
Landowner	21%
Total	100%

Table 5.5 presents the percentage of ownership stake across the U.S., according to the Agricultural Census. This trend in the data is comparable to the findings in the survey, shown in Table 5.4.

Source: Agricultural Census , 2012 and 2007 Agricultural Survey
http://www.agcensus.usda.gov/Publications/1997/Farm_and_Ranch_Irrigation_Survey/fris97.pdf

Anecdotal information from in-person surveys suggests that some tenants may be less willing to go into debt to make a large water conservation investment if it fails to pay off before their lease term ends. This is consistent with findings in the adoption literature, which indicate that the ownership stake of a field influences the type and amount of investment a farmer is willing to make.[2]

Many adoption studies that account for farmer education[3,4,5] indicate that highly educated farmers are more likely to adopt on-farm irrigation technology due to their ability to be selective in gathering information from relevant primary sources and capacity to assimilate and analyze this information. The LCRA survey shows that more than half of the farmers have a college education (Table 5.6) and another one-quarter of the survey respondents have earned a high school degree. Among all survey respondents, 10 percent have earned graduate degrees. The lowest proportion of farmers (5 percent), fall in the group with only some elementary school education. There exists a high education level of most respondents, which is consistent with Anderson[6] findings.

Table 5.6: Highest Level of Education Completed

Year	Percent of farmers
8th grade	3%
High School	27%
College	62%
Graduate School	8%

Source: Survey (2012)

Survey results show the majority of farmers (76 percent) have farmed rice for more than 20 years (Table 5.7).

Table 5.7: Years of Farming Experience

Years of Experience	Percent of Farmers
0-5	8%
6-10	3%
11-15	8%
16-20	5%
Over 20	76%

Source: Survey (2012)

WATER CONSERVATION PRACTICES

Farmers responded to questions about factors that affected their decisions to invest in water conservation. The survey asked farmers about the information they use to decide whether to implement precision leveling. Across Lakeside Irrigation Division, nearly half of the survey respondents (43 percent) identified their 'own experience' as the most important source of their farming knowledge. Farmers' confidence increases with personal learning-by-doing experience. 'Parent and relatives' experience was the second (24 percent) most important source of farming knowledge and farming knowledge from peers ('other farmers'-16 percent) was third.

The literature suggests that a farmer's confidence increases with exposure to neighbors who have experience with the technology,[7] indicating a role for informal knowledge. For example, Feder and Slade,[8] and Smith et al.[9] reported that farmers who invest in more efficient irrigation technology do so in part due to word-of-mouth testimonials, as they "view other farmers as their main source of advice."

Only a few farmers credit extension services as a primary source of farming knowledge. Extension agents disseminate technical information to farmers in at least four ways as extension agents: travel to individual farms and talk to managers; sponsor demonstrations; visit farmers on field days; or meet with farmers. Contact with extension services is commonly chosen as a proxy variable for access to public information.[10]

The majority of farmers identified water savings and labor costs as the two most important reasons affecting their decision to precision-level fields. Labor costs are commonly cited by other research documenting farmers' adoption behavior.[11,12] Farmers, according to previous research, are looking for ways to increase crop yields while reducing costs and labor. However, the literature reviewed does not report 'water savings' as one of the main reason why farmers' precision-level fields. A possible explanation for this inconsistency between previous research and this survey result may be due to a so-called 'social desirability bias.' During the in-person surveys, some participants may have under-represented the reasons affecting their decision to precision-level by trying to 'please' the interviewer. Respondents may have associated the interviewer with LCRA staff and offered an opinion they believed would be agreeable or compatible with the interviewer and LCRA water conservation priorities.

Both financial support and increase yield were reported to be second-level important reasons why farmers' choose to implement precision leveling. Precision leveling a field is an irreversible lump-sum investment to improve irrigation efficiency. Government support programs encourage investment in precision leveling by contributing part of the capital cost of water conservation irrigation technologies through federal-funded and state-funded cost-share programs. Survey respondents were least likely to credit a 'guaranteed contract' as the main reason why they precision-level fields.

Even though precision leveling costs depend on the volume of soil to be moved,[13,14] few producers take into consideration the land's topography versus water savings, labor costs, increase yield and financial support when considering whether or not to precision-level. A possible explanation for this counterintuitive response is that the volume of land to be moved may not be cost-prohibitive. For example, if financial support is available from NRCS for a 50% cost-share, the LCRA can provide 30% cost-share and financial institutions may provide share/match resources for the remaining costs, farmers may not need to make out-of-pocket expenditures to support precision leveling.

Among all survey respondents, water savings and labor costs dominate as reasons why farmers decide to precision-level and adopt multiple inlets. The proportion of farmers that reported 'water savings' as the main reason behind the adoption of multiple inlets is higher than those who reported labor costs. Respondents indicated that financial support was the least likely reason to influence their decision to adopt multiple inlets.

Survey respondents were asked to identify who decides when and how much water to apply to the fields they farm by ownership stake: (a) landowner, (b) cash-rented and (c) share-rented. The majority of producers (73 percent) indicated that when land is cash-rented the tenant makes the water application decision-making. Anecdotal information from some phone and in-person surveys suggests that in cash-rented fields tenants decide when and how much to irrigate, as they bear the full costs of water. Also, in cash-rented fields, tenants decide which crop to plant and what herbicides to use.

Only 43 percent of survey respondents reported that when land is share-rented the tenant decides when and how much water to apply. This survey data coincides with anecdotal information from farmers who reported that in share rented fields, the landowner commonly pays for the volume of irrigation water used, but in some share-rent arrangements the tenant pays for the water. Share rented fields embody a diversity of owner-tenant arrangements from the proportion of profit to the decision-making in infrastructure, crop variety and irrigation water.

One-third of survey respondents indicated that they collect rainfall information on their fields, but of the 19 farmers who collect rainfall information, only few kept records of the information they collected. Collection of daily rainfall information without maintaining records may limit the value of data to farmers, as they may lack data on weather trends. Limited knowledge of precipitation over time may be a barrier to better inform farmers' decision-making on the implementation of water conservation technology and land improvements.

When asked if they 'flush' their fields as a standard irrigation practice before holding a permanent flood, only 10 percent of the farmers reported they flushed. Anecdotal information from some phone and in-person surveys suggests that flushing practices vary from one farmer to the next, but may be fairly consistent across a farmer's fields. The majority of producers indicated that they flush on a 'need' basis, given weather conditions. Other producers flush as a standard practice citing soil moisture.

CONCLUSION

Demographic characteristics, physical conditions, and institutional factors affect farmers' decision to implement water conservation technology and can be useful for the sustainability of any farm water conservation program. The LCRA farmers' survey shows that rice irrigators in Lakeside Irrigation Division are experienced (with more than 20 years in the farming industry), educated (more than half have earned a college degree), and the majority are 41 years or older. One quarter of respondents only farm the land that they own, the rest are involved at least in some tenant farming. Tenants farming the land are frequent in Lakeside Irrigation Division. For this reason, understanding the relationship between farmers' ownership stake and adoption behavior is important, as they are the ones who decide when and how much water to order.

Survey results indicate a role for informal knowledge as a key for bolstering farmers' confidence in implementing conservation measures, such as precision leveling. Farmers report that their key sources of knowledge are personal learning from experience as well as exposure to neighboring farmers' experience with water conservation technologies. Among the majority of survey respondents, water savings and labor costs dominate as reasons why farmers decide to precision-level and adopt multiple inlets. This chapter has reviewed the survey methodology used in this study, and Chapter 6 will explain the multi-level modeling methodology developed for this analysis.

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[1] David P. Anderson, Paul. N. Wilson, and Gary D. Thompson, "Adoption and Diffusion of Level Fields and Basins," *Journal of Agricultural and Resource Economics* 24, no.1 (1999): 186-203, 192.
[2] Gershon Feder and Dina L. Umali, "The adoption of agricultural innovations: a review," *Technological Forecasting and Social Change* 43, no.3-4 (1993): 215-239, 12.
[3] David P. Anderson, Paul. N. Wilson, and Gary D. Thompson, "Adoption and Diffusion of Level Fields and Basins," *Journal of Agricultural and Resource Economics* 24, no.1 (1999): 186-203, 197.
[4] Gregory D. Wozniak, "Joint information acquisition and new technology adoption- late versus early adoption," *Review of Economics and Statistics* 75, no.3 (1993): 438-445, 443.
[5] Henning Bjornlund, Lorraine Nicol and Kurt Klein, "The adoption of improved irrigation technology and management practices-A study of two irrigation districts in Alberta, Canada," *Agricultural Water Management* 96, no.1 (2009): 121-131, 125.
[6] David P. Anderson, Paul. N. Wilson, and Gary D. Thompson, "Adoption and Diffusion of Level Fields and Basins," 195.
[7] Gershon Feder and Dina L. Umali, "The adoption of agricultural innovations," 217.
[8] Gershon Feder and Roger Slade, "The role of public policy in the diffusion of improved agricultural technology," 424.
[9] M.C. Smith and others, "Water use estimates for various rice production systems in Mississippi and Arkansas," *Irrigation Science* 25, (2007): 141-147, 147.
[10] Cheryl R. Doss, "Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement," *Agricultural Economics* 34, no.3 (2006): 207-219, 214.
[11] David H. Laughlin and Robert K. Mehrle, "Straight Versus Contour Levee Rice Production Practices in Mississippi," *Mississippi Agricultural and Forestry Experimental Station*, Bull.1063 (1996): 1-16, 5.
[12] David P. Anderson, Paul. N. Wilson, and Gary D. Thompson, "Adoption and Diffusion of Level Fields and Basins," 197.
[13] Sam H. Johnson III, Zahid. Saeed Khan and Ch. Muhammad Hussain, "The Economics of Precision Leveling: a Case Study from Pakistan," *Agricultural Water Management*, no.1 (1978): 319-331, 323.
[14] David H. Laughlin and Robert K. Mehrle, "Straight Versus Contour Levee Rice Production Practices in Mississippi," 13.

Chapter 6: Multi-Level Modeling

Hierarchical Linear Models (HLM) are well suited to evaluate changes over time and accommodate observations that are not independent due to clustering. Figure 6.1 illustrates the semi-nested structure of farming data; where years when a field is in production is nested within fields and fields are nested within farmers. The arrows depict the relationships among the different levels present in this multi-level structure. The hierarchical dataset consists of three levels: years, fields and farmers. The squares represent Level 1, the YEAR when a field is in production. Rice fields transition in and out of production across crop seasons and years due to crop rotation. Two to three years may elapse before a given field is in production again. Level-1 indicates that the water use of fields in production over time is a function of variation in climate. Level-2 FIELD shows the predictive relationship between the characteristics of fields and the outcome. A level-3 FARMER expresses the predictive relationship between the characteristics of farmers and the outcome.

Farming data is not strictly hierarchical, as a farmer may manage in one year the same field that another farmer manages the next. This is the case of a few fields in the sample. As a result, the data is said to have a cross-classified structure and the model is referred to as a Multi-Level model (MLM). Figure 6.1 graphically explains the situation which leads this data to be an MLM, instead of an HLM.

Figure 6.1: Cross-classified Structure

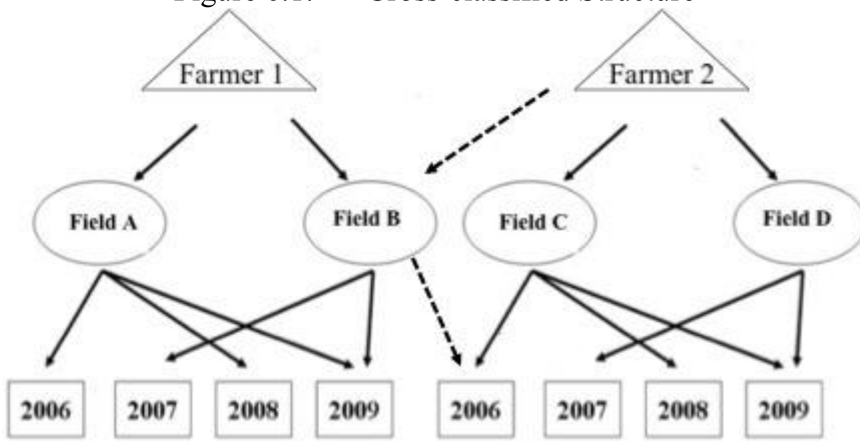
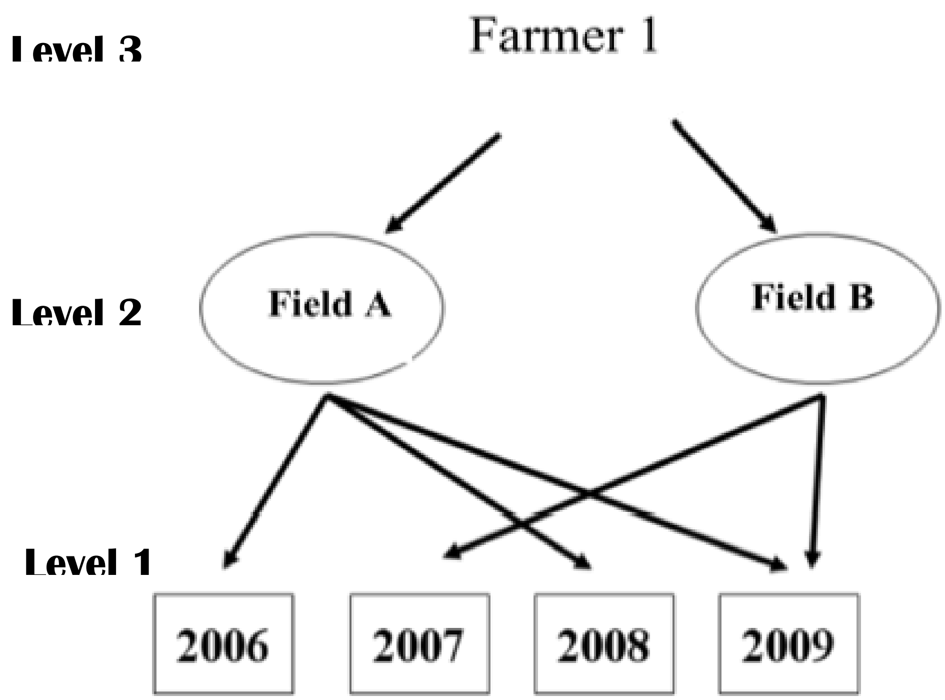


Figure 6.1 illustrates the cross-classified structure of the data, for example field B is in production in 2007 and 2009 with Farmer 1, but is in production in 2006 with Farmer 2. Therefore, the data does not have a purely hierarchical nature.

Source: Ana Ramirez

MLM can yield results when the same data points (fields in this case) do not occur at a regular interval (yearly), resulting in unbalanced data. MLM models allow for unbalanced data, which is important because crop rotation is a common practice in rice farming. Besides MLM, there is no particular good alternative to deal with unbalanced clustered panel data with a large number of clusters with other models.

Figure 6.2: Multi-Level Data



The multi-level data used to account for the relationship between a farmer, the fields he operates, and the years each field is in production due to crop rotation.

Source: Diagram from the report: Ramirez, A.K., Eaton, D. J. "Statistical Testing for Precision Graded Verification"

Using MLM, the dependent variable represents the water use for field *i* of farmer *k* in year *t*, as a function of three types of dependent variable (time, farmer and farm plot), plus within-field random error. Water use is measured in acre-feet of water used over acre farmed. An acre-foot is the amount of water required to cover an area of one acre to a depth of one foot. Due to the availability of only few waves of data (2006-2011), the functional form for a field's water use over time is assumed to be linear.

Table 6.1 lists the variables included in the four models (OLS, FE, MLM, CRE). These variables can be categorized into three groups that affect field water use: weather variation (rain and evapotranspiration); a farmer's investment in infrastructure and land improvements (precision leveling, levee density and multiple inlets); and a farmer's management (irrigation period, rice variety and ownership). Rain, evapotranspiration and year 2011 (proxy variable for extreme drought) are included in all the models to account for year-to-year climate variation. Table 6.2 presents descriptive statistics of these variables.

Table 6.1: Variables Used in Model

FACTORS	DESCRIPTION	VARIABLE	UNITS
EVAPOTRANSPIRATION	Average daily evapotranspiration during the average growing season	EVAP	in/d
RAIN	Average daily precipitation during the average growing season	AVRAIN	in/d
PRECISION LEVELING	Whether a field has been precision leveled or not	LL	binary
LEVEE DENSITY	Number of levees in a field plus one divided by the size of the field	L_DENSITY	levees/ac
WATER DEMAND	Amount of water delivered to a field divided by the field size	y	ac-ft/ac
WATER INLETS	Total number of structures (measured and unmeasured) on a field	W_STRUC	unit
IRRIGATION PERIOD	Number of additional days water was delivered to a field beyond the average growing period	IRR_PERIOD	days
RICE VARIETY	Whether a farmer planted hybrid or seed rice	RICE	binary
CASH-RENTER	When the person who farms the land pays cash to rent the field	CASH	binary
YEAR 2011	Whether the year is 2011 or not (proxy variable for extreme drought)	YEAR_2011	binary

Description of variables used in the models and the units for each variable.

Source: Ana Ramirez

Table 6.2 Descriptive Statistics of Variables Used in Analysis

Variable	Mean	Std. Dev.
Water Demand	2.67	1.03
Rain	0.09	0.07
Evapotranspiration	0.23	0.04
Precision leveling	0.40	0.49
Levee density	0.23	0.23
Water inlets	2.81	1.87
Cash renters	0.40	0.49
Rice Variety	0.45	0.50
Irrigation period	9.47	11.58
Rice * irrigation	4.18	9.10
Leveling * density	0.04	0.08
Year 2011	0.18	0.39

Mean and standard deviation for variables included in the analysis. For binary values, such as precision leveling, a value of 0.40 represents that 40 percent of fields were precision leveled.

Source: Ana Ramirez

MLM is often presented as separate regression equations; in this case, one that accounts for time, another that includes field and farmer level factors that influence field water use. The general model is shown below; with separate equations one for level-1 and level-2; however these equations would be estimated simultaneously. Equation 6.1 presents the general equation for MLM model, where y_{tik} is field water use, X are the level-1 variables, W are field variables and Z are farmer variables in level-2; ϑ are the estimated intercepts and β and γ are the estimated coefficients for field and farmers, and ε, r and u represent error at level-1, random effect that vary across fields and across farmers in level-2 respectively.[1]

Level 1

$$y_{tik} = \vartheta_{0ik} + \pi_{1ik}(X_{1tik}) + \varepsilon_{tik}$$

Level 2

$$\pi_{0ik} = \vartheta_0 + (\beta_{01} + r_{01i})W_i + (\gamma_{02} + u_{02k})Z_k + r_{00i} + u_{00k}$$

$$\pi_{1ik} = \vartheta_1 + r_{10i} + u_{10k}$$

(Equation 6.1)

Equation 6.2 for level 1 states that the water use (y_{tik}) in field *i* of farmer *k* in time *t* is a function of the intercept (ϑ_{0ik}), rain, evapotranspiration and a 2011 year effect as well as the period of time water is delivered to a field.

$$y_{tik} = \pi_{0ik} + \pi_{1ik}RAIN_{tik} + \pi_{2ik}EVAP_{tik} + \pi_{3ik}YEAR\_11_{tik} + \pi_{4ik}IRR\_PERIOD_{tik} + \varepsilon_{tik}$$

(Equation 6.2)

Equation 6.3 for level 2 states that field water use is a function of the type of investment in infrastructure and land improvements present in a field, the crop variety planted in that field and farmers' individual characteristics.

$$\pi_{0ik} = \vartheta_0 + (\beta_{01})LL_i + (\beta_{02})L\_DENSITY_i + (\beta_{03})LL_i * L\_DENSITY_i + (\beta_{04})W\_INLETS_i + (\beta_{05})RICE_i + (\beta_{06})CASH_i + (\beta_{07})RICE * IRR\_PERIOD_i + r_{00i} + u_{00k}$$

$$\pi_{1ik=}\vartheta_1$$

$$\pi_{2ik=}\vartheta_2$$

$$\pi_{3ik=}\vartheta_3$$

(Equation 6.3)

RESULTS AND DISCUSSION

This study evaluates the reduction in field water use due to precision leveling using a sample of 966 field observations over a six-year period (2006-2011). Table 6.3 lists the results. Table 6.4 lists the lessons learned from this study and the percent change water use associated with each of the factors.

Table 6.3: Multi-Level Model Results for 2006 to 2011

Water demand	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Rain	-5.396	0.792	-6.81	0.000	-6.948	-3.844
Evapotranspiration	4.264	1.309	3.26	0.001	1.699	6.830
Precision Leveling	-0.305	0.089	-3.43	0.001	-0.479	-0.131
Levee density	0.479	0.154	3.11	0.002	0.177	0.780
Leveling * density	1.474	0.457	3.23	0.001	0.578	2.370
Water inlets	-0.033	0.016	-2.00	0.045	-0.064	-0.001
Cash renters	-0.114	0.061	-1.87	0.061	-0.233	0.005
Rice Variety	-0.117	0.068	-1.73	0.083	-0.250	0.015
Irrigation period	-0.004	0.003	-1.52	0.129	-0.009	0.001
Rice * Irrigation	0.008	0.004	2.00	0.046	0.0001	0.015
Year 2011	0.641	0.057	11.25	0.000	0.529	0.752
_cons	2.241	0.384	5.84	0.000	1.489	2.994

Coefficient results from the multi-level model using data from 2006-2011. The dependent variable is water use, measured in acre-feet of water per acre of land.

Source: Ana Ramirez

Table 6.4: Percent Change for Each Factor

Factors	% Change	Description
PRECISION LEVELING	- 11%	Precision land leveling reduces water use in fields
WATER INLETS	- 1.15%	Water inlets in a field reduce irrigation water
LEVEE DENSITY	- 2%	A field with less levees (10 levees/acre) uses less irrigation water
LEVEE DENSITY* PRECISION LEVELING	- 7%	If a field is precision leveled, the land is flatter; fewer levees are necessary; water use is reduced (10 levees/acre less).
RAIN	- 20%	A one-tenth inch increase in average daily rain reduces the water use in fields
EVAPOTRANSPIRATION	+ 16%	A one-tenth increase per month in evapotranspiration increases the water use by 16%
CASH	- 4%	A farmer who cash-rent uses less irrigation water than other farmers
RICE*IRRIGATION PERIOD	+ 0.28%	A farmer who plants seed or hybrid rice use more irrigation water
YEAR 2011	+ 25%	During a drought year, a farmer will use more irrigation water

Percent change for each factor in the analysis and a description of the significance of each percent change.

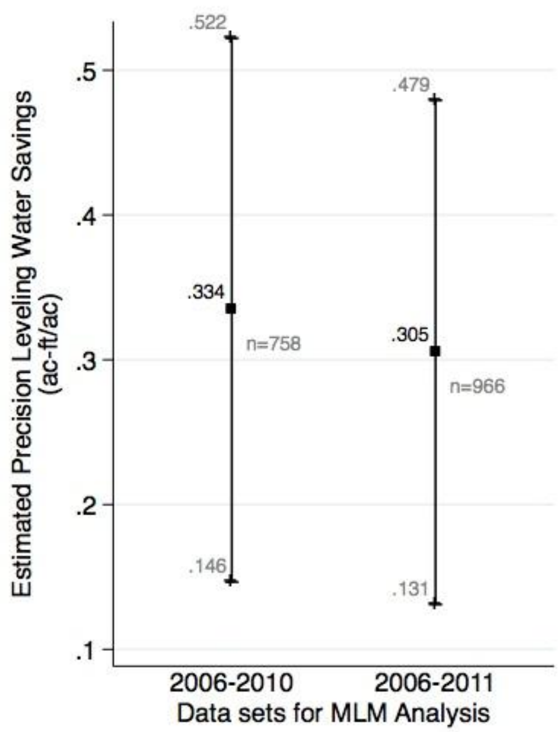
Source: Statistic results estimated using WAMS and the Survey database.

WATER SAVINGS IN PRECISION LEVELED FIELDS

These results document that the impact of water conservation investment in precision leveling has both direct and indirect effects on the water use of fields. A large statistically significant water savings was found in the effect of precision leveling, a level-2 predictor. Precision leveling accounts for a statistical significant (p=.002) 0.30 ac-ft/ac reduction in on-farm water use (Table 6.3). The best estimate of mean water savings year in and year out is 0.30 ac-ft/ac during the first crop due to precision leveling based on six years of data collection (95% confidence interval = 0.12 - 0.47). The precision leveling water savings estimate is robust as the values are essentially the same, or stable over the years of analysis, which include very wet years, very hot and dry years from 2006 to 2011.

The dissertation also included a sensitivity analysis performed by collecting an additional year of data. Figure 6.3 illustrates consistent precision leveling estimates across the 2010 and 2011 analyses. The 2011 analysis has 208 more observations than that of 2010. Figure 6.3 shows that by collecting one more year of data (increasing the sample size by 22 percent) there is a consequent reduction in the standard error of 7%, which tightens the confidence interval associated with the mean precision-leveling water savings estimate.

Figure 6.3: Confidence Intervals MLM Results 2012 and 2011



Precision leveling water savings estimate and confidence intervals for two studies. The 2011 study included 2006 to 2010 data, while the 2012 study included an additional year of data from 2006 to 2011. Water savings are measured in acre-feet of water conserved per acre farmed; n indicates the sample size for each study.

Source: Ana Ramirez

Table 6.5 translates the 0.30 acre-feet of water conserved per acre farmed by estimating the total volume conserved during this study's six-year period. In the Lakeside Irrigation Division 25,275 acres have been precision leveled. The volume of water saved in one year if all fields are in production (7,583 acre-feet) is almost ten times the annual water use of the closest city, Columbus, Texas (782 acre-feet), a community with a population of 3,655 people.[2]

Table 6.5: Water Conserved in Lakeside Irrigation Division

Acres Precision-leveled (ac)	Water Conserved	
	(ac-ft/yr)	(gal /yr)
25,275	7,583	2.47E+09

Total annual water conserved in Lakeside Irrigation Division as a result of precision leveling investment. Results presented both as acre-feet per year and as gallons per year.
Source: Ana Ramirez

INDIRECT EFFECTS OF PRECISION LEVELING

Precision leveling work requires soil movement to relatively uniformly grade land that would otherwise be uneven. In Lakeside Irrigation Division, typical precision leveling practices is to uniform-grade land among a reduced number of straight or slightly bent internal levees. When precision-leveling a field, farmers usually substitute contour levees for a straight-levee system. Table 6.6 shows that a large majority (75 percent) of precision-leveled fields have straight levees, whereas all non-precision leveled fields (100 percent) have contoured levees. This information supports the idea that most naturally sloping fields have serpentine-like levees whereas precision-leveled fields generally have straight levees.

The results also show a high correlation (0.81) between whether a field is precision leveled and a straight levee system. Once a field is precision leveled, the type of levee (straight or contour) does not affect field water use. This finding is consistent with the high correlation (0.81) found in the 2011 study between precision leveling and a straight levee system. A possible explanation for these results is that of the 101 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.

Table 6.6: Fields by Type of Levee System

	Slope	Straight	Contour	Total
Precision leveled	Fields	309	101	410
	Percent	75%	25%	100%
Non-Precision leveled	Fields	0	636	636
	Percent	0%	100%	100%
Total	Fields	309	737	1046
	Percent	30%	70%	100%

The number and percent of precision leveled and non-precision leveled fields by levee system in Lakeside Irrigation Division. Precision-leveled fields can have either a contour or straight levee system. Non-precision leveled fields are unlikely to have a straight levee system, as the levees will likely follow the land's natural topography.

Source: Ana Ramirez

While it is true that precision leveling could influence a field's levee system, it is also true that a field with few or no internal levees is likely to be precision leveled. When a field is precision leveled, the land is flatter because precision leveling decreases the elevation between high and low spots in a field, so fewer levees are necessary to buttress the terrain at different altitudes. Thus, precision leveling has a direct effect on water use and also an indirect effect through the variable "levee density," because precision-leveled fields are more likely to have lower levee density. The factor "levee density" captures the effect that the distribution of internal levees (sparsely or densely distributed) has on a field's water usage. Levee density is measured as a continuous variable that represents the relation between the number of levees in a field and the field size (acres). In Lakeside Irrigation Division, on average precision leveling decreases the levee density by 0.17 levees per acre when a field between the years when precision leveling is implemented (see recommendations on how to improve this estimate).

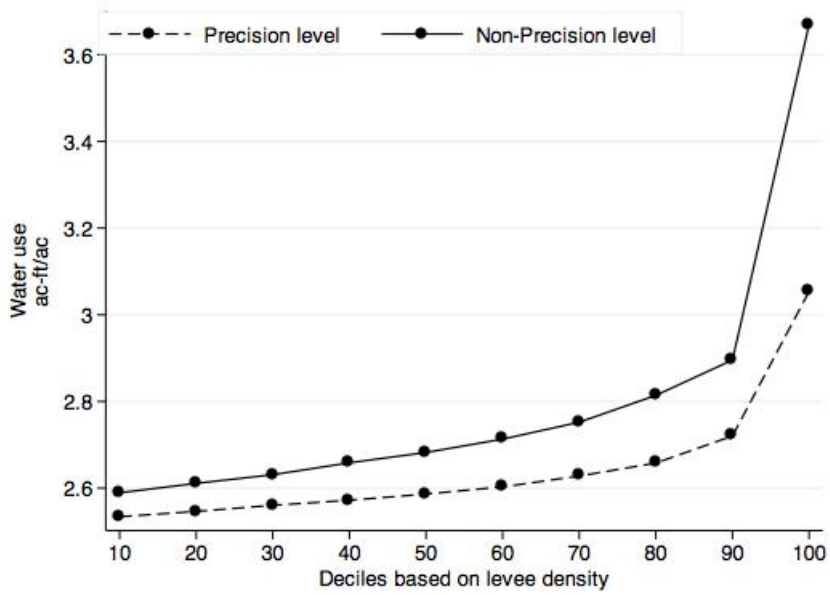
Results suggest that as the levee density of a field increases, so does field water use. Likewise, as the levee density of a field decreases, the water use also decreases. For a non-precision leveled field, a decrease in 1 levee per acre of the levee density will decrease the water use by 0.479 acre-feet per acre. This is reasonable as the levee density of a field can be a proxy variable for the field's topography. A non-precision leveled field with a high levee density suggests a steep topography, while a low density may indicate a relatively flat field.

Precision leveling and levee density are themselves associated. The relationship between water use and precision leveling changes with the levee density of a field. Results show that the variables precision leveling and levee density are statistically significant as well as the relationship between the two variables when looking at the interaction term. As shown in Table 6.3, for a precision-leveled field, a decrease in 1 levee per acre of the levee density will decrease the water use by 1.953 acre-feet per acre (0.479 +1.474 acre-feet per acre). Given that the precision leveling of a field generally decreases the levee density by 0.17 levees per acre, these indirect savings can also be attributable to precision leveling. This could means that an additional 0.33 acre-feet per acre of water savings (0.17 * 1.953) can be attributable to precision leveling, if the levee density could be verified as described in the recommendations section.

The relationship between water use and precision leveling has different strengths depending on the levee density of a field. It is reasonable that the flatter a field becomes, the lower the number of levees required to distribute the water. Levee density can also be a proxy variable for the quality of precision-leveled land. One could expect that the higher the quality of the precision leveling, the greater the movement of soil; the lower the number of levees in a given field, which reduces the water use compared to that of a lower quality precision-leveled field.

Figure 6.4 shows how the water use of precision and non-precision leveled fields vary with a hypothetical levee density, all other variables held constant. These hypothetical values represent the levee density at each of the deciles of the data. By presenting the deciles related to levee density, this graph compares the spread of precision-leveled fields with that of non-precision leveled fields. As expected, Figure 6.4 shows that precision-leveled fields (dotted line) use less irrigation water than non-precision leveled fields (solid line). Figure 6.4 also shows that the effect of precision leveling on field water use varies with different levels of levee density. Precision and non-precision leveled fields with a higher levee density use less water than those with a lower levee density. The water savings are less when comparing precision and non-precision leveled fields in the 2nd decile with that of the 7th decile and above. While the mean water use increases by 2.5 percent between precision and non-precision leveled fields in the 2nd decile, it increases to 5.5 and 6 percent in the 7th and 8th decile, respectively. The slope of the precision and non-precision level lines suggests that levee density impacts the water use of non-precision level fields more than it impacts the water use of precision leveled fields.

Figure 6.4: Average Marginal Effects



The data has been divided by deciles based on the variable levee density (x-ayis). The y-axis shows field water use. This diagram shows that precision leveled fields use less irrigation water than non-precision leveled field and that the effect of precision leveling on field water use changes with the levee density of a field. Precision and non-precision leveled fields with a higher levee density use less water than those with a lower levee density.

Source: Ana Ramirez

It is a challenge to calculate the change in levee density from a non-precision leveled field to a precision-leveled field. Anecdotal information from farmers suggests that some of the fields in this study have been precision leveled twice in a 15-year period.[3] The inclusion of fields that have been precision leveled twice decreases the average levee density for a precision-leveled field. The current estimate (0.1014 levees/ac) may be artificially low, because it does not accurately reflect the change in levee density from non-precision leveled to fields that have been precision-leveled only once. Table 6.7 shows potential precision leveling water savings presented by different ranges of levee reduction, in other words, different levee density. The results in Table 6.7 indicate that direct and indirect benefits from precision-leveled fields could exceed 0.696

acre-feet of water used over an acre farmed, if the levee density was verified (see recommendations).

Table 6.7: Water Savings per 100-acre Field by Levee Density

Description	ac-ft
Precision leveled (levee density remains constant)	**30.5**
Precision leveled + levee density drops 0.11 levees/ac (10 levees/100 ac)	**52.0**
Precision leveled + levee density drops 0.17 levees/ac (20 levees/100 ac) =Average difference	**63.3**

Description of the interaction between precision leveling and levee density. When a field is precision leveled, the levee density will decrease as a result of the leveling. These estimates represent the additional potential water savings resulting from a decreased levee density. The levee density data would need to be further verified in order to use the additional savings for transfer purposes.

Source: Statistic results estimated using the Survey database.

OTHER ON-FARM CONSERVATION TECHNOLOGY

Water inlets in a field reduce irrigation water. Results in the 2011 study show that if a field has one additional multiple inlet, the use of irrigation water will be reduced by 0.035 acre-feet per acre per additional inlet. The variable "water structures" (mi_struc), in the 2012 study, refers to the total number of structures (measurable and not measurable) that distribute water at multiple points in a field. Results in 2012 show that the presence of an additional water inlet (measured or unmeasured) in a field decreases irrigation water by 0.033 ac-ft/ac per additional inlet (Table 6.3). This result is similar to the 2010 results which showed that if a field that has one multiple inlet, the use of irrigation water will be reduced by 0.035 acre-feet per acre

TEMPORAL TRENDS

The purpose of this section is to assess, through time, the effects of climate factors on field water use. This section focuses on evapotranspiration, precipitation and the drought effects in 2011. In a wet year, a farmer uses less irrigation water. The analysis (2006-2011) suggests that the largest statistically significant difference in year-to-year variation in farmers' use of irrigation water is found in precipitation patterns. Rainfall is negatively related to the water usage of fields. The more rainfall, the less the volume of irrigation water applied to a field. The negative relationship indicates that farmers reduce the use of irrigation in years with high rainfall, which contributes to an increased supply of water. Results suggest that the effect of rainfall during a growing season on irrigated land affects the water use of fields significantly. A one-tenth inch increase in average daily precipitation decreases the average field's water demand by 0.542 ac-ft/ac. Rain, as compared to other factors, has the strongest magnitude of relationship with on-farm water use. Given that precipitation is likely to vary significantly by field, an important next step is to adequately represent variability in rainfall measurements (see recommendations).

In a dry and hot year, a farmer uses more irrigation water. During the same time span (2006-2011), results also indicate that changes in evapotranspiration had a statistically significant effect on water demand. Results show a one-inch per month increase in evapotranspiration, water demand increases on average by 4.25 ac-ft/ac. Higher farm water usage is associated with high evaporation, which corresponds to high temperatures and low humidity in a given year. Evapotranspiration accounts for changes in maximum and minimum temperature, humidity, wind speed, and sunshine hours.

During 2011 Texas experienced the hottest summer on record and one of the worst droughts in the past 50 years. Results show a statistically significant effect of the 2011 drought conditions on field water use. A field in production used on average 0.637 ac-ft/ac more irrigation in 2011 water than in any other year during 2006 to 2010. One explanation for the significance of the variable "Year 2011" is that both weather factors represent average rain and evapotranspiration only during the growing season (six months out of the year). It is also true that weather conditions before farmers start taking water influence soil moisture, which affects the water usage of fields. The "average rain" does not capture the frequency of rain events nor is it based on a historical times series.

MANAGEMENT TRENDS

It is reasonable to test whether management characteristics can be expected to influence on-farm water use. However, it is difficult to obtain information on specific management decisions. The farmer is the appropriate individual to ask detailed questions about farming practices and infrastructure upgrades. The personal characteristics of farmers can give some insight into explaining why they take different actions in managing their farms, such as when and how much water to order. In the analysis "farmer" is included as the grouping unit at level-3 of the Multi-Level Model.

Farmers' self-interest may influence how much attention they give to the amount of water they order, the rice variety they cultivate and infrastructure investments they make. The variable—cash—portrays the effect of ownership stake on a field's water use. A cash-renter refers to a farmer who pays cash to rent the field. 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. A farmer who cash-rents the land uses less irrigation water than other farmers. The negative effect of this variable suggests that fields farmed by cash-renters tend to have lower water usage. The water usage decreases by 0.119 ac-ft/ac for fields farmed by cash-renters. Results suggest cash-renters have significantly lower water usage than farmers who farm land they own or share-renters. One explanation for this is that due to the increased financial risk, cash-renters pay more attention to the amount and management of the water they order.

Seed and hybrid rice by themselves do not affect the water usage of a field, but seed and hybrid rice in relation to the growing period do affect water use. Rice variety turned out to be insignificant, suggesting that no direct relationship exists between the rice variety cultivated and water use of a field. The interaction between irrigation period and rice variety captures the joint effect of seed and hybrid variety and length of growing season on water use. Growing season refers to the average time between the first and last water delivery to a given field. The variable used in analysis, the mean centered irrigation period (DIFF_GROW), refers to the additional days beyond the average growing season that a given field takes water. One would expect that an extended growing season would lead to higher levels of water use while a shorter growing season would result in lower on-farm water use. This interaction term was statistically significant. A farmer who plants seed and hybrid rice uses more water in an irrigation period, as farmers are likely to take water for additional days beyond the average growing season when cultivating seed and hybrid rice as opposed to conventional rice. Results also show that farmers that plant seed or hybrid rice use 0.008 ac-ft/ac more irrigation water for each additional day water is delivered to a field, because seed and hybrid rice irrigation continues beyond the average growing period. Seed and hybrid rice in itself does not affect the water usage of a field, but seed and hybrid rice in relation to the growing period does. When farmers plant seed or hybrid rice, this cultivar's longer growing periods lead to higher levels of water usage.

CONCLUSIONS

LCRA is delivering on its promise to monitor its precision-leveling conservation program in Lakeside Irrigation Division. After a 6-year period of precision leveling implementation (2006 through 2011), results show that each grower participating in a precision-leveling program, from planting to harvest during the first crop, saves on average 0.30 acre-feet of water used per acre farmed, based on six years of data collection.

Precision leveling is a catalyst for a range of field upgrades as it increases the likelihood of implementing other associated conservation measures. Hence, it is a more valuable investment than is indicated simply by estimating the difference in water use attributable solely to precision leveling. Benefits attributable to precision leveling also include lower levee density. For example, in precision-leveled fields in which the levee density drops 0.17 levees/ac, farmers save (from planting to harvest during the first crop) an additional 33.2 acre-feet of water used on a single 100-acre field. The water savings return on LCRA's precision leveling program should include all direct and indirect effects of precision leveling. This chapter has described the multi-level modeling methodology in this study, and Chapter 7 will explain the validation procedure used to verify the accuracy of the analytic methods.

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[1] Singer, J. D., and J. B. Willett, Applied Longitudinal Data Analysis: Modeling Change and Event Occurrence, *Oxford University Press.* 2003, 144.
[2] Texas Water Development Board, 2010 Texas Water Use Estimates, https://www.twdb.state.tx.us/waterplanning/waterusesurvey/estimates/2010/doc/2010City.xls

[3]National Resources Conservation Service, Precision Land Forming Code 462 (Washington D.C., NRCS, 2002). http://efotg.sc.egov.usda.gov/references/public/NE/NE464.pdf

Chapter 7: Validation of Analytical Procedures

One challenge for evaluating an on-farm water conservation investment is how to estimate the water saved due to changes in the weather, farmer behavior, as well as the role of other water conservation investments. This chapter focuses on selecting the appropriate method to improve the precision of the mean water savings estimate in this evaluation. In the context of using conservation in agriculture as the 'new source' of water for rural-to-urban transfers, a higher estimate than the actual conserved water could result in insufficient water in the basin. Insufficient water supply could hinder the capacity of water regulators, managers and policymakers to balance and respond to the competing needs of different water users.

This section tests three different statistical approaches to estimate water savings for precision leveling in the Lakeside Irrigation Division in Texas: Ordinary Least Squares (OLS), Fixed Effects (FE), and a Mixed-Level Model (MLM). This multi-method approach improves the precision and robustness of the water savings estimate by assessing the performance of several methods (OLS, FE, MLM). This chapter compares the standard error and the confidence interval of water savings estimates, for each of the methods. The standard error is the conventional way to measure the precision of an estimate.[1] The smaller the standard error, the more precise is the mean estimate. Thus, the uncertainty depends on the sample size[2] and reliability of the data, but also on the choice of analytical method. All other things being equal, the best method will yield both more accurate and precise estimates. The sections below present the specific formulation of each model used in the analysis, followed by a general model formulation.

STATISTICAL MODELS

Ordinary Least Squares Regression

Ordinary Least Square regression (OLS) is the traditional regression analysis in which the dependent variable, field water use, is affected by independent variables. In the

OLS regression, the water use of fields is related to rain, evapotranspiration, precision leveling, levee density, the period of time water is delivered to a field, the crop variety planted in that field, ownership stake, a particular year (2011) and the interaction terms (Equation 7.1). Water use as a dependent variable is related to, α the intercept, all the independent variables X_{ti} (Equation 7.1 and Table 7.1), where $\hat{\beta}$ are the estimated coefficients and $\hat{u}_{ti}$ is the residual.[3]

$$\begin{aligned} y_{ti} = \alpha &+ RAIN_{ti}\hat{\beta}_2 + EVAP_{ti}\hat{\beta}_3 + LL_{ti}\hat{\beta}_4 + L\_DENSITY_{ti}\hat{\beta}_5 + LL_{ti} * L\_DENSITY_{ti}\hat{\beta}_6 + W\_STRUC_{ti}\hat{\beta}_7 \\ &+ CASH_{ti}\hat{\beta}_8 + IRR\_PERIOD_{ti}\hat{\beta}_9 + RICE_{ti}\hat{\beta}_{10} + RICE_{ti} * IRR\_PERIOD_{ti}\hat{\beta}_{11} \\ &+ YEAR\_2011_{ti}\hat{\beta}_{12} + \hat{u}_{ti} \quad i = 1, \dots, 328 \quad t = 1, \dots, 6 \end{aligned}$$

(Equation 7.1)

Equation 7.1 is a specific formulation, where Equation 7.2 represents the general OLS equation.

$$y_{ti} = \alpha + X_{ti}\hat{\beta} + \hat{u}_{ti} \quad i = 1, \dots, 328 \quad t = 1, \dots, 6$$

(Equation 7.2)

Table 7.1 shows the results of the OLS regression. The standard errors are calculated through the method of clustering, which is used to account for the correlation among observations. In this method, each individual farmer is identified by a single index number. The OLS regression groups the data so that each individual farmer is a cluster, thus preventing redundant information for each farmer, to bias the results of the model. With the clustered OLS regression, field observations are clustered by farmer, because the residuals of field observations within the clusters are likely to be correlated. The OLS regression using the cluster option yields robust standard errors to account for this correlation.

Table 7.1: Results of OLS Regression

Water demand	Coef.	Robust Std. Err.	T	P>|t|	[95% Conf.	Interval]
Rain	-5.394	1.021	-5.28	0.000	-7.466	-3.323
Evapotranspiration	4.935	1.393	3.54	0.001	2.109	7.761
Precision leveling	-0.342	0.120	-2.86	0.007	-0.585	-0.100
Levee density	0.492	0.282	1.75	0.089	-0.080	1.064
Water inlets	-0.051	0.022	-2.27	0.030	-0.096	-0.005
Cash renters	-0.229	0.100	-2.29	0.028	-0.432	-0.027
Rice variety	-0.068	0.111	-0.61	0.548	-0.294	0.159
Irrigation period	-0.004	0.003	-1.35	0.185	-0.010	0.002
Rice * irrigation	0.006	0.004	1.48	0.148	-0.002	0.014
Leveling * density	1.694	0.574	2.95	0.006	0.530	2.859
Year 2011	0.597	0.064	9.40	0.000	0.468	0.726
_cons	2.163	0.519	4.17	0.000	1.111	3.215

Coefficients from the OLS regression with robust standard errors. The dependent variable is field water use in terms of acre-feet of water used per acre farmed.

Source: Ana Ramirez

The OLS results indicate that precision leveling reduces by 0.34 acre-feet per acre farmed the water use of fields. However, both correlation between observations (repeated measures per field and per farmer) and correlation in time (observations across the 6-year period) undermine the validity of the use of OLS. Using OLS would violate the Gauss-Markov assumption of independently and identically distributed errors ($\hat{u}$). The effects of violating the Gauss-Markov assumption may entail biased estimates ($\hat{\beta}$), incorrect standard errors and potentially erroneous inferences.

Fixed Effects Model

Although the Fixed Effect model bears some similarities to OLS, the FE estimates water use changes in fields as a function of each farmer's unique characteristics as well as the other factors listed above (Table 7.1). Although this model bears some similarities to OLS, the FE model estimates add new explanatory variables, where k represents each farmer. Equation 7.3 is the general Fixed Effects equation where y_{tik} is the water use in field i at time t, X_{ti} are the variables, β are the estimated coefficients, α_k are the unique intercepts per farmer k, and u_{tik} are the residuals.[4]

$$y_{tik} = \alpha_k + X_{ti}\beta + u_{tik} \qquad i = 1, \ldots, 328 \qquad t = 1, \ldots, 6 \qquad k = 1, \ldots, 37$$

(Equation 7.3)

In a FE model each farmer is associated with a unique intercept (α_k). Equation 7.4 lists the specific FE formulation used in this analysis and states that the water use of fields is a function of the individual characteristics of each farmer as well as the usual independent variables X_{ti}: rain, evapotranspiration, precision leveling, levee density, the period of time water is delivered to a field, the crop variety planted in that field, ownership stake, the year 2011 and the interaction terms.

$$\begin{aligned} y_{tik} = \alpha_k + {} & RAIN_{ti}\hat{\beta}_2 + EVAP_{ti}\hat{\beta}_3 + LL_{ti}\hat{\beta}_4 + L\_DENSITY_{ti}\hat{\beta}_5 + LL_{ti} * L\_DENSITY_{ti}\hat{\beta}_6 \\ & + W\_STRUC_{ti}\hat{\beta}_7 + CASH_{ti}\hat{\beta}_8 + IRR\_PERIOD_{ti}\hat{\beta}_9 + RICE_{ti}\hat{\beta}_{10} \\ & + RICE_{ti} * IRR\_PERIOD_{ti}\hat{\beta}_{11} + YEAR\_2011_t\hat{\beta}_{12} + u_{tik} \end{aligned}$$

$$i = 1, \ldots, 328 \qquad t = 1, \ldots, 6 \qquad k = 1, \ldots, 37$$

(Equation 7.4)

The intercepts (α_i) represents the effect of each farmer's unmeasured, time-invariant characteristics on the water use of the fields he manages. The Fixed Effects model yields a set of intercepts one for each farmer (i.e., the average 'farmer effect'), however these intercepts do not change across time.

Table 7.2: Results of Fixed Effects Regression

w_demand_2	Coef.	Robust Std. Err.	T	P>|t|	[95% Conf.	Interval]
Rain	-5.353	1.012	-5.29	0.000	-7.405	-3.301
Evapotranspiration	4.530	1.618	2.80	0.008	1.248	7.812
Precision leveling	-0.270	0.116	-2.33	0.026	-0.505	-0.035
Levee density	0.566	0.248	2.28	0.028	0.063	1.069
Water inlets	-0.030	0.016	-1.80	0.080	-0.063	0.004
Cash renters	-0.116	0.056	-2.09	0.043	-0.229	-0.004
Rice variety	-0.140	0.067	-2.11	0.042	-0.276	-0.005
Irrigation period	-0.004	0.003	-1.44	0.157	-0.010	0.002
Rice * irrigation	0.008	0.003	2.31	0.027	0.001	0.015
Leveling * density	1.445	0.432	3.34	0.002	0.568	2.321
Year 2011	0.610	0.068	8.94	0.000	0.471	0.748
_cons	2.133	0.486	4.39	0.000	1.148	3.120

Coefficients for the results from the Fixed Effects regression with robust standard errors. The dependent variable is in terms of acre-feet of water saved per acre farmed.

Source: Ana Ramirez

The FE model estimates that precision leveling reduces the water use of fields by 0.27 acre-feet per acre farmed (Table 7.2). The FE model includes invariant farmer characteristics that could bias the precision leveling water saving estimates ($\hat{\beta}_4$) if left unaccounted for. However, farmer characteristics that could change across time are not accounted for in this model. Farmers' management skills and practices may improve over time both with personal experience and with the hands-on learning experience of neighbors. This management improvement, in itself, can reduce the water use of fields. Another drawback of the FE model is that it does not account for correlation across field observations when a single field is farmed in multiple years in the study. The model uses a fixed effect based on the farmer, but it is impractical to use fixed effect based on the individual field, because there are 329 unique fields, which would require too many degrees of freedom.

Hierarchical Linear Model

See detailed specification and results in Chapter 6

Correlated Random Effects Model

Unobserved heterogeneity can result from trends found in the data that are not taken into account by the independent variables. A correlated random effects model is one way to control for this unobserved heterogeneity, by including as additional variables the average of time-varying covariates for each farmer. Adding the time average over the six-year period for each farmer of covariates such as rain, evapotranspiration and irrigation period removes the remaining non-random trends in the residual error term. Equation 7.5 shows the general form of the Correlated Random Effects model, and Equation 7.6 shows the specific form, where y_{tik} is the water use of field *i* at time *t*, X_{tik} are the variables, β are the coefficients, $\bar{X}_k$ are the average of the time-varying covariates for each farmer, ξ are the coefficients for the aggregate time variables, α_k are the fixed effects per farmer *k*, and v_{tik} is the error term.[5]

$$y_{tik} = \alpha_k + x_{tik}\beta + \bar{x}_k\xi + v_{tik}$$

(Equation 7.5)

$$\begin{aligned} y_{tik} = \alpha &+ RAIN_{ti}\hat{\beta}_2 + EVAP_{ti}\hat{\beta}_3 + LL_{ti}\hat{\beta}_4 + L\_DENSITY_{ti}\hat{\beta}_5 + LL_{ti} * L\_DENSITY_{ti}\hat{\beta}_6 + W\_STRUC_{ti}\hat{\beta} \\ &+ CASH_{ti}\hat{\beta}_8 + IRR\_PERIOD_{ti}\hat{\beta}_9 + RICE_{ti}\hat{\beta}_{10} + RICE * IRR\_PERIOD_{ti}\hat{\beta}_{11} \\ &+ YEAR\_2011_{ti}\hat{\beta}_{12} + \overline{RAIN}_k\xi_2 + \overline{EVAP}_k\xi_3 + \overline{IRR\_PERIOD}_k\xi_4 + vt_{tik} \end{aligned}$$

$$i = 1, \ldots, 328 \qquad t = 1, \ldots, 6 \qquad k = 1, \ldots, 37$$

(Equation 7.6)

The average of time-varying covariates for each farmer are not statistically significant. Results show that the precision leveling water savings estimate is consistent; precision leveling saves, on average, 0.27 acre-feet of water per acre farmed. This relatively unchanging estimation suggests that the precision leveling water savings estimate is not sensitive to the model specification.

The small size of the correlation between the fixed and random effects and the error term (0.0455) suggests that there was little unobserved heterogeneity in the residual term. The small correlation also suggests that MLM's strong assumption of independence between the error components and the fixed and random effects is plausible in this analysis, and therefore suggests that the MLM results are unlikely to be biased.

Table 7.3: Results of Correlated Random Effects

Water demand	Coef.	Robust Std. Err.	T	P>|t|	[95% Conf.	Interval]
Rain	-5.392	1.006	-5.36	0.000	-7.364	-3.420
Evapotranspiration	4.468	1.600	2.79	0.005	1.333	7.603
Precision Leveling	-0.266	0.114	-2.34	0.019	-0.489	-0.044
Levee density	0.571	0.248	2.30	0.021	0.085	1.057
Water inlets	-0.033	0.017	-2.00	0.046	-0.065	-0.001
Cash renters	-0.126	0.054	-2.35	0.019	-0.231	-0.021
Rice Variety	-0.125	0.068	-1.85	0.065	-0.257	0.008
Irrigation period	-0.004	0.003	-1.44	0.149	-0.009	0.001
Rice * irrigation	0.008	0.003	2.31	0.021	0.001	0.015
Leveling * density	1.428	0.440	3.24	0.001	0.565	2.290
Year 2011	0.605	0.067	9.02	0.000	0.473	0.736
Average irrigation	-0.025	0.023	-1.08	0.281	-0.071	0.021
Average Rain	4.877	4.871	1.00	0.317	-4.670	14.425
Averaga evap	9.385	12.122	0.77	0.439	-14.373	33.143
_cons	-0.213	3.113	-0.07	0.946	-6.314	5.888

Coefficients for the results from the Correlated Random Effects regression with robust standard errors. The dependent variable is in terms of acre-feet of water saved per acre farmed.

Source: Ana Ramirez

THE IMPACT OF PRECISION LEVELING ON FIELDS WATER USE

Farmers who precision-level fields use less irrigation water. Table 7.4 lists precision leveling evaluation results from the OLS, FE and MLM models using the same dataset and variables. The precision-leveling water-saving estimates are consistent across the three statistical approaches. Based on the MLM estimates, precision leveling accounts for a 0.30 acre-feet reduction of irrigation water per acre leveled (Table 7.4).

Table 7.4: Mixed-Method Results 2012

Water demand	OLS	FE	MLM
Rain	-5.394**	-5.353**	-5.396**
	(1.021)	(1.012)	(0.792)
Evapotranspiration	4.935**	4.53**	4.264**
	(1.393)	(1.618)	(1.309)
Precision leveling	-0.342**	-0.27**	-0.305**
	(0.120)	(0.116)	(0.089)
Levee density	0.492*	0.566**	0.479**
	(0.282)	(0.248)	(0.154)
Water inlets	-0.051**	-0.03*	-0.033**
	(0.022)	(0.016)	(0.016)
Cash renters	-0.229**	-0.116**	-0.114*
	(0.100)	(0.056)	(0.061)
Rice variety	-0.068	-0.14**	-0.117*
	(0.111)	(0.067)	(0.068)
Irrigation period	-0.004	-0.004	-0.004
	(0.003)	(0.003)	(0.003)
Rice * irrigation	0.006	0.008**	0.008**
	(0.004)	(0.003)	(0.004)
Leveling * density	1.694**	1.445**	1.474**
	(0.574)	(0.432)	(0.457)
Year 2011	0.597**	0.61**	0.641**
	(0.063)	(0.068)	(0.057)
_cons	2.163	2.133	2.241

A */** next to the coefficient indicates significance at the 10/5% level , standard error in parenthesis

Results of the mixed methods used for the validation. This table present the results of each method alongside for comparison with robust standard errors in parenthesis.

Source: Ana Ramirez

The MLM estimate for precision leveling water savings is more precise than either the OLS or FE likely because it likely accounts for correlation across fields managed by the same farmer and correlation across repeated field measurements over time. Figure 7.1 shows the upper and lower boundaries of the 95 percent confidence level for each of the three precision leveling water saving estimates (OLS, FE, MLM). To assess the value of the reduced uncertainty, it is possible to compare the standard error of the two other methods (OLS and FE) with that of MLM, as the standard error is the conventional way to measure the precision of an estimate.[6] The smaller the standard error, the more precise is the mean estimate. The standard error is 0.12 acre feet per acre and 0.116 acre feet per acre for OLS and FE respectively, whereas the standard error for MLM is 0.089 acre feet per acre (Table 7.5). The MLM model provides a more precise mean estimate for the precision leveling water savings, as it reduces the error by 26 and 23 percent for the OLS and FE model, respectively. The choice of method (MLM versus FE and OLS) reduces the standard error, which tightens the upper and lower boundaries of the confidence interval around the MLM average water savings estimate.

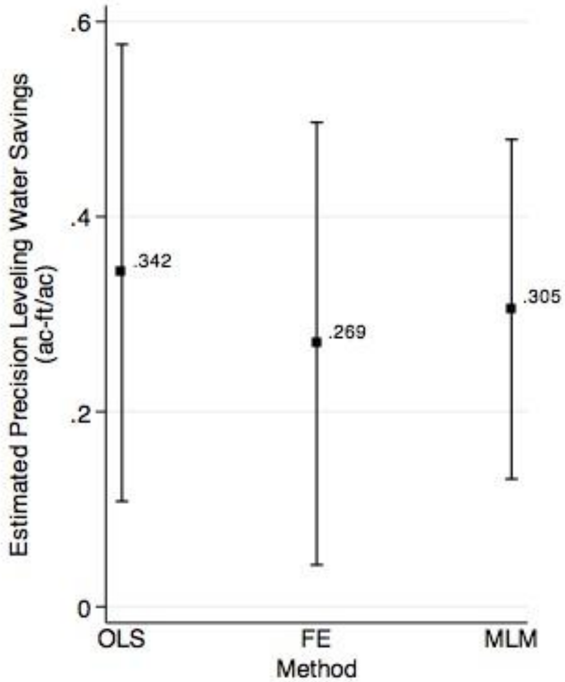
Table 7.5: Comparison of Standard Error between the Three Methods

Method	Standard Error (ac-ft/ac)	Percent reduction in error in MLM
MLM	0.089	0%
OLS	0.120	26%
Fixed Effects	0.116	23%

The standard error associated with the mean precision leveling water savings as estimated by each of the models (MLM, OLS, FE). The percent reduction in the standard error is relative to the MLM mean estimate.

Source: Statistic results estimated using the Survey database.

Figure 7.1: Precision Leveling Estimates by Statistical Method



Mean precision leveling water savings estimates and the associated confidence intervals for each of the three models (OLS, FE, MLM) using the same number of observations (n=966) and covariates. Water savings are measured in acre-feet of water conserved per acre farmed. (OLS= Ordinary least square regression, FE= Fixed effects and MLM= Multi-Level model)

Source: Ana Ramirez

META-ANALYSIS

The previous section demonstrated that MLM yields the most precise water savings estimate due to precision leveling, 0.30 acre-feet per acre farmed for the first crop. This section describes the application of meta-analysis, a statistical technique that combines the results from previous independent studies. With meta-analysis, this dissertation shifts the emphasis from a single case study in Lakeside Irrigation Division to three other studies in Mississippi and Arkansas which increases the generalizability of this study's precision leveling water savings estimate to three of the four major rice farming states in the U.S. Table 7.6 lists other studies in the U.S. that estimate precision leveling water savings, which range from 0.26 to 0.58 acre-feet per acre farmed.[7,8,9]

Table 7.6: Precision Leveling Studies Included in the Meta-analysis

Study	Outcome Measurement	Location	Sample	Mean Water Savings (ac-ft/ac)	Standard Error Water Savings (ac-ft/ac)
Smith et al. 2007	Flow meter	MS (USA)	28 fields	0.58	0.17
Smith et al. 2007	Flow meter	AR (USA)	48 fields	0.45	0.25
Cook et al. 1996	Flow meter	MS (USA)	96 fields	0.26	0.14
Ramírez and Eaton 2012	Flow meter	TX (USA)	328 fields	0.39	0.09

Source: Compiled by Ana Ramírez

Not all published precision leveling studies were included in the meta-analysis, as all studies were not comparable. To ensure comparability between the studies, the meta-analysis' selection criteria only includes studies from a similar population that have similar data quality. The studies selected for the meta-analysis were all commercial farms in the U.S.. Each study measured water use (the dependent variable) using flow meters,, and they all reported the mean estimates and the standard errors. Uniformity in the instruments and procedures to measure fields' water use reduces the variability in the studies' results due to measurement error. All selected studies take place in the U.S.; a common country of origin controls for country-specific characteristics such as water, farming regulations or farmer skills and practices based on cultural traditions. Each of the independent prior studies from Mississippi and Arkansas has an estimated precision leveling savings coefficient and standard error, which are required when combining the results of separate studies (Table 7.6). To quantitatively evaluate whether the four studies included in the meta-analysis are sufficiently similar, this dissertation performs a chi-square test of homogeneity. Under the null hypothesis, this statistical test evaluates whether the independent studies come from the same population and thus have a common population mean. Results from the homogeneity test indicate that the null hypothesis cannot be rejected, meaning that it is not reasonable on the basis of the results alone to suggest that the four studies (Table 7.6) come from different populations. The precision leveling studies from three rice-producing U.S. states are comparable, which validates the meta-analysis. Equation 7.7 presents the equation for the chi-square test:

$$\chi^2 = \sum_{j=1}^{n} w_j \, (e_j - \bar{e})^2 \tag{Equation 7.7}$$

where χ^2 is the chi-square, w_j is the estimated variance of j, e_j is the estimate of j, and $\bar{e}$ is the posterior mean estimate.[10]

Using the fixed effect approach to meta-analysis, the mean water savings estimate from three previous studies are combined. Equation 7.8 calculates the posterior mean estimate as the standard error weighted average of each prior study's means estimate, where the mean estimates are denoted by j and the standard error by i. The mean estimate of each study is weighted by its variance (w_j) to account for the uncertainty associated with each estimate.[11]

$$\bar{e} = \frac{\sum_{j=1}^{k} w_j \, e_j}{\sum_{j=1}^{k} w_j} \tag{Equation 7.8}$$

Figure 7.2 illustrates the meta-analysis results as well as the mean, confidence interval and sample size of each of the studies. In Figure 7.2, the black dash line indicates the estimated posterior mean precision leveling effect of 0.309 acre-feet per acre farmed and the gray dashed lines show the confidence interval calculated from the posterior error variance of 0.087.

Figure 7.2: Graphical Depiction of Studies in the Meta-analysis and Results

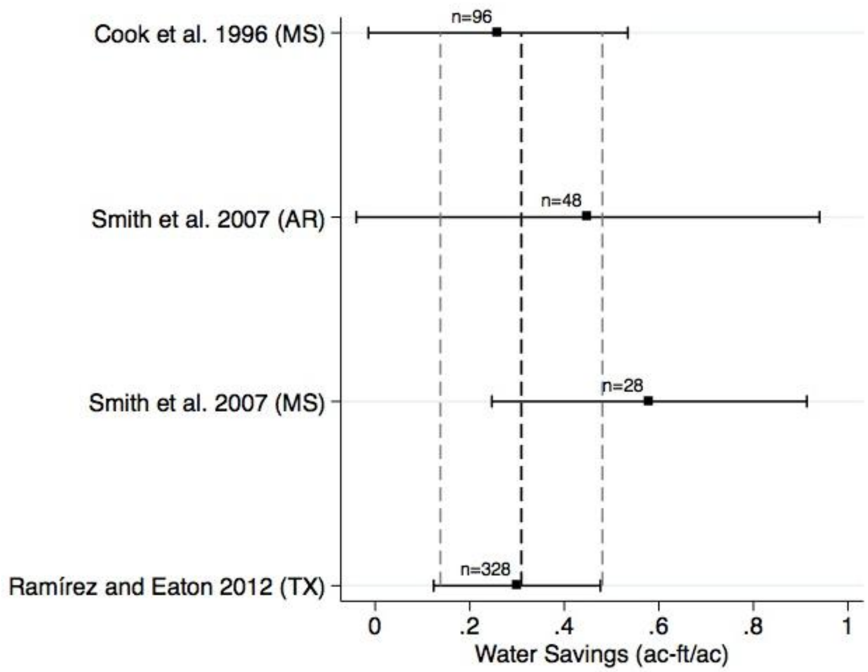


Figure 7.2 shows the precision leveling water savings estimates and confidence intervals of four studies; n indicates the sample size for each study. The black dotted line represents the posterior mean estimate for precision leveling as calculated in the meta-analysis, while the gray dotted lines indicate the lower and upper bounds of the confidence interval. Water savings is measured as acre-feet of water conserved per acre farmed. (MS= Mississippi, AR=Arkansas and TX=Texas).

Source: Ana Ramirez

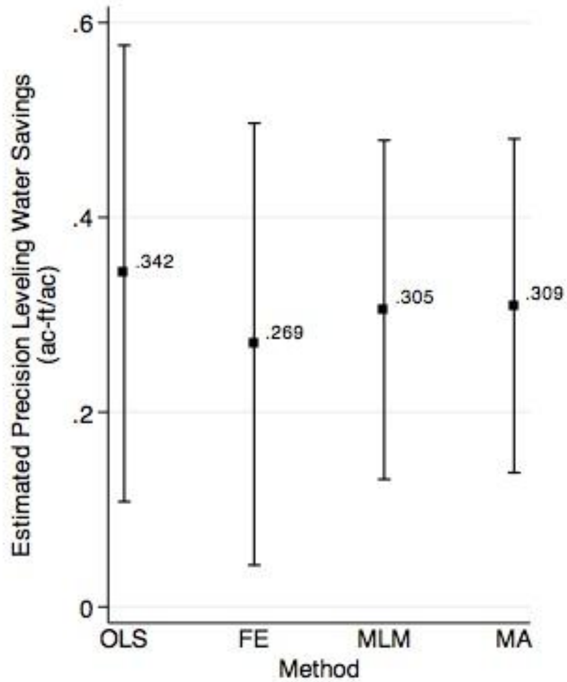
The meta-analysis shrinks the error variance of the precision leveling coefficient, which allows for a more precise water savings estimates as compared to that of only one study. The decreased uncertainty is evident from the narrower confidence intervals associated with the posterior mean estimate. The meta-analysis also makes the precision leveling savings estimate more generalizable, applicable to populations similar to that of the different studies in Texas, Mississippi and Arkansas.

CONCLUSIONS

This study performs an analysis in order to determine the most appropriate model to evaluate water savings in agricultural conservation. The results indicate that the MLM model provides the estimate with the least amount of uncertainty. The uncertainty in the amount of water conserved depends not only on the study's sample size and reliability of the data, but also on the choice of method. Results show that while increasing the sample size by one-fifth reduces the standard error by 7 percent, the choice of method reduces the standard error upwards of 23 percent, or three fold. For large samples, the marginal effect of selecting an appropriate methodology may outweigh that of more data collection in reducing uncertainty. To reduce the uncertainty associated with conservation estimates, the choice of method can be a more cost-effective strategy when considering the time and money costs associated with data collection.

The MLM model reduces the uncertainty associated with the amount of water savings accrued from precision leveling. Although the posterior mean estimate of the meta-analysis (0.309 ac-ft/ac) is similar to the MLM estimate (0.30 ac-ft/ac) (Figure 7.3), the meta-analysis does further reduce the standard error of the mean precision leveling estimate by 2 percent. A better approximation of the acre-feet water savings per acre farmed translates into less uncertainty for water regulators, managers and policymakers regarding the volume of conserved water that is available for transfer.

Figure 7.3: Precision Leveling Estimates from MLM, FE, OLS and Meta-analysis



Precision leveling water savings mean estimates and associated confidence intervals for each of the four statistical analysis (OLS= Ordinary Least Square Regression, FE= Fixed Effects, MLM= Multi-Level model and MA=Meta-Analysis). Water Savings is measured as acre-feet of water conserved per acre farmed.

Source: Ana Ramirez

It is counter intuitive to consider the mean estimate and confidence interval in the units of acre-feet per acre, and it is easier to understand the magnitude when converting it to more recognizable units, such as the total number of households that could consume that water as well as the amount of income LCRA would receive from those water users. Putting these numbers in terms of the average household water use (400 gal/day), the difference in the mean estimate between MLM-OLS and MLM-FE amount to the total water use that 1,213 and 1,472 average households of four have in one year, respectively (Figure 7.4).

Figure 7.4: Precision Leveling Water Savings as Household Water Use

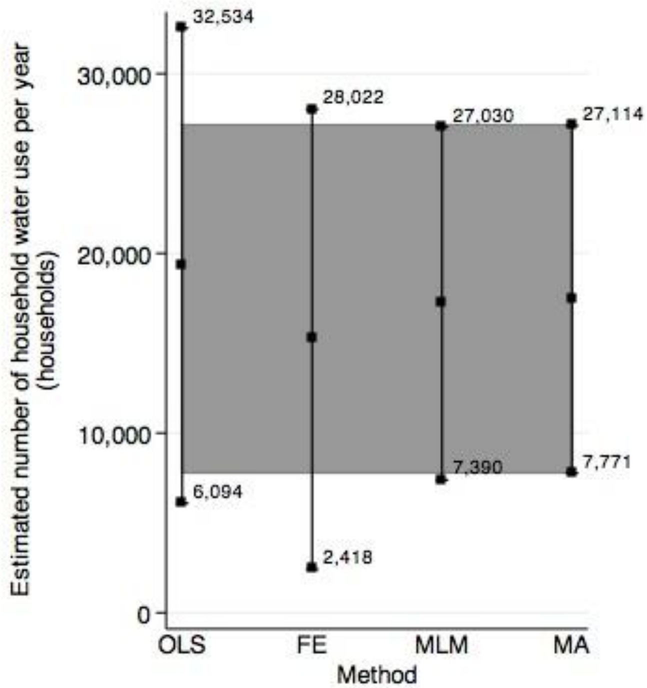


Figure 7.4 shows the precision leveling water savings estimates and confidence intervals in terms of the number of households' water use per year. This estimate uses the EPA estimate of water use for the average household of four (400 gal per day per household) to calculate the returns of agricultural conservation in Lakeside Irrigation Division valued as urban water use. (OLS= Ordinary least square regression, FE= Fixed Effects, MLM= Multi-Level model and MA=Meta-Analysis). The gray box represents the confidence interval of the meta-analysis (the tightest confidence interval) for comparison to other models.

Source: Ana Ramirez

Another more recognizable unit is dollar amount of billable water LCRA would receive from municipal water users. Putting these numbers in terms of billable water, the difference in the upper boundary of the confidence interval between MA-OLS is 3 million dollars in billable municipal water per year.

Figure 7.5: Precision Leveling Water Savings as Billable Water Use

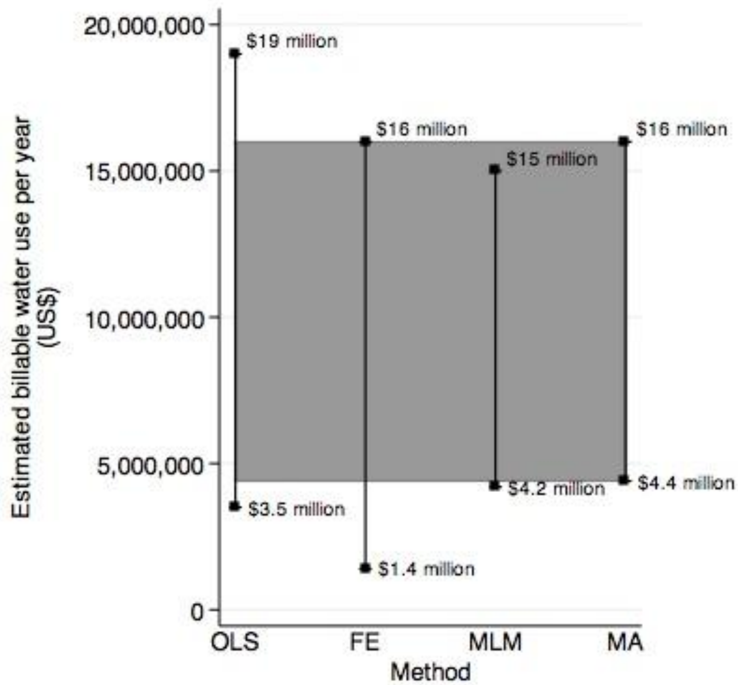


Figure 7.5 shows the precision leveling water savings estimates and confidence intervals expressed in terms of billable water value for urban customers. This estimate uses the city of Austin's cost of urban water ($7.92 per 1,000 gallons) to calculate the returns of agricultural conservation in Lakeside Irrigation District valued as billable urban water value. The water pay schedule for using between 9,001 and 15,000 gallons per year is $7.91. (OLS= Ordinary Least Square regression, FE= Fixed Effects, MLM= Multi-Level model and MA=Meta-Analysis).

Source: Ana Ramirez

Capitalizing on the results of previous published studies, meta-analysis is a useful statistical technique to decrease the uncertainty associated with the precision leveling estimate and to generalize the water savings across three of the four U.S. states with the largest rice production: Arkansas, Mississippi and Texas. This chapter has described the validation methodology for verifying the analytical procedures, and Chapter 8 will provide the conclusions and recommendations developed from this study.

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[1] Gujarati, N. D. (2003), Basic Econometrics, *McGraw-Hill*, Chapter 3, 76.
[2] Alan Agresti and Barbara Finlay (1997), Statistical Methods for the Social Sciences, *Prentice Hall, Inc.,* 80-110, 100.
[3] Gujarati, N. D. (2003), Basic Econometrics, *McGraw-Hill*, Chapter 3, 58.
[4] Ibid., 642.

[5]Jeffrey Wooldridge and others, “Correlated Random Effects Models with Unbalanced Panels,” Michigan State University, Manuscript Version May 2010.
[6] Gujarati, N. D. (2003), Basic Econometrics, *McGraw-Hill*, 76.
[7] Fred T. Cooke Jr., DeWitt. F. Caillavet and James C. Walker III, “Rice Water Use and Cost in the Mississippi Delta,” *Mississippi Agricultural and Forestry Experimental Station* Bull.1039, (1996): 1-8, 2.
[8] M.C. Smith and others, “Water use estimates for various rice production systems in Mississippi and Arkansas,” *Irrigation Science* 25, (2007): 141-147, 143.
[9] Ibid, 146.
[10] David M. Eddy, Vic Hasselblad and Ross Shachter (1992), Meta-Analysis by the confidence profile method: The Statistical Synthesis of Evidence. Academic Press, Inc., 354.
[11] Ibid.

Chapter 8: Recommendations, Policy Implications and Conclusions

A conservation verification program represents an important step in making the case for ongoing investment of federal, regional and state funding in water conservation to increase irrigation efficiency. This dissertation formulates and answers empirical and theoretical questions about water savings. Table 8.1 lists five specific contributions this dissertation makes. It develops a quantitative methodology to evaluate the effectiveness of conservation investments to reduce irrigation water use. It provides practical guidance on reporting and developing a transparent and rigorous quantitative and qualitative verification program. The dissertation also quantifies the water savings in Lakeside Irrigation Division.

Table 8.1: Contributions of Dissertation

No.	Contributions
1	Empirical marginal effects of a range of conservation measures as currently applied by farmers and irrigation districts.
2	Results will help water regulators better identify policy objectives and select appropriate means of accomplishing them resulting in smarter conservation investments.
3	Guidelines on monitoring and verification reporting
4	Insight into the cost-effectiveness of different on-farm investments (precision leveling, multiple inlets)
5	General methodology for verifying conservation program outcomes.

Source: Ana Ramírez

The outcomes from this research are presented to answer the research questions designed at the beginning of this study.

Research Question #1: Do precision-leveled fields use less irrigation water than non-precision leveled fields?

This question asking if precision leveling programs save water, and the subsequent verification of the quantified savings, is the key to any effective water transfer program. Results show that each grower participating in a precision-leveling program (2006 through 2011) directly saves on average 0.30 acre-feet of irrigation water per acre farmed per year for the first crop alone. This water savings coefficient is robust as the values are essentially the same, or stable, over three different analyses, which span six years and include very wet years as well as very hot and dry years from 2006 to 2011.

The precision leveling program indirectly saves more than 0.30 acre-feet of water per acre farmed, because precision leveling is a catalyst for a whole range of field upgrades. Water conservation investment in precision leveling has at least three indirect effects on field water use: (a) reduction in the levee density, (b) precision leveling savings during the ratoon crop, and (c) cropping changes. For example, benefits attributable to precision leveling also include lower levee density. In precision-leveled fields in which the levee density drops 0.21 levees/acre, farmers are likely to save an incremental 0.40 acre-feet per acre from planting to harvest during the first crop. Hence, it is a more valuable investment than is indicated simply by estimating the difference in water use attributable solely to precision leveling. The water savings return on a precision leveling program should include all direct and indirect effects of precision leveling. Verifying these indirect water savings from precision leveling, although outside of the scope of this analysis, is an important next step.

A field that has been precision-leveled with fewer levees uses less irrigation water. For a precision-leveled field, a decrease in 1 levee/acre of the levee density will likely decrease the water use by 1.907 ac-ft/ac. Given that the precision leveling of a field generally decreases the levee density; these indirect savings from levee density can also be attributable to precision leveling. For example, the potential direct and indirect benefits from precision-leveled fields could exceed 0.696 acre-feet of water used over an acre farmed (Table 6.7) if the decrease in the number of internal levees in a field was monitored before and after precision leveling. If at some point water utilities and irrigation districts would like to compute and verify water savings associated with the reduction of levees due to precision leveling, data collection on levees by physical field versus aggregate field would be necessary.

Another factor that decreases water use is the decreased likelihood of watering and harvesting a ratoon crop on precision-leveled fields. The data suggests that for non-precision leveled fields, farmers are likely to plant conventional rice varieties, while for precision-leveled fields farmers tend to plant seed or hybrid rice. When farmers plant seed and hybrid rice, a cultivar's longer growing periods constrain planting a ratoon crop. As a result of the increasing number of precision-leveled fields that use seed and hybrid rice, the number of fields during the ratoon crop has decreased. Some of the factors that increase water use in the first crop include longer irrigation periods due to rice variety change. There likely are higher total savings due to not watering a ratoon crop. If at some point the LCRA would like to compute and verify saving due to change in the cropping pattern, more data would have to be collected.

Through answering the first research question, this dissertation contributes to non-experimental research in agriculture a multi-method analytical approach and a precision leveling water savings estimate both of which differ from previous on-station and on-farm experimental evaluations. The difference between this study's results and other on-station and on-farm trials, in terms of the precision leveling water savings estimate, do not contradict with, but instead complements current knowledge by introducing a valuable methodological approach to evaluate precision leveling water savings that accounts for farmers' actual farm operations in situations where farmers self-select into conservation programs, such as in the EQUIP and HB1437 grants. Previous evaluations provide valuable water savings estimates from on-farm and on-station experimental research. These estimates can be used as benchmarks against which to assess the actual (in-situ) performance of conservation practices considering farmers' irrigation systems and management skills. This dissertation evaluates the uncertainty of different estimation methods to determine a better model to evaluate water savings in agricultural conservation. This study compares the results from a previous experimental study in the Lakeside Irrigation Division on precision leveling with the results of three statistical evaluation methods (OLS, FE, and MLM) of field water use in the same location.[1] The analysis of the uncertainty determined that the MLM model provides the more robust estimate with the least amount of uncertainty. Results suggest that the previous experimental evaluation, controlled by scientists as opposed to farmer's actual production, over-estimates the impact of precision leveling (0.75 ac-ft/ac)[2] compared with the estimates for the direct effects of precision leveling found in farmer's actual operations (0.30 ac-ft/ac). There are additional indirect affects to precision leveling that, with the proper verification of levee densities, could potentially double the amount of water savings attributable to precision leveling. However, it is also true that the statistical analysis ought to be compared directly to the experimental studies in the same geographic area, because the experimental studies do not account for any factors specific to the region. Therefore, the water savings from an experimental study in Lakeside Irrigation Division may not be directly comparable to an experimental study in Arkansas or Pakistan. Future research would need to be performed to test in different settings whether on-station and on-farm experimental research consistently over-estimates the water conservation estimates of non-experimental evaluations.

Research Question #2: Do fields managed by different farmers experience a different pattern of water use?

The inclusion of farmers' management skills and practices as evaluation considerations is central to a rigorous statistical evaluation, because the effects of farm management can be confounded with the effects of precision leveling on field water use. This dissertation finds that of the total variation in the outcome (field water use), 22 percent occurs at the farmer-level. This dissertation separates the 'field' effect from 'management skills' effect on field water use and finds that farmers who cash-rent use less irrigation water and that farmers' choice of rice variety influences field water use. Results also suggest that the type of levee system (straight or contour) of a precision level field may not affect field water use in the presence of good management skills. Because farmer's skills and practices in rice farming account for some portion of the variation in field water use, future research should not overlook the farmer as an important evaluation consideration by assuming constant farmers' management practices throughout fields.

Research Question #3: Does on-farm water use change through time and can we predict these changes?

Because time-varying covariates such as weather factors influence water use, the analysis includes rain, evapotranspiration and year 2011 (as proxy variable for extreme drought) to isolate the effect of the precision leveling program from year-to-year changes in field water use due to weather variation. Results indicate that time varying covariates such as rain and evapotranspiration have the strongest magnitude of effect on field water use. From a program evaluation perspective, this highlights the need to more accurately represent weather variation at a finer spatial scale in future research. In terms of the methodology, this dissertation identifies Multi-level models as useful statistical models to analyze unbalanced agricultural data due to crop rotation as well as to account for correlation across observations due to repeated field measurements in longitudinal research.

RECOMMENDATIONS

This section includes specific recommendations regarding the statistical analysis and the variables included to capture changes in field water use. Increasing the effectiveness of water conservation programs, such as the HB1437 precision leveling program, entails the proper inclusion of variables influencing water use in the verification, as evaluation considerations.

LCRA is delivering on its promise to monitor its precision-leveling conservation program and has succeeded in verifying the precision leveling savings in a thorough and rigorous statistical analysis of Lakeside Irrigation Division. There is a high degree of confidence in the estimates presented for the direct water conservation estimates for precision leveling. It is also true that if LCRA could collect more information, the indirect effects of precision leveling could be verified as well and yield more accurate estimates for precision leveling. There are a few additional factors that may affect field water use that could be collected, some additional predictors of fields' water usage may include soil moisture, soil type and flushing.

One way to improve information is to collect data based on existing farmer application processes. Irrigation divisions and water utilities, like the LCRA, could use their annual contracting process to gather critical pieces of information for precision leveling verification. The annual contracting process could be the basis of the monitoring system because it is practical and reduces the excessive burden of data collection. The statistically significant factors that could be gathered on a yearly basis include: rice variety, ownership stake, whether the field is precision leveled, number of levees and multiple inlets. If written into the contracting-billing protocol, this information could be gathered more reliably and practically on a yearly basis.

LCRA could also gather data through the annual HB1437 grant application process by collecting data from the yearly HB1437 application forms such as the number and type of levees by physical field, which would allow for accurate data on levees before and after precision leveling, but only for precision-leveled fields funded through HB1437 grants. Adding questions to an existing application processes does not encumber farmers with an additional round of data collection from an additional questionnaire.

Because the quality of the verification analysis depends on the quality of the data collected, famers should be encouraged to participate when possible in face-to-face surveys, as opposed to mail-in surveys. An advantage of implementing face-to-face surveys is better quality data due to the interviewer's ability to probe the interviewee if questions are skipped and clarify if questions are not clear enough to be understood. Also, the interviewer's ability to visually verify with the farmer in maps the field being discussed and proceed with questions about this field decreases the likelihood of confusion or misreporting. Face-to-face surveys are a particularly good alternative when dealing with a number of different fields per farmer across a six-year period. The interviewer can help the farmer refer to each field in production and in which year of cultivation.

The 'physical' field represents the best data collection unit for irrigation districts and water utilizes like LCRA. Survey data ought to be collected by 'physical' field to compute and verify water savings associated with the reduction of levees due to precision leveling and multiple inlets. For billing purposes, irrigation districts and water utilities like the LCRA, sometimes aggregate a number of different "physical" fields into a 'billing' field. Each of the 'physical' fields, within the boundaries of a 'billing' field can have a different number of levees and multiple inlets. Inaccuracies in the number of levees and multiple inlets in turn will lead to inaccurate estimates of water savings associated with these irrigation improvements. A general guideline may be to collect the most disaggregated data, when possible. Face-to-face and phone surveys showed that most farmers know off the top of their heads the number of inlets and levees in each of their 'physical' fields.[3] The farmer, not the contract holder, is the appropriate individual to ask detailed questions about farming practices and infrastructure upgrades.

POLICY IMPLICATIONS

In its HB1437 program, the LCRA must ensure 'no-net loss' from the Colorado River while making water transfer decisions based on water conservation estimates, meaning that the estimates must accurately represent the true amount of water conserved. An initial study to evaluate water conservation savings, funded by LCRA and conducted by Texas A&M Agricultural Extension Station, evaluated precision leveling with a sample of 8 plots; the result was an estimate of water savings of 0.75 acre-feet per acre farmed. This dissertation study finds the direct effects of precision leveling alone to be 0.30 ac-ft/ac. If only the direct effects of precision leveling are considered, LCRA's current 0.75 ac-ft/ac savings coefficient is too high a water savings estimate, which could result in allocating more water for transfer than is actually available in the basin. If both direct and indirect water savings associated with the precision leveling conservation program are considered the savings could be 0.69 acre-feet per acre, once the indirect water savings are verified.

This applied research has already served to inform LCRA's policy decisions. The lower than expected verified precision leveling water savings has encouraged LCRA to look at alternative conservation investment opportunities. For instance, multiple inlets are a less costly conservation measure than precision leveling and may have comparable water savings. Multiple inlets is an on-farm water conservation measure LCRA can invest in to complement precision leveling and further reduce the volume of water used by agricultural customers. Moreover, this verification study has the added benefit of having estimated the water savings coefficient for water inlets. Also, this verification methodology has encouraged LCRA to review and refine the HB1437 grant requirements for the implementation of precision leveling. A minimum threshold requirement on levee reduction is one way to ensure higher-quality precision leveling and higher water savings that can be attributed to precision leveling with greater levee reduction.

Tenants farming the land is not only frequent in Lakeside Irrigation Division, but tenant farming is a national trend. Over time, the ownership stake of fields may have shifted from fields farmed by owner to tenant farming. There are policy implications for both tenant farming and aging farmer population, for example, rethinking the conditions to participate in precision leveling cost-share programs, such as proof of ownership from participants. Also, program participation may be already much stronger for farmers who own and farm the land. With their fields as collateral, they may have greater access to financial resources and credit at low interest rates to make the lump-sum investments required, for example, in cost-share precision-leveling programs. Receipt of cost-share funding is conditional on whether the applicant farmer can provide proof of supplemental financial resources that will help the farmer cover 100 percent of the precision leveling costs. Specific effort should be directed to encourage tenants to participate and invest in conservation programs, as they may be less likely to do so also because they assess the return horizon of investments against their lease terms and arrangements.

Potential Water Savings in LCRA Irrigation Division

Table 8.2 and 8.3 show the potential savings from precision leveling under two scenarios. These scenarios describe full-scale implementation of precision leveling in Lakeside, Garwood and Gulf Coast to illustrate plausible water savings. If all irrigated acreage in Lakeside Irrigation Division was precision leveled, LCRA could save on average 7,680 ac-ft of irrigation water per year. If all irrigated acreage in LCRA’s three irrigation division (Lakeside, Garwood and Gulf Coast) were to be precision leveled, the water savings per year would amount to 19,320 ac-ft, approximately 18 percent of the water used by the city of Austin (106,622 ac-ft) and 11 percent of the water used by the city of San Antonio (175,000 ac-ft) per year.

Table 8.2: Potential Water Savings for Lakeside Irrigation Division First Crop

Year	All Irrigated Acreage	Water Savings
2006	21,451	6,435
2007	22,758	6,827
2008	27,973	8,392
2009	27,786	8,336
2010	26,951	8,086
2011	27,554	8,266

Potential water savings possible in Lakeside Irrigation Division. Table 8.2 shows the total irrigated acreage for each of the years of the study (precision leveled and non-precision leveled) and the total water that could be saved if all fields in the irrigation divison where precision leveled.

Source: Statistics estimated using WAMS database and 2012 results, Ana Ramírez 2012

Table 8.3: Potential Water Savings for three LCRA Irrigation Division First Crop

Irrigation Division	All Irrigated Acreage	Water Savings
Lakeside	25,600	7,680
Garwood	16,900	5,070
Gulf Coast	21,900	6,570

Potential water savings possible for LCRA if they precision leveled all irrigated fields for the irrigation districts of Lakeside, Garwood, and Gulf Coast

Source: Internal LCRA document 2011, Unpublished & Water savings estimated using 2012 Results

Cost Benefit Ratios of Water Conservation Technologies

Policy makers and water regulators may use the results of this research to evaluate alternative strategic investments in water conservation. Results will be of interest to water utilities, irrigation districts throughout the nation who want to make smart investments to reduce irrigation water use. Table 8.4 provides a comparative assessment between upfront costs in precision leveling, and agricultural conservation program, and residential conservation programs. Results suggest that the precision leveling program is more cost effective than some urban conservation measures. Table 8.4 indicates that the upfont costs is ten times more to save an acre-foot of residential water through providing high-efficiency residential fixtures than to save an acre-feet of water by precision leveling. The upfront cost per acre-feet of water saved for precision leveling is $212 per acre-feet, whereas changing residential showerheads is $3,491 per acre-feet, changing to high efficiency residential toilets cost $8,566 per acre-feet and changing kitchen faucets for aeration costs $2,029 per acre feet. An example of these urban conservation programs is the City of Austin, which provides free showerheads and faucet aerators for kitchen and bathrooms to decrease residential water use.

Table 8.4: Upfront Cost of Water Savings

Conservation Measure	Cost per ac-ft saved
Precision Leveling	$212
Residential showerhead	$3,491
Residential toilet	$8,566
Residential kitchen faucet	$2,029

Source: Estimated by Ana Ramirez. The estimates are upfront costs of water savings. The assumptions are: (a) high efficiency showerheads of 1.5 gallons per minute replace 2.5 gallon per minute showerheads, (b) high efficiency kitchen faucets of 2.2 gallons per minute replace 2.75 gallon per minute showerheads, (c) high efficiency toilets (1.28 gallons per flush) replace pre-1996 toilets with a water use of 3.5 gallons per flush.

CONCLUSIONS

This dissertation develops a methodology for verifying conservation program outcomes and estimating valid and reliable water conservation estimates for precision leveling. The methodology can be generalized across statistical methods, locations, grain crops and the type of on-farm conservation technology. Because results hold across four different statistical methods (OLS, FE, MLM, CRE) and three different settings (AR, MS, TX), the methods developed, tested, and validated in this study can be useful for policy makers and water regulators to quantify water savings from conservation programs in agriculture. This study also provides practical guidance on data collection and monitoring to environmental regulators, river authorities, water utility districts and irrigation districts that wish to perform a verification program.

The methodology was tested in Lakeside Irrigation Division (Texas), but can be extended to different farming regions for future conservation verification efforts. The sample of farmers in Lakeside Irrigation Division is representative of the U.S. farming population in terms of age, education and tenure arrangements. The majority of farmers are 41 years or older and educated. Tenant farming arrangements are common in the irrigation district. In order to compare these results with other farming regions, a chi-square test of homogeneity showed that similar water savings from precision leveling can be expected from rice production in Arkansas, Mississippi and Texas; three of the four most important rice producing states in the U.S.

One major contribution this dissertation makes to the existing body of research is the large sample size (328 fields over 6 years) and the extended number of factors for which data was collected. While previous studies provide estimates of water savings from a few intensively studied fields, this dissertation estimates water savings for an entire irrigation district. A study two decades ago focused on 96 fields, one-third of the fields this dissertation used to evaluate water savings from precision leveling across Lakeside Irritation Division. The sample size for the analysis in this dissertation is approximately seven times larger than the sample size of a similar study, a decade ago. This large sample size was achieved through scheduling multiple one-on-one interviews with each farmer over several years, actively engaging stakeholders in the development of the survey methodology, and by diligently collecting data on all the possible factors that influence water savings. This dissertation's evaluation with a larger number of observations yields more robust results than other previous studies with smaller samples. Having a larger number of observations provides more accurate estimates of the effects of conservation measures on the water use of fields.

The methodology developed in this dissertation can be used by water resource managers to statistically verify the water savings attributable to conservation technology. The mixed methods approach is applicable for ex-post program evaluation where random assignment is not possible, such as agricultural conservation programs in which participation is often self-selected. Because water management decisions have to be made in a timely manner, they must also be made with a reasonable amount of uncertainty. Perfect information is costly both in time and money; it is unrealistic to expect water regulators, managers and policy makers to defer decision-making until all data from field-measurements of every precision-leveled field each year are collected. Nevertheless, uncertainties in water availability should be minimized, especially as this resource becomes scarcer. The selection of the appropriate method for program evaluation is an important way to minimize the amount of uncertainty. MLM are useful to model agriculture water conservation because it incorporates the hierarchical nature of the data (fields, tenants, and landowners) as well as crop rotation (fields in and out of production). MLM provides the most precise estimate of the effect of precision leveling on a field's water usage. The MLM estimate was within the 95% confidence interval of the other three models, thus verifying the accuracy and robustness of the statistical findings and model. The other three methods provide verification of the accuracy and appropriateness of the MLM model and create a robust comparison of the water savings estimates. This multi-method analysis also provides insight in terms of the methodological value of each statistical method, a substantive contribution to non-experimental research in agriculture.

Using conservation in farming as a source of 'new water' requires accurately quantifying the efficiency gains of irrigation technology under farmers' actual operations and practices. Producers' actual field operations and irrigation systems add significant complexity to the analysis as it includes a number of important factors such as technological improvements over time, field size and tenure, among others factors that may be absent in on-station or on-farm experimental trials. The statistical analyses yield accurate water savings estimates because they consider farmers' actual irrigation technology and practices. These reliable water savings results are useful for water transfer decisions. This dissertation examines savings from water conservation technology under farmers' actual production systems and management. These water savings measure the 'in situ' effect of the technology, considering farmers' actual irrigation practices and technology. While on-station and on-farm experimental trials play an important role in developing new technology, if water managers were to use the water savings from experimental field studies to reallocate the 'new water', it is possible they could allocate more water than is actually saved by farmers. Inaccurate quantification of water savings risks hindering government agencies and water utilities' ability to balance and respond to municipal, manufacturing and irrigation water needs. Estimating water savings from farmers' day-to-day operations allows water managers and policy makers to make informed decisions on the amount of water that can be transferred.

[1] G. McCauley, R. Skala, G. Crenwelge and W. Bohmfalk, "Progress Report on Cooperative Rice Irrigation Study 1986 Crop Season," Technical Report on Cooperative Rice Irrigation Study, Bmt. Center Tech. Rep. 83 10,1

[2] Ibid.

[3] Personal communication with farmers during face-to-face surveys, Eagle Lake, TX

Appendices

Appendix A includes a list of abbreviations used in this dissertation and a description of what they refer to. Appendix B, C, and D include the three letters (2009, 2010 and 2011) sent to farmers and contract holders encouraging them to participate in the survey effort and explaining the purpose of the study. Appendix E is the survey instrument. Appendix F includes a mock-up of the kind of data provided by LCRA and collected in the survey. The data in Appendix F were fabricated to simulate the actual data, such as contract names, field names and other data.

APPENDIX A: LIST OF ABBREVIATIONS

Abbreviation	Term
CRE	Correlated Random Effects Model
BRA	Brazos River Authority
EQUIP	Environmental Quality Incentive Program
FAO	The Food and Agricultural Organization of the United Nations
FE	Fixed Effects Model
HB1437	House Bill 1437 Legislation
HB1437 Ag Funds	House Bill 1437 Agricultural Funds
HB1437 Committee	HB1437 Agricultural Fund Advisory Committee
LCRA	Lower Colorado River Authority
MA	Meta-analysis
MLM	Multi-Level Model
NRCS	U.S. Department of Agriculture's Natural Resources Conservation Service
OLS	Ordinary Least Square Model
USDA	United States Department of Agriculture
WAMS	Water Application Management System

APPENDIX B: LETTER TO SURVEY PARTICIPANTS 2010

LCRA
ENERGY • WATER • COMMUNITY SERVICES

February 4, 2010

Re: Survey Supporting Precision Leveling Verification Study

Dear LCRA Customer,

The Lower Colorado River Authority (LCRA) is developing a program to verify water savings from precision leveling. This is important so we can comply with the requirements of the House Bill 1437 legislation.

LCRA is working with the University of Texas at Austin's LBJ School of Public Affairs to develop a statistical model to verify water savings and consider other factors that influence water use. The Lakeside division will be used to test this model. The statistical model was presented to the HB1437 Agricultural Water Conservation Committee at its November 3, 2009 meeting, and committee members recommended that a survey be given to every contract holder in the Lakeside Irrigation Division. LCRA needs the participation of all Lakeside division water contract holders so that we have accurate and complete data to verify water savings.

The purpose of the enclosed survey is to collect information that is not available from LCRA's billing system. The information will be analyzed to investigate how precision leveling and other water conservation measures and management practices, as currently applied by the farmers, influence on-farm water use. Your participation in this survey is important to determine how much water is saved through agricultural water conservation. The accuracy of the results of this analysis depends on the information collected from you and other farmers and could influence the direction of future cost-share funds for precision leveling.

If you decide to participate, you or your designee can fill out the survey and return it in the enclosed envelope, set up a time to go over it on the phone, or schedule a time to come into LCRA's Eagle Lake office. If we do not hear back from you by February 19, 2010, an LCRA staff person will contact you. Please let us know as soon as possible if you prefer an appointment. A mapbook of your fields from 2006-2009 is enclosed for your reference. Please refer to your farm records before and during the survey to make the information as accurate as possible. Your response to the survey is voluntary. LCRA will not release your information unless required to do so by law. A blank survey will be posted at http://www.hb1437.com if you need another copy. If you have any questions about the survey, please contact Stacy Pandey at (512)473-3200/ 1-800-776-5272 or send an email to stacy.pandey@lcra.org.

We appreciate your time and effort and look forward to your participation.

Sincerely,

Kyle Jensen
Manager, Water Operations

P.O. BOX 220 • AUSTIN, TEXAS • 78767-0220 • (512) 473-3200 • 1-800-776-5272 • WWW.LCRA.ORG

APPENDIX C: LETTER TO SURVEY PARTICIPANTS 2011

LCRA
ENERGY • WATER • COMMUNITY SERVICES

January 28, 2011

Dear LCRA Customer,

Last year, LCRA partnered with the University of Texas at Austin LBJ School of Public Affairs to develop a survey and statistical model to assess the effectiveness of various water conservation practices. The Lakeside Division was used to test the model. This survey was mailed last February and approximately 60 percent of Lakeside farmers participated. This was an exceptional response rate. I'd like to thank everyone who participated. An interim report with study results is available online at http://www.hb1437.com.

The study shows that precision leveling accounts for a significant reduction in water use and that fields with straight levees also use significantly less water. However, with only four years of data, there was not enough to differentiate first and second crop water use patterns. We believe that an additional year of data will make this possible.

Therefore, LCRA is again requesting your help. We'd like you to update the enclosed survey with 2010 field data. The survey is similar to last year's. If you filled out the survey last year, we only need 2010 field data this year. If this is your first time responding to the survey, please include data for all five years. Your participation in this water use survey is vital to LCRA's efforts to measure water savings and could influence the direction of future funding for on-field conservation practices.

You can complete the survey in several ways:

- Call our Austin office and answer the questions over the phone
- Fill out the survey and return it in the enclosed envelope; or
- Make an appointment to visit LCRA's Eagle Lake office and complete the survey there

Please contact us or return the survey by Feb. 11, 2011. If you prefer to visit the office, please make an appointment. To assist you with completing the survey, a mapbook of your 2010 fields is enclosed. If you did not complete the survey from last year, the 2006-2009 map is also enclosed. Additional copies of the survey form are available at http://www.hb1437.com.

Your participation in this survey is voluntary and the information provided will not be released by LCRA unless required to do so by law. If you have any questions about the survey, please contact Stacy Pandey or Ana Ramirez at (512)473-3200/ 1-800-776-5272 or send an email to watercon@lcra.org. We appreciate your time and effort and look forward to your participation.

Sincerely,

Kyle Jensen
Manager, Water Operations

P.O. BOX 220 • AUSTIN, TEXAS • 78767-0220 • (512) 473-3200 • 1-800-776-5272 • WWW.LCRA.ORG

APPENDIX D: LETTER TO SURVEY PARTICIPANTS 2012

LCRA
ENERGY • WATER • COMMUNITY SERVICES

Feb. 8, 2012

Dear LCRA Customer,

For the past several years, LCRA has partnered with the University of Texas at Austin LBJ School of Public Affairs to develop a survey and statistical model to assess the effectiveness of various water conservation practices. LCRA is again requesting your help with the survey. We'd like to meet with you to update the enclosed survey with 2011 field data.

The survey is similar to last year's. If you filled out the survey last year, we only need 2011 field data this year. If this is your first time responding to the survey, please include data for all six years. Your participation is vital to LCRA's efforts to measure water savings and could influence the direction of future funding for on-farm conservation practices.

We would appreciate it if you could come to the Eagle Lake office to fill out the survey. Last year, we had to eliminate some information from mailed-in surveys because of missing data. We believe personal interviews will eliminate that issue. If this is not possible, we can work with you to answer survey questions over the phone.

LCRA staff will contact you to make an appointment to visit LCRA's Eagle Lake office in the next few weeks. A mapbook of your 2011 fields is enclosed to assist with the survey. If you did not complete the survey from last year, a 2006-2011 map is enclosed. Additional copies of the survey form are available at hb1437.com.

Last year, almost 90 percent of Lakeside farmers participated in the survey. This is an exceptional response rate, and I'd like to thank everyone who participated.

The study shows that precision leveling accounts for a significant reduction in water use, 0.33 acre-feet per acre for first crop, and that fields with multiple inlets use significantly less water. With the small number of land leveled fields in production during second crop, there was not enough data to determine how much water was saved in second crop. With six years of data, this will be possible. This year's survey will be the last in this study, which will be completed in June. A draft report from UT with updated 2011 study results is available at hb1437.com.

Your participation in this survey is voluntary and the information provided will not be released by LCRA unless required to do so by law. If you have any questions about the survey, please contact Stacy Pandey at 512-473-3200, x7471 or 1-800-776-5272. We appreciate your time and effort and look forward to your participation.

Sincerely,

Mike Shoppa

Mike Shoppa
Manager, Irrigation Operations

APPENDIX E: SURVEY INSTRUMENT

Please place a check in the appropriate box to describe your management decisions and practices used on the fields you farmed from 2006 to 2009

Survey ID:

PART I:

GENERAL INFORMATION

Name ________________

Role ________________

Gender: ☐ Male ☐ Female

What is the total area of your farm operation? _______acres

How long have you been working in farming?

Years farming
☐ 0-5
☐ 6-10
☐ 11-15
☐ 16-20
☐ more than 20

How many years have you been farming in Lakeside?

Years farming
☐ 0-5
☐ 6-10
☐ 11-15
☐ 16-20
☐ more than 20

OPTIONAL:

Age
☐ less than 30
☐ 31-40
☐ 41-50
☐ 51-60
☐ more than 60

OPTIONAL:

Highest level of education completed
☐ 8th grade
☐ High School
☐ College
☐ Graduate School
☐ Other (please specify) ____________

PART 2: FARMING PRACTICES

1. What percent of your total working time (that is, time spent on acitivities that provide you with means of livelihood) do you spend working on

	Percentage of total working time
Farms you own	____________
Farms rented for cash	____________
Off-farm activities (please specify) ____________	____________

2. In your farming practice, who makes the management decisions (that is, decisions on farming practices such as crop variety, pesticides, water use, labor and infrastructure investments)

a) Farmed by owner	b) Rented for cash	c) Share rented
☐ Land Owner	☐ Land Owner	☐ Land Owner
☐ Tenant	☐ Tenant	☐ Tenant
☐ Manager	☐ Manager	☐ Manager
☐ Field Hand	☐ Field Hand	☐ Field Hand
☐ Crop consultant	☐ Crop consultant	☐ Crop consultant
☐ Other (please specify) ____________	☐ Other (please specify) ____________	☐ Other (please specify) ____________

3. In your farming practice, who decides when and how much water to order when land is

a) Farmed by owner	b) Rented for cash	c) Share rented
☐ Land Owner	☐ Land Owner	☐ Land Owner
☐ Tenant	☐ Tenant	☐ Tenant
☐ Manager	☐ Manager	☐ Manager
☐ Field Hand	☐ Field Hand	☐ Field Hand
☐ Crop consultant	☐ Crop consultant	☐ Crop consultant
☐ Other (please specify) ____________	☐ Other (please specify) ____________	☐ Other (please specify) ____________

4. Do you currently practice conservation measures like precision leveling, multiple inlets or permanent levees to reduce water use? ☐ Yes ☐ No

5. If yes, on a scale of 1 to 5 (1 being most influential and 5 least influential), rank what people influenced you to implement the conservation measure?

a) Precision Leveling	b) Multiple Inlets	c) Permanent Levees
____ Personal experience	____ Personal experience	____ Personal experience
____ Other producers	____ Other producers	____ Other producers
____ Crop consultant	____ Crop consultant	____ Crop consultant
____ Extension agent	____ Extension agent	____ Extension agent
____ Other (please specify) ____________	____ Other (please specify) ____________	____ Other (please specify) ____________

6. Please estimate the percentage of your farmland that has been precision leveled (that is, land that is graded to a slope less than 2%?______________

7. 1 being most important and 5 being least important, rank the reasons affecting your decision to adopt the following conservation measures?

a) Precision Leveling	b) Multiple Inlets	c) Permanent Levees
____ Increase yield	____ Increase yield	____ Increase yield
____ Land topography	____ Land topography	____ Land topography
____ Reduce labor costs	____ Reduce labor costs	____ Reduce labor costs
____ Water savings	____ Water savings	____ Water savings
____ Financial support	____ Financial support	____ Financial support
____ Guaranteed contract	____ Guaranteed contract	____ Guaranteed contract
____ Other (please specify) ____________	____ Other (please specify) ____________	____ Other (please specify) ____________

8. Have you ever adopted a conservation measure but are not currently practicing it?
☐ Yes ☐ No

9. 1 being most important and 5 being least important, rank the reasons affecting your decision to abandon or never adopt the following conservation measures?

a) Precision Leveling	b) Multiple Inlets	c) Permanent Levees
_____Return period of investment	_____Return period of investment	_____Return period of investment
_____Low participation by peers	_____Low participation by peers	_____Low participation by peers
_____Investment costs	_____Investment costs	_____Investment costs
_____Other (please specify) ____________	_____Other (please specify) ____________	_____Other (please specify) ____________

10. Please rank on a scale of 1 to 6 (1 being most influential and 6 least influential), which of these sources have you received most of your farming knowledge?

Sources
_____Own practice/experience
_____ Parents/relatives
_____ Other farmers
_____ Extension services
_____ School
_____ Other (please specify) ____________

11. On your fields, do you collect rainfall or other weather data? ☐ Yes ☐ No

12. If yes, what kind?____________________________

13. Would you be willing to provide data reports from your farm rain gauges? ☐ Yes ☐ No

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

Other comments:

APPENDIX E: CONTINUED

PART 3: FIELD CHARACTERISTICS *Please list the fields you farmed from 2006 to 2009 and place a check in the appropriate box to describe each field* Survey ID:

		Crop Season		Management Skills			Conservation Measures						
Field name	Flushes	Year	Failed 2nd Crop	Row Crop	Rice Variety	Ownership stake	Conservation Measures	Number of Multiple Inlets	Type of Levee	Slope	Multiple Inlet Funding	Precision Leveling Funding	Water by wells
LCRA: Acres: Owner: FSA number Description	☐0 ☐ 1 ☐ 2 ☐ 3 ☐ Other ______	☐2006 ☐ 2007 ☐ 2008 ☐ 2009	☐Yes ☐ No	☐Yes ☐ No	☐Conventional ☐ Seed ☐ Hybrid ☐ Other ______	☐Farmed by owner ☐ Rented for cash ☐ Share rented ☐ Manager ☐ Other (please specify) __________	☐Precision Leveled ______yr % of field leveled ______ ☐ Multiple Inlets ______yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ <4 ☐ 4-6 ☐ 6-8 ☐ 8-10 ☐ Other ______	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) ______	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Zero grade ☐ Other (please specify) __________ Number of Levees _____	NRCS funding ☐ Yes ☐ No	NRCS funding ☐ Yes ☐ No Private funding ☐ Yes ☐ No ☐ Other__________	☐Yes if Yes, %water ____ ☐ No
LCRA: Acres: Owner: FSA number Description	☐0 ☐ 1 ☐ 2 ☐ 3 ☐ Other ______	☐2006 ☐ 2007 ☐ 2008 ☐ 2009	☐Yes ☐ No	☐Yes ☐ No	☐Conventional ☐ Seed ☐ Hybrid ☐ Other ______	☐Farmed by owner ☐ Rented for cash ☐ Share rented ☐ Manager ☐ Other (please specify) __________	☐Precision Leveled ______yr % of field leveled ______ ☐ Multiple Inlets ______yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ <4 ☐ 4-6 ☐ 6-8 ☐ 8-10 ☐ Other ______	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) ______	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Zero grade ☐ Other (please specify) __________ Number of Levees _____	NRCS funding ☐ Yes ☐ No	NRCS funding ☐ Yes ☐ No Private funding ☐ Yes ☐ No ☐ Other__________	☐Yes if Yes, %water ____ ☐ No
LCRA: Acres: Owner: FSA number Description	☐0 ☐ 1 ☐ 2 ☐ 3 ☐ Other ______	☐2006 ☐ 2007 ☐ 2008 ☐ 2009	☐Yes ☐ No	☐Yes ☐ No	☐Conventional ☐ Seed ☐ Hybrid ☐ Other ______	☐Farmed by owner ☐ Rented for cash ☐ Share rented ☐ Manager ☐ Other (please specify) __________	☐Precision Leveled ______yr % of field leveled ______ ☐ Multiple Inlets ______yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ <4 ☐ 4-6 ☐ 6-8 ☐ 8-10 ☐ Other ______	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) ______	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Zero grade ☐ Other (please specify) __________ Number of Levees _____	NRCS funding ☐ Yes ☐ No	NRCS funding ☐ Yes ☐ No Private funding ☐ Yes ☐ No ☐ Other__________	☐Yes if Yes, %water ____ ☐ No
LCRA: Acres: Owner: FSA number Description	☐0 ☐ 1 ☐ 2 ☐ 3 ☐ Other ______	☐2006 ☐ 2007 ☐ 2008 ☐ 2009	☐Yes ☐ No	☐Yes ☐ No	☐Conventional ☐ Seed ☐ Hybrid ☐ Other ______	☐Farmed by owner ☐ Rented for cash ☐ Share rented ☐ Manager ☐ Other (please specify) __________	☐Precision Leveled ______yr % of field leveled ______ ☐ Multiple Inlets ______yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ <4 ☐ 4-6 ☐ 6-8 ☐ 8-10 ☐ Other ______	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) ______	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Zero grade ☐ Other (please specify) __________ Number of Levees _____	NRCS funding ☐ Yes ☐ No	NRCS funding ☐ Yes ☐ No Private funding ☐ Yes ☐ No ☐ Other__________	☐Yes if Yes, %water ____ ☐ No
LCRA: Acres: Owner: FSA number Description	☐0 ☐ 1 ☐ 2 ☐ 3 ☐ Other ______	☐2006 ☐ 2007 ☐ 2008 ☐ 2009	☐Yes ☐ No	☐Yes ☐ No	☐Conventional ☐ Seed ☐ Hybrid ☐ Other ______	☐Farmed by owner ☐ Rented for cash ☐ Share rented ☐ Manager ☐ Other (please specify) __________	☐Precision Leveled ______yr % of field leveled ______ ☐ Multiple Inlets ______yr ☐ Permanent Perimeter Levees ☐ Conservation Tillage ☐ Other (please specify) __________	☐ <4 ☐ 4-6 ☐ 6-8 ☐ 8-10 ☐ Other ______	☐Permanent ☐ Straight ☐ Contour ☐ None ☐ Other (specify) ______	☐Slope = 0.2% ☐ 0.2% > Slope > 0.1% ☐ Slope = 0.1% ☐ Zero grade ☐ Other (please specify) __________ Number of Levees _____	NRCS funding ☐ Yes ☐ No	NRCS funding ☐ Yes ☐ No Private funding ☐ Yes ☐ No ☐ Other__________	☐Yes if Yes, %water ____ ☐ No

APPENDIX E: CONTINUED

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 which has an average growing season
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
LEVEE DENSITY	Number of levees used in the field as part of the irrigation system to cascade water from one level to the next will be used to determine levee density (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 the 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, the landlord share the crop production from this field
STRAIGHT LEVEE	Fields with 0.1 percent grade, where levees are usually straight or have a slight bending
WELL	Whether or not wells were used to supplement water to irrigate a field
YEAR	Year when a field was in production (crop year)
ZERO GRADE	All slopes are removed; the fields are devoid of internal levees

APPENDIX F: SAMPLE DATA

CONTRACT_NAME	FIELD_NAME	YEAR	WATER DEMAND	TIME	MI	LL	LEVEES	# of Struct	2nd Crop	RAIN	TEMP
			(ac-ft/ac)	(days)	(Y/N)	(Y/N)	(count)	(count)	(Y/N)	(inches)	(F)
EAGLE VENTURE	PEAGLE-1	2006	2.613056	106	N	N		1	N	12.65	78.3898
EAGLE VENTURE	PEAGLE-1	2008	2.624558	108	N	N		1	N	4.31	80.4061
MILL CREEK CO.	GMCREEK-1	2006	3.135427	96	N	N		1	Y	12.65	78.3898
MILL CREEK CO.	GMCREEK-1	2007	2.339072	82	N	N		1	N	15.66	78.9818
MILL CREEK CO.	GMCREEK-1	2008	4.172817	103	N	N		1	Y	4.31	80.4061
PIERCE CO.	CNPIERCE-1	2006	2.198459	95	N	N		1	Y	12.65	78.3898
PIERCE CO.	CNPIERCE-1	2007	1.418583	84	N	Y		1	Y	15.66	78.9818
PIERCE CO.	PCPIERCE-1-1	2006	1.400293	58	Y	Y	1	1	N	12.65	78.3898
PIERCE CO.	PCPIERCE-1-1	2008	3.005228	90	Y	Y	1	2	N	4.31	80.4061
PIERCE CO.	EPIERCE-1	2006	1.800462	74	N	Y	5	3	Y	12.65	78.3898
PIERCE CO.	EPIERCE-1	2008	2.532379	96	N	Y	5	3	Y	4.31	80.4061

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