Attachment I
Responses to Review Comments

1. Report title “South Texas Rice Fields” should be more specific. Since the report only addresses rice fields within LCRA’s jurisdiction, not all of the South Texas rice growing areas. Please consider changing the title to portray better the project’s scope, for example, “Rice Water Irrigation Conservation in LCRA Irrigation Districts.”

Title has been changed as suggested

2. The two volumes should be labeled clearly as: Volume I of II and Volume II of II.

The two volumes have been combined into one

3. Maps would be easier to interpret in color. Consideration should be given to enlarging maps. Review tables and figures for consistency and accuracy.

Maps have been revised for clarity and printed in color. Figures and tables have been checked.

4. An Executive Summary should be included, including the fact that the LCRA sponsored the report.

Executive summary added, sponsorship noted.

5. Policy Research Project Participants face should note Jobaid Kabir’s affiliation with LCRA.

Kabir’s affiliation is noted

6. Correct reference for Mike Personett to indicate his current employment.

M. Personett’s affiliation has been changed

7. Rewrite first sentence, Chapter 1.

Change made as requested

8. Standardize water use characteristics to single year.

Data standardized to 1992 values

9. Change “program” to “programs:

Change made as requested

10. Correct statement (former page 2) to reflect operating and water rights practices more appropriately.

Statement changed to reflect actual operating and water right practices.

11. Page is missing.

Find enclosed the material from page 3

12. Please describe methodologies used by LCRA irrigation managers to estimate or measure water used by each farmer.

A description of the methodology is now included

13. Explain why the report states that measurements can be straightforward, while measuring water flows can be complicated.

Removed statement suggesting measurements of water flow were straightforward

14. Describe Water Management Project when it is first referenced.

Water Management Project now described before the term is used

15. Explain terminology ("undershot: and "water box") in a more clear manner.

Clarification of definitions now included in this report

16. Rewrite sentence (former page 9) to remove the word paradox and provide content that is more meaningful.

Sentence rewritten and clarified as requested

17. Reference the number of global flow meters and cost.

Numbers of global flow meters and their unit cost now included in report

18. Figure 1.2 reflects acres irrigated since 1968; text uses 1960 as starting period.

Text and table now in concordance

19. Chapter 3, page 54 (old): remove the word "the water" from the sentence.

Change made as requested

20. Report stated that additional water projects were unlikely; recommend changing unlikely to "more challenging"

Change made as requested

21. Summary of Results section should come after Methods section. Farmer attitudes should be addressed. Questionable usage of the word "purifies."

Suggested change in order made. Report now notes that farmer attitudes are addressed in chapter 8. The word "purifies" has been changed.

22. Change "that" to "in" for grammatical purposes. The statement that water use is more efficient as field size increases should not be unexpected. Define more precisely what "water use" means.

Grammatical change made. Questionable conclusion removed. Clarification of unit usage included.

23. Change "included" to "include."

Change made as requested

24. Chapter 6 does not address third party costs.

The requested change is beyond the scope of this report

25. Add "be between "flows to" and "available"

Change made as requested

26. Change "represented" to "represent."

Change made as requested

27. Change "when supply exceeds demand" to "when demand exceeds supply."

Change made as requested

28. Some figures and pages missing, some data not sourced.

Missing pages/figures included, all data now sourced.

29. Chapter 6 does not adequately address subsidence problems. Socioeconomic feasibility analysis is inadequate.

The requested change is beyond the scope of this report

30. Please include conclusion section.

Chapter 7 contained a conclusion section; the reason for this comment is unclear

31. The picture purporting to show East Matagorda Bay actually shows Matagorda Bay.

Copyrighted map of East Matagorda Bay included in this report; published version will contain a public domain map from LCRA.

32. Zones 3 and 6 are referenced as being in the "western end of the bay." They are actually in the east.

Change made as requested

33. Calculation of constant alpha unclear from text.

Sentence clarified as requested

34. It is clear why the sum of rainfall intensity and runoff as a value is important.

Sentences clarified as requested

35. Sentence refers to a variable as being in Equation 7.2 when it is actually in Equation 7.3

Reference is now to Equation 7.3 from Equation 7.2

36. Column headers for Table 7.2 are unclear.

Table 7.2 has now been split into three tables for the sake of clarification

37. Unclear conclusion relating to Table 7.2

Rationale for conclusion now more fully explained

38. Last sentence of paragraph (old page 67, lines 12-14) seems redundant.

Sentence deleted as requested

39. Draft report contained two copies of page 74.

Noted

Lyndon B. Johnson School of Public Affairs
Policy Research Project
Number xxxxxx

Rice Water Irrigation Conservation in LCRA Irrigation Districts

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2000

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Foreword

The Lyndon B. Johnson School of Public Affairs has established interdisciplinary research on policy problems as the core of its educational program. A major part of this program is the nine-month policy research project, in the course of which two or more faculty members from different disciplines direct the research of ten to thirty graduate students of diverse backgrounds on a policy issue of concern to a government or nonprofit agency. This "client orientation" brings the students face to face with administrators, legislators, and other officials active in the policy process and demonstrates that research in a policy environment demands special talents. It also illuminates the occasional difficulties of relating research findings to the world of political realities.

This project represents an evaluation of the Lower Colorado River Authorities' agricultural water conservation program over the five year period between 1988 and 1993. This research began in 1992 and was completed in 1995. Research findings show that the Lower Colorado River Authority achieved significant water savings through its water conservation efforts. Findings also show that further investments in agricultural water conservation will continue to produce water savings at substantially lower costs than investments in development of alternative sources of water. This research was supported by a grant from the Texas Water Development Board and by in-kind support from the Lower Colorado River Authority.

The curriculum of the LBJ School is intended not only to develop effective public servants but also to produce research that will enlighten and inform those already engaged in the policy process. The project that resulted in this report has helped to accomplish the first task; it is our hope that the report itself will contribute to the second.

It should be noted that neither the LBJ School nor the University of Texas at Austin necessarily endorses the views or findings of this report.

Edwin Dorn, Ph.D.
Dean

Acknowledgements

Project members wish to acknowledge the assistance of several individuals who provided valuable assistance, counsel, and guidance during the course of this project. Bruce Hicks, Mike Shoppa, Henry Bradford, Thomas Pivonka, Kelly Weber, Larry Harbers, and the entire staff of the LCRA Lakeside and Gulf Coast Irrigation Districts cooperated with project members in all aspects of this research. Quentin Martin also provided especially valuable insights and counsel to team members in the analysis of LCRA's databases. Angie Taylor and Alan Faries also assisted in discussions of LCRA's rate system. Finally, we wish to acknowledge the contributions of Comer Tuck, and Craig Pedersen of the Texas Water Development Board and Mike Personett, Turner, Collie and Braden Inc., formerly an employee of the Texas Water Development Board and the LCRA, whose support made this project possible and whose advice improved the quality of the product substantially. This project includes interviews and surveys conducted among rice farmers on LCRA's irrigation districts. Haskell Simon assisted the LBJ School staff in many ways, including help in arranging interviews with the Texas rice farmers who participated in this study. UT staff also thanks those rice farmers who completed surveys or spent time in interviews. Project team members remain responsible for any errors or omissions remaining in this study.

Executive Summary

The purpose of this report is to evaluate a multi-year experiment conducted by the Lower Colorado River Authority (LCRA) in agricultural water conservation. During the 1980s and 1990s the LCRA implemented agricultural water conservation programs to reduce water consumption in the Gulf Coast and Lakeside irrigation districts. The program consists of four components: canal rehabilitation, technology transfer to farmers, on-field water measurement, and volumetric pricing. The LCRA has invested in rehabilitating the canals of the Lakeside and Gulf Coast districts and has encouraged farmers to invest in their own land to reduce unnecessary water utilization. In 1992 the LCRA began to measure water withdrawals from canals and on farms in both districts. During 1993 the LCRA began to charge for water withdrawals for rice farming based on the volumes utilized by farmers. These programs sought to sustain the productivity of rice farming by reducing the volume of water utilized for irrigation. The purpose of this report is to evaluate the LCRA's large scale experiment and quantify water conservation savings.

The LCRA operates a water reservoir system with a storage capacity of 2.3 million acre-feet and it has authority to market 1.5 million acre-feet of that storage capacity on an annual basis. In addition, the LCRA manages the natural flow of the Lower Colorado River and facilitates the withdrawal by users of both groundwater and run-off river water. The LCRA has approximately 0.445 million acre-feet of firm water available to be marketed from stored water and approximately 1.055 million acre-feet of stored water is available as interruptible water (water sold with the understanding that this water may not be available to customers during drought periods).

Findings, Chapter 1—Irrigation Districts

During the period of 1968 - 1983, the land irrigated in Lakeside remained relatively stable, fluctuating between 19,000 acres and 27,000 acres. During the same period irrigation in Gulf Coast fluctuated on the order of 50 percent, from as high as 44,000 feet to as low as 22,000 acre-feet. Both the stability of irrigated acreage within Lakeside and the volatility of irrigated acreage within Gulf Coast reflect many factors, including changing market conditions for rice, federal price stabilization programs, and other factors. The volume of water withdrawn to irrigate these rice crops has been even more volatile. The amount of water diverted in Lakeside fluctuated from at or below 100,000 acre-feet in the early 1970s and late 1960s to over 150,000 acre-feet in the late 1980s. Water use in Gulf Coast dropped from between 250,000 and 300,000 acre-feet throughout the 1950s to early 1980s to as low as under 150,000 acre-feet in the early 1990s.

There is a difference in the rate of water use between the two districts. Lakeside appears to use fewer acre-feet of water per acre of irrigated land, reflecting a more comprehensive maintenance program, regular pump ratings, and superior water-ordering policy. Between 1987 and 1992 attempts were made to improve the water conservation performance of farmers in Gulf Coast. A contributing factor to lower efficiency observed in Gulf Coast is the amount of acreage in irrigation. As the irrigated acreage in the Gulf Coast has fallen below historic levels, there is inherently less efficient water use in Gulf Coast than in Lakeside.

Findings, Chapter 2—Water Conservation

The LCRA has sought to achieve a goal of no more than 5.25 acre-feet of water applied per irrigated rice acre, based on two crops per season. Rice can be farmed in one or two crops per season. The LCRA sought to improve the efficiency of on-farm water use by canal rehabilitation, management practices to minimize losses, a system of technology transfer for improving on-farm water use, and assistance to public and private sector initiatives to develop, demonstrate and apply irrigation practices that improve on-farm water use efficiency. Beginning in 1982 the LCRA made significant capital investments in canal rehabilitation. Beginning in 1992, the LCRA sought to measure water withdrawn for each plot of land farmed for rice in Lakeside and Gulf Coast. Beginning in 1993 the LCRA began to bill farmers for water in part on a volumetric basis.

These efforts resulted in reduction of the volume of water required to produce rice in the Lower Colorado River Basin. First crop water efficiency was reduced from as high as 6.3 acre-feet of water applied per irrigated acre in 1987 to slightly more than 3 acre-feet of water applied per irrigated acre in the early 1990s in Gulf Coast. In Lakeside the improvement has not been quite as dramatic, with reductions in first crop water use from 3 acre-feet of water applied per irrigated acre to slightly more than 2 acre-feet of water applied per irrigated acre. Water use for the second crop did not decline during this period, but rather fluctuated in response to rainfall patterns.

Water measurement and a volumetric price on water does encourage land owners to improve their land. The incentive is less clear for on-land water investments for farmers and tenants.

Finding, Chapter 3—Water Accounting Database

The LCRA developed a water accounting database to report on-farm water use and support the system of volumetric water pricing. This study reviewed that database in its initial year of operation. A U.S. Bureau of Reclamation study found that the on-farm measurement devices were working properly. The accounting software was awkward and time consuming to use and some components failed to operate properly. A review of the performance of the water accounting software did identify computational errors in the database calling into question some aggregate data at the farm level.

Findings, Chapter 4—Water Conservation Programs

Table ES.1 is a summary of results presented in Chapter 4 evaluating water conservation, water management and water measurement in Lakeside and Gulf Coast. That table reproduces Table 4.3 that is presented in Chapter 4 below. A significant volume of water was saved in the Gulf Coast District, primarily from water rehabilitation during 1988 to 1993. Water savings was also associated with volumetric pricing during 1992-93 on both the Lakeside and Gulf Coast Districts. There remained in 1993 additional potential significant water savings from on-farm water conservation in both Lakeside and Gulf Coast.

The experiment in the Lower Colorado River Basin provides evidence to justify investment in canal rehabilitation, volumetric measurement, and volumetric pricing as means for reducing water utilization in rice farming. Of all the potential sources of savings in on-farm water use, canal rehabilitation is the most significant single source of saved water. Many factors that could affect water consumption do not appear to do so on a systematic basis; those factors include differences in soil permeability, length of time of irrigation, education of farmer, or ethnicity of farmer, or water coordinator supervision.

Findings, Chapter 5—Geographical Information Systems

This project developed a geographical information system (GIS) as a means of integrating on-farm water utilization data with information on soil conservation, size of farm, identity and demographic information of farmers, and other factors. GIS applications showed promise for improving analysis of water usage but were constrained by insufficient field information. GIS has the potential to deliver daily or weekly information on water use; this would provide a precise feedback method that the LCRA could use to provide information so farmers can manage their land, maximize their economic return, and conserve water.

Findings, Chapter 6—Conjunctive Use

This chapter identified the potential for conjunctive use, the coordinated management of surface and groundwater sources. A conjunctive use strategy can take surface water when river water is available and groundwater as a supplement to run-of-river flow or water stored in the Highland Lakes. A sustainable conjunctive use system is possible in the Lower Colorado River Basin as long as three conditions are met: artificial recharge is employed; the cost of the system would be paid from water sales to municipalities; and farmers contribute to the system by managing conjunctively (reducing their risks by groundwater utilization during drought conditions). This chapter presented preliminary ideas that could be utilized in design of a conjunctive water use system. Further investigation would be required in a number of areas, including: selection of the best sites for aquifer recharge facilities; improvement in the groundwater models, such as development of a more finely discretized analysis and efforts to validate fluctuations in groundwater levels with respect to withdrawals; and investigation of the financial feasibility of artificial recharge.

Findings, Chapter 7—Salinity of East Matagorda Bay

This chapter reported on the pattern of salinity levels in East Matagorda Bay and examined how rain flow and river flow offset salinity levels in the mouth of the Lower

Colorado River. Salinity levels did not appear to vary spatially within East Matagorda Bay. Precipitation appeared to have a larger effect on salinity in the Bay than river flows, although that conclusion was tentative and based on limited information. If rainfall is more important than streamflow in affecting salt content of the Bay, then trying to manage salinity levels in the Bay by controlling river flows may not be feasible.

Findings, Chapter 8—The Opinion Survey of Rice Farmers

All farmers on land irrigated by LCRA water (230 farmers) were asked to respond to a mail survey. The response was quite high: 39 percent in Lakeside (40 of 102 surveys) and 30 percent in Gulf Coast (30 of 128 surveys). There were 50 questions asked, so there was a large volume of useful information obtained reflecting farmer knowledge and preferences for water management practices.

At the time of the survey (1993) only 42 percent of farmers maintained any type of field water-use records. Field records provide an economical means of improving water management and may assist in changing farmer attitudes, as keeping records on water use promotes a more systematic approach to farming practice. A more systematic approach may help many farmers improve irrigation efficiency and become more receptive to new technology.

Farmers indicated concern over the accuracy of the water measurements. Some farmers responded positively to the idea of volumetric pricing but did not endorse the program because of perceived inaccuracies in water measurement methods. Farmers' willingness to accept volumetric pricing could be improved if the LCRA can assuage concerns with the issue of accuracy of irrigation water measurement. For example, if a third party, selected by farmers on the irrigation districts, could take measurements independently at several delivery structures over an extended time period, farmers could observe the correspondence between water use and measure watered use. Such an approach could deal with the issue of measurement accuracy due to fluctuations in the depth water in the canal between measurements.

Many farmers indicated that communication between the LCRA and farmers could be improved. Improving communications with farmers could help convince farmers that the LCRA's water measurements are accurate and the districts are interested in the farmers' welfare. Although many farmers expressed a generally positive attitude toward the LCRA, others felt that their concerns were not being given enough weight. The farmers want to feel that they are a part of the decision-making process. In light of the fact that a majority of farmers indicated that farmer meetings with the LCRA were of value, it is in the LCRA's interest to hold meetings regularly.

The excellent response rate to this survey indicates that the farmers appreciate the opportunity to express their views. Future surveys could continue monitoring farm water management practices and farmers' opinions. The fact that this survey, conducted by a third party, received an excellent response rate suggests that future surveys could also be conducted by third parties.

Table ES-1
Summary of Water Conservation Results

	Lakeside District	Gulf Coast District
Water Conservation		
Water savings associated with canal rehabilitation, 1988-93.[a]	N/A	69,891 acre-feet
Water savings associated with volumetric pricing, 1992-93.[a]	0.52 acre-feet per-acre	e-feet per-acre
Additional water savings potential associated with an on-farm water conservation program.*	0.65 acre-feet per-acre	1.80 acre-feet per-acre
Water Management		
Average water use, first crop, 1993.	2.44 acre-feet per-acre	3.79 acre-feet per-acre
Average water use, second crop, 1993.	1.92 acre-feet per-acre	2.26 acre-feet per-acre
Average effect of field acreage on total first crop water use.	2.14 acre-feet per-acre	3.42 acre-feet per-acre
Average effect of soil permeability on per-acre water use.[b]	No discernable effect	No discernable effect
Average effect of one inch of rainfall on irrigation inflows.	-0.07 acre-feet per-acre per-inch of rain	No discernable effect
Average effect of irrigation period length on per-acre water use.	0.017 acre-feet per-acre per-day	No discernable effect
Water Measurement		
The consistency of water measurement between water coordinators. (Average difference in measurements in parenthesis.)	1 water coordinator inconsistent (-0.29 acre-feet per-acre)	2 water coordinators inconsistent (0.35 and -0.51 acre-feet per-acre)
The consistency of water measurements between types of delivery structures.	No discernable difference between types of structures	No discernable difference between types of structures.

Note: All estimates based on 1993 water use except as indicated. (a) Represents the water savings over the interim. (b) Based on 1992 water measurements.

* Martin T. Schultz, "Estimation of Derived Demand for Surface Water on Two Rice Irrigation Districts in the Lower Colorado River Basin, Texas," (Professional Report, Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin, 1994.)

Chapter 1. LCRA Irrigation Districts

In recent years the Lower Colorado River Authority (LCRA) has owned and operated the two largest irrigation districts within the lower Colorado River basin, a ten county area in central Texas. As a public agency, it is charged with managing and promoting the development of land and water resources and contributing to the economic health of the region. The agency operates under the statutory authority of the Texas state administrative codes and the LCRA Act, which established the agency as a conservation and reclamation district in 1934.[1]

To meet its objectives, the LCRA depends upon its ability to control, use, and conserve the water in the Colorado River. As part of the effort to conserve water, the LCRA has implemented an agricultural water conservation program in its irrigation districts to reduce the total consumption of water and to increase water efficiency. The amount of water available to users in the lower Colorado River basin varies from year to year as the region alternates between periods of average rainfall, drought, and flood. If the irrigation districts could produce more rice with less water, farmers in the region could plant with less concern over minor fluctuations in rainfall. The purpose of this chapter is to describe the physical and operational characteristics of the irrigation districts and the changes that are taking place as part of the conservation effort.

The LCRA purchased the Gulf Coast Irrigation District in 1959 and the Lakeside Irrigation District in 1983. Both districts are part of a group of four irrigation districts that serve rice farming communities in the lower Colorado River basin (Figure 1.1).[2] In 1992 Pierce Ranch and Garwood Irrigation Company, the two other irrigation districts, were privately owned. Garwood was purchased by the LCRA in 1999. Together, Colorado, Wharton, and Matagorda counties accounted for about 40 percent of the state's 1992 rice acreage. In 1992, the four districts accounted for 57 percent of the rice acreage in the three-county area, or 23 percent of the statewide rice acreage.[3] In 1992, the value of rice production in the three county area was about $65 million.[4] All four irrigation districts own water rights in the lower Colorado River. Table 1.1 displays the acreage levels and water use in the four districts during 1992. The Texas State Legislature granted water rights to Gulf Coast District in 1900 and to Lakeside District in 1901. Rice crops dominate the irrigation water demands in the river basin, but turf grass and row crops also account for a small percentage of irrigation water demand. Along the Texas Gulf Coast's rice-belt, water is used to meet the evapotranspiration requirements of the rice plants and to serve as a non-chemical pesticide.[5] In 1992, rice farming accounted for approximately 75 percent of the total surface and groundwater demand within the LCRA's service area.[6]

During the 1980s and 1990s, the Lower Colorado River Authority implemented agricultural water conservation programs to reduce water consumption in the Gulf Coast and Lakeside Irrigation Districts. The program consisted of three main components. The *canal rehabilitation project* was initiated in the fall of 1987 to improve the operational efficiency of the 100-year old canal system on Gulf Coast District. The project consisted of infrastructural improvement through cross-sectioning and sloping of the canal bed, and the removal of vegetation from canal banks. The *water measurement project* was initiated in 1990 to evaluate the volume of water used by each farmer. The LCRA intended to reduce water losses that result from poor on-farm water management practices by creating a financial incentive for farmers to save water through volumetric pricing. Beginning in 1993, rates for irrigation services consisted of charges for both the volume of water used and the area of land farmed. The LCRA's third program component, *technology transfer*, encourages the research and implementation of technological improvements in regional rice farming. The LCRA promotes these techniques through conservation demonstrations and extension efforts.

Implementation of the program has had a substantial impact on how the LCRA operates the canal systems. Although the districts operate similarly, Gulf Coast District typically uses a greater volume of water per irrigated acre than Lakeside District. LCRA managers have made efforts to standardize operations and water management practices between districts. The LCRA has tightened its control over the water pumping and delivery processes and is establishing new ways of working with its customers.

Overview of Water Management

The LCRA operates six dams and reservoirs with a storage capacity of 2.3 million acre-feet.[7] This system of water control structures is known locally as the Highland Lakes. In a 1988 decision, the 264th District Court of Bell County, Texas, established the LCRA's exclusive authority to market 1.5 million acre-feet of that storage capacity on an annual basis.[8] The LCRA sells water for municipal, industrial, and agricultural uses. Industrial users include the LCRA's own hydroelectric and coal-fired power generation facilities.

The natural flow in the lower Colorado River that would occur without the control of the Highland Lakes is labeled *run-of-river* water. This water is available to holders of legal water rights in quantities and for uses specified by the Texas Natural Resource Conservation Commission (TNRCC). With certain exceptions, priority of use between the owners of water rights is established according to the chronological order in which the rights were granted. The oldest water rights have the highest priority. The LCRA coordinates the demand for water in the river basin using a *Computer-Based Daily Allocation Model* that was developed as part of the LCRA's *Water Management Plan.*[9] Once the water needs of the holders of downstream water rights have been satisfied, the LCRA has the authority to store run-of-river water behind its dams. Once stored behind the dams, water is no longer available to downstream users as run-of-river water. For this reason, the LCRA must coordinate the demands of water rights users who divert water from points along the lower Colorado River. If the natural run-of-river flow is not adequate to satisfy the water demands of holders of water rights within the basin, the LCRA could supplement the natural flow of water by releasing water from the Highland Lakes. The LCRA has developed a drought management plan that is part of the water management plan that specifies how and to whom water would be allocated during a drought.

The term *stored water* refers to water retained behind the dams to be marketed by the LCRA for future use. Stored water is further divided into firm and interruptible water. *Firm water* is marketed with the understanding that its supply is guaranteed to the customer even under the conditions similar to the worst drought of record. Each year approximately 445,000 acre-feet of firm water is available.[10] In 1992, firm water was marketed for municipal, industrial, and irrigation purposes at a price of $105 per acre-foot. In 1992, 76 percent of the LCRA's firm water supplies were committed under contract.[11] During typical non-drought years only about 20 percent of the water which is available under those contracts is actually used.[12]

In the event that firm water reserved under contract is not used by a customer it continues to serve a purpose for the contract holder. The flow of water in the Colorado River Basin fluctuates widely from year to year and is dependent upon annual rainfall to replenish water supplies. During drought periods, the Highland Lakes provide the only source of surface water for contract holders. Firm water that is committed under long-term contracts but that typically goes unused from year to year serves the purpose of reducing each contract holder's risk of economic loss from periodic drought.

Each year, approximately 1,055,000 acre-feet of LCRA's stored water is available as *interruptible water.*[13] Interruptible water is sold with the understanding that this water may not be available to the customer during drought periods. Agricultural users were LCRA's only customers for interruptible water, and in 1992 paid $4.50 per acre-foot.

Because the LCRA is responsible for coordinating the distribution of all water in the river basin, every water user who diverts run-of-river or stored water supplies must inform LCRA headquarters in Austin of water requirements at least seven days prior to diverting that water from the river. When run-of-river supplies are not sufficient to meet downstream water requirements, the LCRA releases stored water. After coordinating supply and demand according to the water management plan and allocating run-of-river water to senior water rights owners first, the LCRA charges water users for the stored water they have ordered.

In the past, the LCRA built the expected annual cost of supplying stored water to the irrigation districts into a flat per-acre irrigation rate. Under the new volumetric irrigation rate for farmers, the LCRA passed stored water cost on to individual irrigators according to the volume of stored water that each farmer used. The proportion of water used for irrigation water that is classified as stored water will be higher in dry years when the run-of-river flows are low. On average, the Gulf Coast District diverts less stored water than the Lakeside District because it owns senior water rights relative to Lakeside District. Table 1.2 lists the percentage of irrigation water diverted from the river that has been classified as stored water in previous years.

Overview of the Irrigation Districts

Historical records show that Gulf Coast District has had a greater number of acres under cultivation than Lakeside District. Figure 1.2 shows the number of acres irrigated in each district since 1968. In 1983, the number of acres under cultivation in Gulf Coast District began to drop substantially. Between 1980 and 1987, the number of acres under cultivation in Gulf Coast District dropped about 51 percent. Table 1.3 summarizes some additional characteristics that can be used as a basis for comparing the two irrigation districts.

This drop in acreage in part reflects federal price stabilization programs. The Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture administered programs that encourage farmers to leave up to half their lands unplanted. The program is designed to generate year-to-year stability of crop supply and farm income by restricting the supply of particular crops, raising the prices farmers receive, and reducing the volume of product that reaches the market. As an incentive to participate, farmers are compensated for withholding their lands from production. Because price supports provide a more predictable income for farmers, banks may decide not to lend money to farmers who do not participate in the program.[14]

Each year, the U.S. Department of Agriculture altered its programs to accommodate changing market conditions. Major changes in program rules affect the number of acres irrigated each year. Large reductions in the amount of land under irrigation could jeopardize the district's ability to meet fixed operational and maintenance expenses. Low acreage levels contribute to operational inefficiencies in the districts because irrigated lands are distributed more sparsely. Large quantities of water must be pumped into and through the canals to move water to farmers' delivery structures. This increases the total water diversions per irrigated acre but reduces the total run-of-river and stored water diversions from the lower Colorado River. Figure 1.3 shows each district's total annual diversion of water from the river since 1968.

A decline in the number of acres farmed is not the only source of fluctuating water demands. Many farmers raise a second crop after harvesting the first crop in July. This second crop, also called a "ratoon crop," yields less rice than the first crop but can be profitable because farmers do not incur the costs of field preparation or planting. A farmer's decision to irrigate a second crop may be influenced by delays in the planting of the first crop. If the first crop is delayed, farmers will be reluctant to invest in a second crop because fall rains can make it difficult to harvest.[15] Between 80 to 100 percent of first crop acreage is used for a second rice crop in Lakeside District. Since 1980, the second cropping rate in Gulf Coast District has decreased from a level similar to Lakeside District's second cropping rate. Between 30 and 60 percent of Gulf Coast's first crop acreage is irrigated for a second crop (Figure 1.4). The second crop requires only about half as much water as the first crop because the rice plants are well established by the end of July.[16]

Historical records of per-acre water use reveal a lower rate of water use in Lakeside District than in Gulf Coast District despite similarities in soil and climate. These rates are calculated by dividing total water diversions measured at the pumps on the river by total acreage irrigated during each crop period. Figure 1.5 and Figure 1.6 show per acre rates of water diversion for the first and second crops respectively. Water diversions before

July 30 are attributed to the production of first crop acreage and water diversions after July 30 are attributed to second crop acreage. This date, July 30, was chosen because in most years farmers harvest their first crop in July. However, some farmers first or second crop periods may overlap these dates.

Despite Lakeside District's greater water efficiency, a study concluded that since 1968 the Lakeside District's water use increased at an average rate of 0.023 acre-feet per-acre each year.[17] Lakeside District is the only one of the four districts for which a statistically significant trend indicating ongoing increases in water use had been established.

In 1992, the LCRA's Irrigation Operations Department was part of the Office of Natural Resources (ONR) of the LCRA. At the time of this study, Mr. William West, the executive director of ONR, reported to the general manager of the LCRA. The offices were located at the LCRA's Corporate Headquarters in Austin, Texas. The executive director was responsible for overseeing and approving the activities of four departments (Figure 1.7) including the Irrigation Operations and Water Resources Departments. Water Resources supplied most technical and engineering assistance to the districts. Prior to 1992, responsibility for the overall direction of the Agricultural Water Conservation Program was shared by the Office of Natural Resources and the Office of Conservation and Environmental Protection. In 1992, the Water Resources Department assumed the entire responsibility for agricultural water conservation.

At the time of this study, the LCRA Irrigation Operations Department employed 51 people. With the exception of the manager, the LCRA assigned each employee to one of the two districts (Figure 1.8). The organizational structure in each district was similar. The following discussion outlines the responsibilities of the key individuals involved in implementation of the Agricultural Water Conservation Program.

Mr. Bruce Hicks, manager of the Irrigation Operations Department, assumed responsibility for the Lakeside District when it was purchased by the LCRA in 1983 and assumed responsibility for the Gulf Coast Irrigation District in 1987. He was the senior officer in the Irrigation Operations Division and reported directly to the executive director of the Office of Natural Resources.

When Mr. Hicks accepted his position, the LCRA outlined the objectives they wanted him to achieve. His tasks were to reduce the costs of canal operation, reduce the use of water in the district, and improve customer and employee relations. At the time of this study, he continued to work towards these goals and measured his staff's performance on the same basis.[18] Typically, Mr. Hicks spent about one day each week at the LCRA headquarters in Austin and maintained a central Irrigation Operations Office at the Lakeside District Office in Eagle Lake. He lived in Bay City, the location of the Gulf Coast Irrigation District.

District Superintendents, Area Supervisors, and Water Coordinators

The superintendent of each district reported directly to the manager of Irrigation Operations and supervised the general administrative and supervisory functions of the district. In the Gulf Coast District, the district superintendent's responsibilities also included pump operation and maintenance.

Area supervisors assisted the district superintendent by taking primary responsibility for the functional areas of irrigation operations and maintenance. At the time the study began, there were two area supervisors in Lakeside District. The area supervisor for pump operation and maintenance, Ralph Johnson, supervised the pump operators and ensured that general maintenance and repairs were done. During the irrigation season, he coordinated the flow of water being pumped so that it met the farmers' demands. The second area supervisor, Butch Herman, was responsible for canal maintenance. He supervised the canal maintenance crew and maintenance project contractors working along the canal.

Gulf Coast District also had two area supervisors in 1992. The area supervisor for canal operations, Kelly Weber, provided leadership for the district's six water coordinators. He trained and supervised them in the water measurement project, maintained quality control over the measurement data, and worked to solve problems between farmers and the district. The area supervisor for canal maintenance, Melvin Rouse, supervised the canal rehabilitation project, a canal maintenance work crew, and canal rehabilitation contracts.

Until 1992, three water coordinators staffed each district. In 1992, three additional water coordinators joined each district to accommodate the increased demands of water measurement. Water coordinators were responsible for operating the canal system and providing the LCRA with most of its customer support. Outside of the growing season, when the canal is dry, they work on canal maintenance projects. Table 1.4 lists the water coordinators and their years of service, as of 1992.

Each water coordinator serviced up to 80 delivery structures on an assigned canal section during the irrigation season (see Table 1.4). Water coordinators coordinated the flow of water at canal delivery structures and bulkheads to maintain the proper flow of water through the canal system. Because a farmer's demand for water may change daily, water coordinators worked seven days a week during the rice season. In addition to adjusting canal structures to control and direct the flow of water, water coordinators measured the flow of water into each farmer's field through the use of standardized concrete delivery structures, pipe and valve gates, and electronic Grainland meters.

The job of measuring and managing water flow to meet demand can be complex. Water coordinators exercised considerable judgement in distributing water between farmers and in anticipating weekly demand.[19] Water coordinators often worked closely with farmers to meet changing needs like increases in the demand for water and used their judgement to predict demand for the following week so that the districts could report expected water diversions to the LCRA. As a result, each water coordinator developed extensive knowledge about his section of the system and worked only on an assigned section of the canal. Both districts have considered cross-training water coordinators on different canal sections to reduce the limitations imposed by this constraint.[20]

Prior to 1993, there were no standard performance measures developed for water coordinators. Beginning in 1993, performance ratings were based on the ability to accurately measure water flow as determined by supervisory spot checks and customer satisfaction.[21] Although water coordinators recognized that accuracy was important, Gulf Coast District water coordinators argued that their real priority was to keep LCRA managers and customers happy. Lakeside District water coordinators echoed this sentiment.[22]

Canal Operations, Customer Contacts, and Ordering Water

Each district operates its canal system between mid-March and the end of October. The canals are drained in November when district personnel begin working on maintenance and improvement tasks until the next growing season. The agricultural water conservation program is an integral part of both halves of this annual cycle. The following section outlines the activities in the districts and gives special emphasis to those activities that are particularly relevant to the Water Measurement and Canal Rehabilitation Projects.

Operation and maintenance expenses in the LCRA irrigation districts are met exclusively by revenues from the sale of irrigation services. The districts forward the revenues to the Austin office that maintains a current account. The manager of irrigation operations and district superintendents draw on this account to meet the expenses of labor, equipment, and supplies for canal operation and maintenance.

Labor and electric utility costs for pump operation make up the bulk of operational expenses. During rainy years, rice requires less irrigated water than in dry years and the reduced need for electricity to pump water from the river generates savings. The district must also meet fixed costs associated with the year-round operation and maintenance of the canal system regardless of the amount of water sold. The districts traditionally established water rates on the basis of the number of acres of farmland irrigated. In 1993, the districts began charging customers on a volumetric basis in addition to a reduced per-acre rate.

In the Lakeside Water District, the Water Measurement Project (described on page 10) led to an increase in overtime labor costs despite an increase in total district staffing. Although the district budgeted regular and overtime pay for six water coordinators, labor pay ran six percent over budget in fiscal year 1993. In addition, transportation fuel costs were higher than expected.[23]

The process of arranging irrigation services with farmers begins after the fall harvest. The LCRA contacts farmers to determine which fields will be planted in the upcoming year. Because farmers plant their fields in three- or four- year rotations, the combination of fields that are farmed and the delivery structures that are used change from year to year. During this period, Gulf Coast District personnel also survey each farmer's field to determine the acreage under cultivation. These acreage determinations have served as the basis for billing farmers on a per acre basis. In the Lakeside District, fields tend to be more permanent and there is less need to keep up with changes. District personnel feel that the maps they have created over the years are a reliable source of acreage figures and surveys are no longer necessary.[24]

During the meetings prior to the irrigation season, district personnel discuss the configuration of the field and the needs for additional or modified water delivery systems. Farmers in Gulf Coast District may make changes to the configuration of their levees from year to year in addition to rotating fields.[25] Because temporary levees are more likely to break under stress during heavy rains and contribute to an inefficient use of water in the districts, there is a policy of discouraging this practice in the districts. Talking with farmers about their water delivery systems also provides an opportunity to reduce the number of delivery structures which will be used and promote the use of in-field laterals as water conservation devices. With advance planning, farmers can sometimes share delivery structures by altering the days on which they receive water.

Once the acreage is established and the plans for delivery of water to a farmer's fields are complete, the farmers and the LCRA sign a contract for irrigation services. That contract establishes the water rates, the areas to be irrigated, and the rights and obligations of both parties. The contract represents the only source of information on the rules and regulations of the irrigation districts.

The contract requires farmers to order water six days before actual delivery. Prior to 1992, farmers contacted the district office or met with the water coordinator in the field. Because office personnel are unfamiliar with the complex physical details of the canal systems, this method was a major source of confusion.[26] According to some reports, some farmers may have used the inability to contact the water coordinator as an excuse for allegedly tampering with control structures. In 1992, the LCRA purchased cellular phones for water coordinators to simplify the process of ordering water.

As of 1992, the process of ordering water varied between districts. Gulf Coast District farmers continued to call the office to order water. Lakeside District farmers were required to speak directly with the water coordinator in charge of their canal section. Attempts at standardizing water-ordering procedures led to the practice of logging farmer communication with water coordinators. Water coordinators in the Gulf Coast District carried notebooks in which to record conversations with farmers. The record serves as an aid in remembering the specific orders as well as for settling disputes concerning how much water a farmer has ordered, which field it was for, and when it was wanted. The number of complaints declined under the new system.[27]

The irrigation service contract states that farmers are required to place their orders for water from the irrigation districts at least six days in advance of the actual delivery date. In practice, however, water is delivered to customers on shorter notice. Lakeside District water coordinators reported that it is generally no problem to supply water to farmers with one day of notice.[28] Gulf Coast District water coordinators reported that, in 1992, no farmers waited more than three days for water.[29] Enough water flows through the canal system so that water coordinators can generally juggle water between farmers to meet demand on short notice.[30]

Farmers ordered water in "boxes." For the purpose of the districts' water accounting methods, one box of water is equivalent to a rate of flow of 3,000 gallons per minute. The concept of the water box, as a unit of flow measure (3,000 gal/min), has been a central part of the Lakeside District's water accounting methodology for many years; it has now been introduced in the Gulf Coast District. Standardized concrete delivery structures are designed to distribute this amount of water to the field. If a farmer ordered one box of water, however, he might not receive water at a rate of 3,000 gallons per minute; water coordinators deliver water at a rate that, in their judgement, is consistent with the volume of water needed to adequately water a field. The farmer does, however, receive an adequate flow of water to satisfy his needs.[31] Districts calculate the total volume of water delivered by determining the average flow rate over the period of water delivery based on daily measured flow rates.

In the past, farmers ordered continuous small streams of water to satisfy the losses incurred from evaporation and transpiration. In an effort to improve watering practices by encouraging farmers to take bulk water deliveries rather than smaller streams of water, in 1991 Lakeside District placed stricter limits on how water is delivered, requiring farmers to order water in increments of one full box.[32] Deliveries are automatically discontinued and water is reallocated to another farmer when the field is full. Bulk water deliveries increase the efficient use of water in the districts by reducing the level of water that must be maintained in the canal at any one time and by increasing the speed at which water travels from the upper to the lower end of fields.

Pumping Water

Water coordinators submit irrigation water orders to the District Office where pump managers coordinate the water-pumping rates to meet the demand. The Lakeside District system was automated in 1990 so that a single Lakeside District plant operator can operate all plants electronically and similar plans were made to automate the pumping plants at Gulf Coast District. Central operation of the plants reduces labor costs and enhances the ability of the staff to coordinate the pumps to meet demand more precisely. Appendix A contains a listing of pumping plant capacities. The pumping capacity of each plant provides an indication of the flexibility that pump managers have in coordinating water flow to meet the demands of the system.

In 1992, the Gulf Coast District had three pumping plants that drew water from the Colorado River. The Lakeside District had one plant that drew water directly from the river and two re-lift plants that raised water to higher elevations. The flow of water in Lakeside canals could also be supplemented with water from one of six groundwater pumps. In 1992, groundwater pumps accounted for 1.37 percent of the water supply.

Problems with water measurement and water accounting can exaggerate water use on the irrigation districts. When Bruce Hicks took over at the Gulf Coast Irrigation District in

1987, the irrigation pumps on the river had not been rated to determine their pumping capacity in several years. The discrepancy between actual pump ratings and theoretical ratings resulted in an over-estimate of water use in the district. Regular maintenance and annual pump ratings have contributed to reductions in total reported diversions.

Some personnel have attributed much of the difference in water use between districts to the coordination of pump operations with water demands in the district.[33] In Lakeside District, the pumps have always been monitored closely to meet the demand as precisely as possible. Delivery structures are standardized and the rate that water is pumped into the canal is regulated to match the amount of water being delivered to the fields. Lakeside District has an overall advantage over the Gulf Coast District in accounting for water flow because re-lift plants in each main canal provide verification of the volume of water flowing through the canal system.

In addition to regulating the flow of water, Lakeside personnel curtail the supply of water during rainy periods.[34] Even during light rains, pump managers will turn the pumps off for up to two days. This reduces water use in the irrigation district by allowing rainwater to accumulate in the rice fields.

Prior to 1987, there had been no real effort to control the rate of water flow in the Gulf Coast District; the water management policy was to keep the canals full of water so that all farmers could draw on the system continuously. There were two reasons for using this operating style. First, district personnel were concerned that turning pumps on and off could lead to higher maintenance costs. Second, there was no accurate water accounting system available, and the only way to ensure an adequate supply of water for the farmers at the end of the line was to keep the canals full.

Water Measurement

The *Water Measurement Project* was an effort to improve control over the flow of water and the water accounting system in both districts. Water coordinators start at the head of their assigned stretch of the canal and work downstream, adjusting the level of water in canal sections, and adjusting and measuring the flow of water at field delivery structures. In 1992, Lakeside District water coordinators visited and measured the flow at operational delivery stations daily. Through the 1992 season, Gulf Coast District water coordinators measured flow rates only when they initiated the delivery of water or changed the rate of flow. By comparing these results with Lakeside District's data, LCRA managers confirmed their hypothesis that daily observations at delivery structures could yield a much more accurate determination of the volume of water delivered to a farmer.[35] In 1993, water coordinators on Gulf Coast District began taking daily measurements at all delivery structures.

A key issue limiting the public acceptability of volumetric irrigation pricing is the farmers' acceptance of the water measurement methodology. The U.S. Bureau of Reclamation (the Bureau) independently certified the accuracy of the LCRA's methods of water measurement in a laboratory setting.[36] In general, the accuracy of water measurement increases with the frequency of measurement, the rate of water flow, and the head differential at the delivery structure. Despite this, some farmers believe that fluctuations in the head differential due to changes in the level of water in the canal will influence delivery rates over the course of a day and that intermittent sampling will not account for these changes.

Flow rates are determined by recording the size of the opening and the height of the water on both sides of the canal structure to the nearest one-hundredth of a foot. Water coordinators use current meters, mechanical wands that can be easily transported between delivery structures to determine the rate of flow at pipe turnouts. According to both LCRA managers and water coordinators, the process is a simple one and measurement errors are not common. Several options have been proposed to verify the accuracy of the measurements taken by water coordinators. One method would entail the use of "independent monitors" who could independently verify LCRA's results for farmers. Another possibility would be to teach farmers how to verify water measurements.

One apparently intractable issue throughout the development of the water measurement project was the irrigation of lands that have a higher elevation relative to the canal than others. Because of their elevation, there is neither a strong enough flow of water nor a large enough head differential to ensure accurate measurement. The LCRA considered the proposal that these farmers be required to purchase and use metered re-lift pumps but rejected this solution because of the concern that this expense would force these farmers to stop irrigating those fields.[37] This decision would have contributed to the more general problem of declining acreage. In 1993, the LCRA solved the problem by introducing "global flow meters" that can measure water velocity at 0.1 feet per second.[38] In contrast, the standard propeller meters are only accurate to a minimum velocity of 0.5 feet per second. Global flow meters may be used at either pipe turnouts or water boxes. These are handheld devices, costing $200 to $300, that work with pipe and valve gate systems. The LCRA has 20 of these devices.[39]

Water coordinators' lack of access to field delivery structures was also a problem. Gulf Coast District water coordinators have an advantage over the Lakeside District water coordinators because most of the Gulf Coast District canal system is accessible by a service road which runs along the dike itself. In Lakeside District, the dike is too small to build a road, so water coordinators must use a combination of the main county roads and farm service roads to access the canal structures. Because many of the roads are unsuitable for pickups, Lakeside District managers purchased all-terrain vehicles for water coordinators to use in reaching the canals.[40]

To coordinate the collection of water measurement data and volumetric billing, the Bureau developed a water accounting database. The database includes information about the location, size, and type of each structure used to measure water. Responsibility for management of the water accounting database and data entry has been delegated to one water coordinator in each district who enters the raw flow measurement data provided by all of the water coordinators. The project then calculates the rate of flow and the volume of water delivered to each field. Reports can be designed for any segment of the canal or for any specified time period for which the data are available.[41]

Under the old per-acre rate system, each district billed water customers after the first crop and again after the second crop. With the conversion to a volumetric pricing system, farmers' bills were prepared once at the end of the irrigation season. During the season, farmers could contact the districts and inquire about the status of their water use. Information on the amount of water used to date was designed to be available to farmers three days after receipt of the last water delivery. Farmers were also to be told how much of the water they used was classified as stored water.

Managing On-Farm Water Use

At the time of this study, district personnel were preparing a comprehensive handbook of policies and procedures for the irrigation districts.[42] The water contract establishes a few basic rules for ordering water and for providing irrigation services, but it is not comprehensive. The objective of the handbook was to create standard guidelines to improve relations and establish groundrules for communication between farmers and the LCRA.

According to the manager of Irrigation Operations, the LCRA has sought to develop a set of rules and procedures that is effective but non-confrontational. Mr. Hicks believed that any sanctions for breaking the code should be minimal. District employees who have more frequent contact with LCRA customers would prefer a more stringent set of standard procedures for initiating and severing water deliveries to discourage farmers from tampering with delivery structures or taking unauthorized deliveries of water.[43]

Texas state law forbids farmers from making changes to the rate of flow at farm delivery structures.[44] District policy regarding this issue conforms to this standard. However, water coordinators have not always applied this policy consistently. In the past, when farmers have made requests for water, water coordinators have sometimes given them instructions to go out and adjust the farm delivery structure themselves.[45] The districts recognize that several farmers have also made a habit of adjusting control structures without contacting the water coordinator.[46] By adjusting control structures, farmers could cause distribution problems in the canal system, a practice that could undermine the integrity of the LCRA's water measurements.

The LCRA districts are interested in controlling on-farm water use as well as the operational use of water in the canals. Because the cost of pumping water represents such a large portion of district operating costs and on-farm water use offers the potential for significant water savings, on-farm water conservation efforts could reduce the cost of irrigation services. During the early stages of the program, farmers gained information on techniques for improving on-farm water efficiency through the "Less Water-More Rice" research project.

One source of inefficient on-farm water use was the practice of taking water in a continuous stream. In Gulf Coast District, farmers used these flows to maintain holding streams that reduce the time and effort required to tend fields. When farmers use a holding stream, there is a continuous flow of water moving through the field and over the dike. Pricing incentives may encourage some farmers to eliminate these kinds of losses.

The elimination of holding streams will reduce the total amount of water flow that is needed in the canals. An order on/order off water delivery policy will force farmers to take bulk water deliveries with several days between watering. If farmers take their water in bulk deliveries with several days between watering, water coordinators can juggle the water between farmers while maintaining a lower total flow of water in the canal.[47] The practice also reduces the number of days between a farmer's water order and deliveries, which allows a more consistent flow of water in the canal.

Without holding streams, farmers tend fields more often.[48] Water coordinators in both districts report that this is the greatest single improvement farmers can make in their watering practices. Because it is more labor intensive, water coordinators anticipate that farmers who rely on field hands to check the water levels will suffer more from this change than will small independent farmers. Farmers with many fields can trust workers to perform the task of checking a holding stream but may not be able to delegate the task of making qualitative visual judgements on the level of water in a field.

Another method of on-farm water conservation is the use of multiple delivery points to evenly distribute the flow of water in a field.[49] However, there is a tradeoff associated with this practice. Multiple delivery points place a burden on the irrigation district by raising the number of delivery sites that must be serviced. In-field laterals reduce the number of delivery points directly on the canal and ease the water coordinator's workload. To solve this problem, the districts may even begin to assist farmers in designing and building in-field laterals.[50] Many of the on-farm water conservation methods that have been promoted through the "Less Water-More Rice" research project require capital investments to improve the structure of the field. Tenant farmers have little incentive to improve the fields by laser-leveling or constructing permanent levees and in-field laterals because they do not own the land they farm.

Canal Maintenance

Canal maintenance is a year-round project in the irrigation districts. During the irrigation season, workers clear debris from delivery structures, control canal bank vegetation, and cut back aquatic weeds. However, most of the maintenance work takes place in the off-season after the canal has been drained for the winter. Between November and March, district personnel focus attention on the following tasks: repairing and maintaining pumps, clearing vegetation, removing sandbars, desilting the canal bed, ripp-rapping or constructing bulwarks, and installing and repairing delivery structures.

Each district employs a small, full-time maintenance crew and water coordinators assume maintenance responsibilities during the non-irrigation season. Contract services are frequently used to supplement these efforts. Maintaining a large field crew is inefficient when work is interrupted frequently by rainy weather. Even small rains can make operating heavy equipment in and around the canals difficult.

Even under private ownership, Lakeside Irrigation District always placed a heavy emphasis on regular preventive maintenance. During the same period in the Gulf Coast District, there was a somewhat less aggressive approach to general canal maintenance. There are several important components of a comprehensive maintenance program.

The first of these is the control of bankside vegetation. Prior to the canal rehabilitation project, the Gulf Coast District canal system had become overgrown with brush and trees that actively draw water from the canal. Canal bank vegetation grows quickly; some reports estimate that one twelve-foot tree can draw as much as 300 gallons of water from a canal in one day.[51] In Gulf Coast District, the area supervisor for canal maintenance estimated that it takes two months to mow the entire canal system once the canal has been cleared of brush and trees. The "ground cover project" is LCRA's effort to find a suitable grass species to plant on the canal banks. An ideal species would be a strong competitor with easy maintenance requirements.[52]

Floating aquatic plants like alligator weed (*Alternanthera philoxeroides*) and smartweed (*Polygonum* spp.), which grow and regenerate quickly, have become an increasingly burdensome problem in the Gulf Coast District.[53] They increase the rate of sedimentation and clog delivery structures. Two possible reasons for the increase in aquatic vegetation in the Gulf Coast District are a reduction in the number of nutria (*Myocaster coypu*) and a reduction in the amount of water flow. An overall reduction in the number of acres farmed since 1980 has meant that less water needs to be pumped into the canal. Another possible cause might be warmer-than-average winters. Freezing can help control these weeds, but no more than a few light frosts have occurred in the area over the past several years.[54]

Gulf Coast and Lakeside District personnel report that the most difficult task in controlling aquatic vegetation is finding an effective herbicide that has been approved by the EPA.[55] Even if a herbicide were available, Gulf Coast District personnel report that they have neither the maintenance funds nor the personnel to implement a comprehensive spraying program.[56]

Leaks are a major structural problem in some sections of both canal systems. In the Gulf Coast District, the area supervisor for canal maintenance estimates that leaks cause 20 percent of the water loss in the canal system. Ordinarily, the district repairs leaks as soon as possible at the end of the irrigation season, but they repair particularly serious leaks during the irrigation season. District personnel perform an operational hydraulic analysis during the irrigation season to minimize damage from acute problems such as leaks.[57] Leak detection and analysis is an art developed by district staff based on experience with the irrigation system.[58]

As part of this analysis, Gulf Coast District personnel make bimonthly overflights of the canal system in an airplane. The information gathered on these flights is particularly useful in locating leaks. Until 1983, overflights were conducted in the Lakeside District using a district-owned helicopter. Lakeside District personnel reported that although they do an occasional overflight in fixed wing aircraft, the visibility and usefulness of these flights is much less than those using helicopters.[59]

Conclusions

Several operational differences appear to account for the disparity in water efficiency between the two districts. Lakeside District's canal maintenance program, regular pump ratings, and water-ordering policies provide a contrast to past management practices in the Gulf Coast District. Since 1987, efforts to improve the operations in Gulf Coast District, standardize management practices and customer relations, and improve on-farm water management were geared towards increasing overall water efficiency.

One important factor that seems to be related to changes in water efficiency in the districts is acreage. Both first and second crop acreage under irrigation in the Gulf Coast District are well below historic levels. As acreage decreases and rice fields become more sparsely distributed, water efficiency decreases. The LCRA has initiated several programs to improve efficiency but has not dealt with the issue of fluctuating acreage levels. Thus, an increase in the amount of irrigated acreage during the crop season could improve the performance of the irrigation districts.

As this summary of district operations shows, many changes are taking place in the districts. Each of these changes is being made with the goal of reducing total diversions. Chapter two discusses the development, implementation, and funding of LCRA's agricultural water conservation program.

Notes

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[1] Senate Bill 2, 43rd Legislature, 4th Called Session (1934).

[2] Lower Colorado River Authority (LCRA) and U.S. Bureau of Reclamation (USBR), *Water Management Study of the Lower Colorado River Basin* (Austin, Texas, November 1992).

[3] Texas Agricultural Statistics Service, *1992 Texas Crop Statistics* (Austin, Texas, 1993).

[4] U.S. Bureau of the Census, *1992 Census of Agriculture, Volume 1: Geographic Area Series, Part 43: Texas State and County Data* (Washington, DC, 1989). Note that this accounts for farms with sales over $10,000. Value of rice production was determined by using the amounts reported for "Other Grains."

[5] Quentin Martin, "Economic Evaluation of Rice Cropping Alternatives," (Austin, Texas: LCRA October 19, 1990).

[6] The Lower Colorado River Authority (LCRA), *Drop by Drop: The Life Cycle of the Lower Colorado River Basin* (Austin, Tex., October 1997), p. 8.

[7] *Ibid.*, p. 5.

[8] Texas, 264th Judicial District, "Final Judgement and Decree," (Bell County, Texas, April 20, 1988).

[9] LCRA, "Water Management Plan, Volume I: Policy and Operations" (draft), (Austin, Texas, March 1988).

[10] LCRA, "Water Management Plan, Volume II: Technical Report" (draft), (Austin, Texas, March 1988), pp. 2-33.

[11] Kevin Crittendon, Engineer, Water Resources, LCRA, interview by Martin Schultz, January 25, 1993.

[12] LCRA, "LCRA Drought Management Plan," (Austin, Texas, July 11, 1990), p. 11.

[13] LCRA, "Water Management Plan, Volume II," pp. 2-33.

[14] Kevin Humphrey, Executive Director, Colorado County Agricultural Stabilization and Conservation Service, Columbus, Texas, telephone interview by Martin Schultz, December 14, 1992.

[15] Quentin Martin, "Estimation of Climatic Influences on the Monthly and Annual Colorado River Diversion for Rice Irrigation in the LCRA District," (Austin, Texas: LCRA, April 1988).

[16] *Ibid.*

[17] Quentin Martin, "Evaluation of Alternative Rice Cropping Decisions," (Austin, Texas: LCRA, October 19, 1990), p.15.

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[18] Bruce Hicks, Manager, Irrigation Operations, LCRA, interview by Martin Schultz, November 17 and December 15, 1992; January 26, and February 17, 1993.

[19] *Ibid.*

[20] Mike Shoppa, District Superintendent, Lakeside Irrigation Division, LCRA, Eagle Lake, Texas, interview by Martin Schultz, January 19, 1992.

[21] Hicks interview, 1992.

[22] Various Water Coordinators, LCRA, Lakeside and Gulf Coast Irrigation Districts, Bay City, TX and Eagle Lake, TX, interviews by Martin Schultz, November 18-19, 1992.

[24] Shoppa interview, 1992.

[25] *Ibid.*

[26] Melvin Rouse, Area Supervisor, Canal Maintenance, Gulf Coast Irrigation Division, interview by Martin Schultz, November 18, 1992.

[27] Various Water Coordinators interviews, 1992.

[28] *Ibid.*

[29] *Ibid.*

[30] *Ibid.*

[31] Hicks interview, 1992.

[32] Alton Herman, Crew Leader, Canal Maintenance, Lakeside Irrigation District, Eagle Lake, Texas, interview by Martin Schultz, December 15, 1992 and November 19, 1993.

[33] Shoppa interview, 1992.

[34] *Ibid.*

[35] Herman interview, 1993.

[36] Hicks interview, 1992.

[37] Jobaid Kabir, "Technical Memorandum 1: The Technical Feasibility of Water Measurement," (Austin, Texas: LCRA, November 1991).

[38] Memorandum from Mike Personett, Bruce Hicks, and Angie Taylor, LCRA to Agricultural Water Conservation Task Force Members, July 31, 1990.

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[39] Hicks interview, 1993.

[39] Jobaid Kabir, Senior Engineer, LCRA, Eagle Lake, Texas, telephone interview by George Purcell, November 4, 1999.

[40] Shoppa interview, 1992.

[41] LCRA and USBR, *Water Management Study.*

[42] Hicks interview, 1992.

[43] Shoppa interview, 1992; Various Water Coordinators interviews, 1992.

[44] Hicks interview, 1993.

[45] Mike Personett, former Manager, Water Efficiency Department, Office of Conservation and Environmental Protection, LCRA, Austin, Texas, interview by Martin Schultz, March 8, 1993.

[46] Shoppa interview, 1992.

[47] Hicks interview, 1993.

[48] Various Water Coordinator interviews, 1992.

[49] Texas Agricultural Experiment Station, U.S. Soil Conservation Service, and Texas Rice Research Foundation, "Less Water-More Rice," (Beaumont, Texas, n.d.).

[50] Shoppa interview, 1992.

[51] Rouse interview, 1992.

[52] Hicks interview, 1992.

[53] Rouse interview, 1992.

[54] *Ibid.*

[55] Shoppa interview, 1992.

[56] Rouse interview, 1992.

[57] Hicks interview, 1992.

[58] Henry Bradford, District Superintendent, Gulf Coast Irrigation District, LCRA, interview by Martin Schultz, November 17, 1992.

[59] Shoppa interview, 1992.

Table 1.1
Irrigation District Water Diversions in 1992

District	First Crop Acreage	Total Water Diversions (Acre-Feet)	Average Water Use per Acre
Gulf Coast	26,850	132,967	4.95
Lakeside	28,827	131,014	4.54
Pierce Ranch	4,720	55,416	11.74
Garwood	20,421	92,681	4.54

Source: Lower Colorado River Authority, "Report of Surface Water Use," (Austin, Texas, January 1993); and Texas Water Commission, "Report of Surface Water Use for Year Ending December 31, 1992," (Austin, Texas, March 1993).

Note: One acre-foot equals 1,230.26 cubic meters.

Table 1.2
Percent of Irrigation Water that is Stored Water, 1989-93

Year	Lakeside District (percent)	Gulf Coast (percent)
1989	59.41	36.15
1990	42.80	45.74
1991	56.17	13.05
1992	11.61	0.00
1993	54.92	53.84

Source: Lower Colorado River Authority, "Texas Water Commission Report of Surface Water Use," (Austin, Texas, March 1990-92).

Note: Figures represent the volume of stored water used for irrigation on the LCRA irrigation districts as a percentage of total diversions.

Table 1.3
Characteristics of Lakeside and Gulf Coast Districts

	Lakeside District	Gulf Coast District
Acre-feet of water rights as adjudicated in 1988	131,250	262,500
Estimated mileage of canal system	275	375
Estimated maximum arable acreage	122,455	400,000
Number of customer contracts 1992	94	149
Number of acres irrigated 1992	26,850	28,827
Percent of acreage irrigated for second crop in 1992	83%	31%
Number of farm delivery structures Serviced in 1992	306	375
Water boxes	224	64
Pipe turnouts	82	304
Grainland meters	0	7

Sources: Lower Colorado River Authority, "Fact Sheet - Irrigation Operations/Lakeside," Eagle Lake, Texas, n.d.; Bruce Hicks, Manager, Irrigation Operations, LCRA, Bay City, Texas and Eagle Lake, Texas, interviews by Martin Schultz, November 17, 1992 and January 26, 1993.

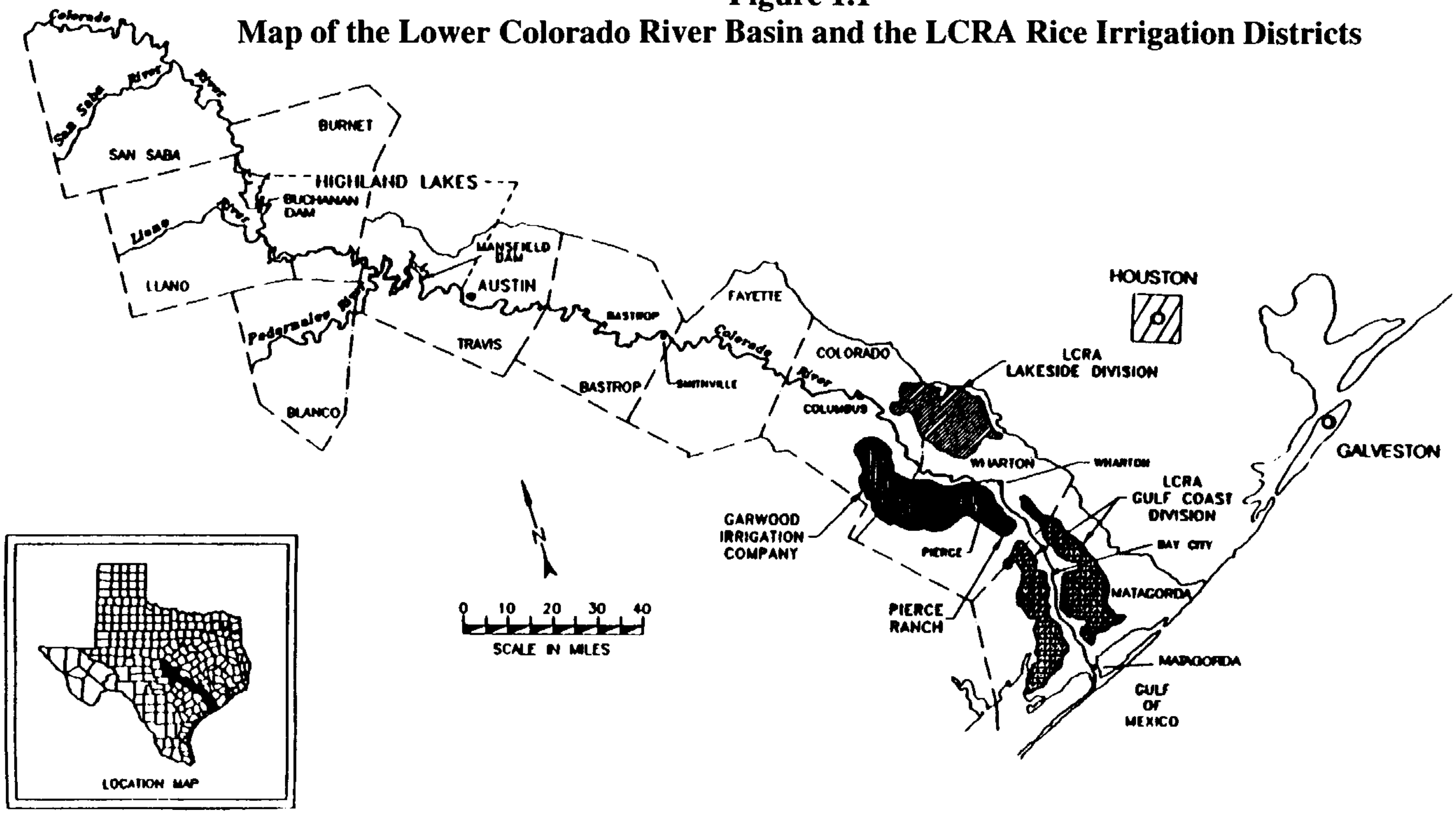
Table 1.4
Water Coordinator Experience Levels and Work Loads, 1992

Gulf Coast Districts	Years of Service	Delivery Structures Serviced in 1992
Manuel Benavides	22	84
Al Denham	2	80
Raymond Chavez	1	67
Gale (Monty) Kramer	13	68
Craig Kucera*	1	56
James Vacek	12	67
Lakeside Districts		
Cody Breeding	10	69
Dave Ellis	16	52
Randy Epps*	1	63
Len Matula	1	46
Joe McReary	17	41
Alex Ramirez	1	39

Source: Various District Water Coordinators, Lower Colorado River Authority, Lakeside and Gulf Coast Irrigation Districts, Eagle Lake and Bay City, Texas, interviews conducted November 18-19, 1992.[1]

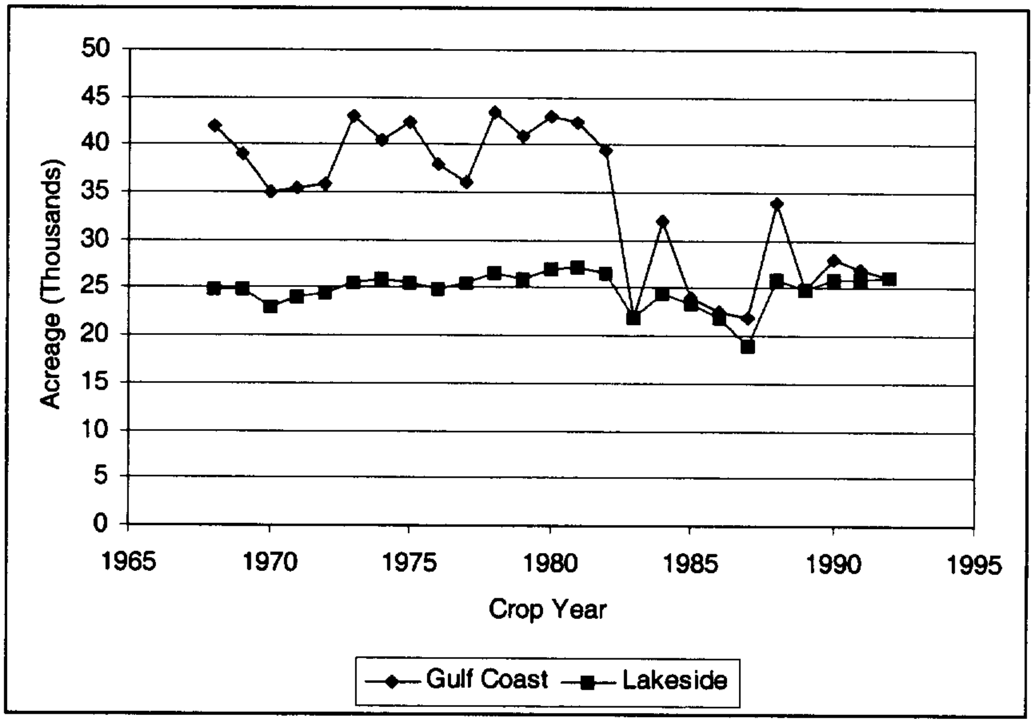
Note: All figures are self-reported by the water coordinators. Asterisks (*) indicate those water coordinators who also have primary responsibility for the water accounting database.

Figure 1.1
Map of the Lower Colorado River Basin and the LCRA Rice Irrigation Districts



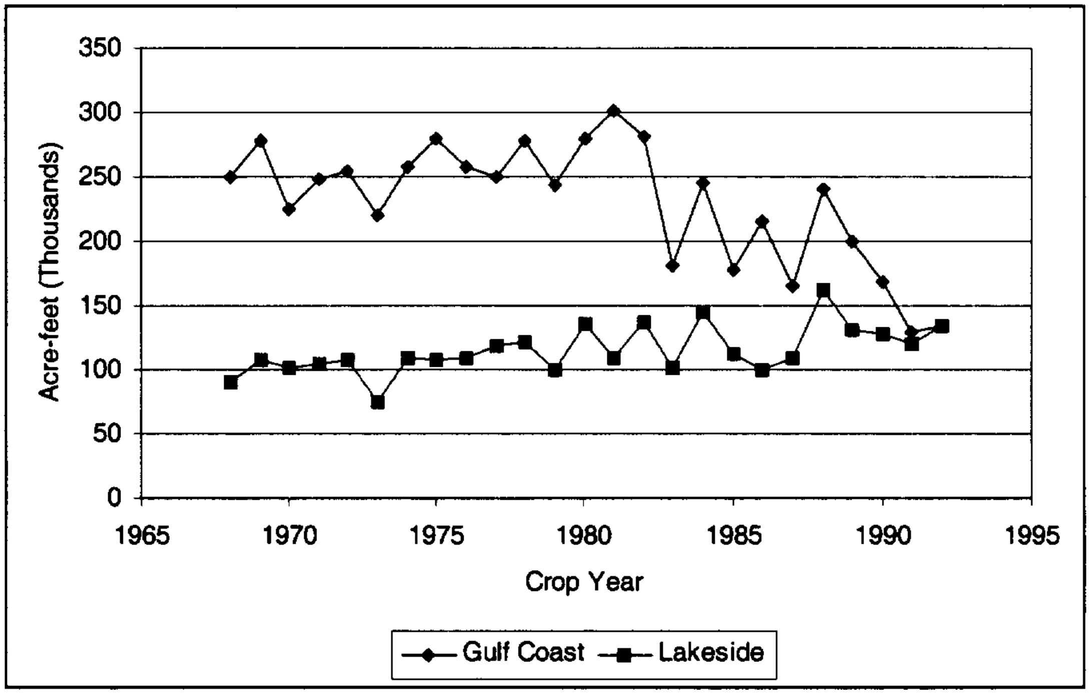
Source: Lower Colorado River Authority and U.S. Bureau of Reclamation, "Water Management Study of the Lower Colorado River Basin," (Austin, Texas, November 1992). (Special Report.)

Figure 1.2
First Crop Acreage



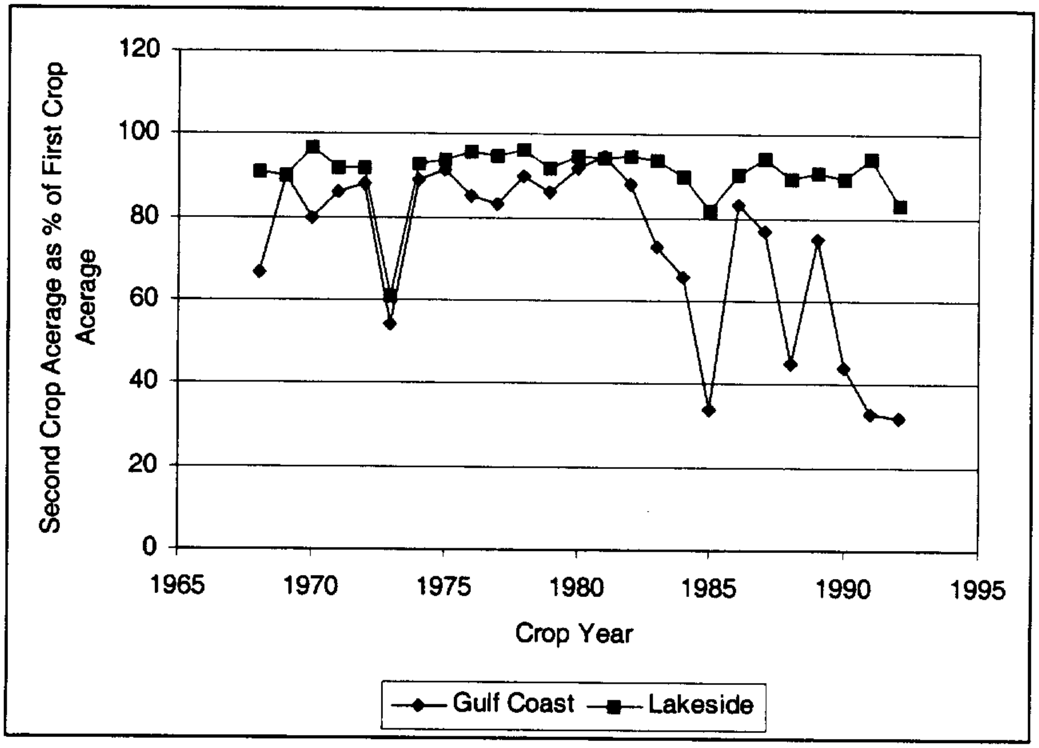
Source: Derived from data provided by Quentin Martin, Water and Wastewater Utilities, Lower Colorado River Authority (Austin, Texas, 1993).

Figure 1.3
Annual Water Diversions



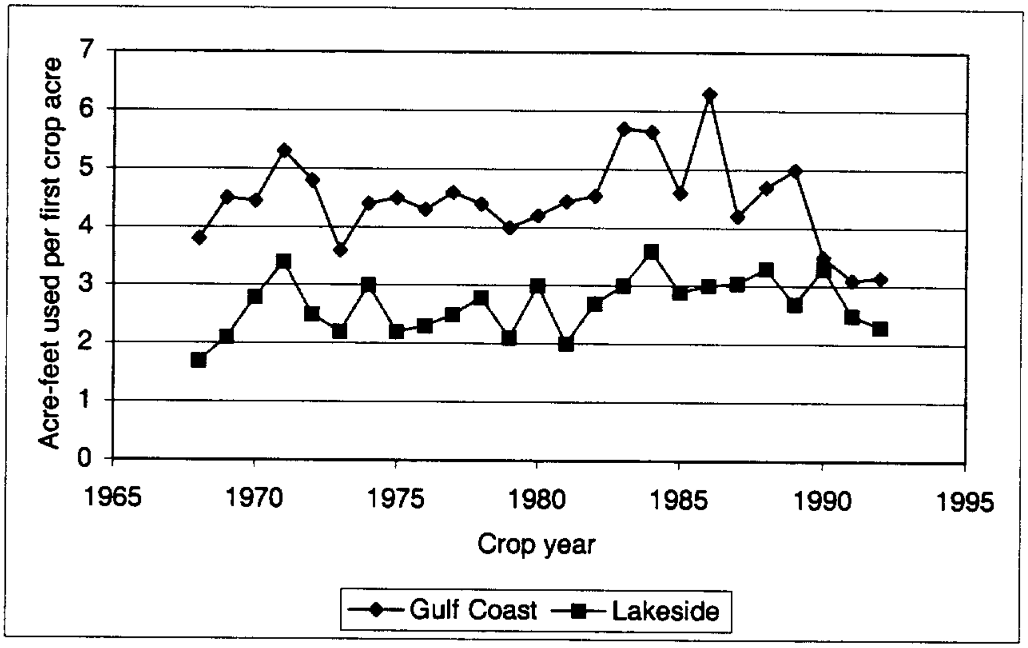
Source: Derived from data provided by Quentin Martin, Water and Wastewater Utilities, Lower Colorado River Authority (Austin, Texas, 1993).

Figure 1.4
Second Crop Acreage



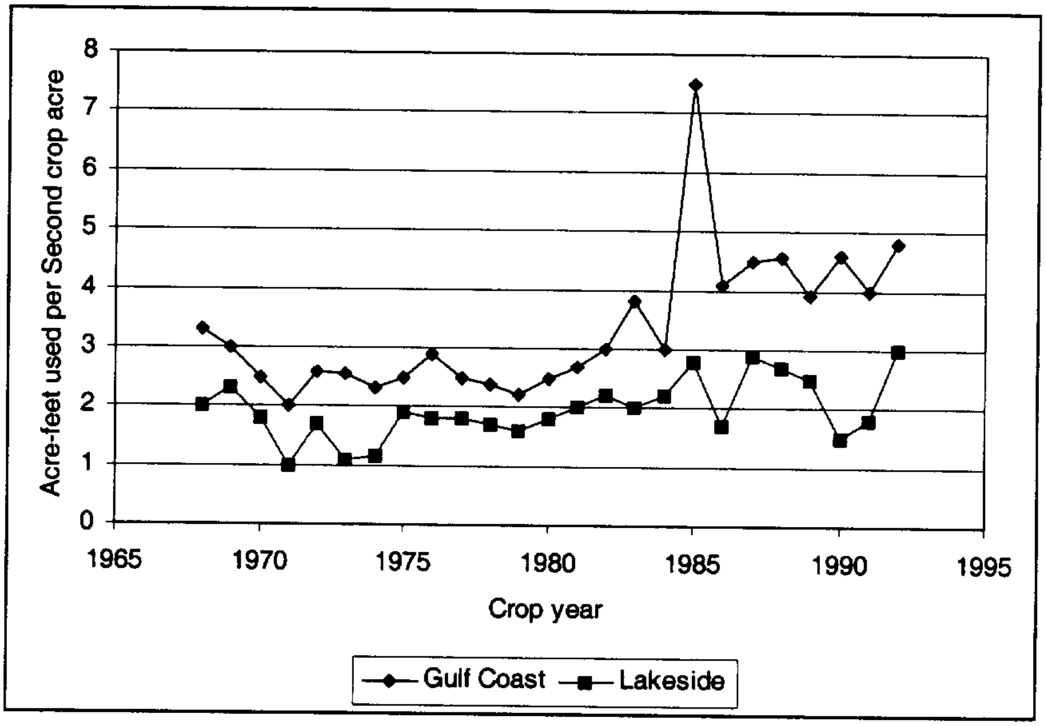
Source: Derived from data provided by Quentin Martin, Water and Wastewater Utilities, Lower Colorado River Authority (Austin, Texas, 1993).

Figure 1.5
First Crop Water Efficiency



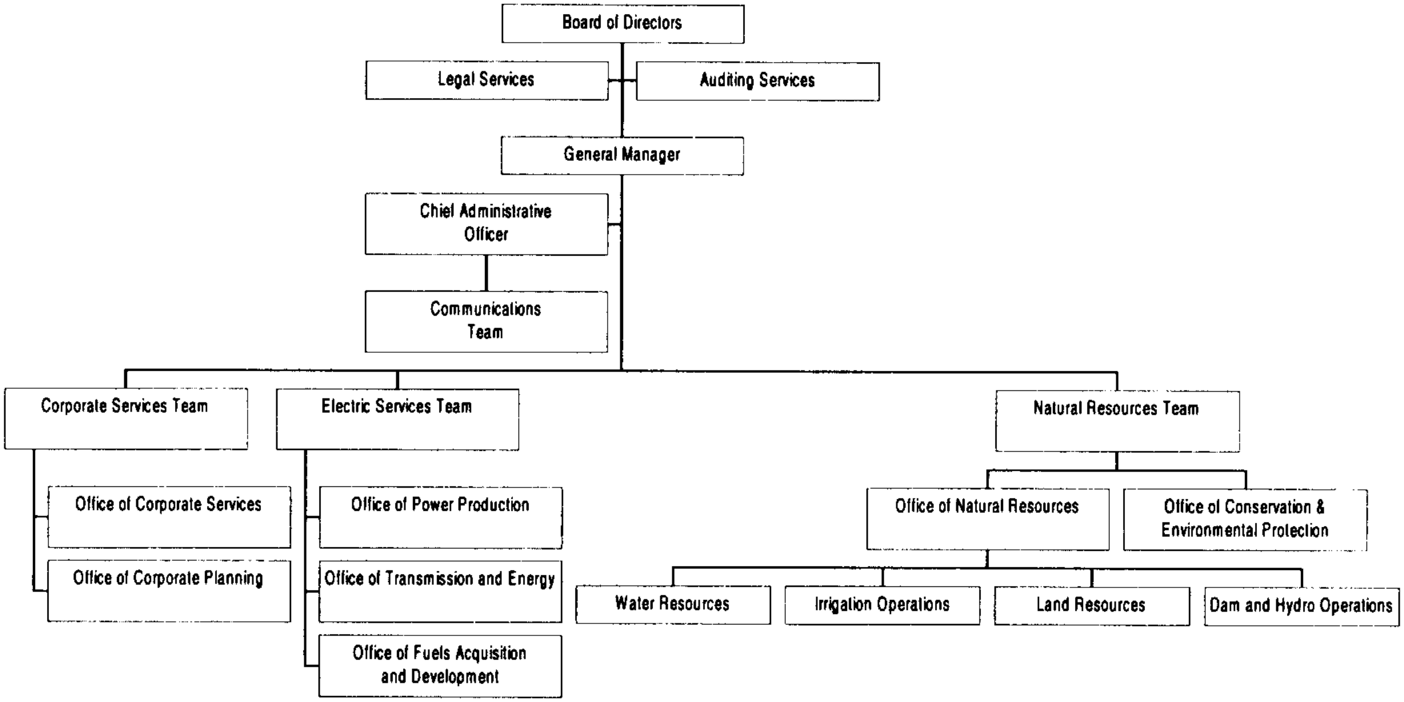
Source: Derived from data provided by Quentin Martin, Water and Wastewater Utilities, Lower Colorado River Authority (Austin, Texas, 1993).

Figure 1.6
Second Crop Water Efficiency



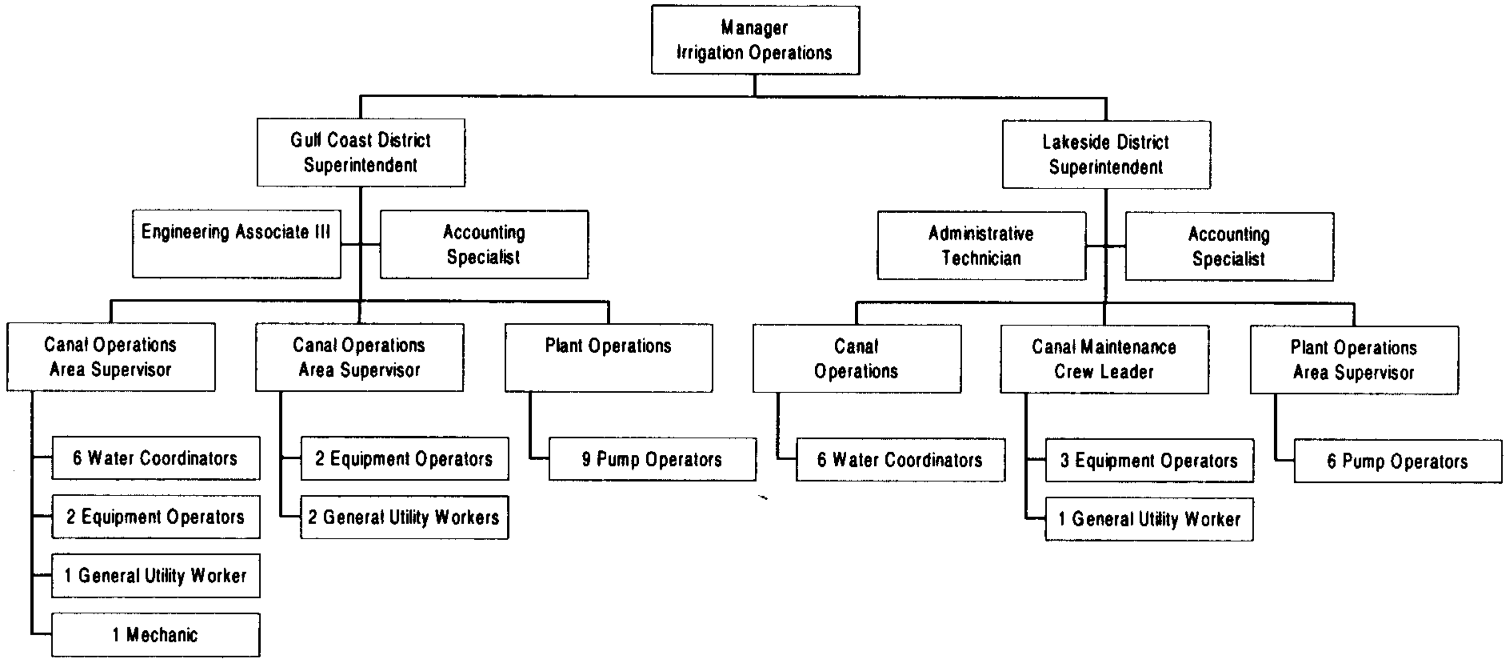
Source: Derived from data provided by Quentin Martin, Water and Wastewater Utilities, Lower Colorado River Authority (Austin, Texas, 1993).

Figure 1.7
Organization of the LCRA



Note: Adapted from *Guide to Texas State Agencies*, 8th ed. (Austin, Texas: LBJ School of Public Affairs, The University of Texas at Austin, 1994).

Figure 1.8
LCRA Irrigation Operations Division



Note: Adapted from *Guide to Texas State Agencies*, 8th ed. (Austin, Texas: LBJ School of Public Affairs, The University of Texas at Austin, 1994).

Chapter 2. LCRA Water Conservation Policy

The Lower Colorado River Authority's (LCRA's) agricultural water conservation program has sought to maximize the operational efficiency of the canal systems, create water conservation incentives through the use of a volumetric rate structure, and promote on-farm water conservation through the use of better farm water management practices. The LCRA's water conservation programs are calculated to save run-of-river water and stored water in direct proportion to their use.[1] Because the irrigation districts are the largest single users of water in the river basin, the LCRA has concentrated its conservation efforts in the agricultural sector.

There were several reasons for pursuing water conservation in the irrigation districts when the programs began in 1986. Mr. S. David Freeman became general manager of the LCRA in 1986 and conservation rated high on his list of priorities.[2] Another reason for implementing water conservation in the irrigation districts was to reduce the demand for water within the region to a point below the maximum amount of water that could be made available in a severe drought year. The LCRA and the lower Colorado River Basin typically have an excess annual supply of water, even though there is a risk of water shortage during a drought year. Water shortages will have a negative economic impact in the river basin.

However, the largest impetus for water conservation was a more immediate need to reduce the rapidly increasing operational costs on the districts. Electricity purchases from Central Power and Light represent a significant portion of the operational costs and this cost varies in direct proportion to the volume of water pumped from the river. In 1986, rate increases threatened to make operation of the irrigation districts and rice farming uneconomical. The LCRA hoped to reduce the costs of irrigation by reducing the volume of water it pumped from the river.

Another goal of LCRA's conservation policies and programs is to comply with state regulations regarding the use of surface water. In 1986, the Texas Water Commission made several changes to the Texas Water Code that are addressed in concurrent LCRA Board Policy Statements. The Texas Water Commission's 1988 adjudication of water rights on the lower Colorado River provided additional direction for the conservation programs by establishing guidelines for water use.

State Regulations

In the spring of 1988, the Texas Water Commission issued Certificates of Adjudication defining LCRA's irrigation district water rights. These certificates limit the total volume of water that may be pumped from the Colorado River for irrigation purposes. The volume of the water rights was:

> ...quantified based on reasonable projections of the acreage that will be irrigated in peak irrigation years, times a reasonable duty of water. This is the method used to quantify other irrigation rights in the Lower Colorado River Basin. A reasonable duty of water for rice irrigation is 5.25 acre feet of water per acre. This duty has been used previously by the Commission and is appropriate for reasons of equity and consistency in the Lower Colorado River Basin.[3]

The 5.25 acre foot standard of water used per double-cropped acre of rice irrigated was established through the "Less Water-More Rice" research program that ran from 1982 through 1987. This program was a cooperative effort between the U.S. Department of Agriculture's (USDA) Soil Conservation Service, local Soil and Water Conservation Districts, Texas A & M University, the Texas Agricultural Experiment Station, and the Texas Rice Research Foundation.[4] The report "Modified Findings and Conclusions Defining LCRA's Water Rights," appended to the *Water Management Plan*, provides more detail on this standard for water use. The document states that:

> ...5.25 acre-feet of water per annum per irrigated acre of land is the maximum amount of water that can reasonably and diligently be used without waste for the irrigation of double crops of rice along the Texas Gulf Coast.[5]

The Texas Water Commission adopted a figure of 5.25 acre-feet per acre as a factor to determine the maximum amount of water that could be used by the districts for rice irrigation purposes. The water rights themselves do not specify that the water must be used at this rate. However, there is some speculation that this figure could also be used as a standard for quantifying the degree to which the use of water is beneficial and not wasteful. Under the Texas Water Code, holders of water rights permits may only apply water for beneficial uses. The Texas state law defines beneficial use as:

> ...use of the amount of water which is economically necessary for a purpose authorized by law, when reasonable intelligence and reasonable diligence are used in applying the water to that purpose.[6]

It is possible that the LCRA could lose the water rights if the districts were challenged for wasting water or for applying water to non-beneficial uses. Non-beneficial use of water could be defined as use of water in excess of "...a reasonable duty of water for rice irrigation."[7] Attainment of the 5.25 acre foot per acre maximum rate of irrigation water use has become an objective of the LCRA's water conservation programs.

State regulations provided additional incentive and guidance for water conservation programs. Along with several other major revisions to the Texas Water Code in 1986, the Texas Water Commission adopted a ruling that requires irrigation districts to charge their customers on a volumetric basis. This ruling was originally a Sierra Club proposal to introduce conservation oriented irrigation rates into the industry.[8] Although the rule was adopted in May 1986, it has never been enforced.[9] The Texas Water Code states that:

> Persons supplying state water for irrigation purposes shall charge the purchaser on a volumetric basis. The Commission may direct suppliers of state water to implement appropriate procedures for determining the volume of water delivered.[10]

The LCRA adopted "Board Policy Statement WFC 505.00," the document that outlines the agency's water conservation policy, the day after the effective date of this and other water code revisions.

LCRA Conservation Policy and Programs

The LCRA Act of 1934 provides a strong mandate for the agency to manage water supplies and promote water conservation. The *Water Management Plan* describes the LCRA's approach and is supported by Board Policy Statements.[11] LCRA Board Policy Statements indicate that water conservation programs rank high on the agenda. Table 2.1 outlines the board's objectives for the agricultural water conservation program as they were stated in 1986. The policy was revised in October 1988. The 1992 agricultural water conservation policy stated that:

> LCRA shall support and assist public and private-sector initiatives to develop, demonstrate, apply cultivation and irrigation practices to improve on-farm water use efficiency.
>
> LCRA shall assist with the transfer of information and technology for improving on-farm water use efficiency from research to the producer.
>
> LCRA shall undertake maintenance, rehabilitation and management practices to minimize water losses from LCRA irrigation water delivery systems.[12]

According to the *Water Management Plan*, the LCRA's efforts to conserve water in the agricultural sector will be in the areas of canal rehabilitation and on-farm water efficiency. The programs, outlined in Table 2.2, evolved between 1987 and 1992.[13] The LCRA adopted as a guiding principle the idea that the most effective program should consist of several complementary elements including customer education, canal rehabilitation, on-farm water conservation, and volumetric pricing. The LCRA decided to improve the operational and structural integrity of its own water delivery system before asking farmers to use water more efficiently.

The LCRA realized that on-farm patterns of water use were culturally rooted in farming practices. Therefore, change would come about slowly and program implementation could proceed only at the pace at which farmers were willing to change. The LCRA staff met periodically with farmers throughout implementation of the program to keep them informed and to ask for their comments. The Agricultural Water Conservation Task Force meetings provided a forum for discussion during program design and implementation. In June 1989, the LCRA extended the offer to participate in the task force to 18 farmers. In formulating the task force, the LCRA strove for a representative mix of supporters and skeptics.[14] Four meetings were held between September 1989 and

September 1990. The second process began in 1987 when the LCRA periodically held meetings open to all farmers to promote water conservation and provide farmers with information on the status of the project. Each irrigation district revived a practice of maintaining a Farmer Advisory Group to provide informal feedback to the LCRA regarding farmer-agency relations and irrigation operations.

Canal Rehabilitation

To develop an understanding of the dynamics of water use and provide a basis on which to make improvements to the canal systems, the LCRA asked the U.S. Bureau of Reclamation (the Bureau) to conduct a water efficiency study in the irrigation districts. The Bureau began its study of the Gulf Coast canal system in September 1986. A December 1987 report by the Bureau outlined potential improvements that the LCRA could make.[15] The report stated that several operational and structural problems were contributing to the system's inefficiency (Table 2.3).

The LCRA rejected the Bureau's initial recommendation that an in-depth five-year study be conducted to develop a comprehensive and detailed rehabilitation plan. LCRA managers decided that it would be more cost-effective to fix the obvious problems that were known to offer the greatest potential for water savings.[16] According to the Bureau's analysis, canal bank vegetation and poor hydraulics contributed to water loss.

The LCRA initiated the canal rehabilitation project as a ten-year capital improvement project in 1987. The LCRA cleared vegetation, narrowed canals, and improved canal slopes where needed. The LCRA sought to convert farm delivery structures to standard concrete water boxes where they are in need of replacement. By 1991, both the pace of the project and its funding levels were increased to accomplish the project within five years. Under that funding level, LCRA managers expected to complete canal rehabilitation at the following rate: 90 miles of canal in fiscal year 1990; an additional 60 to 70 miles in 1991; and 70 to 100 miles in 1992.[17] Although this plan was adopted by the board in 1990, bad weather during the canal rehabilitation season in 1991 and 1992 disrupted the pace of work and the project fell behind schedule. As of 1992, the Gulf Coast District had rehabilitated about 240 miles of canal. According to a 1993 report, 106 miles of the 375 mile canal system had been completely rehabilitated through improvement of the infrastructure and removal of canal bank vegetation.[18] Where structural improvements had not yet been made, the district had applied herbicides to remove canal bank vegetation that contributes to water losses through evapotranspiration.[19] Table 2.4 lists the number of miles of canal that were rehabilitated in each fiscal year of the project. The project was completed on schedule in 1996.[20]

Basic Research and Technology Transfer

To complement improvements to the irrigation canal system, the LCRA granted $90,000 and in-kind assistance to a Texas Agricultural Experiment Station (TAES) Cooperative Rice Research Project in 1987. The TAES research project, popularly referred to as the "Less Water-More Rice" project, explored the role of water as a factor in the rice production process and identified ways that farmers could conserve water without suffering production losses. This research determined that on-farm water conservation practices should focus on maintaining a shallow level of water in the fields and improving the methods of water delivery into and through fields. On-farm water conservation practices were projected to reduce water use by 25 to 30 percent and perhaps increase yields by as much as 17 percent.[21]

In 1987 and 1988, the LCRA held several farmer meetings to promote on-farm water conservation. They provided farmers with fact sheets, conducted field demonstrations, and provided one-on-one consultations.[22] The LCRA continued to promote on-farm conservation practices during farmer meetings that were designed to gather public input on the conservation program, although initial intensive efforts to promote on-farm water conservation were not sustained into the 1990s.[23] An informal survey among farmers by the LCRA indicated that farmers were familiar with those conservation practices and plan to use them.[24]

Water Measurement

The final step in the agricultural water conservation program is the change to a volumetric pricing system. This system is designed to create a financial incentive for farmers to implement "Less Water-More Rice" technology. Volumetric pricing is an equitable way to distribute the cost of irrigation services among farmers.[25] Farmers who place greater demands on the irrigation system because they are inefficient users of water will pay a higher price per acre for irrigation services. The price structure consists of both a per-acre rate and a smaller volume rate. The system is designed to reflect both the fixed costs and the marginal costs of supplying water to farmers. As the volume of water used for irrigation decreases, so will the districts' operating costs.

LCRA managers began the conversion to a volumetric rate structure in 1990 by conducting research to determine the technical feasibility of proposed methods.[26] In 1990, the method of determining volumetric billing was field tested in two areas serving 9,000 acres of rice farms in both districts. In 1991, the method was further tested on 24,000 acres of rice or 40 percent of the irrigated area. After confirming the accuracy of the method, LCRA managers successfully implemented the water measurement project in both districts in 1992 while retaining the old rate structure. Farmers were charged the per-acre rate as before. At the end of the season, the LCRA informed farmers of the volume of water they had used and what the charges would have been if levied under a volumetric system.

In 1993, the LCRA began charging farmers for irrigation water on a volumetric basis, using a rule that no farmer's average cost per acre in 1993 could be greater than 110 percent of that farmer's 1992 irrigation cost. Irrigation district managers decided that another trial year was necessary because the resistance among farmers was still high. Most of the resistance is due to a lack of confidence in the ability of the LCRA to measure the volume of water. Farmers are also concerned about how each individual farmer's irrigation costs would change. The second trial year (the 1993 crop year) was designed to give farmers feedback during the season so that they can assess the impact that their water management practices have on the volume of water they use. To provide feedback as rapidly as possible, each farmer had access to information on the volume of water delivered to him within three days of its actual delivery.

In 1990, the U.S. Bureau of Reclamation independently certified that the Lakeside's water accounting system and the water measurement methodology were accurate within a ten percent range.[27] The Bureau indicated that only slight modification of Lakeside District's delivery structures was needed to satisfy water measurement standards. In the Gulf Coast District, concrete boxes represent a much smaller percentage of the farm delivery structures. LCRA decided that non-standard structures, steel pipe turnouts, and old wooden water boxes would be replaced with concrete water boxes when their level of deterioration justifies the expense.[28] Standardization of water boxes was designed to simplify data collection and volume calculations.

Cost Benefit Analysis

In 1991, LCRA staff conducted a cost benefit analysis of the canal rehabilitation and irrigation water measurement projects.[29] In the base case scenario, they estimated the water savings from the volumetric pricing incentive provided by the water measurement project to be 25 percent of field inflow in the Gulf Coast District and ten percent of field inflow in the Lakeside District. In addition to these on-farm water savings, LCRA staff also predicted an additional 2.05 acre-feet per acre water savings from improved canal operations in Gulf Coast.

In calculating the program costs, LCRA staff used actual project costs for fiscal years 1989 to 1991 and estimated costs for fiscal years 1992 to 1995 (the expected term of project funding). In addition to project costs, the cost factor in the analysis also included a $63,000 a year increase in the annual maintenance expenses for upkeep of the rebuilt canals. Rainy weather in 1991 and 1992 delayed the completion of the canal rehabilitation project and costs will probably exceed the original projections.

Reduced electric power costs in the districts and reduced demand for stored water in the Highland Lakes are considered the two direct economic benefits associated with water savings. Less tangible and indirect benefits of agricultural water conservation were not included in the calculations. These secondary benefits include: reduced risk of water shortage during drought; compliance with the LCRA's water rights and the Water Management Plan; and more equitable and reliable service to LCRA irrigation customers.[30] A discount rate of 5.9 percent and a term of 20 years were used in the analysis. The benefit cost ratios for the canal rehabilitation project and the irrigation water measurement project in both districts combined are: low case 1.47; base case 2.37; and high case 2.80.

Financial Management

Operation and maintenance of the canal systems is supported by irrigation district revenues. In addition to its operation and maintenance budget, Irrigation Operations drew on several capital improvement funds. Capital improvement projects are funded by LCRA revenues from the sale of water and electricity. Table 2.5 lists funds relevant to the water conservation effort. In general, capital improvement funds are approved by the LCRA board to increase the value of their investment in the irrigation districts. In return, the districts allocate a portion of their revenues to make payments toward the LCRA's total debt service. The irrigation district's annual obligation to the LCRA is determined as the percentage of the LCRA's total capital improvement budget that has been allocated specifically to the irrigation division in that year.[31]

Because the LCRA's entire customer base is expected to benefit from the investment in water conservation, the canal rehabilitation project is an exception to this rule. To determine each irrigation district's debt service obligations, the LCRA board does not include the cost of canal rehabilitation in the calculations. The cost for canal rehabilitation is carried by non-agricultural stored water sales (firm water sales). This decision has prevented an increase in irrigation rates to farmers.

Capital improvement funds are provided on an annual basis. Each district must apply for funding in a competitive process each year and funding is dependent on past project success.[32] In making requests for project funds, each district requests money in terms of broad objectives. By doing so, they preserve the flexibility to re-allocate funds within their budgets. This flexibility is necessary to address the sometimes unpredictable problems which can arise with the equipment and the canal.[33] Each district submits its budget to the LCRA's Board of Directors for the upcoming fiscal year in January. The fiscal year begins in July and runs through the following June. Table 2.6 lists budgets and expenses for water conservation for the fiscal years 1989 through 1992.

In addition to direct funding, the districts have received indirect financial assistance for the conversion to a volumetric pricing system. The conversion from a flat rate per irrigated acre to a volumetric pricing system would not have been possible without the financial support of the LCRA's capital improvement funds and other outside sources.[34]

Water measurement project funds were provided by the LCRA Board of Directors to Water Resources in the Office of Natural Resources. The districts drew on these funds with the approval of Water Resources to cover expenses related to volumetric pricing and water measurement. During fiscal years 1990 through 1992, Water Resources covered $713,877 of expenses relating to water measurement. The project goals were: to assess the technical and economic feasibility of water measurement; to convert delivery structures to water measurement devices; to develop volumetric water rates; and to implement the volumetric pricing program. Like canal rehabilitation funds, debt service payments on this fund are not billed against district revenues.

Additional support for the water conservation effort has been provided by the U.S. Bureau of Reclamation and the Texas Water Development Board (TWDB). Over a four-year period, the Bureau appropriated $800,000 of in-kind assistance for the LCRA's water conservation program[35] to cover reclamation expenses related to the calibration of the water boxes and training of LCRA staff. The TWDB provided a $49,800 grant in 1991 and a $22,000 grant in 1992 for the purchase of materials and supplies related to water measurement.

Rates and Rate Development

The rate structure for the volumetric pricing system was approved by the LCRA Board of Directors on December 16, 1992, as illustrated in Table 2.7. Farmers pay a diversion charge for each acre-foot of water they use. The rate is designed to cover the cost of electricity and the overtime field labor and transportation costs associated with pumping additional water. The fixed costs of operating the district during the period that farmers are raising the second crop are also included in this element.[36] The large difference in the volumetric rates between the two districts is due to the fact that Lakeside must re-lift its water a second time in each of its main canals, which raises the cost of delivering each acre-foot of water to the farmer.

When farmers receive interruptible stored water from the Highland Lakes, as determined by the LCRA's Daily Water Allocation Model, a $5.27 surcharge is added to the diversion charge. The surcharge represents the LCRA's standard interruptible stored water rate ($4.50) plus a cost factor of 17 percent of the interruptible stored water rate to account for operational water losses. Operational water losses are those water losses which occur between the irrigation district's diversion point on the Colorado River and the farmer's delivery point.

The final element of the LCRA's volumetric rate structure is a per-acre charge which, like the old rate, is based strictly on the number of acres a farmer irrigates. This charge reflects the fixed costs of operating the districts regardless of the actual amount of water delivered in any particular year. The slightly lower per-acre charge on Lakeside District is due to the somewhat more efficient labor costs in that district.

The LCRA considered several alternate rate structures.[37] LCRA rate managers considered separate per-acre charges for first and second crops. They felt that doing so would create a more stable income for the districts. Farmers, however, suggested that this left little incentive for conservation in the variable per acre-foot charges. They also complained that the LCRA was trying to reduce the amount of stored water used in the districts by making the second crop uneconomical. Many farmers consider the second crop to be an economic necessity. Therefore, second crop charges, along with the proposed flushing charges, were included as part of the variable diversion charge.

LCRA managers also considered including individual diversion point charges for each water delivery structure a farmer used. Their objective in doing so was to create an incentive to discourage farmers from using multiple delivery points to one field. Texas

A&M University's "Less Water-More Rice" research project advocates in-field laterals as a means of increasing water efficiency. The LCRA also hoped to reduce the cost and workload of measuring the flow of water to farmer's fields. After long discussions with farmers about this issue, the LCRA rejected the delivery point charge. Farmers disapproved because it was a new type of charge with which they were unfamiliar and because of the complexity of the problems it seemed to create. The LCRA concluded that this objective could be more easily achieved through other methods.[38]

Throughout the process of redesigning the rate structure, LCRA managers were constrained by one overriding policy. The LCRA's board of directors granted the districts authority to raise their irrigation rates by 31 percent over a four-year period beginning in 1989 but stipulated that these rates would remain constant until reviewed again in five years. LCRA rates managers had to be careful that in transforming the rate structure there was no increase in the amount of total income generated by the districts.

LCRA chose the 1993 rate structure on the basis of its acceptability to the farmers. Based on the LCRA's estimates, a typical farmer could expect 40 to 50 percent of annual water charges to be based on the variable rate element. Depending on the amount of rainfall, stored water charges can make up more or less of this component. Figure 2.1 through Figure 2.4 display how the volumetric water rates can vary, and how stored water charges can influence a farmers' water rate under different patterns of water use.[39] Under this pattern of water use and a fixed per-acre rate system, Gulf Coast farmers could expect to pay $87.26 and Lakeside farmers could expect to pay $92.43. Because farmers have limited control over variable stored water costs, the LCRA has considered averaging stored water costs over a monthly or an annual period to increase the predictability of the stored water charges. However, farmers were against the idea because they wanted to take advantage of the lower rates during these relatively wet years.[40] They were also unsure of how much longer they would farm in the area. The farmers did not want to pay higher rates in the short-run unless they were sure to collect the benefits during dry years.

Conclusions

LCRA policies and programs call for significant reductions in water use through increased water efficiency. Much has been done well, particularly in the Gulf Coast District. In a period of five years, the LCRA has taken a decrepit, out-dated, and mismanaged canal system and created a relatively well organized and efficient water delivery service. The LCRA has also worked within tight financial constraints and profited by putting cost-effective engineering technology to work. The success of the program so far is perhaps also due to the LCRA's initiative and investment in improving the management and structure of the canal system rather than relying primarily on savings among end users.

Despite the gains that have been made, the magnitude and scope of the job the LCRA has ahead should not be understated. As the water demands in central Texas grow, so will the necessity of further improvements in water use. As the canal system approaches maximum efficiency, the LCRA should plan to continue its efforts by working more closely with farmers on comprehensive solutions to on-farm water management problems.

The LCRA implemented agricultural water conservation as a series of component programs: canal rehabilitation, on-farm water management, water measurement, volumetric pricing, etc. Although the objective of each component was to increase water efficiency, coordination between water conservation components appears to have been limited.

There are two types of components: operational program components and project components. Changes in the way that districts manage their pumping and delivery systems and day-to-day operations can be described as "operational program components." Changes associated with discrete LCRA water conservation projects, like the water measurement and canal rehabilitation projects, can be described as "project components." The difference between the two components is in whether or not the changes that result from them come directly from a planned capital improvement project. When the districts implement a capital improvement project, defined changes take place to accomplish well-defined goals. For example, the water measurement project was implemented with the objective of developing a volumetric pricing incentive for water conservation. The project required: the retraining and addition of water bosses; the standardization of farm delivery structures; the creation of data reporting and database management systems; and the development of appropriate technologies for water measurement. Various degrees of planning have gone into each of the programmed changes, but each is a necessary step in the attainment of the project goal.

Operational components result in changes such as: the establishment of order on/order off water delivery policies, the creation of standard water ordering procedures, and improvements in on-farm water management practices. One characteristic of operational components is that they tend to lack a formal planning stage. The distinction between the two kinds of components is useful because it reveals the fragmentation within the program. In general, programs that suffer from a fragmented approach tend to be inefficient because project goals may overlap or conflict with each other.

The districts might improve the effectiveness of the water conservation effort by developing a comprehensive plan. The purpose of that plan should be to identify the issues and potential problems; develop solutions; and specify a plan of action. The plan should outline the specific objectives and proposed policies in the districts and the means for measuring successful implementation. Successful implementation can be measured in terms of the economic productivity of the district's rice industry as well as water efficiency.

The LCRA has established performance measures in terms of a water efficiency level of 5.25 acre-feet per acre of irrigated land. This measure of water input per land area is not per se an efficiency measure, however, because there are significant differences in the outputs of identical fields when the allocation of inputs such as water, fertilizer, pesticide, and labor are altered.

The use of irrigation efficiency as a performance measure also reflects a value judgement that water conservation is preferable to alternative uses. The emphasis is on saving water rather than on maximizing economic benefits to the region.[41] Irrigation systems that have particularly high water efficiencies may be economically inefficient. The high efficiency only reflects the scarcity of water rather than the success of farm management. Water efficiency is a descriptive measure of performance, but may not be a good management goal. The LCRA should be particularly careful about applying a water efficiency performance standard to individual irrigators.

Each farmer will allocate agricultural inputs to maximize individual economic returns. Water provides economic value to farmers by substituting for infrastructural and maintenance investments as well as satisfying the evapotranspiration needs of the rice plant. Water that is used to flood the field substitutes for chemical pesticides and mechanical weeding. Water that is used solely to transport water molecules used in evapotranspiration across the field can substitute for in-field laterals. When the water level within a field is maintained at a greater depth in some areas more than others to make up for differences in elevation within that field, water is a substitute for mechanical land leveling. When farmers use holding streams as an indicator of the water level in the field, water substitutes for the labor inputs which would otherwise be needed to inspect the water level in that field more closely.

The farmer's decision to use water as a substitute for more costly inputs is a perfectly rational one. Under a fixed per acre rate system, cost was not associated with the water, but with the irrigation service. Farmers were able to maximize their returns by using unlimited supplies of water. In the past, individual farmers' returns on investment have been subsidized by the availability of relatively cheap water.

Because it places a value on the volume of water a farmer uses, the volumetric pricing system is a stride forward in increasing the economic efficiency of the districts and the river basin as a whole. However, to maximize economic efficiency, the price of water is more properly equated with the potential returns the water will bring to the purchaser. In the current system, the price of water is associated with the district's variable cost of providing the water. This may be too low. The districts should consider the potential for minimizing each farmer's use of water by establishing a competitive price for water.

As the value of water becomes more competitive with the value of other agricultural inputs, landowners and farmers will have an incentive to improve their land in ways that reduce water consumption. However, for these districts, the fact that many of the farmers are land tenants poses a problem. For these tenants, infrastructural improvements to the fields may not represent an economic tradeoff for water. In-field laterals and laser land-leveling, which have high up-front costs, generate benefits over the long term. In addition, those benefits may be tied to the land itself and manifested only in the sale price of the land. Tenant farmers who invest in these kinds of improvements may not realize the potential benefits. The possibility that tenants will be expected to make infrastructural improvements to reduce water consumption reveals a potential gap in the water conservation program.

A final question for the water conservation program is declining acreage. The LCRA has limited control over this problem, but could increase the efficiency of the canal system by raising the amount of land area under irrigation. Although the expansion of acreage under rice cultivation conflicts with the Agricultural Stabilization and Conservation Service's programs, the LCRA could explore the possibility of diversifying the types of crops grown in the districts.

This chapter has discussed the LCRA's conservation programs and policies. These were developed and implemented in part through information found in the LCRA's irrigation water accounting database, the topic of the next chapter.

Notes

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[1] Kevin Crittendon, Engineer, Water Resources, Lower Colorado River Authority (LCRA), Austin, Texas, interview by Martin Schultz, January 25, 1993.

[2] Jobaid Kabir, Project Manager, Agricultural Water Conservation Program, Water Resources, LCRA, Austin, Texas, interview by Martin Schultz October 28, 1992; Mike Personett, former Manager, Water Efficiency Department, LCRA, Austin, Texas, interview by Martin Schultz December 22, 1992.

[3] Texas Water Commission, "Resolution Agreeing to Settlement of Cause No. 115, 414-A-1 (LCRA and Austin)," Austin, Texas, February 4, 1988, pp.8-9.

[4] Mike Personett, "Growing Rice with Less Water," Austin, Texas, April 10, 1990.

[5] LCRA, "Modified Findings and Conclusions Defining LCRA's Water Rights with Respect to its Lakeside Water District, Attachment No. 3 to Judgement in Cause No. 115.414-A-1," *Water Management Plan (Appendix)* (Austin, Texas, March 1988), p. 4; and LCRA, "Modified Findings and Conclusions Defining LCRA's Water Rights with Respect to its Gulf Coast Water District, Attachment No.4 to Judgement in Cause No. 115.414-A-1," *Water Management Plan (Appendix)* (Austin, Texas, March 1988), p. 10.

[6] Texas Administrative Code, 31 TAC 297.1.

[7] Personett interview, 1992.

[8] *Texas Register*, vol. 11, no. 37 (May 16, 1986), p. 2328.

[9] Jerry Boyd, Water Rights and Permitting Department, Texas Water Commission, Austin, Texas, interview by Martin Schultz, December 16, 1992.

[10] Texas Administrative Codes, 31 TAC 297.46.

[11] LCRA, "Water Management Plan, Volume 1: Policy and Operations" (Draft), Austin, Texas, March 1988.

[12] LCRA, "LCRA Board Policy Statement 509 - Water Conservation," Austin, Texas, October 20, 1988.

[13] Personett, "Growing Rice," p. 2.

[14] Memorandum from Mike Personett, Manager, LCRA Water Efficiency, to Bill West, Executive Director, LCRA Natural Resources Team, June 13, 1989.

[15] U.S. Bureau of Reclamation (USBR), "Technical Memorandum: Irrigation System Efficiency Study, Lower Colorado River Basin, Texas," Southwest Region, Amarillo, Texas, December 1987.

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[16] Bruce Hicks, Manager, Irrigation Operations, LCRA, Bay City, Texas, interview by Martin Schultz, November 17, 1992.

[17] LCRA, "Operating Plan, Fiscal Year 1990," Austin, Texas, October 1990.

[18] LCRA, "Working Copy, Fiscal Year 1993, Business Plan," Austin, Texas, n.d.

[19] Bruce Hicks, Manager, Irrigation Operations, LCRA, Eagle Lake, Texas, April 14, 1993.

[20] Telephone Interview with Bruce Hicks, Manager, Irrigation Operations, LCRA, Eagle Lake, Texas, telephone interview by Martin Schultz , February 13, 1993.

[21] Personett, "Growing Rice," p. 4.

[22] *Ibid.*

[23] Personett interview, 1992.

[24] Personett, "Growing Rice," p. 5.

[25] Mike Personett, former Manager, Water Efficiency Department, Office of Conservation and Environmental Protection, LCRA, Austin, Texas, interview by Martin Schultz, March 8, 1993.

[26] USBR, "LCRA Water Box Calibrations," Denver, Colorado, October 1990.

[27] LCRA, "Technical Issues of water measurement project to be Discussed in the November 18, 1992, LCRA Board Meeting," Eagle Lake, Texas, November 12, 1992.

[28] Bruce Hicks, General Manager, LCRA Irrigation Operations Division, Eagle Lake, Texas, interview by Martin Schultz, January 26, 1993.

[29] LCRA, "Technical Memorandum 2: The Economic Feasibility of Irrigation Water Measurement," Austin, Texas, November 1991.

[30] LCRA, "Technical Memorandum 2."

[31] Hicks interview, 1993.

[32] Hicks interview, 1992.

[33] *Ibid.*

[34] Mike Shoppa, District Superintendent, Lakeside Irrigation District, LCRA, Eagle Lake, Texas, interview by Martin Schultz, November 19, 1992.

[35] Personett, "Growing Rice," p. 5.

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[36] Angie Taylor Rubottom, Rates Manager, LCRA, Austin, Texas, interview by Martin Schultz, January 25, 1993.

[37] Rubottom interview, 1993.

[38] *Ibid.*

[39] LCRA, "Gulf Coast and Lakeside Volumetric Rate Analysis," Austin, Texas, January 1993.

[40] Rubottom interview, 1993.

[41] Leslie E. Small, *Evaluating Irrigation System Performance with Measures of Irrigation Efficiencies* (London, UK: Overseas Development Institute, October 1992).

Table 2.1
LCRA Conservation Objectives

Ensure efficient end uses of water through the:
- development of conservation devices and practices;
- establishment of water pricing and incentive strategies;
- use more efficient devices and practices by agricultural and industrial users;
- promotion of theft detection services to local distribution systems;

Investigate dams and surface water storage as a means of augmenting water supply to develop:
- programs to control interbasin transfers.
- water re-use strategies that will result in greater water return to the river basin.

Source: Lower Colorado River Authority, "Board Policy Statement WFC 505.00," Austin, Texas, May 29, 1986.

Table 2.2
Agricultural Water Conservation Program Components

Canal Improvement Projects
1. Improving the operational control and management of the canal system.
2. Removing and controlling the canal bank vegetation.
3. Improving the hydraulic characteristics of the canals.
4. Automating the water diversion facilities.

On-Farm Water Efficiency
1. Direct support (funding and staff) for the Cooperative Rice Water Management Research Program ("Less Water-More Rice").
2. Assistance with the transfer of the information from the rice research project to the farmers.
3. Development, testing, and demonstration of an automated levee gate.
4. Inclusion of water conservation stipulations in the LCRA's standard irrigation water service contract.

Source: Lower Colorado River Authority, "Water Management Plan, Volume 1: Policy and Operations," Austin, Texas, March 1988, p.77. (Draft.)

Table 2.3
Problems Identified as Contributing to Irrigation

System Inefficiencies

1. Potentially sub-optimal on-farm water efficiency.
2. Inefficiencies or operational losses in the delivery system.
3. Excess water use due to the lack of measuring devices and the reliance on water boss judgement.
4. Poor control of canal bank vegetation and erosion.
5. Poor structural maintenance.
6. Lack of an incentive for water conservation in the LCRA's rate structure.
7. Low efficiency due to the lack of modernization and automation of checks and gates, and the lack of standard canal operation procedures between water bosses.
8. Possible excessive loss due to seepage in the main canals.

Source: U.S. Bureau of Reclamation, Southwest Region, "Technical Memorandum: Irrigation Efficiency Study," Amarillo, Texas, December 1987.

Table 2.4
Mileage of Canal Rehabilitation by Year

Fiscal Year	Mileage Rehabilitated*	Cumulative Mileage*
1988	20	20
1989	30	50
1990	20	70
1991	15	85
1992	14	99
1993	4	103

Source: Jobaid Kabir, Water Resources, Lower Colorado River Authority, telephone interview by David Eaton, Austin, Texas, April 1993.

Note: (*) The total number of canal miles rehabilitated varies slightly from other material that has been referenced in the text due to problems inherent in estimating mileage from maps.

Table 2.5
Capital Improvement Funds

General Additions Fund
One fund for each district to cover additions, replacements, modifications and improvements to plant which are necessary to efficient operation.

Canal Rehabilitation Fund
A fund for improving the structural integrity of the Gulf Coast canal System through vegetation removal, sloping, and cross-sectioning.

Pumping Plant Automation Fund
A fund for Gulf Coast District to cover the expenses of automating its pumping plants.

Source: Lower Colorado River Authority, "Working Copy, Fiscal Year 1993, Business Plan," Austin, Texas, January 1993.

Table 2.6
Budgets and Expenses for Water Conservation Program

	Water Measurement Project		**Canal Rehabilitation Project**		**Conservation Demonstration Projects**		**Outside Grants**
Fiscal Year	Budget	Expenses	Budget	Expenses	Budget	Expenses	
1988	-	-	175,000	59,697	-	-	-
1989	-	-	129,000	109,469	86,000	6,000	-
1990	409,000	146,277	120,000	141,771	-	-	-
1991	240,000	310,600	259,000	238,300	-	-	49,800
1992	285,000	257,558	259,000	238,250	-	-	-
1993	170,000	175,000	-	-	-	-	22,000
1994	170,000						

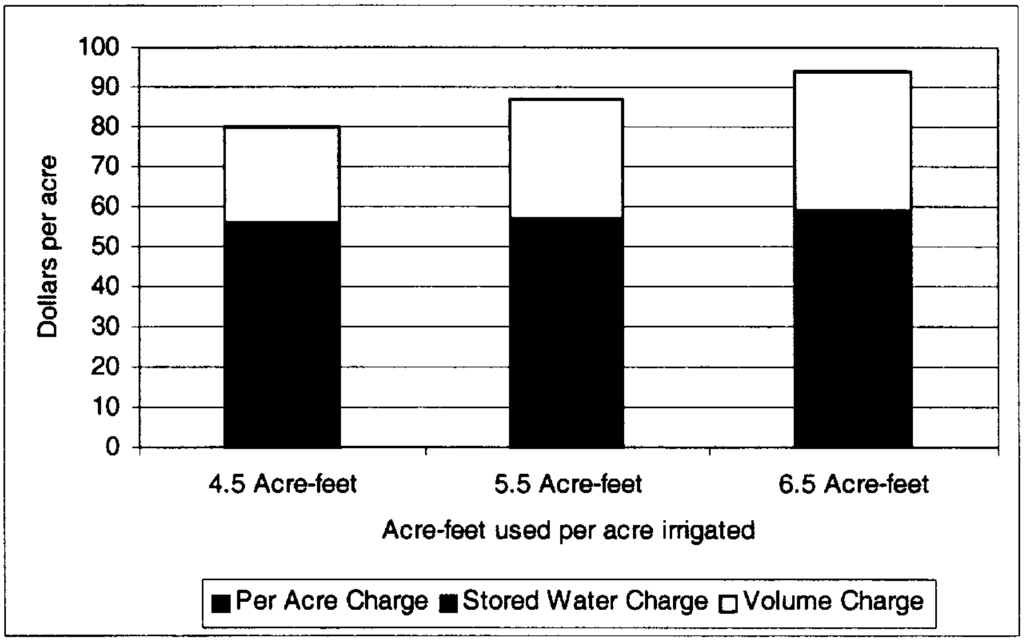
Source: Lower Colorado River Authority (LCRA), "Annual Budget Report," Austin, Texas, Fiscal Year 1988-90 and Fiscal Year 1992-93. (Computer printout.); and LCRA, "Operating Plan," Austin, Texas, Fiscal Year 1992.

Table 2.7
LCRA's Volumetric Rate Structure

Variable Charges	**Gulf Coast District**	**Lakeside District**
Volume Charge per acre-foot:	$5.40	$9.25
Stored Water Charge per acre-foot:	$5.27	$5.27
Fixed Charges (per acre)		
Irrigated Rice	$49.50	$42.50
Irrigated Turf Grass	$22.20	N/A

Source: Lower Colorado River Authority, "Board Meeting Agenda," December 16, 1992.

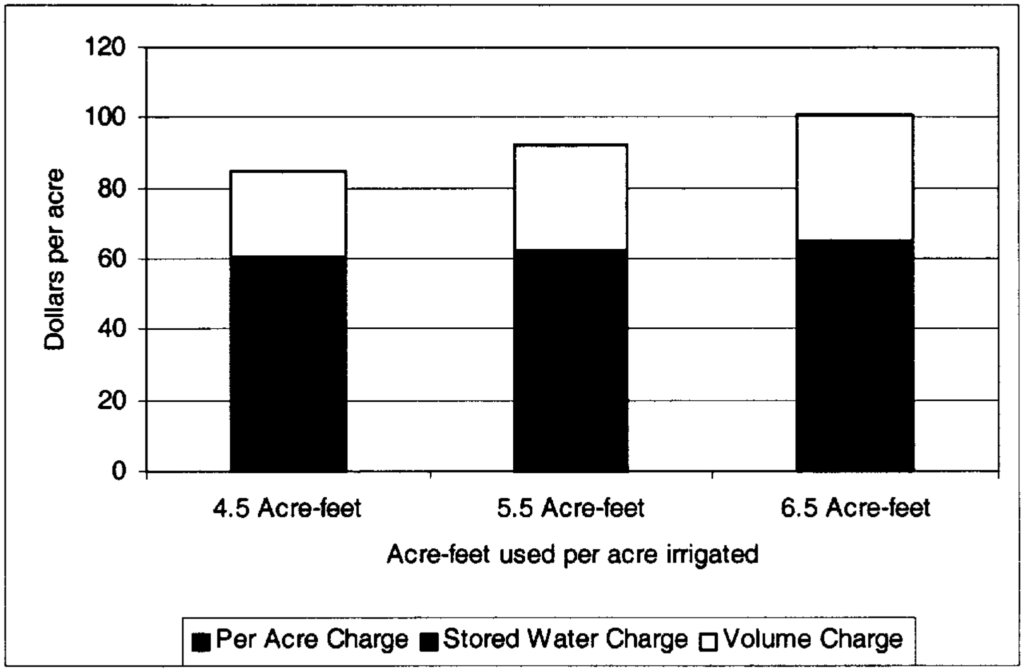
Figure 2.1
Gulf Coast Rate Scenario: Stored Water Use Ratio 20 Percent First Crop and 40 Percent Second Crop



Source: Derived from data provided by Alan Faries, Rates Management, Lower Colorado River Authority, Austin, Texas, March 1993.

Notes: The figure displays the distribution of charges in the approved rate structure on Gulf Coast Irrigation District when a farmer uses 20 percent stored water during the first crop and 40 percent during the second crop. As the farmer uses more water to irrigate rice, his irrigation charges increase.

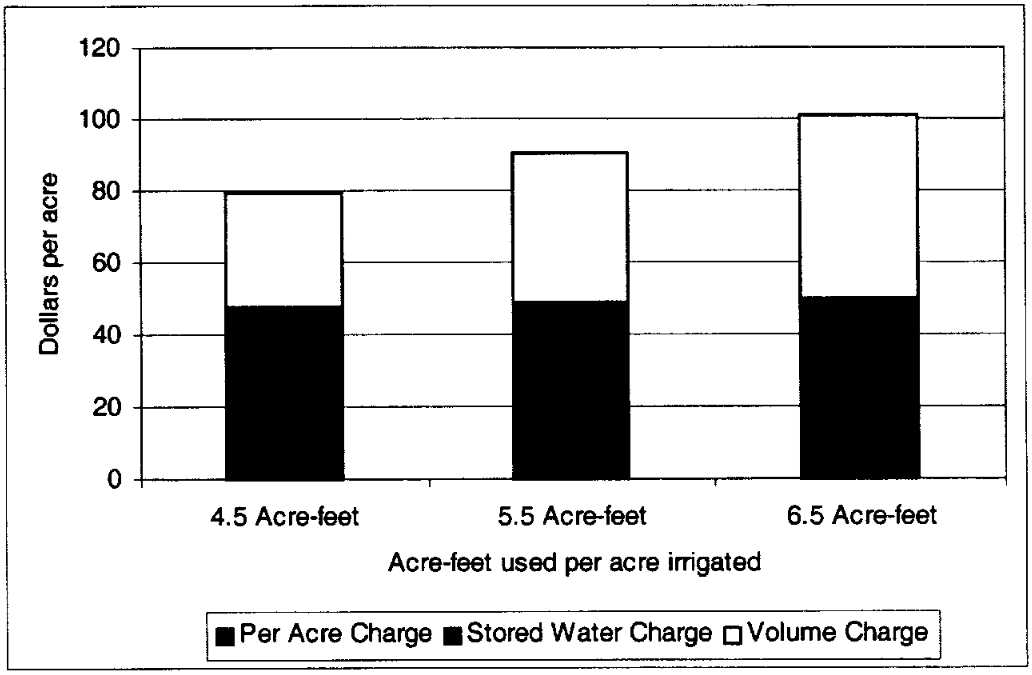
Figure 2.2
Gulf Coast Rate Scenario: Stored Water Use Ratio: 40 Percent First Crop and 60 Percent Second Crop



Source: Derived from data provided by Alan Faries, Rates Management, Lower Colorado River Authority, Austin, Texas, March 1993.

Notes: The figure displays the distribution of charges in the approved rate structure on Gulf Coast Irrigation District when a farmer uses 40 percent stored water during the first crop and 60 percent during the second crop. As the farmer uses more water to irrigate rice, his irrigation charges increase.

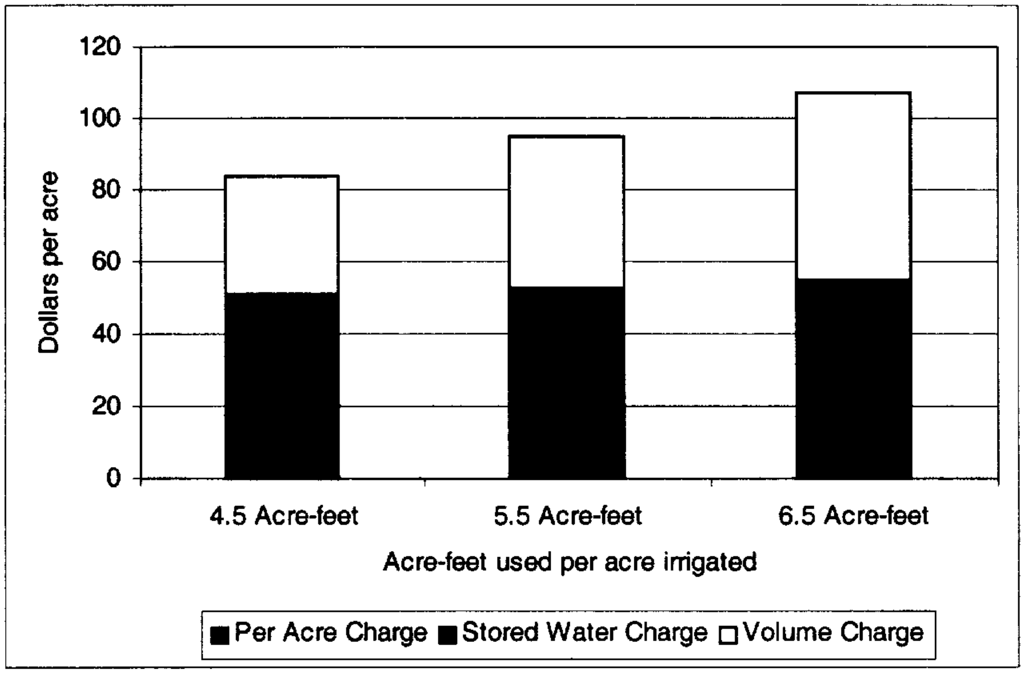
Figure 2.3
Lakeside Rate Scenario: Stored Water Use Ratio: 20 Percent First Crop and 40 Percent Second Crop



Source: Derived from data provided by Alan Faries, Rates Management, Lower Colorado River Authority, Austin, Texas, March 1993.

Notes: The figure displays the distribution of charges in the approved rate structure on Lakeside Irrigation District when a farmer uses 20 percent stored water during the first crop and 40 percent during the second crop. As the farmer uses more water to irrigate his rice, irrigation charges increase.

Figure 2.4
Lakeside Rate Scenario: Stored Water Ratio: 40 Percent First Crop and 60 Percent Second Crop



Source: Derived from data provided by Alan Faries, Rates Management, Lower Colorado River Authority, Austin, Texas, March 1993.

Notes: The figure displays the distribution of charges in the approved rate structure on Lakeside Irrigation District when a farmer uses 40 percent stored water during the first crop and 60 percent during the second crop. As the farmer uses more water to irrigate his rice, irrigation charges increase.

Chapter 3. The Irrigation Water Accounting Database

The Lower Colorado River Authority (LCRA) uses the irrigation water accounting database on the irrigation districts to store, process, and retrieve data collected by water coordinators at field delivery structures. The U.S. Bureau of Reclamation (the Bureau) designed the system as a comprehensive water accounting system and the LCRA uses it to bill customers under the volumetric rate structure. This study is the first attempt to use information contained in the database for purposes other than billing customers. During the course of this study, attempts to work with the database were complicated by its design and performance level. This first section of this chapter describes the database and the second section provides a brief description of data contained within the database.

The irrigation water accounting database consists of three distinct data sets. Lakeside District maintains one database for all fields on the district. The Gulf Coast District maintains one database for fields on the east side of the river, and one database for fields on the west side of the river. The database consists of records on the size of fields, the size and shape of delivery structures, and water measurements at those structures. For an individual field, water use is the sum of water measurements at all delivery structures entering the field.

The water accounting database was written in DBASE IV software and was accompanied by a user-interface for users unfamiliar with DBASE programming. The system was installed by the Bureau in May 1992, and since this time it was corrected and updated for both irrigation districts. Physical characteristics that describe features on the irrigation districts are located in a static data manager that includes information on the canals, laterals, and field delivery structures. Users may view, add, delete, or edit information and coefficients contained in the static data manager. Data are organized by main canal, lateral, and sub-lateral (reach). Up to two additional sub-laterals may be added to the system.

A dynamic data manager allows the user to access and store data collected by water coordinators at individual field delivery structures. The software identifies delivery structures by an alphanumeric code and a field name. The dynamic data manager accepts data on the device head, the sill head, the upstream and downstream velocities, and the upstream and downstream heads at each structure. A hydrograph program then calculates the volume of water flowing through that structure since the last reading and stores the data in a temporary file. In fact, water coordinators measure only the upstream and downstream heads at concrete delivery structures. At pipe turnouts, water coordinators measure only the velocity of water flowing through the pipe. These variables are sufficient to calculate water flow when the orifice of the delivery structure is not submerged.[1]

Irrigation district personnel use reporting software ("manager reports") to retrieve summary data on field water use for the season. Data retrieval is an awkward and time-consuming task because summary reports may not be viewed on screen or printed to external files, but must be printed. As of 1992, the manager reports program only allowed users to retrieve data on total water use in a field for the entire season.[2] Information on daily water deliveries at individual fields is stored within the system, but may only be extracted with carefully crafted database programs. Other features of the manager reports menu allows the retrieval of water measurements at individual delivery structures and total water deliveries by canal segment. Such information might be useful in detecting systematic errors in the system or in locating regions of excessive water use on the districts.

As of 1992, a water scheduling component provided by the accounting database did not operate. Such a program could encourage more efficient planning by enabling the districts to collect orders for the future and look beyond the conventional one or two day horizon of most water scheduling software. If the irrigation districts were to collect water orders seven days in advance, this feature could also allow the LCRA to coordinate more accurately stored water releases from the Highland Lakes with on-farm water demand. Although irrigation service contracts state that farmers are required to order water not less than six days before delivery, the practice on the irrigation districts has been to provide water on short notice and rely on estimates of on-farm demand in reporting anticipated water diversions for the following week to the LCRA in Austin.

Table 3.1 and Table 3.2 list the input and output variables available in the database. Because LCRA's application of the database was limited, not all variables were in use and not all output programs were functional. For the purposes of this project, data were retrieved from the database and written to external files using customized DBASE programs. A complete discussion of the water accounting database is beyond the scope of this report. More information is available from the Bureau *Dbase IV Water Accounting Software Package User's Manual.*[3]

Suggestions and recommendations that could lead to improvements in the water accounting system on the irrigation districts emerged in the process of working with these databases. A list of problems encountered in using the database is provided in Table 3.3. Short of discarding the current system in favor of a better system designed specifically for billing and data retrieval, the recommendations provided in Table 3.4 could improve the performance of the existing system and enhance the credibility of LCRA's volumetric billing procedures.

For the purposes of this project, only a few of the variables contained in the water accounting database have been used to evaluate water measurement and water savings associated with on-farm water conservation. Table 3.5 provides a cross-sectional view of the water accounting database from Lakeside Irrigation District. (Customer names and field identification codes were changed in this table to preserve the privacy of irrigation district customers.) The first two data fields provide the customer's first and last name. The third column, the customer identification code headed "USER_ID," is either the customers three initials or a four-letter code. If the code is four letters it indicates that the landowner, or someone other than the farm operator, is responsible for the water contract.

In this case, the first two letters of the customer identification code are the first and last initials of the farm operator, and the last two letters are the first and last initials of the person responsible for the water contract.

The field identification code, "FIELD NAME," in the fourth column identifies the rice field. The first three letters of this code are usually, but not always, identical to the three-digit user identification code. The last two characters of the code are a number and a letter. The number identifies the relative position of the field on the sub-lateral, and the letter identifies the water coordinator. Field acreage is listed in the fifth column. Second crop acreage is often less than first crop acreage if the farmer irrigated only a portion of the field during the second crop period. In some cases, field acreage can even be larger than first crop acreage. The column headed "VOLUME" represents the total volume of water deliveries in acre-feet at the field. It is the sum of water deliveries at each structure servicing the field. The two columns headed "START_DATE" and "END_DATE" list the first day the farmer took water and the last day the farmer took water respectively.

The column headed "WATER USE" is the per-acre water use in the field. This is calculated by dividing total water deliveries by field acreage. The last column is a dummy variable entitled "CROP." If the CROP variable equals zero, it indicates the observation is a first crop rice field. If the CROP variable is equal to one, the observation is for a second crop rice field. During the course of this study, several variables were used in the analysis of water use. These variables are defined in Table 3.6.

Water Balance on the Irrigation Districts

The Bureau designed the water accounting database to serve as a comprehensive water accounting system. As implemented in 1992 by the LCRA, the database was used for storing some of the water use data but did not include water flows at in-line canal structures or environmental conditions such as rainfall and evaporation.

When estimates of the amount of water entering the canal system and the amount of water leaving the canal system are used to estimate canal efficiency, the results include some values that cannot be explained easily. This is probably due to the fact that LCRA uses one method to measure the volume of water flowing into the canal, and two completely different methods to measure water leaving the canal system. Pump managers measure inflows to the canal system at several diversion points along the river by multiplying the pumping rate (gallons per minute) by the length of the pumping period. Pump sizes vary from between 26 thousand and 79 thousand gallons per minute (see Appendix A). Over the period of the growing season, it is possible that small errors in estimating pumping rates could translate into large errors in estimated diversions. Water coordinators measure outflows from the canal system at individual delivery structures.

The difference between inflows and outflows should represent canal losses. Total water diversions should be greater than total water deliveries and the difference between the two should represent canal losses from spills, seepage, leaks, and evaporation. Table 3.7

lists the total water diversions, the total water deliveries, and the estimated canal losses for the crop years 1992 and 1993. Estimated canal losses reported in the table represent the difference between total diversions and total deliveries. Canal efficiency may be calculated as the ratio of total water deliveries to total water diversions from the river. The only reasonably good estimate of canal efficiency appears to be on Lakeside District in 1993 because all other estimates are around 100 percent. Although 100 percent canal efficiency is possible, it is not likely. Losses from evapotranspiration, phreatophytes, and seepage would be expected to be greater than gains from runoff, precipitation, and groundwater infiltration into the canals. Table 3.8 lists possible sources of error. Physical defects in measurement devices, computational errors in the equations used to calculate volume estimates, errors in the subroutine that aggregates water measurements, errors in water measurements at delivery structures, or incomplete records of either total water diversions or farm deliveries might explain these discrepancies.

The potential for small and large errors in accounting for water has already been discussed. During the course of this project, some computational errors in the 1992 water accounting database were identified. Water use at approximately five percent of the delivery structures on Gulf Coast District was underestimated during the 1992 crop season when the flows were calculated. LCRA has corrected the problem, but flow data were not recalculated.[4] A similar problem affects data on both irrigation districts. Water measurements at approximately 15 percent of the delivery structures were over-estimated because the width of openings in delivery structures were incorrectly specified in the static data manager.[5] These errors also remain embedded in the 1992 data. Without recalculating all water use, the degree to which these errors might have affected the data is not known.

Descriptive Statistics from the Water Accounting Database

Three tables (Table 3.9, Table 3.10, and Table 3.11) provide statistics that describe the range and distribution of data on fields and water use, based on the 1992 and 1993 water accounting database. Data on first and second crop water use were not available from the database for the east side of Gulf Coast District because no observations included start dates, end dates, or crop separation dates. Therefore, it was not possible to distinguish between water deliveries during the first crop period and water deliveries during the second crop period. Many observations from Gulf Coast District's 1993 database are also missing these variables.

Table 3.9 lists descriptive statistics obtained from the water accounting database for the first crop period. For example, Lakeside District irrigated 172 fields during the first crop period in 1993. The combined acreage of these fields was 25,021 acres. The size of these fields ranged from between 12 and 600 acres, but the average field size was only 134.4 acres. The total volume of water measured at farm delivery structures was 51,126 acre-feet. The maximum amount of water delivered to any one field on Lakeside District in 1993 was 1,238 acre-feet, and the minimum amount of water delivered to any one field was 33 acre-feet. First crop water use in acre-feet per acre ranged from 0.8 to 6.5 acre-feet per acre. The average farmer on Lakeside District used approximately 2.5 acre-feet per acre to raise the first crop of rice.

This chapter has described and assessed the irrigation water accounting database. The irrigation figures and the source of the data for evaluating the water conservation program are discussed in the following chapter.

Notes

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[1] Jobaid Kabir, Lower Colorado River Authority, "Technical Feasibility of Water Measurement, Technical Memorandum No. 1," (Austin, Texas, October 1991).

[2] U.S. Bureau of Reclamation, *Dbase IV Water Accounting Software Package User Manual* (Amarillo, Texas, May 1992).

[3] *Ibid.*

[4] Craig Kucera, LCRA, Bay City, Texas, interviewed on April 13, 1992.

[5] Jobaid Kabir, LCRA, Austin, Texas, interviewed on April 22, 1992.

Table 3.1
Input Variables in the Water Accounting Database Program

STATIC DATA MANAGER

- I. Canal name and number
- II. Canal reach name and number
  1. Capacity
  2. Losses per day (cfs)
- III. Lateral name and number
- IV. Delivery structure identification code
- V. Location
- VI. Customer identification number (if applicable)
- VII. Delivery structure data
  1. Type
  2. Capacity
  3. Width and length
  4. Coefficient of Q
  5. Exponent
- VIII. Function
  1. Main headgate or other device at the head of the canal
  2. Farm turnout
  3. Inflow points such as a pump
  4. Outflow points such as waste ways
  5. Non-recording measurement device
  6. Rain gauge
  7. Inline re-lift (usually a pump)
  8. Flow recording device (recorder)
  9. Reach control structure and device
  10. Lateral turnout
- IX. Hydrograph status
  - N. No hydrograph available
  - Y. Hydrograph available
- X. Customer information
  1. First and Last Name
  2. Address, City, State, Zip Code
  3. Phone number
  4. Farm operator name
  5. Customer (User) Identification Code
- XI. Field and delivery structure information
  1. Canal level identification
  2. Canal reach number
  3. Field delivery structure identification code
  4. Field name
  5. User identification code
  6. Customer contract number
  7. Township, Range, Section, Quarter section
  8. Land class
  9. First and second crop acreage
  10. First & second crop separation date

Source: U.S. Bureau of Reclamation, *Dbase IV Water Accounting Software Package User Manual,* (Amarillo, Texas, 1992).

Table 3.2
Output Variables in the Water Accounting Database Program

DYNAMIC DATA MANAGER

I. Hydrograph
  1. Date
  2. Discharge (cfs)
  3. Daily volume (acre-feet)
  4. Cumulative seasonal volume (acre-feet)
  5. Monthly total volume
  6. Calculated upstream flow
  7. Calculated downstream flow

II. Individual customer water use to date or by period
  1. Last date read
  2. Flow (cfs)
  3. Total volume of water used (acre-feet)
  4. Turnout identification code
  5. Field name
  6. Customer identification code
  7. Customer water deliveries
    a) First crop (acre-feet)
    b) Second crop (acre-feet)
    c) Field acreage (first and second crop)
    d) Total customer acreage
    e) Water use per acre by field
    f) Total customer water use.

III. Water use at in-line canal device (bulkheads)
  1. Reach – location
  2. Device – structure
  3. Total water passing (acre-feet)
  4. Last date read
  5. Flow (cfs)

IV. Forecast reports
  1. Customer device forecast
  2. Date
  3. Forecasted flows (cfs)
  4. Customer
  5. Field
  6. Date
  7. Ditchrider (canal reach) forecast
  8. Device
  9. Customer
  10. Field
  11. Date
  12. Forecasted flow (cfs)

WATER ACCOUNTING REPORT

I. Lateral or reach name or number
II. Water inflow
III. Water gains
IV. Water losses
V. Unaccounted for water
VI. Outflow
  1. To fields
  2. To laterals and sub-laterals
  3. Waste
VII. Canal efficiency

Source: U.S. Bureau of Reclamation, *Dbase IV Water Accounting Software Package User Manual*, (Amarillo, Texas, 1992).

Table 3.3
Problems Encountered in Extracting Data

- Missing values for irrigation start and end dates, and crop separation dates.
- Inconsistent entry of acreage values.
- Discrepancies in summation of water and acreage values relative to manager reports printouts.
- Typographical errors in field names and farmer identification codes.

Table 3.4
Recommendations for Improving the Water Accounting Database

- Commission a full audit of the water accounting database system by a reputable consulting firm.
- Personnel responsible for operating the water accounting database and entering data should be trained in DBASE programming.
- Simplify data retrieval to expand the analytical potential associated with the database.
- Improve quality control over data entry.

Table 3.5
Selected Variable from the Water Accounting Database, Lakeside District, 1993

Last Name	First Name	Field User ID	Field Name	Total Acreage	Start Date	End Date	Water Use	Crop	Volume
Andrews	Phillip	LFPA	LDF1C	57.82	220	19930605	19930813	3.8	0
Andrews	Phillip	LFPA	LDF1C	57.82	141	19930814	19931010	2.44	1
Bailey Farms	T.S.Bailey	TBBF	TSB1J	123.8	324.1	19930607	19930824	2.62	0
Bailey Farms	T.S.Bailey	TBBF	TSB1J	123.8	187.4	19930825	19931008	1.51	1
Bailey Farms	T.S.Bailey	TBBF	TSB2J	36	49.4	19930611	19930824	1.37	0
Bailey Farms	T.S.Bailey	TBBF	TSB2J	36	44.1	19930825	19931008	1.23	1
Bannister	é	TAB	TAB1C	117.4	152.3	19930514	19930809	1.3	0
Butler	John	JOB	JOB1C	65.47	137.3	19930529	19930802	2.1	0
Butler	John	JOB	JOB1C	65.47	106.6	19930803	19931013	1.63	1
Butler	Mike	MTB	MTB1J	160	288.5	19930602	19930819	1.8	0
Caldwell	Frank	FCC	FCC1A	247	530.7	19930607	19930818	2.15	0
Caldwell	Frank	FCC	FCC1C	239.06	716.5	19930515	19930718	3	0
Caldwell	Frank	FCC	FCC1C	239.06	535.2	19930719	19930911	2.24	1
Caldwell	Frank	FCC	FCC1R	104.7	199.7	19930518	19930806	1.91	0
Chester	Arthur	ARC	ARC1R	104.7	158.7	19930807	19930923	1.52	1
Chester	Arthur	ARC	ARC2C	63.9	128.6	19930604	19930821	2.01	0
Chester	Arthur	ARC	ARC1C	140.6	521.7	19930516	19930805	3.71	0
Chester	Arthur	ARC	ARC1C	140.6	817.8	19930806	19931012	5.82	1
Chester	Arthur	ARC	ARC1R	173.4	456.3	19930608	19930819	2.63	0

Table 3.6
Variables Used in the Analysis of Irrigation Water Use

Variable	Symbol	Description
Water Deliveries	(V)	Total volume of water in acre-feet used at the field during either the first or second crop period. The sum of water deliveries at each delivery structure entering the field.
Water Use	(W)	The water use, in acre-feet per acre, at a particular field. Water use is equal to total water deliveries during the irrigation period divided by the field acreage.
Acres	(A)	Field acreage.
Days	(D)	The number of days over which the farmer took water during the crop period. The number of days between the start date and ending date.
Rainfall	(R)	Rainfall intensity at a particular field during the crop period. Calculated as the sum of daily rainfall, in inches, during the period between the first and last day of the irrigation period at that field. Measurements were taken at the National Weather Service Station closest to the irrigation district.
Crop	(C)	The crop type. A dummy variable is set equal to zero for the first crop and equal to one for the second crop.
Gulf Coast	(G)	A dummy variable to identify the database. The variable is set equal to zero for those observations from Lakeside District and to one for Gulf Coast District observations.
INTG	(INTG)	A dummy variable to identify second crop fields on Gulf Coast District. The variable is set equal to one for second crop fields on Gulf Coast District, and equal to zero for all other observations.
Boss	(B)	A dummy variable to identify specific water coordinators.
Structure	(Q)	A dummy variable to identify specific types of delivery structures. The variable is set equal to zero in fields for which all delivery structures are steel pipe turnouts and to one for fields for which all delivery structures are concrete water boxes.

Table 3.7
Water Diversions, Water Deliveries, and Canal Efficiency (Acre-Feet)

	Lakeside District		Gulf Coast District	
Crop Year	**1992**	**1993**	**1992**	**1993**
Total Water Diversions	131,014[a]	96,462[b]	132,967[a]	105,505[b]
Total Water Deliveries[c]	129,982	75,432	141,302	95,325*
Estimated Canal Losses	1,031	21,029	-8,065	10,179
Estimated Canal Efficiency	99.21%	78.19%	106.26%	90.35%

Sources: a) Lower Colorado River Authority (LCRA), "Report of Surface Water Use," Austin, Texas, March 1993.; b) LCRA, "Total and Stored Water diversions by Lakeside and Gulf Coast Irrigation Districts," Austin, Texas, n.d.; c) LCRA, *Irrigation Water Accounting Database* (1992 and 1993).

Note: (*) Includes 7,277.49 acre-feet of water delivered to non-rice crops and industrial users.

Table 3.8
Possible Causes of Error in Estimating Canal Efficiency

Water Measurement

- Errors in estimating and applying pump ratings to measure total diversions.
- Systematic errors in the measurement of water at individual delivery structures.

Computational Problems

- Computational errors in hydrograph programs.
- Errors in calculating seasonal water use at individual fields.
- Errors in computing total on-farm water use.

Database Problems

- Errors in data entry and/or data storage in the water accounting database.

Table 3.9
Descriptive Statistics, First Crop Fields

	Gulf Coast District				Lakeside District	
	East Side		West Side			
	1992	1993	1992	1993	1992	1993
First Crop Acreage (Acres)						
Number of Fields:	138	127	124	95	190	172
Total Acreage:	14,833.7	11,502.4	12,126.0	10,203.6	26,415.6	25,020.7
Maximum	-	497.0	439.6	399.3	614.8	600.0
Minimum	-	6.5	5.0	3.8	8.4	12.0
Mean	-	97.8	107.4	139.0	134.4	90.6
Standard Deviation	-	67.5	74.8	80.3	106.7	107.1
First Crop Water Deliveries (Acre-Feet)						
Total Volume	-	43,376.3	49,036.4	34,971.2	68,687.9	51,126.3
Maximum*	-	1,834.7	2,074.3	1,776.6	1,446.9	1,238.2
Minimum*	-	42.2	17.1	38.4	26.8	33.2
Mean*	-	341.5	395.5	368.1	361.5	297.3
Standard Deviation*	-	256.0	336.2	292.9	262.5	244.3
First Crop Water Use (Acre-Feet/Acre)						
Minimum	-	9.5	16.7	10.10	8.4	6.5
Minimum	-	1.5	0.9	1.7	1.0	0.8
Mean	-	3.9	4.5	3.6	2.8	2.5
Standard Deviation	-	1.2	2.4	1.4	1.0	0.9

Source: Lower Colorado River Authority, *Irrigation Water Accounting Database.*

Note: (*) Water deliveries to individual fields.

Table 3.10
Descriptive Statistics, Second Crop Fields

	Gulf Coast District				Lakeside District	
	East Side		West Side			
	1992	1993	1992	1993	1992	1993
Second Crop Acreage (Acres)						
Number of Fields:	-	25	40	16	160	111
Total Acreage:	-	2,194.5	4,482.2	2,018.0	22,858.4	12,627.6
Maximum	-	225.0	439.6	399.3	614.8	585.7
Minimum	-	29.8	5.0	29.0	8.4	12.0
Mean	-	87.8	112.1	126.1	142.9	113.7
Standard Deviation	-	50.2	77.1	97.5	108.2	85.9
Second Crop Water Deliveries (Acre-Feet)						
Total Deliveries	-	5,174.0	11,689.2	4,526.3	61,555.1	23,694.4
Maximum*	-	599.6	1,177.4	1,369.5	1,663.9	1,108.3
Minimum*	-	40.0	0.4	41.3	35.9	18.4
Mean*	-	206.9	292.2	282.9	384.7	213.5
Standard Deviation*	-	161.5	257.5	317.5	322.8	183.0
Second Crop Water Use (Acre-Feet/Acres)						
Minimum	-	5.1	5.4	4.0	7.3	5.8
Minimum	-	0.5	0.1	1.2	0.5	0.3
Mean	-	2.4	2.5	2.1	2.8	1.9
Standard Deviation	-	1.2	1.3	0.9	1.2	0.9

Source: Lower Colorado River Authority, *Irrigation Water Accounting Database.*

Note: (*) Water Deliveries to individual fields.

Table 3.11
Descriptive Statistics, 1992 Total Water Use for the Crop Season

	Gulf Coast		Lakeside
	East Side	West Side	
Number of Fields	138	123	192
Number of Farmers	67	52	55
Water Use by Field (Acre Feet/Acre)			
Maximum	21.99	16.65	12.95
Minimum	0.89	0.93	1.33
Mean	6.57	5.14	5.10
Standard Deviation	4.09	2.58	1.84
Water Use by Farmer (Acre Feet/Acre)			
Maximum	17.30	13.41	12.59
Minimum	2.13	1.26	2.37
Mean	5.80	5.08	5.00
Standard Deviation	2.91	2.21	1.70

Source: Lower Colorado River Authority, *Irrigation Water Accounting Database.*

Note: Total water use is the sum of first crop water deliveries and second crop water deliveries to a particular field. Some fields may not have been second-cropped.

Chapter 4. Evaluating the Water Conservation Program

Water conservation, an alternative to supply augmentation, can be preferred because environmental and economic considerations make construction of new water supply projects more challenging. Quantitative objectives often accompany water conservation plans and programs. However, there may be few means to compute how much water is actually saved through conservation efforts to determine cost-effective approaches to conservation. This chapter provides an empirical assessment of the Lower Colorado River Authority's (LCRA) water conservation program on its Lakeside and Gulf Coast Irrigation Districts. Data for this study were obtained from each district's records of total water diversions, on-farm water deliveries, and field records. This chapter computes savings that have occurred and discusses factors that influence water use on the irrigation districts. This information may also be useful in establishing and evaluating water conservation programs on other irrigation districts. Note that this chapter does not address behavioral variables, which are covered in chapter 8, nor does it delve into the legal an political issues surrounding the issue of water conservation, which are beyond the scope of this report.

The LCRA's primary water conservation program element is the Canal Rehabilitation Program on the Gulf Coast District. The program began in 1988 and represents a significant investment in canal infrastructure. The first section of this paper analyzes the water savings associated with canal rehabilitation. This analysis indicates that canal rehabilitation has contributed to a reduction in the annual diversion rate. Similar rehabilitation efforts might be a cost-effective substitute for supply augmentation investment where unlined earthen canal systems deliver water to agriculture, and agriculture is responsible for a large percentage of surface water consumption.

Estimates of the volume of water savings associated with the canal rehabilitation project are based on the change in total water diversions in Gulf Coast District over the period of the project. These savings represent reductions in canal losses that have occurred as a result of the removal of vegetation from canal banks, and the cross-sectioning and sloping of the canal bed. The total water savings that may be attributed to canal rehabilitation is approximately 69,893 acre-feet, after accounting for differences in rice acreage, second cropping rate, and rainfall between years. This estimate may be regarded as the increased volume of water that is available to other users within the river basin. Because this water was previously lost in the process of transporting water to fields, it does not represent a transfer from farmers or an improvement in irrigation practices.

Annual water savings associated with canal rehabilitation efforts appear strongly related to canal rehabilitation expenses. In addition, the program displays proportional returns to scale in relation to both cumulative and annual expenses. Increases in canal rehabilitation investment appear to result in proportional increases in water savings, which provides a rationale for any future investments in canal rehabilitation as a means of increasing the availability of run-of-river water supplies within the basin.

As a result of LCRA's accounting methods, it may be that some canal rehabilitation expenses are actually related to improved canal maintenance and water measurement. If so, then this estimate more appropriately reflects water savings associated with the water conservation effort as a whole. However, this analysis shows that similar water conservation efforts in Lakeside Irrigation District have not resulted in water savings. This tends to support the conclusion that water savings may be attributed to canal rehabilitation. On the other hand, the inability to detect water savings in Lakeside District may also be related to more efficient operation of the canal system and more efficient on-farm water use in that district.

Despite the inability to detect on-farm water savings in a time-series model, cross-sectional models based on data collected at field delivery structures in 1992 and 1993 indicate farmers have reduced their water use. After accounting for differences in the duration of the irrigation period and the rainfall intensity during the irrigation period, on-farm water deliveries have decreased approximately 0.52 acre-feet per-acre on Lakeside District, and approximately 0.31 acre-feet per-acre in Gulf Coast District. The difference in water savings between years may be affected by an increasing marginal cost of water. These water savings may be attributed to volumetric water pricing or water measurement because economic theory suggests that, as the marginal cost of water increases, farmers will alter their input ratio by increasing the use of substitutes for water. Substitutes for water include herbicides, labor, infrastructural improvements, and farm management.

Implementation of a water measurement program and a volumetric rate structure require that LCRA water coordinators measure water accurately. This chapter presents an empirical evaluation of the water measurement program to determine whether or not water coordinators measure water consistently at different delivery structures. This information may be used to build farmers' confidence in the water measurement methods and to develop an internal evaluation mechanism. Using mean confidence intervals around predicted values of water use at individual fields, LCRA managers can identify those fields at which water measurements may be out of the ordinary. This chapter provides two examples of how confidence intervals might be applied.

Farmers have been concerned about LCRA's volumetric pricing program because some may believe that the methods LCRA uses to measure water could lead to inaccurate results. To determine whether or not the volume of water measured at the farm gate was influenced in part by the individual assigned to measure water at that structure, each water coordinator's measurements were compared against his peer's measurements. When evaluated among their peers, most water coordinators showed no outstanding tendency to over- or under-measure the volume of water delivered to fields. However, at least one water coordinator in each district appears to measure water differently than the other water coordinators in that district. Despite these exceptions, these results support the conclusion that LCRA's methods may be applied consistently throughout the district even if an argument can be made for more training and supervision of water coordinators. This report also includes a similar analysis with respect to water delivery structures. LCRA uses a combination of pipe delivery structures and concrete water boxes on its districts, and water coordinators use a different method of measurement depending upon the type of structure through which water enters the field. This analysis shows that, during the 1993 crop season, differences in the type of delivery structure resulted in no tendency to under- or over-measure the volume of water entering a field.

A complex set of environmental factors appears capable of influencing on-farm water use, and rice producers and scientists differ on the relative importance of each variable. Despite the level of interest this issue arouses, few studies have attempted to measure the marginal effect of environmental factors on water use. Environmental factors that might influence on-farm water use in these irrigation districts include the rainfall intensity during the irrigation period and the length of the irrigation period. The length of the irrigation period reflects the length of the growing season that in turn represents a combined influence of many environmental factors. This report analyzes information contained in LCRA's water accounting database to estimate the influence these variables have on water use.

Several qualities of the soil type within a field may also influence water use. Some farmers believe that the difference in water use between fields in irrigation districts can be related to soil type. Soil scientists report that in these irrigation districts soil type has only a small effect on water use.[1] This report shows that, when soil types are grouped according to their permeabilities, there is no statistically significant pattern of water use between fields. Other qualities of soil type, such as water-holding capacity, texture, or soil series, have not been analyzed in this report. Finally, it may be that the size, slope, and configuration of a field influences irrigation water use. Using data collected during the 1992 crop season, this report shows that water use may be negatively correlated with increasing field size. Other information about individual fields was not available for this study, and therefore, the influence of other field characteristics on water use were not analyzed.

Methods

Prior to LCRA's implementation of the water conservation program, Quentin Martin, Ph.D., developed a time-series regression model to describe the effect of climatic influences on annual water diversions in the lower Colorado River Basin.[2] He designed separate models based on historic records of water diversions between 1968 and 1986 for each of four public and private irrigation districts. Those models have served as a tool for estimating the impact of various elements of LCRA's water conservation program including canal rehabilitation, volumetric pricing, and general water conservation efforts.

The equations below (Eq. 4.1 and Eq. 4.2) state that the volume of water diversions is a product of first crop acreage, second crop acreage, and rainfall. Equation 4.1 also includes a trend variable because there has been an overall increase in water diversions on Lakeside District that cannot be explained in terms of changes in acreage or rainfall. Equations 4.1 and 4.2 give the general form of those equations for Lakeside District and Gulf Coast District respectively:

$$WD = \beta_0 + [(.61 A_1 + .39 A_2) * (\beta_1 + \beta_2 R + \beta_3 T)] \qquad \text{(Eq. 4.1)}$$

$$WD = \beta_0 + [(.66\,A_1 + .34\,A_2) * (\beta_1 + \beta_2 R)] \qquad \text{(Eq. 4.2)}$$

The term WD represents annual water diversions in thousand acre-feet, the variable A_1 is the acreage of rice irrigated on the districts during the first crop period, and the variable A_2 is the acreage irrigated during the second crop period. In equation 4.1, the variable T is a trend variable for the number of years after 1968. The trend variable is excluded from equation 4.2 because Dr. Martin's analysis did not indicate a significant trend in water diversions in Gulf Coast District. All β coefficients are estimated with ordinary least squares regression.

Table 4.1 lists parameter estimates and t-statistics for the original models and lists parameter estimates and t-statistics for the extended time series, 1986-92.[3] The interpretation of results is straightforward. The coefficient β_1 is the expected increase in water diversions associated with one additional acre of rice that is both first and second cropped. For Lakeside District, its value is positive and indicates that one additional acre of rice on the irrigation districts will increase the total diversions on that district by approximately 3.7 to 3.9 acre feet. This estimate includes any increase in canal losses that may be attributed to the increased flow of water in the canal, and therefore may not be equated with on-farm water use. The coefficient β_2 represents the decrease in total water diversions that is attributable to one additional inch of rainfall during the growing season. The coefficient β_3 for Lakeside District represents the unexplained increasing trend in total water diversions on that district.

These equations are valuable because they enable **ex-post** estimates of water diversion during the period on which the model is based. When additional variables are included in these equations, ordinary least squares regression provides a means of evaluating the differential effect of water conservation program elements on total district diversions. The original time series may be extended to include the years 1987 through 1992, and variables may be added to each equation to determine the differential effect of water conservation efforts. Equation 4.3 gives the equation for this step in the analysis for Lakeside District, and equation 4.4 gives the equation for Gulf Coast District. The equation states that water diversions may be explained by those parameters in equation 4.1 (or 4.2) and the LCRA's water conservation efforts:

$$WD = \beta_0 + [(.61\,A_1 + .39\,A_2) * (\beta_1 + \beta_2 R + \beta_3 T)] + \beta_4 C \qquad \text{(Eq. 4.3)}$$

$$WD = \beta_0 + [(.66\,A_1 + .34\,A_2) * (\beta_1 + \beta_2 R)] + \beta_4 C \qquad \text{(Eq. 4.4)}$$

With the exception of the variable C, the equations are identical to equations 4.1 and 4.2. The variable C is a dummy variable for those years during which at least some element of the conservation program was in place. Table 4.2 lists parameter estimates and t-statistics for equations 4.3 and 4.4 on both Lakeside and Gulf Coast Districts. Conservation efforts on Lakeside District do not appear related to any reduction in water diversions. However, water conservation efforts do appear related to reductions in water diversions in Gulf Coast District. This may be explained by the relative intensity of the water conservation effort. Infrastructural improvements in the canal system through canal rehabilitation represent a more intense water conservation effort than those in Lakeside District.

Summary of Results

Table 4.3 summarizes some of the empirical results obtained from the analysis presented in this chapter. The table lists the water savings attributed to canal rehabilitation and on-farm water conservation. Potential water savings associated with on-farm water conservation represents the water savings that could be achieved through a comprehensive on-farm water conservation program based on demonstrated performance in sample fields throughout the Gulf Coast Region.

Factors listed under water management reflect empirical estimates of how field characteristics and environmental factors influence water use. Lines 4 and 5 in Table 4.3 list average per-acre water use by field for the first and second crop periods. The estimate in line 6 lists how field acreage affects on first crop water use, the increase in water use that results from adding an additional acre of land to a field with no change in the irrigation period or the rainfall intensity. This is a better estimate for assessing the efficacy of water management practices across field than the simple averages presented in lines 4 and 5. Line 7 indicates soil permeability was found to have no systematic affect on water use in either district. Rainfall intensity and irrigation period length (lines 8 and 9, respectively) were found to have a systematic influence only in Lakeside Irrigation District; this may be related to the more efficient water management practices in that district. Lines 10 and 11 list conclusions about factors related to the accuracy of water measurement in Lakeside and Gulf Coast Districts. In Lakeside District, one water coordinator has a tendency to measure, on average, 0.29 acre-feet per-acre less than other water coordinators in that district over the period of the irrigation season. For example, a hypothetical farmer who owns a 100 acre field serviced by this water coordinator would not be charged for 29 acre-feet of water delivered to his field over the course of a first or a second crop period.

Canal Rehabilitation in Gulf Coast District

Further analysis shows that reductions in water diversions related to water conservation efforts in Gulf Coast District appear more specifically related to canal rehabilitation. In equation 4.5, the addition of a mileage variable changes the meaning of the equation slightly. Equation 4.5 states that water diversions may be explained in terms of equation 4.4 and the number of miles of canal fully rehabilitated:

$$WD = \beta_0 + [(.66\,A_1 + .34\,A_2) * (\beta_1 + \beta_2 R)] + \beta_4 C + \beta_5 M \qquad \text{(Eq. 4.5)}$$

The variables are identical to those described in equation 4.4. The variable M represents the cumulative number of canal miles fully rehabilitated. Addition of the mileage variable makes the parameter estimate for C statistically insignificant. This indicates that there is a stronger statistical basis for associating water savings with canal rehabilitation than with general water conservation efforts. This interpretation is consistent with the results of equation 4.3 for Lakeside District.

Because the conservation variable in equation 4.5 is insignificant, it may be dropped from the expression. Equation 4.6 shows the form of the regression equation with a mileage variable:

$$WD = \beta_0 + [(.66\,A_1 + .34\,A_2)*(\beta_1 + \beta_2 R)] + \beta_5 M \qquad \text{(Eq. 4.6)}$$

Table 4.4 presents the parameter estimates and t-statistics for each equation. These results show that, in the Gulf Coast District, there is strong empirical support for inferring that canal rehabilitation is the significant program element that contributes to water conservation. In equation 4.6, the mileage variable (M) indicates that full rehabilitation of one mile of canal results in 544 acre-feet of water savings. This is a dramatic result. However, further consideration of this estimate suggests a re-evaluation of the actual savings associated with canal rehabilitation.

Full rehabilitation of canal segments requires mechanical clearing of vegetation and re-shaping of the unlined canal bed. The district's ability to make these structural changes is limited. For example, in some years rainfall during the late fall, winter, and early spring precludes the operation of heavy equipment in and around the canal. A variable that only measures the cumulative miles of canal rehabilitated fully does not reflect that other aspects of canal rehabilitation such as the spraying of herbicides or the installation and improvement of canal structures. An alternative variable, canal rehabilitation expenses, does provide a measure of the overall canal rehabilitation and maintenance effort. Equation 4.7, in which the variable E represents cumulative canal rehabilitation expenses, gives an alternative model for predicting water diversions:

$$WD = \beta_0 + [(.66\,A_1 + .34\,A_2)*(\beta_1 + \beta_2 R)] + \beta_6 E \qquad \text{(Eq. 4.7)}$$

Similar to the parameter estimate for the mileage variable (M) in equation 4.6, the parameter estimate β_3 in equation 4.7 measures the average volume of water saved per dollar invested in canal rehabilitation. The parameter estimate indicates canal rehabilitation has resulted in 0.075 acre feet of water savings per dollar of project expenses.

The effect of canal rehabilitation can be seen more clearly in Figure 4.1. The graph shows actual water diversions between 1968 and 1993, and two estimates of annual water diversions. The 1968-87 model of water diversions is based on equation 4.2. In that model, estimates for years from 1988 through 1993 represent a forecast of what water diversions would have been without canal rehabilitation. The 1968-1993 model incorporates information on canal rehabilitation expenses and is based on equation 4.7. The difference between the estimates in the years 1988 through 1993 reflects water savings associated with canal rehabilitation. Table 4.5 shows canal rehabilitation expenses and estimated water savings in each year of the project.

This findings show a positive return on LCRA's investment in canal rehabilitation and provides a means of estimating the benefit cost ratio of canal rehabilitation. Less-senior owners of water rights benefit through the district's water savings because it enables them to divert water at no cost under their own water rights rather than purchase stored water from the Highland Lakes. Under the assumption that water users will maintain their long-term LCRA water contracts, these water users save $52.50 for every acre-foot of water LCRA saves through canal rehabilitation.

This analysis can also address the issue of whether or not the LCRA has exhausted the potential for canal rehabilitation or should continue the project and can answer the question of whether the amount of money expended in any one year yields a consistent volume of water savings. As LCRA increases the level of canal efficiency to a point near maximum efficiency, continued investment should yield diminishing returns on investment. At some point in this range, LCRA may decide that either the benefits of further canal rehabilitation are inefficient, or that it needs to adjust the way it implements the project to achieve more efficient water savings.

Equation 4.8 is a log-linear regression model that describes LCRA's returns to scale on investment. The equation states that the incremental water savings is proportional to incremental investment in canal rehabilitation. The parameter estimate β_1 gives returns to scale on investment:

$$WS = \beta_0 E^{\beta_1} \qquad \text{(Eq. 4.8)}$$

The variable WS is the cumulative water savings in a given year as estimated by the difference in water diversions between years (equation 4.7). The variable E is cumulative canal rehabilitation expenses as of that year. If the project is achieving diminishing returns, the parameter estimate, β_1, will be less than one. If there are increasing returns to scale on the project, the parameter estimate will be greater than one. When the variables WS and E represent water savings and canal rehabilitation expenses in year i respectively, this equation also provides an indication of whether or not proportional changes in project expenses yield a proportionally similar change in water savings. Table 4.6 provides parameter estimates and t-statistics for equation 4.8.

When WD is equal to the cumulative project cost, β_1 is 1.06. This estimate reflects constant returns to scale. As the LCRA continues to invest in canal rehabilitation, the project will yield water savings that are proportional to the increase in its overall investment. If there are constant returns to scale, this would be empirical support to encourage the LCRA to continue implementing canal rehabilitation in the future. Because this analysis is sensitive to changes in program implementation and the condition of the canal system, its application beyond a few years is questionable. As canal efficiency increases, the potential water savings will decrease. Figure 4.2 shows the relationship between cumulative canal rehabilitation expenses and cumulative water savings.

When WD is equal to the annual project cost, the parameter estimate β_1 is 1.12. This shows that, within the range of 1988 to 1993 project expenses, the volume of water savings in any one year is proportional to the amount of money spent on canal rehabilitation in that year. The LCRA Board can adjust the annual water savings by changing the amount of money it allocates to the project each year. This relationship also reflects that managers on the Gulf Coast Irrigation District make equally efficient use of larger canal rehabilitation budgets as they do smaller budgets. Figure 4.3 shows the relationship between annual canal rehabilitation expenditures and annual water savings.

The evidence presented so far seems to indicate that most of the water savings in Gulf Coast District can be attributed to canal rehabilitation. However, since the LCRA's water conservation program has several elements (of which canal rehabilitation is only one part), it does not seem entirely appropriate to ignore the other water conservation efforts. LCRA has held numerous meetings with farmers to emphasize the importance of water conservation in addition to implementing a water measurement program in 1992 and a volumetric pricing program in 1993. There is contradictory empirical evidence to both support and refute the hypothesis that all of the water savings accounted for by regression of equation 4.7 is associated with canal rehabilitation. These analyses are provided in subsequent sections of this paper.

Time-Series Assessment of the Volumetric Pricing Program

LCRA introduced the volumetric rate structure in 1993. Because farmers were reluctant to accept the rate structure during the 1993 crop season, LCRA placed a ten percent cap on the difference between farmers water costs in 1992 and 1993. Although the final charge for water in 1993 was very close to the 1992 charge, many farmers found they would otherwise have reduced their water costs. The existence of a cap on water costs makes an evaluation of the impact of volumetric water pricing difficult.

The method used here is much like the method used in the preceding analysis of canal rehabilitation. Equations 4.1 and 4.7 were re-estimated with an extended time series and a dummy variable to represent the implementation of volumetric pricing in 1993:

$$WD = \beta_0 + [(.66\,A_1 + .34\,A_2) * (\beta_1 + \beta_2 R)] + \beta_5 E + \beta_6 P \qquad \text{(Eq. 4.9)}$$

With exception of the variable P, all variables are as in equation 4.7. The variable P is a dummy variable that equals 1 for the year 1993 and represents implementation of the volumetric pricing program. The equations test whether or not total district diversions are significantly less than expected without volumetric pricing. Table 4.7 presents the results of this analysis. The fact that total water diversions are not significantly less than otherwise expected indicates volumetric pricing has not contributed a reduction in water diversions.

These results are not a final statement of the potential water savings associated with volumetric pricing. Two years of data is not enough for time series analysis. In addition, the ten percent cap in 1993 probably contributes to the insignificance of the estimates. The volumetric pricing parameter estimate for Lakeside District is negative. This indicates that the district diverted less water than expected in 1993, but this difference is indistinguishable from random error. In contrast, Gulf Coast District water diversions were higher than expected in 1993.

Cross-sectional Assessment of the Volumetric Pricing Program

Cross-sectional models of on-farm water use can demonstrate that field inflows during the 1993 crop season are lower than field inflows during the 1992 crop season. The introduction of a volumetric pricing strategy in 1993 helps explain why this is so. Under the district's fixed irrigation charge during the 1992 crop season, farmers had no control over their water costs. Economic theory suggests that, given an opportunity to reduce water costs and increase farm profits, farmers will use less water. Therefore, the 1993 transition from a completely fixed irrigation water charge to one with a volumetric price component presents an opportunity to evaluate farmers responses to changes in the marginal cost of water.

In 1992, the LCRA measured water deliveries at each field delivery structure, but continued to charge farmers on a per-acre basis. The objective was to give farmers an opportunity to learn how their management practices affect irrigation water use. In 1993, LCRA implemented its new rate structure with a ten percent cap on the difference between each farmer's 1992 and 1993 per-acre cost of water. LCRA's objective was to give the farmers another opportunity to see how management practices influenced irrigation water use. The presence of this ten percent cap on the difference in water costs makes it difficult to draw inferences about the long term effect of price on water use, or to predict the potential water savings associated with volumetric water prices. However, if this evaluation is based on the models of on-farm water use, they show that farmers are able to reduce their water use in response to prices. Equation 4.10 presents the ordinary least squares regression equation used to estimate farmer's reactions to changes in the marginal cost of water. As in the previous models, this equation states that the volume of water used in irrigation is a function of the size of the field, the number of days over which a farmer takes water, and the crop type:

$$V = \beta_0 + \beta_1 PE + \beta_2 A + \beta_3 D + \beta_4 C \qquad \text{(Eq. 4.10)}$$

The variable V is the total volume of water the farmer uses in his field, and the variable PE is the effective marginal cost of water. A description of how the effective price is calculated is provided below (equation 4.12). The variable A is field acreage, and the variable D is the number of days over which the farmer took water. C is a dummy variable that indicates whether an observation is for a first or second crop. To test whether or not there is a significant difference between farmer's reactions in Gulf Coast District and on Lakeside District, the districts were combined in a single model using dummy variables and interactions terms, as indicated in equation 4.11:

$$V = \beta_0 + \beta_1 PE + \beta_2 A + \beta_3 D + \beta_4 C + \beta_5 G + \beta_6 INTG \qquad \text{(Eq. 4.11)}$$

With the exception of the variables G and INTG, the variables are identical to those in equation 4.10. The variable G is a dummy variable denoting field observations from the Gulf Coast District, and the variable INTG is an interaction term equal to G times the effective price of water in Gulf Coast District. This variable is designed to capture the differential effect of price on these farmers, and to test whether or not there is a statistically significant difference in farmer's reactions to these prices.

Because the districts charge an additional volumetric fee for stored water, and farmers do not know whether they are purchasing stored water, farmers react to an anticipated price of water. Therefore, the effective price is calculated on the basis of the probability that the farmer draws stored water. Equation 4.12 states that the effective price of water during each crop period is equal to the volumetric price of water diverted under irrigation district water rights plus the expected cost of drawing stored water during that crop period.

$$PE_i = PD + [(\sum_j FROM_j \times VS_j \div \sum_j VT_j) \times PS] \qquad \text{(Eq. 4.12)}$$

The variable PE is the effective price of water, i is an index denoting first or second crop, and j is an index denoting district. The variables PD and PS are the variable price of water on the irrigation district and the price of stored water from the Highland Lakes respectively. The variables VS and VT are the volume of stored water diversions on the district and the total volume of water diversions on the district respectively. In Lakeside District, the effective price of water during the first crop period is \$10.22 and during the second crop period is \$12.59. In the Gulf Coast District, the effective price of water during the first crop period is \$6.11 and during the second crop period is \$7.27.

Equation 4.13 is a modification of equation 4.11. It relates changes in the effective marginal cost of water to on-farm irrigation water use. The dependent variable represents acre-feet per acre rather than field water use. Equation 4.12 states that irrigation water use is related to rainfall during the crop period, the number of days over which the farmer takes water during the growing season, the price of water, and the crop type:

$$\mathrm{W} = \beta_0 + \beta_1 \mathrm{PE} + \beta_3 \mathrm{D} + \beta_4 \mathrm{C} + \beta_5 \mathrm{G} + \beta_6 \mathrm{INTG} \qquad \text{(Eq. 4.13)}$$

The variable W is irrigation water use in acre-feet per acre and i is an index of crop year. All other variables are identical to those in equation 4.11

Table 4.8 presents the parameter estimates and t-statistics for equations 4.11 and 4.13. The parameter estimate for the effective price (PE) provides a measure of the absolute change in volume (or water use per acre) that results from a change in the effective marginal cost of water. The fraction of the variance explained in equation 4.11 is relatively high because acreage has a strong influence on field water use. When the dependent variable is per-acre water use, as in equation 4.13, the regression model loses explanatory power. However, this does not invalidate the parameter estimates. The facts that the t-statistic for PE, the effective marginal cost of water, and the model F-statistic are consistently significant across the two specifications supports the use of equation 4.13 as a tool for anticipating farmers reactions to changes in the price of water.

The data on which these estimates are based include only two price points. Clearly, an estimate of how farmers react to changes in the price of water will improve with an increase in the number of observations at different prices. However, the data with which to make a better empirical estimate of this reaction is not available for these districts. Another problem with this estimate is the functional form of the equation. The functional form used here is linear; therefore, it does not reflect farmers diminishing marginal propensity to save water. The linear model imposes a constant absolute change for a unit increase in price.

Because one would expect a strong reaction on the part of farmers initially, and a generally diminishing reaction at higher water prices, the model probably underestimates the water savings that can be achieved by assigning a low marginal cost to water. Similarly, the model probably overestimates the savings that can be achieved by assigning a higher marginal cost to water.

Factors Affecting On-Farm Water Use and Measurement

The purpose of this section is to develop a model that tests hypotheses about factors that may influence on-farm water use and water measurement. This analysis differs from the preceding analysis in that most statistical inferences are made on the basis of differences between fields, rather than differences between years. Lakeside and Gulf Coast District water coordinators measured water at field delivery structures during the 1992 and 1993 crop seasons.

Equation 4.14 describes water deliveries to individual fields states that the volume of water delivered to a field is a function of field acreage, the number of days over which the farmer took water in that field, the intensity of rainfall during the irrigation period, and the crop type:

$$V = \beta_0 + \beta_1 A + \beta_2 D + \beta_3 P + \beta_4 C \qquad \text{(Eq. 4.14)}$$

The dependent variable V represents the volume of water measured at each delivery structure. When two or more delivery structures service a field, the sum of measurements represents the total volume of water entering the field. The variable A is field acreage, and the variable D is the number of days between the first water delivery and the last water delivery. The length of the growing season may vary from field to field depending on site specific environmental factors and the date of planting. It seems reasonable that fields where the growing season is longer should have higher levels of water use all other factors being equal. The variable C is a dummy variable that indicates the crop type. In general, second crop fields tend to use less water than first crop fields because the rice plants are already well established. The variable P represents the intensity of rainfall on the irrigation district during the period the farmer took water in a particular field. Daily measurements of rainfall were available at only one site on each district; therefore, this variable does not represent the exact volume of rainfall entering each field. Data on rainfall intensity were obtained from the National Weather Service reporting stations at Columbus for Lakeside District, and Bay City Waterworks for Gulf Coast District.

Table 4.9 lists the mean and standard deviation for each variable in equation 4.14. Some differences between the two irrigation districts can be inferred from these simple statistics. The average volume of water delivered to fields is less in 1993 than in 1992. However, this difference cannot be attributed to volumetric water pricing without taking all relevant factors into account. Field size on Lakeside District is generally larger than in Gulf Coast District. Finally, farmers in Gulf Coast District generally took water over a longer period during the growing season than did farmers on Lakeside District. Of some interest are the relatively large standard deviations for almost all parameters used in this analysis. This suggests that farming practices and conditions are highly variable on both irrigation districts.

Table 4.10 lists the parameter estimates and t-statistics estimated for five subsets of the data contained in the water accounting databases. Data is subset by year and by district. In Gulf Coast District, the equation is estimated separately for the east side and the west side. No estimates are presented for data collected in 1992 in Gulf Coast District's east side because this data set is incomplete and contains no crop separation dates. The remaining data for Gulf Coast District is also incomplete because start and end dates for the irrigation period in each field are missing from the record. These dates are necessary to calculate the days and rainfall variables; therefore, estimates in Table 4.9 and Table 4.10 are based on only those few observations for which a sufficient record exists.

When the variables are specified, these equations provide an estimate of the expected volume of water use in a field. For example, a 100 acre field on Lakeside District in 1992 for which the length of the irrigation period and the rainfall intensity are 68 days and 12.48 inches respectively would be expected to use 272.32 acre-feet of water during the first crop:

$$-150.72 + (2.24*100) + (4.32*68) + (-7.59*12.48) + (-81.16*0) = 272.317 \quad \text{(Eq. 4.15)}$$

Because the equation includes information on the length of the irrigation period and the rainfall intensity, it is possible to compare how water use varies between fields for which the value of these parameters is different. For example, the length of the growing season and the rainfall intensity at an individual field may be substituted for the average values used here. The result will indicate the volume of water the average farmer would be expected to use under those conditions. The difference between a farmer's expected water use and actual water use reflects the effectiveness of his water management practices, the accuracy of water measurement, and other possible factors.

Some differences in the water use between fields can be regarded as a reflection of slightly different soil types, farming practices, or evaporation rates. These factors represent variables that might make one farmer's water use higher than another farmer's despite identical model estimates. Because an assessment of water measurements at individual fields must also incorporate information about the reliability of the estimate, it is necessary to establish a confidence interval around the predicted value before concluding whether or not a particular observation is out of the ordinary. The estimation of confidence limits around predicted values requires a complex series of calculations.

To demonstrate how such confidence intervals might be applied, Figure 4.4 shows the confidence intervals around model estimates for a range of field acreages when other parameter estimates are fixed at their mean values. The regression line in this figure is based on equation 4.14 and estimated from observations on Lakeside District during the 1993 crop season. The narrow lines above and below the thick center line represent 95 percent confidence limits. Differences between field observations and predicted values may be attributed to random error if the field observations fall within the confidence limits. Field observations that lie on the plane above the upper line, or below the lower line, can be regarded as suspect observations with a 95 percent level of certainty that the cause of the difference is not related random differences between fields.

At least two possibilities for such large differences in the predicted value and the observed value exist. One possibility is that the farmer's water management practices are significantly better or worse than the typical management practices on the irrigation district. Another possibility is that the water coordinator made an error in measuring the volume of water entering the field. These kinds of limits might provide a simple tool for resolving disputes about water measurements between farmers and irrigation district managers.

The confidence limits in Figure 4.4 are based on mean values for model parameters. These intervals will be narrower than those confidence intervals based on parameter values that are far from the mean. For example, Figure 4.5 shows the confidence interval around the predicted value of water use for a farmer that took water over a 56-day period during which the rainfall intensity was 17.48 acre -inches per acre. Although the rainfall intensity is typical for fields on Lakeside District, this farmer's irrigation period is much less than average. This observation is atypical because the value of at least one model variable is much different than the average case. Therefore, water use may be predicted with less certainty than for the average case in Figure 4.4. This is reflected in the slightly larger confidence band.

The parameter estimate for the acreage variable, β_1, defines average water use per-acre on each district as the difference in water use between fields that may be attributed to acreage alone. Under the assumption that soil types have little influence on the volume of water use, marginal differences between fields may reflect environmental factors. The number of days over which a farmer must irrigate his crop reflects many uncontrollable environmental factors that influence crop development. The rainfall variable is included in this equation to reflect a potential relationship between differences in rainfall and differences in water use between fields. The parameter estimate is significant in Lakeside District, but not in Gulf Coast District. This may be related to the fact that managers in Lakeside District turn the river pumps off whenever it rains. Although this is not the practice in Gulf Coast District, the LCRA has also observed a negative correlation between total water diversions at the river pumps and rainfall on that district.[4] Therefore, differences in the magnitude and significance of parameter estimates between districts remain unexplained.

Evaluation of Water Measurement at Delivery Structures

Farmers on both irrigation districts have indicated that LCRA is inconsistent in the way it measures the volume of water entering fields. The following analysis attempts to determine the source of any possible inconsistencies in measurements between fields by evaluating the consistency with which water coordinators measure water and the consistency of measurements taken at different types of delivery structures. The water accounting database on each district includes information about the delivery structures and the water coordinator responsible for taking those measurements.

It is possible to use the equations developed in the preceding section to examine the consistency with which LCRA's water coordinators measure the volume of water entering a field. In equation 4.16, a dummy variable is added to indicate which of six water coordinators was responsible for taking measurements at a particular field:

$$V = \beta_0 + \beta_1 A + \beta_2 D + \beta_3 P + \beta_4 C + \beta_5 Q \qquad \text{(Eq. 4.16)}$$

The variable V is the volume of water measured at the delivery structure. The variable A is field acreage, the variable D is the length of the irrigation period in days, and the variable P is rainfall intensity during the irrigation period. The variable C is a dummy variable equal to 1 for second crop observations, and the variable Q is a dummy variable equal to 1 for the water coordinator under investigation. The equation is estimated for each water coordinator so that his measurements are compared directly against his peers' measurements. The analysis reveals whether or not the water coordinator's measurements are consistently high or low. The parameter estimate β_5 represents the difference in total water deliveries between fields that may be specifically attributed to an individual water coordinator's tendency to under- or over-measure the volume of water entering a field. If the t-statistic for this parameter estimate is insignificant, it is possible to conclude that this water coordinator's measurements are consistent with all other water coordinators measurements.

Table 4.11 and Table 4.12 list the parameter estimates and t-statistics for Lakeside District in 1992 and 1993 respectively. During the 1992 crop season, water coordinators appear to have been consistent in their methods. While any individual water coordinator may have under- or over-measured at particular fields, these water coordinators did not consistently under- or over-measure in any fields. With one exception, the t-statistics for β_5 in Table 4.12 are insignificant. This indicates that during the 1993 crop season water coordinator number 6 had an overall tendency to measure less water at delivery structures. The interpretation is that he had a tendency to under-measure water by approximately 35.97 acre-feet.

Table 4.13 lists parameter estimates and t-statistics for equation 4.16 estimated using information contained in the water accounting database for the 1992 crop season in Gulf Coast District. For 1992, all observations on Gulf Coast's east side have been disregarded because those records do not include crop separation dates. Many other data from the remaining observations are also missing. For this reason, the irrigation period and rainfall intensity variables have been removed from the analysis.

Of the three water coordinators analyzed for the 1992 crop season, results show that no water coordinators had a tendency to over- or under-measure water deliveries relative to their peers. However, results for 1993 (Table 4.14) show that two water coordinators displayed an overall tendency to over- or under-measure the volume of water entering a field during that crop season. Water coordinator number 1 had a tendency to over-measure water by approximately 42.17 acre-feet. Water coordinator number 6 had an overall tendency to under-measure water by approximately 62.25 acre-feet.

These results suggest that the volume of water measured at a field may depend in part on which water coordinator measures the water entering the field. There is a case for more training of water coordinators and perhaps more double-checking of water coordinator measurements by district managers. An alternative explanation for the differences observed in this analysis is related to the location of the water coordinator's canal segments. There is some concern that fluctuating water levels in the canal could lead to differences in measurement at delivery structures located at the head of the canal and those located at the foot of the canal.

A similar analysis can be conducted on each district to determine whether or not the specific type of structure used to deliver and measure water has any consistent influence on the volume of water measured at that structure. Equation 4.16 below includes a dummy variable for the structure type rather than the water coordinators. The equation states that the volume of water measured at the delivery structure is a function of field acreage, length of the irrigation period:

$$V = \beta_0 + \beta_1 A + \beta_2 D + \beta_3 P + \beta_4 C + \beta_5 S \qquad \text{(Eq. 4.17)}$$

The variable V is the volume of water measured at the delivery structure. The variable A is the field acreage, the variable D is the number of days in which the farmer took water, and the variable P is the intensity of rainfall during the time that the farmer took water. The variable C is a dummy variable equal to 1 for second crop observations, and the variable S is a dummy variable equal to 1 for observations in those fields where concrete water boxes are used to deliver and measure irrigation inflows. The alternative type of delivery structure is a steel "culvert-style" pipe at which water coordinators use hand-held flow meters to measure the rate of water flow. If the parameter estimate for the dummy variable S is statistically insignificant, it indicates that no differences in water measurements to individual fields may attributed specifically to the type of structure or the method of measurement at that structure. Table 4.15 lists parameter estimates and t-statistics for equation 4.17. The results show that, in 1992, measurements at concrete water boxes were on average 33.81 acre-feet lower than at pipe delivery structures. The converse is true in Gulf Coast District during the 1992 crop season. Water measurements at concrete water boxes on that district had a tendency to be much higher than at pipe delivery structures. However, there is no evidence of any difference in measurements between the two types of structures during the 1993 crop season.

The Effect of Soil Permeability on Field Water Use

The following analysis of soils was completed in 1993 and is based on information on field water use collected by water coordinators during the 1992 crop season. Since then, several changes have occurred with respect to the methods used to analyze the data. Therefore, the discussion in this section differs from the discussion in previous sections of this chapter and this report. These results are presented here using 1992 data because soil types were not reassessed with respect to data from the 1993 crop season.

Soil series designations were obtained from U.S. Soil Conservation Service maps for Colorado, Wharton, and Matagorda Counties.[5] Table 4.16 lists the soil permeability group to which the soil series was assigned for this analysis. Permeability is "that quality of a soil that enables it to transmit water or air."[6] Soils have been grouped according to the permeability of the first layer, but soils will have different permeabilities at different depths. The column labeled "permeability" lists the permeability in inches per hour for each defined layer in the soil series. The typical profile is also listed in Table 4.16, which shows the depth at which each layer occurs and the soil texture in that layer. The texture of a given soil approximates the relative presence of sand, silt, and clay particles below 2 millimeters in diameter. In general, finer soils are classified as clay, less finely textured soils are classified as silt, and course textured soils are classified as sand.[7] General comments describing the soil follow in the next two columns. Agricultural drainage describes the rate at which water flows through soils. Saturation or ponding of water is a characteristic of those soils with slow permeability. The last column, features affecting rice irrigation, indicates particular soil characteristics of interest when attempting to grow rice on a particular soil.

While many soil characteristics will affect water use and rice yield, soil permeability provides an easily quantified factor for analysis. Table 4.17, Table 4.18, and Table 4.19 summarize the frequency of each soil series in each district. It may be that an alternative grouping of soils, based on water-holding capacity or some other quantifiable soil characteristic might provide different results. The soil permeability group assignments are based on the permeability of the first layer of each soil. If soil permeability in the first layer differs from that in subsequent layers, the assumption is that the first layer's permeability will have the greatest potential influence on percolation. To simplify the analysis, different soil types are grouped in three categories according to their permeability. Group I soils have the lowest permeability, 0.06 - 0.2 in./hr. Group II soils have a moderate permeability, 0.2 - 0.6 inches per hour (in/hr), and Group III soils have the highest permeability, 0.6 - 2.0 in./hr.

$$W = \beta_0 + \beta_1 \ln A + \beta_2 S + \beta_3 C \qquad \text{(Eq. 4.18)}$$

Ordinary least square regressions were applied to the data to determine the effect of second cropping, farm acreage, and soil type on per-acre water use in individual fields. Equation 4.18 states that per-acre water use is a function of acreage, soil type, and second cropping.

The dependent variable W is water use in acre-feet per-acre. The variable A represents field acreage. In this equation, the natural logarithm of field acreage is used because it gives more efficient estimates of the regression coefficient. The variable S represents the mean permeability for each permeability group. Group I, Group II, and Group III soils have average permeabilities of 0.13 inches per hour, 0.4 inches per hour, and 1.3 inches per hour respectively. The variable C is a dummy variable equal to 1 in those fields that were second cropped.

Parameter estimates and t-statistics are provided in Table 4.20. In all cases, acreage has a diminishing marginal effect on water use. Runs in which the acreage variable was specified without the natural-log transformation showed similar results. The coefficient for the soils variable is negative but insignificant indicating that soil permeability groups provide little or no insight into differences in water use between fields. For Gulf Coast West and Lakeside District, the second cropping variable indicates the average water use associated with the second crop. No estimate is presented for this variable in Gulf Coast East because crop separation dates were not included in the database.

Each regression shows similar results. Acreage and second cropping are significant factors in determining per-acre water use. As field size increases, water use per acre decreases. It is possible that this reflects a superior degree of management in larger fields; as the level of farmer's investments increases with field size, the incentive to manage those fields efficiently is also larger. Regressions for both Gulf Coast West and Lakeside show that per-acre water use increases with second cropping. In Gulf Coast West, second cropping increases a field's water use by about 2.3 acre-feet per-acre. In Lakeside District, second cropping increases a field's water use by 1.9 acre-feet per-acre. These values may be interpreted as average water use.

Conclusions

This analysis leads to several conclusions about LCRA's water conservation program and the potential for similar conservation programs in other parts of the state. There is a significant water savings potential associated with canal rehabilitation and volumetric water pricing. While other programs may have potentially significant effects, those program elements were not quantified for this study. This analysis presents an approach to the problem of estimating water savings using two separate sources of data. The first set of data is a time series that explains total district water diversions in terms of rice acreage and rainfall. The second set of data is a cross-sectional database of on-farm water deliveries. If it were possible to combine the data sets in a single analysis and quantify the other program elements, the results would reflect a broader data base. For example, it may be that other program elements such as education have contributed to reductions in on-farm water use and that these water savings have inappropriately been attributed to canal rehabilitation. What is needed is a more sophisticated method of tracking the water conservation program.

After accounting for differences in acreage and rainfall between years, this analysis shows that canal rehabilitation has resulted in a 69,893 acre-foot reduction in total water diversions on the Gulf Coast District. Similarly, after accounting for differences in acreage, rainfall, and the length of the irrigation period between fields, a substantial reduction in on-farm water use may be attributed to volumetric pricing. Lakeside District farmers appear to have responded to volumetric pricing by reducing their water use by 0.52 acre-feet per acre. Gulf Coast District farmers appear to have responded to volumetric pricing by reducing their water use by 0.31 acre-feet per acre. The difference in savings between the districts may be attributed to the difference in the variable price of water between districts.

Both canal rehabilitation and volumetric water pricing exhibit potential for use in other areas of the state. However, volumetric water pricing may be implemented only if reliable methods of water measurement exist. LCRA has implemented one method, a basic water measurement system. From the farmers' perspective, there are many questions about whether or not LCRA's system is adequate. Although the methods applied by the LCRA are consistent in laboratory settings, the analysis presented in this report shows that not all water coordinators obtain consistent results.[8] In both the Lakeside District and the Gulf Coast District, the volume of water measured may depend in part on which water coordinator takes the measurements. When factors that cause differences in water use between fields are accounted for in the equation, one water coordinator on Lakeside District appears to under-measure water deliveries. In Gulf Coast District, one water coordinator appears to over-measure water deliveries, and one appears to under-measure water deliveries. However, the water accounting database for Gulf Coast District is missing much of the data that might account for these differences in water measurements between fields. In order to conduct the analysis, it was necessary to exclude those parameters from the model of on-farm water use.

Any systematic inconsistency in measurements related to the type of delivery structure at which measurements were taken in 1992 appears to have been resolved in the 1993 crop season. The results presented in this paper suggest that the LCRA's methods are perhaps more reliable than some farmers seem to think; however, there may be some remaining inconsistencies in the way that individual water coordinators measure water at delivery structures. This suggests that LCRA should perhaps place more emphasis on the supervision and training on these water coordinators. One potential source of the differences in measurement between water coordinators is that differences related to the location of a water coordinator's assigned canal segment have not been included in the analysis. Water coordinators are responsible for measuring water at delivery structures along assigned canal segments. It may be that the method of water measurement used on these districts produces different results at the head of the canal than at the foot of the canal. If this is true, then some of the differences attributed to water coordinators may actually be related to the fact that a water coordinator's assigned canal segment is at the head or at the foot of the canal.

This analysis of water coordinators and delivery structures can identify water coordinator's consistent tendency to under- or over-measure water. By measuring water use at individual physical structures, it is possible to evaluate the probability that the volume of water measured at a particular field is adequate. These results show how such an evaluation might be made using confidence limits around the modeled estimates of expected water diversions given specific field characteristics. This model might be applied to resolve disputes between individual farmers and the LCRA over whether or not the volume of water measured at a particular field is accurate.

This chapter has demonstrated how unified water use data can be used to make inferences about program efficiency or effectiveness and even evaluate staff and equipment. The task for many agricultural conservation projects is to determine how to collect and validate such data. Water conservation program evaluation requires that cross-sectional on-farm data to evaluate on those factors be collected for individual fields. Chapter five describes how cross-sectional and time series data can be processed through geographical information systems for analyzing irrigation water conservation.

Notes

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[1] Gerald Crenwelge, Soil Scientist, U.S. Soil Conservation Service (SCS), Beaumont, Texas, telephone interview by Martin Schultz, December 1, 1993.

[2] Quentin Martin, "Estimation of Climatic Influences on the Monthly and Annual Colorado River Diversions for Rice Irrigation in the LCRA District," Lower Colorado River Authority (LCRA), Austin, Texas, April 1993.

[3] Martin, "Estimation of Climatic Influences," 1988

[4] Quentin Martin, Manager, Water and Wastewater, LCRA, Austin, Texas, interview, February 24, 1993.

[5] SCS, Soil Surveys of Colorado, Wharton, and Matagorda Counties, Texas, U.S. Department of Agriculture, Washington, D.C., March 1974.

[6] SCS, Soil Survey of Wharton County, Texas, U.S. Department of Agriculture, Washington, D.C., March 1974, p. 34.

[7] SCS, *Soil Survey*, p. 43.

[8] U.S. Bureau of Reclamation, "Lower Colorado River Authority Water Box Calibration Study," Denver, Colorado, October 1990.

Table 4.1
Parameter Estimates and T-Statistics for Equations 4.1

Regression Coefficient	Lakeside District		Gulf Coast District	
	1968-1986[a]	**1968-1992**	**1968-1986**[a]	**1968-1992**
β_0	37.97	35.62	107.98	60.46
β_1	3.712	3.939	5.054	6.505
	(5.92)*	(5.93)*	(9.14)*	(9.51)*
β_2	-0.616	-0.645	-0.358	-0.435
	(-6.72)*	(-6.03)*	(-3.27)	(-2.74)*
β_3	0.060	1.271	-	-
	(5.32)*	(5.59)*	-	-
R-squared	0.880	0.838	0.85	0.83
Adjusted R-squared				0.81
Model F	N/A	N/A	N/A	50.12

Source: (a) Quentin Martin, Lower Colorado River Authority, Water and Wastewater Utilities, "Estimation of climatic influences on the monthly Colorado River diversions for rice irrigation in the LCRA District," (Austin, Texas, April 1988).

Table 4.2
Parameter Estimates and T-Statistics for Equation 4.3 and 4.4

Regression Coefficient	Lakeside District Eq. 4.3	Gulf Coast District Eq. 4.4
β_0	35.655	99.057
β_1	3.938	5.529
	(5.78)*	(7.98)*
β_2	-0.645	-0.444
β_3	1.271	-
β_4	0.013	-30.411
	(0.002)	(-2.79)*
R-squared	0.838	0.877
Adjusted R-squared	0.806	0.859
Model F	25.975	50.115

Note: t-statistics given in parentheses. Asterisks indicate significance at the 95 percent confidence level.

Table 4.3
Summary of Results Presented in this Chapter

	Lakeside District	Gulf Coast District
Water Conservation		
1. Water savings associated with canal rehabilitation, 1988-93.[a]	N/A	69,891 acre-feet
2. Water savings associated with volumetric pricing, 1992-93.[a]	0.52 acre-feet per-acre	0.31 acre-feet per-acre
3. Additional water savings potential associated with an on-farm water conservation program.*	0.65 acre-feet per-acre	1.80 acre-feet per-acre
Water Management		
4. Average water use, first crop, 1993.	2.44 acre-feet per-acre	3.79 acre-feet per-acre
5. Average water use, second crop, 1993.	1.92 acre-feet per-acre	2.26 acre-feet per-acre
6. Average effect of field acreage on total first crop water use.	2.14 acre-feet per-acre	3.42 acre-feet per-acre
7. Average effect of soil permeability on per-acre water use.[b]	No discernable effect	No discernable effect
8. Average effect of one inch of rainfall on irrigation inflows.	-0.07 acre-feet per-acre per-inch of rain	No discernable effect
9. Average effect of irrigation period length on per-acre water use.	0.017 acre-feet per-acre per-day	No discernable effect
Water Measurement		
10. The consistency of water measurement between water coordinators. (Average difference in measurements in parenthesis.)	1 water coordinator inconsistent (-0.29 acre-feet per-acre)	2 water coordinators inconsistent (0.35 and -0.51 acre-feet per-acre)
11. The consistency of water measurements between types of delivery structures.	No discernable difference between types of structures	No discernable difference between types of structures

Note: All estimates based on 1993 water use except as indicated. (a) Represents the water savings over the interim. (b) Based on 1992 water measurements.

* Martin T. Schultz, "Estimation of Derived Demand for Surface Water on Two Rice Irrigation Districts in the Lower Colorado River Basin, Texas," (Professional Report, Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin, 1994.)

Table 4.4
Canal Rehabilitation Program Evaluation

Regression Coefficient	Eq. 4.5	Eq. 4.6	Eq. 4.7
β_0	100.88	99.199	95.498
β_1	5.325	5.358	5.412
	(8.68)*	(9.25)*	(9.89)*
β_2	-0.383	-0.379	-0.368
	(3.10)*	(3.18)*	(-3.21)*
β_4	-3.016	-	-
	(0.22)	-	-
β_5	-0.514	-0.544	-
	(2.69)*	(4.25)*	-
β_6	-	-	-7.5E-05
	-	-	(-5.21)*
R-squared	0.910	0.916	0.931
Adjusted R-squared	0.892	0.896	0.922
Model F	50.480	70.490	99.241

Note: t-statistics given in parentheses. Asterisks indicate significance at the 95 percent confidence level.

Table 4.5
Canal Rehabilitation Expenses and Estimated Water Savings by Year

Year	Canal Rehabilitation Expenses	Canal Mileage Rehabilitated (miles)	Annual Water Savings (acre-feet)	Cumulative Water Savings (acre-feet)
1988	$59,697	20	3,691	3,691
1989	$109,469	30	8,362	12,053
1990	$141,771	20	10,771	22,824
1991	$238,300	15	17,888	40,712
1992	$238,250	14	18,040	58,752
1993	$155,000	4	11,139	69,891

Source: (a) Lower Colorado River Authority (LCRA), "Annual Budget Report," (Austin, Texas, 1989-1993), (Computer Printout). (b) Bruce Hicks, Manager, Irrigation Operations, LCRA, Eagle Lake, Texas, Telephone Interview, February 1993. (c) Jobaid Kabir, Manager, Environmental Services, LCRA, Austin, Texas, telephone interview with David Eaton, April 1993.

Table 4.6
Parameter Estimates and T-Statistics for Equation 4.8

Regression Coefficient	Cumulative Expenses	Annual Expenses
β_0	-10.341	-10.958
β_1	1.062	1.120
	(71.53)*	(22.35)*
R-squared	0.999	0.992
Adj. R-squared	0.999	0.990
Model F	5116.238	499.652

Note: t-statistics given in parenthesis. Asterisks indicate significance at the 95 percent confidence level.

Table 4.7
Parameter Estimates and T-Statistics for Equation 4.9

Regression Coefficient	Lakeside District	Gulf Coast District
β_0	54.584	96.139
β_1	3.179	5.384
	(4.659)*	(9.714)*
β_2	-0.649	-0.361
	(-5.969)*	(-3.106)*
β_3	0.052	-
	(5.502)*	-
β_5	-	-8.3E-05
	-	(-4.555)*
β_6	-6.418	15.509
	(-.674)	(0.742)
R-squared	0.844	0.933
Adjusted R-squared	0.813	0.920
Model F	28.115	73.050

Note: t-statistics given in parenthesis. Asterisks indicate significance at the 95 percent confidence level.

Table 4.8
Parameter Estimates and T-Statistics for the Model of Farmers Reactions

Regression Coefficients	Eq. 4.11	Eq. 4.13
β_0	-137.852	1.418
β_1	-3.872	-.047
	(-3.516)*	(-4.205)*
β_2	2.629	-
	(47.181)*	-
β_3	2.148	0.022
	(7.939)*	(8.017)*
β_4	-28.487	-0.409
	(-2.670)*	(-3.796)*
β_5	59.554	0.714
	(3.491)*	(4.758)*
β_6	-0.737	-0.024
	(-0.271)	(-.858)
R-squared	0.742	0.243
Adjusted R-squared	0.740	0.239
Model F	422.272	56.608

Note: t-statistics given in parenthesis. Asterisks indicate significance at the 95 percent confidence level.

Table 4.9
Means and Standard Deviations for Eq. 4.14

		Water Deliveries (acre-feet) Mean	Std. Dev.	Variable field acreage (acres) Mean	Std. Dev.	Number of Days Mean	Std. Dev.	Rainfall (inches) Mean	Std. dev.	Number of Observations
Lakeside										
1992	First Crop	362.80	262.23	139.63	107.12	68.54	16.71	12.48	5.12	187
1993	First Crop	297.24	244.30	122.03	87.09	78.81	11.37	17.48	5.22	172
1992	Second Crop	386.77	324.07	143.97	108.41	77.89	15.04	5.28	1.12	158
1993	Second Crop	213.46	182.97	113.76	85.97	59.86	12.64	1.84	1.39	111
Gulf Coast – West Side										
1992	First Crop	395.44	336.23	97.79	74.82	98.84	21.06	26.10	5.87	124
1993	First Crop	333.50	271.00	102.06	73.62	95.73	14.61	13.89	5.00	60
1992	Second Crop			Not	Available					
1993	Second Crop	275.27	337.95	106.08	94.73	79.93	11.74	20.75	32.75	14
Gulf Coast – East Side										
1993	First Crop	343.54	274.29	89.20	73.04	88.65	16.48	13.05	4.66	89
1993	Second Crop	141.70	106.86	74.12	39.53					10

Table 4.10
Parameter Estimates and T-Statistics for Equation 4.14

Regression Coefficient	Lakeside	Gulf Coast		
	1993	1993	1992^a	1992^b
β_0	-150.72	26.88	-105.48	-11.35
β_1	2.24	2.14	3.45	3.43
	(29.98)*	(26.76)*	(18.73)*	(32.72)*
β_2	4.32	-0.645	-0.358	-0.435
	(6.28)*	(2.94)*	(3.06)	(0.11)*
β_3	-7.59	-8.55	-2.83	1.24
	(-2.71)*	(-4.28)*	(-0.86)	(0.39)
β_4	-81.16	-166.42	-142.79	-108.70
	(-2.75)*	(-5.62)*	(-2.15)*	(-4.32)*
R-squared	0.74	0.75	0.71	0.87
Adjusted R-squared	0.75	0.70	0.87	
Model F	250.61	212.91	99.20	284.83

Note: t-Statistics in parenthesis. Asterisks denote significance at the 95 percent confidence level. (a) Includes data from only Gulf Coast West. (b) Excludes many observations for which the irrigation start-date and/or the irrigation end-date are not provided in the water accounting database.

Table 4.11
Lakeside 1992: Parameter Estimates and T-Statistics for Equation 4.16

Regression Coefficient	**Water Coordinator**					
	1	2	3	4	5	6
β_0	-150.31	-150.52	-144.85	-152.26	-150.49	-150.26
β_1	2.24	2.24	2.24	2.24	2.24	2.24
	(29.90)*	(29.59)*	(29.95)*	(29.95)*	(29.73)*	(29.87)*
β_2	4.32	4.33	4.34	4.36	4.32	4.32
	(6.24)*	(6.25)*	(6.29)*	(6.31)*	(6.26)*	(6.27)*
β_3	-7.58	-7.60	-7.97	-7.83	-7.65	-7.58
	(-2.70)*	(-2.70)*	(-2.80)*	(-2.78)*	(-2.72)*	(-2.70)*
β_4	-81.05	-81.22	-83.85	-83.27	-81.45	-81.08
	(-2.74)*	(-2.74)*	(-2.82)*	(-2.81)*	(-2.76)*	(-2.74)*
β_5	-2.27	-0.71	-18.20	17.74	6.29	-2.81
	(0.09)	(-0.04)	(-0.78)	(0.75)	(0.30)	(-0.13)
R-squared	0.74	0.74	0.74	0.74	0.74	0.74
Adjusted R-squared	0.74	0.74	0.74	0.74	0.74	0.74
Model F	199.92	199.91	200.38	200.34	199.98	199.92

Note: t-statistics given in parenthesis. Asterisks indicate significance at the 95 percent confidence level.

Table 4.12

Lakeside 1993: Parameter Estimates and T-Statistics for Equation 4.16

Regression Coefficient	**Water Coordinator**					
	1	2	3	4	5	6
β_0	-27.72	18.45	25.62	23.59	28.79	32.76
β_1	2.14	2.16	2.13	2.12	2.13	2.11
	(26.72)*	(26.91)*	(26.36)*	(25.85)*	(26.67)*	(26.41)*
β_2	2.10	2.24	2.13	2.10	2.14	2.18
	(2.93)*	(3.14)*	(2.97)*	(2.93)*	(2.98)*	(3.07)*
β_3	-8.54	-9.19	-8.63	-8.34	-8.67	-8.77
	(-4.27)*	(-4.55)*	(-4.32)*	(-4.16)*	(-4.32)*	(-4.41)*
β_4	-166.28	-174.54	-167.46	-163.41	-168.13	-166.56
	(-5.61)*	(-5.85)*	(-5.64)*	(-5.46)*	(-5.65)*	(-5.66)*
β_5	-7.78	31.64	14.74	15.96	-11.12	-35.97
	(0.39)	(1.86)	(0.72)	(0.75)	(0.70)	(-2.05)*
R-squared	0.75	0.76	0.75	0.75	0.75	0.76
Adjusted R-squared	0.74	0.75	0.75	0.75	0.75	0.75
Model F	169.83	172.53	170.13	170.17	170.11	173.12

Note: t-statistics given in parenthesis. Asterisks indicate significance at the 95 percent confidence level.

Table 4.13

Gulf Coast 1992: Parameter Estimates and T-Statistics for Equation 4.16

Regression Coefficient	**Water Coordinator**		
	1	2	3
β_0	64.15	49.59	31.05
β_1	3.55	3.51	3.56
	(19.01)*	(18.80)*	(18.91)*
β_4	-142.53	-153.11	-144.31
	(-4.31)*	(-4.68)*	(-4.37)*
β_5	-48.26	8.45	45.40
	(-1.64)*	(0.27)*	(1.46)*
R-squared	0.70	0.69	0.70
Adjusted R-squared	0.69	0.69	0.69
Model F	179.13	123.57	

Note: t-statistics given in parenthesis. Asterisks indicate significance at the 95 percent confidence level.

Table 4.14
Gulf Coast 1993: Parameter Estimates and T-Statistics for Equation 4.16

Regression Coefficient	Water Coordinator					
	1	2	3	4	5	6
β_0	21.24	29.11	27.89	28.50	31.66	37.81
β_1	3.31	3.31	3.31	3.29	3.31	3.32
	(35.62)*	(34.98)*	(35.26)*	(34.93)*	(35.28)*	(36.05)*
β_4	-125.43	-132.78	-134.88	-131.29	-131.59	-134.47
	(-6.61)*	(-7.02)*	(-7.02)*	(6.91)*	(-6.94)*	(-7.25)*
β_5	42.17	2.70	10.67	15.52	-14.65	-62.25
	(2.31)*	(0.16)	(0.61)	(0.74)	(-0.77)	(-3.25)*
R-squared	0.84	0.83	.83	0.83	0.83	0.84
Adjusted R-squared	0.83	0.83	.83	0.83	0.83	0.84
Model F	436.99	426.50	427.19	427.54	427.61	447.39

Note: t-statistics given in parenthesis. Asterisks indicate significance at the 95 percent confidence level.

Table 4.15
Parameter Estimates and T-Statistics for Equations 4.17

Regression Coefficient	Lakeside		Gulf Coast	
	1992	1993	1992	1993
β_0	-146.97	41.27	32.49	23.69
β_1	2.33	2.43	3.53	3.38
	(26.45)*	(27.34)*	(19.19)*	(32.07)*
β_2	3.57	1.26	-	-
	(5.08)*	(1.92)*	-	-
β_3	-6.43	-7.67	-	-
	(-2.24)*	(-4.34)*	-	-
β_4	-70.36	-136.33	-149.34	-131.30
	(-2.36)*	(-5.22)*	(-4.55)*	(-5.24)*
β_5	-33.81	9.25	145.90	-6.67
	(-1.98)*	(0.63)	(3.63)*	(-0.16)
R-squared	0.74	0.80	0.73	0.84
Adjusted R-squared	0.74	0.80	0.74	0.84
Model F	152.12	212.91	132.57	355.41

Note: t-Statistics in parenthesis. Asterisks denote significance at the 95 percent confidence level.

Insufficient data to include all variables in Gulf Coast District.

Table 4.16
List of Soil Permeability Types

Soil Series (Map Symbol)	Irrigation District	Permeability Group	Permeability (inches/hour)	Typical Depth (inches)	Profile Texture	Agricultural drainage	Features affecting use of soil for rice cultivation
Bacliff (BaA)	GC West, GC East	III	0.6-2.0	0-38	Clay	Percolates slowly	Wetness
			0.0-0.06	38-80			
Bernard (BcA, BcB, BeA)	GC East	II	0.2-0.06	0-7	Clay loam	Very slow permeability	Surface drainage needed
			<0.06	7-52	Clay		
				52-60	Clay loam		
Crowley (Cr)	Lakeside	III	0.63-2.00	0-15	Fine sandy loam	Very slow permeability	Small mounds, surface drainage needed
			<0.06	15-22	Clay		
			0.06-0.20	22-38	Sandy clay		
			0.06-0.20	38-62	Sandy clay		
Dacosta (DaA)	GC West, GC East	II	0.63-2.00	0-9	Sandy clay loam	Percolates slowly	Wetness
			0.00-0.06	9-36			
			0.00-0.06	36-60			
Edna (EdA, EdB, EtA)	Lakeside, GC West, GC East	III	0.20-0.60	0-9	Fine sandy loam	Very slow permeability	Small mounds, surface drainage needed
			<0.06	9-38	Clay		
			0.06-0.20	38-50	Clay loam		
			0.20-0.63	50-65	Sandy clay loam		

(Continued from previous page)

Katy (KaB)	Lakeside	III	0.60-2.00	0-17	Fine sandy loam	Percolates slowly	Wetness and soil blowing
			0.60-2.00	17-22			
			0.06-0.20	22-44			
			0.20-0.63	44-80			
Laewest (LaA)	GC West, GC East	I	0.06-0.20	0-10	Clay	Percolates slowly	Wetness
			<0.06	10-68			
			<0.06	68-80			
Lake Charles (LcC)	Lakeside, GC East	I	<0.06	0-63	Clay	Very slow permeability	Surface drainage needed
Livia (LvA)	GC West, GC East	III	0.60-2.00	0-8	Very fine sandy loam	Percolates slowly, excess salt	Wetness, droughty
			<0.06	8-42			
			<0.06	42-80			
Telferner (TfA)	GC West, GC East	III	0.60-2.00	0-15	Very fine sandy loam	Percolates slowly	Wetness
			<0.06	15-52			
			0.06-0.20	52-80			
Texana (TxA)	GC West, GC East	III	0.60-2.00	0-20	Fine sandy loam	Percolates slowly	Wetness and soil blowing
			<0.06	20-42			
			0.06-0.20	42-80			

Note: Type I soils have permeabilities between 0.06 and 0.2 inches per hour. Type II soils have permeabilities between 0.20 and 0.60 inches per hour. Type III soils have permeabilities between 0.60 and 2.0 inches per hour

Table 4.17
Frequency of Soil Types, Lakeside

Soil Series	Permeability (inches/hour)	Frequency	Mean water use (acre-feet per acre)	Standard deviation (acre-feet per acre)
LcA	0.06-0.2	2	5.40	0.80
Cr	0.6-2.0	86	5.19	2.06
EdA	0.6-2.0	12	5.46	1.50
EdB	0.6-2.0	1	6.50	-
EtA	0.6-2.0	1	4.58	-
KaB	0.6-2.0	91	4.98	1.64

Note: Calculated based on information from Lower Colorado River Authority, Water Accounting Database (Lakeside, Texas, 1992) and Soil Conservation Service Soil Survey of Matagorda County, Texas, U.S. Department of Agriculture, Washington, D.C., March 1974.

Table 4.18
Frequency of Soil Types, Gulf Coast East

Soil Series	Permeability (inches/hour)	Frequency	Mean water use (acre-feet per acre)	Standard deviation (acre-feet per acre)
LaA	0.06-0.2	32	6.42	3.37
LcA	0.06-0.2	7	9.26	6.62
LoA	0.06-0.2	5	6.40	2.74
BeA	0.2-0.6	6	9.15	4.61
DaA	0.2-0.6	30	5.85	2.99
BaA	0.6-2.0	2	4.30	0.05
EdA	0.6-2.0	37	6.52	4.26
LvA	0.6-2.0	1	4.36	-
TfA	0.6-2.0	3	11.61	6.22
TxA	0.6-2.0	11	6.02	4.29

Note: Calculated based on information from Lower Colorado River Authority, Water Accounting Database (Lakeside, Texas, 1992) and Soil Conservation Service Soil Survey of Matagorda County, Texas, U.S. Department of Agriculture, Washington, D.C., March 1974.

Table 4.19
Frequency of Soil Types, Gulf Coast West

Soil Series	Permeability (inches/hour)	Frequency	Mean water use (acre-feet per acre)	Standard deviation (acre-feet per acre)
LaA	0.06-0.2	32	6.42	3.37
LcA	0.06-0.2	7	9.26	6.62
DaA	0.2-0.6	30	5.85	2.99
BaA	0.6-2.0	2	4.30	0.05
EdA	0.6-2.0	37	6.52	4.26
LvA	0.6-2.0	1	4.36	-
TfA	0.6-2.0	3	11.61	6.22
TxA	0.6-2.0	11	6.02	4.29

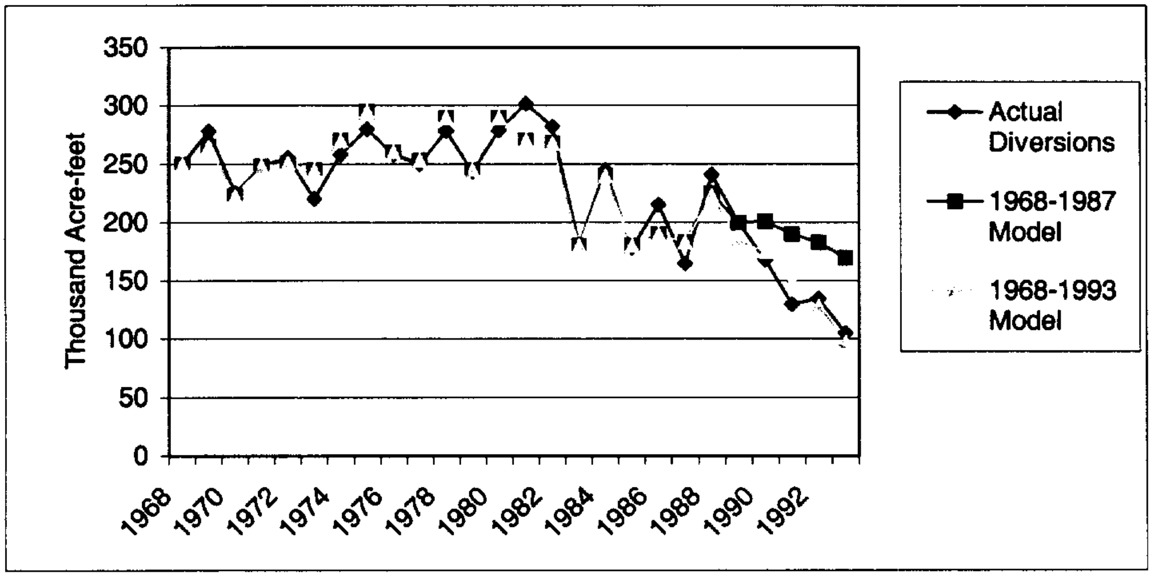
Note: Calculated based on information from Lower Colorado River Authority, Water Accounting Database (Lakeside, Texas, 1992) and Soil Conservation Service Soil Survey of Matagorda County, Texas, U.S. Department of Agriculture, Washington, D.C., March 1974.

Table 4.20
Parameter Estimates and T-Statistics for Soil Types

Regression Coefficient	Gulf Coast West	Gulf Coast East	Lakeside District
β_0	8.339	16.056	7.394
β_1	-0.823	-2.086	-0.613
	(2.994)*	(5.209)*	(3.973)*
β_2	-0.367	-0.56	-1.079
	(0.889)	(-0.916)	(1.11)
β_3	1.922	-	2.343
	(3.913)*	-	(7.337)*
R-squared	0.157	0.168	0.256
Adjusted R-squared	0.135	0.156	0.244

Note: t-statistic given in parentheses. (*)Asterisks indicate significance at the 95 percent confidence level.

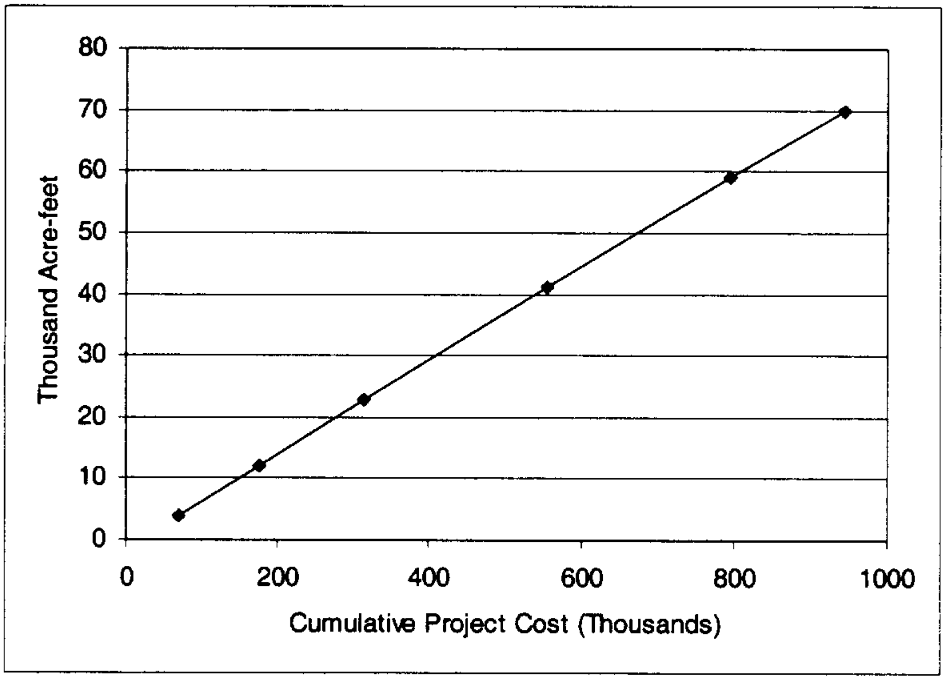
Figure 4.1
Water Diversions, 1968 to 1992



Source: Lower Colorado River Authority, *Irrigation Water Accounting Database*

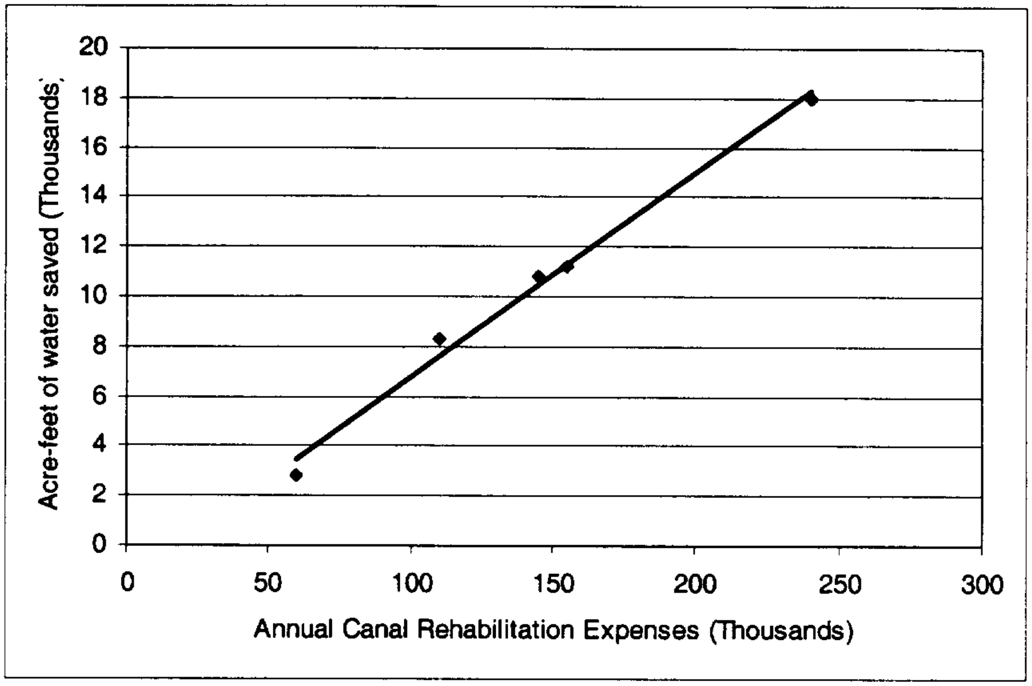
Figure 4.2

Relationship between Cumulative Rehabilitation Expenses and Water Savings



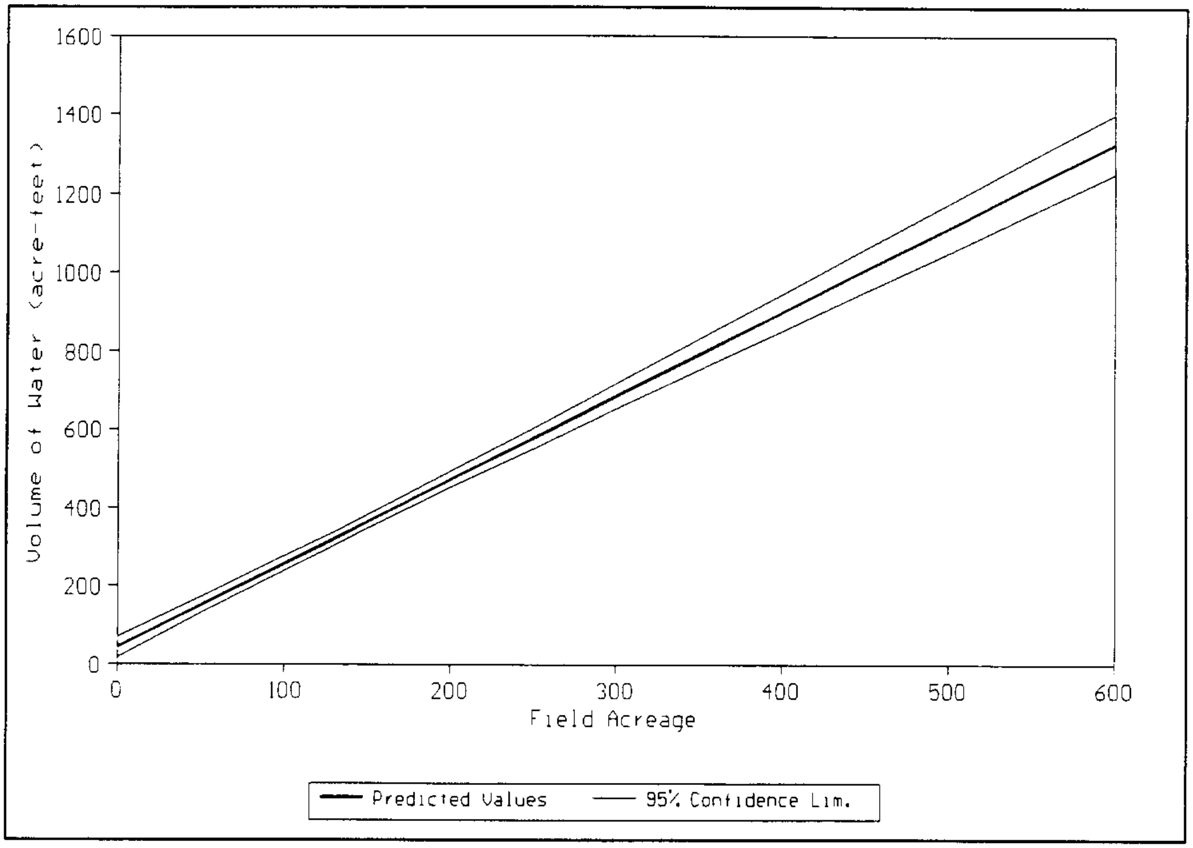
Source: Lower Colorado River Authority, *Irrigation Water Accounting Database*

Figure 4.3
Relationship between Annual Rehabilitation Expenses and Water Savings



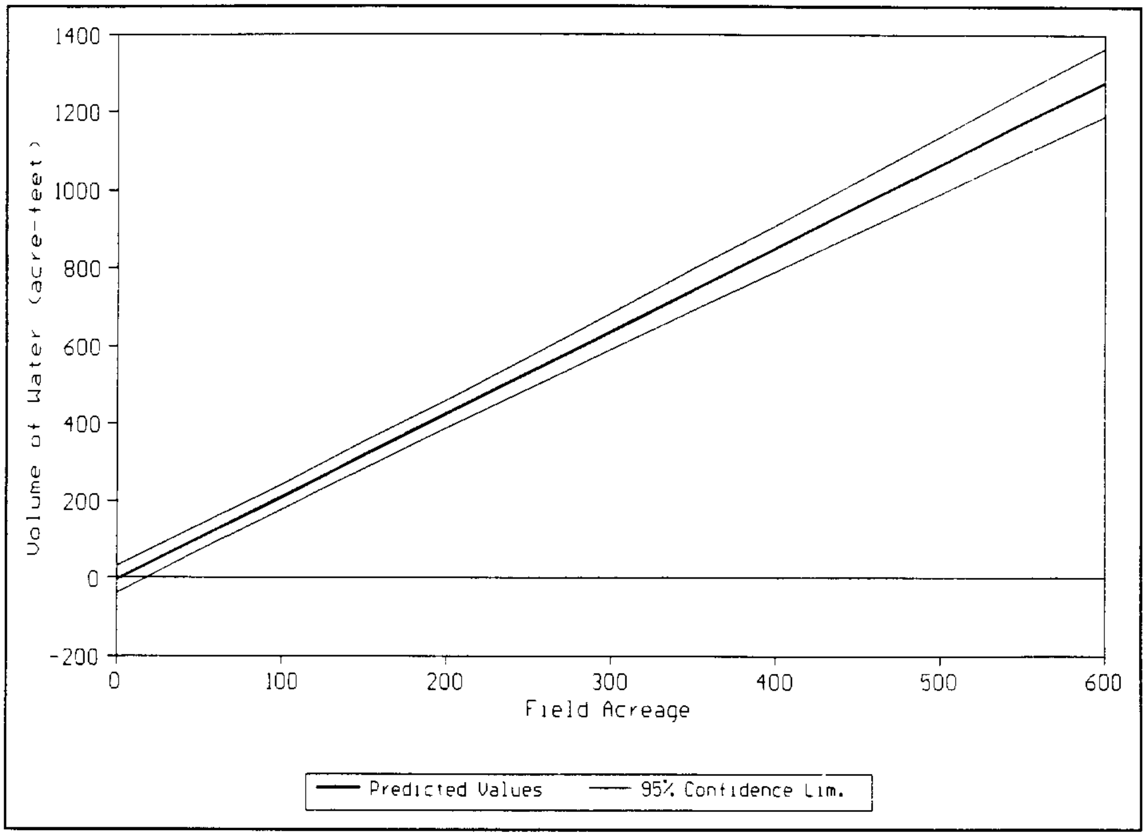
Source: Lower Colorado River Authority, *Irrigation Water Accounting Database*

Figure 4.4
Confidence Intervals, Mean Values for Model Parameters



Source: Derived from data in Lower Colorado River Authority, *Irrigation Water Accounting Database*

Figure 4.5
Confidence Intervals, 56-day Period, Intensity 17.48 in/acre



Source: Derived from data in Lower Colorado River Authority, *Irrigation Water Accounting Database*.

Chapter 5. GIS as a Tool for Irrigation Water Management

Introduction

The purpose of this chapter is to illustrate how geographical information system (GIS) software can be used in analysis and management of rice irrigation data. Advanced computer software offers a user new ways to examine and analyze data. Databases, spreadsheets, and statistical packages are the most common analytical tools for processing large amounts of data. The graphical presentation of data enhances these analyses by facilitating the visualization of relationships or trends. While most analytical software packages can produce useful analysis and print data in tabular or simple graphical form, few offer a method of displaying data in geographical form. The annexation of GIS software to databases can enhance the analytical power associated with that database. In the case of the Lower Colorado River Authority (LCRA) irrigation districts, such a system could also provide an interactive management tool for controlling water use in the districts and communicating with farmers.

This chapter illustrates how one GIS system could be applied on the LCRA districts. The GIS software package used to produce this report is ATLAS GIS, marketed by Strategic Mapping, Inc in Santa Clara, California. ATLAS GIS is written for DOS and requires an IBM compatible computer.

GIS software relates the information in a database to physical locations on a map. A GIS program may contain many base maps such as country, state and county maps. However, it is also possible to create customized maps for specialized applications through a time-consuming process called *digitizing*. Many GIS packages also accept data from computer-aided drafting programs.

Once stored within a computer, geographic details such as roads, canals, lakes, streams, towns, and individual data points can be arranged in "layers." Any combination of layers may be added to or removed from a base map with primary geographical features such as state, zip code regions, or rice fields. GIS systems also contain a built-in database management facility that permits the user to enter, display, edit, or print data on the map. Thematic expressions of raw or processed data are the power of the GIS system. In this chapter, data on farm water use is related to the location of fields. These maps allow the user to compare the water use between rice fields with an enhanced understanding of physical relationships that might influence water use and differences in water use between fields.

Other features contained in ATLAS GIS include *spatial selection*. This feature allows the user to focus on specific subregions in the area or map regions. ATLAS GIS also allows a user to point at an object on the map and obtain a pop-up list of its attribute data. For example, an individual rice field may be selected with the mouse and data regarding its size, owner, and water use will be displayed on-screen. Many other features within

ATLAS GIS could make it a powerful analytical tool, but a complete discussion of these features is beyond the scope of this chapter. Throughout the following discussion, it should become apparent that GIS programs would become a useful tool in the management, interpretation and expression of information contained in the water accounting database.

Applications of GIS Systems to Irrigation Water Management

In this demonstration, the goal is to identify possible relationships between water use, field size and location. The base maps and database used in this study are for Lakeside District, 1992. The map includes information on rice fields, irrigation canals, natural water ways, towns, and roads. Each field is assigned attributes from the irrigation water accounting database such as first and second crop water deliveries, and acreage. The GIS allows all rice fields to be subset according to their relative size and water use. Although it has not been done here, it would also be possible to further enhance the maps with topographical features, soil descriptions, or information about individual farmers.

Due to technical problems at the time these maps were made, not all of the records in Lakeside District's 1992 water accounting database file are linked to the GIS system, and not all geographical features are described in the figures. Although the database includes 191 rice fields, the GIS base map includes only 154 fields, 39 of which could not be identified in the 1992 water accounting database. This problem is a result of the information available at the time the map was digitized, and may also represent errors that occurred in digitizing the base map or in identifying fields within the database. Because the purpose of this study is to demonstrate the use of GIS rather than to draw systematic conclusions about the irrigation districts from these maps, these problems have not been corrected. More time and information would be needed to digitize the additional features. Similarly, not all canals, creeks, roads, and bulwarks have been digitized. In the case that a GIS system were to be installed on the irrigation districts, these problems could be corrected.

Although not all fields are shown in the figures, those fields that are shown appear to be representative of the records contained in the database, at least regarding water consumption per acre. Average first crop water use in all 191 fields in the 1992 Lakeside Irrigation District database is 2.79 acre-feet per acre. For the 115 fields identified in the GIS, the average first crop water use is 2.74 acre-feet per acre.

General Area Map of Lakeside Irrigation District

The maps for chapter 5 are contained in Appendix D. Figures D1 and D2 provide a general view of the Lakeside Irrigation District in 1992. Figure D1 displays the 154 fields digitized for the purpose of this demonstration. In Figure D1, geographic details include canals, creek beds, and the town of Eagle Lake. For the sake of clarity, the roads which define the town and which run throughout the district are not shown on these maps. The general location of the Colorado River is represented by a sinuous line. The thick blue lines show the irrigation canals. The thin black shapes outline irrigated fields for which water use data existed in 1992.

Figure D2 illustrates the level of detail available in ATLAS GIS through magnification of the area around Eagle Lake. The map symbol representing the town of Eagle Lake has been replaced with the network of roads that are depicted in red. Bulkheads used to control the flow of water between canal segments have been added and appear as black tick marks along the canals.

It is possible to test the proposition that differences in water use between fields may be related to field size. The average field size on Lakeside District in 1992 was approximately 130 acres. Figures D3 and D4 display the relative levels of water use in those fields that are smaller than average. There appears to be no concentration of fields with high or low water use.[1] Similarly, Figures D5 and D6 show no unusual distribution of high or low water use among larger fields during either the first or second crop periods. However, these figures indicate that water use in small fields may tend to be higher on average and more variable than water use in large fields. This can be seen by comparing the difference between the values for maximum and minimum water use that define the central 70 percent of observations in each group.

Also of interest is that average second crop water use in large fields is greater than average first crop water use. Average second crop water use is 2.54 acre-feet per acre and the average first crop water use is 2.42 acre-feet per acre. This is the opposite of what is generally expected and may be related to problems with the quality of the 1992 data, the level of precipitation during this period, or some other factor. It is also interesting to note that farmers appear more likely to raise a second crop on large fields versus small fields. For example, there is no second crop activity reported in sixteen percent of small fields, but no second crop activity reported in only four percent of "large" fields.

Recommendations

The GIS applications are limited by the availability of data. A more comprehensive data set would improve the resolution of the maps and facilitate the ability to draw conclusions from them. For example, additional information, such as soil type or irrigation technologies could add an additional dimension for analysis. These maps should also be completed and revised. This would involve digitizing all of the fields that were irrigated in 1992 but that do not appear on the maps, and identifying all of the fields within the database. There were 191 fields irrigated in 1992, but only 115 fields were both digitized and identified in the map. A complete district map would include all fields irrigated in the district throughout the three year field rotation cycle.

The canal system should be completely digitized so that all of the main canals, laterals, and sub-laterals are displayed on the map. This information should also include delivery structures to identify the laterals from which water enters the field. Information on the direction of water flow, distance to each delivery structure from the pumps on the river and groundwater pumps would add an additional dimension to the analysis.

Finally, if regular or even daily data on water use could be obtained by linking the GIS system to the water accounting database, an "up to the moment" picture could be created to help with daily or weekly management decisions. Such monitoring could also provide a source of feedback to help identify farmers with high levels of water use.

Notes

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[1] Although ATLAS GIS is capable of retaining accurate polygon sizes, many of the fields in this base map were digitized from hand-drawn maps. Therefore, the relative size of fields may not appear accurate.

Chapter 6. The Potential for Conjunctive Use in Water Conservation and Drought Contingency Planning

Introduction

Water conservation education, volumetric pricing, and canal rehabilitation are certainly essential elements in the LCRA's drought contingency planning. Conjunctive use of surface and groundwater is another possible aspect of a drought contingency plan which deserves further consideration. The LCRA is aware of the potential for groundwater use in the districts to conserve water and reduce their dependence on surface water[1], but because of explicit cost considerations, the LCRA pumps very little groundwater in the Lakeside Irrigation District and none in the Gulf Coast Irrigation District, though some farmers pump private wells.

The following implicit costs and benefits could make groundwater use more attractive to the LCRA: reduced risk to the rice farmers in the event of a drought; increased "effective yield" of the basin; less wasted water due to unpredictable rainfall; and the opportunity for the LCRA to meet increased municipal water demands. These implicit costs and benefits will be discussed in more detail and the feasibility of conjunctive use will be assessed. This preliminary assessment also includes an appraisal of surface and groundwater availability; the use of a regional groundwater model; an estimate of costs and benefits; and a brief discussion of social factors affecting conjunctive use. It is beyond the scope of this chapter to comprehensively address third party costs impacts and costs, however. It is also beyond the scope of this chapter to deal with subsidence issues related to conjunctive use or the possible impact on water table levels that could result from conjunctive use.

Potential Benefits of Conjunctive Use

Surface and groundwater systems, while physically inseparable, are often managed independently. However, in many cases it would be more efficient to operate surface water systems and groundwater systems together to take advantage of the best characteristics of each system. Such joint operation, called conjunctive use, often results in greater and more economical yields.[2]

In evaluating the benefits of using groundwater along with surface water to meet rice irrigation demands, one must consider three types of water users: the LCRA, rice farmers, and other potential LCRA customers (municipalities). The intent of this section is to present some of the implicit benefits of conjunctive use which are the motivation for this study. A preliminary cost/benefit analysis will be outlined later.

Potential Benefits to the LCRA

In 1993, the LCRA relied on groundwater to meet about two percent of the demand for irrigation[3]. All of that groundwater pumping occured in the Lakeside District where wells are used to meet peak demand. Since the river pumps are constant-speed pumps, the marginal cost of operating a low-capacity well pump is often less than that of turning on another river pump. A summary of pump capacities in the Lakeside District is given in Table 6.1.[4]

Increased use of groundwater could conserve water by reducing evaporative losses and excess river flows to the Gulf. For example, the planning model used by the LCRA assumes a 15 percent loss between the amount of water released from Lake Travis and the amount diverted by the irrigation districts.[5] When run-of-the-river flow is low, the LCRA must release stored water from the Highland Lakes to meet irrigation demands. Because of the seven-day time lag between the release of water from the Highland Lakes to the delivery to the irrigation districts, evaporative losses are significant. Much water can be wasted due to unpredictable rainfall, such as when the irrigation districts order the water in advance but do not use it if rainfall satisfies irrigation demands.

One potential benefit of increased groundwater use to the LCRA is the foregone opportunity cost of not meeting additional municipal demands. Each year, a number of entities with no on-going water contract approach the LCRA to purchase water for the succeeding year. If the Highland Lakes are not at a certain fraction of capacity, the LCRA must turn them down. Though it is difficult to justify additional groundwater pumping on this basis without perfect knowledge of the future, regional water resources scenarios can be formulated which make conjunctive use economically feasible.

Potential Benefits to Farmers

Increasing the use of groundwater will benefit farmers by increasing the level of convenience and decreasing the risks of drought. Groundwater is a more convenient source because there is little or no delay between the time it is "ordered" and the time it is applied to the field. Also, increasing groundwater pumping capacity could mitigate the effects of surface water curtailment in times of severe drought. The LCRA's "Drought Management Plan" calls for the total cutoff of interruptible stored water when the January 1 storage level of the Highland Lakes is below 400,000 acre-feet.[6] Although this emergency measure has never been invoked, it represents a great risk to the rice farmers who rely exclusively on interruptible surface water.

Potential Benefits to Other LCRA Customers

Besides conserving stored water, conjunctive use of surface and groundwater in the irrigation districts would effectively increase the "firm yield" of the Lower Colorado River-Gulf Coast aquifer system. Thus, more water would be available for sale to municipalities, possibly at a lower cost than the municipalities' other alternatives. That is, though transmission costs may be high, the cost of water from the LCRA may still be less than the cost of developing new water supplies (reservoirs, well fields, etc.).

Assessment of Hydrologic Feasibility

Surface Water Availability

Average annual rainfall in the lower Colorado River Basin ranges from about 42 inches per year in Matagorda County to about 26 inches per year in San Saba County.[7] Net evaporation from the Highland Lakes is about 40 inches per year, or approximately 120,000 acre-feet per year when multiplied by the surface area. The resulting firm yield of the Highland Lakes' system, which has a capacity of about 1.5 million acre-feet, is only about 500,000 acre-feet per year. As of 1992, approximately 90 percent of this firm yield was contracted to municipal and industrial users. During a repeat of the drought of record, the LCRA would be required to supply approximately 450,000 acre-feet per year.[8]

To meet instream use requirements, the LCRA maintains minimum flows in the Colorado River of 12,000 acre-feet per month and 272,000 acre feet per year at a gauge just below the Gulf Coast District diversion point.[9] As shown in Figure 6.1, the flow at this point is typically much greater than the instream use requirement. In the six years shown — excluding 1988 — the total flow exceeded the instream use requirement by 8.5 million acre-feet, or about 1.4 million acre-feet per year. While much of this flow is attributed to unpredictable floods, some volume of water could be diverted from excess flows for groundwater recharge.

Groundwater Use and Availability

Historical groundwater and surface water use in the three-county region (from 1958 to 1984) is summarized as follows: in Colorado County, two to three times more surface water has been used than groundwater; in Matagorda County, five to ten times more surface water has been used than groundwater; and in Wharton County, slightly more groundwater than surface water has been used.[10] Overall, irrigation has accounted for more than 90 percent of the total demand in the region.[11] Historic and projected total groundwater use are shown in Table 6.2.

Regional Geohydrology

While many references on the regional geohydrology are available from the Texas Water Development Board (TWDB) and the US Geological Survey, the scope of this evaluation is limited to three studies. Dutton and Richter discuss the development of a numerical model of the Gulf Coast Aquifer.[12] Loskot *et al* assess the groundwater resources of Colorado, Wharton, and Lavaca Counties.[13] Hammond assesses the groundwater resources of Matagorda County.[14] In general, the hydrostratigraphy of the region consists of three layers: Layer 1, nearest the surface, alluvium and the Beaumont formation aquifer units; Layer 2, between Beaumont and Evangeline, the Chicot Aquifer unit; and Layer 3, deepest, the Evangeline Aquifer unit. These are shown conceptually in Figure 6.2.

No well-defined confining layer separates any of these units. Instead, the units are differentiated by the trends in sand bed thicknesses. Thus, the sandy Evangeline aquifer is "confined" by the clay beds in the Chicot Aquifer, and the Chicot Aquifer is essentially confined by the clayey Beaumont formation. Though the Beaumont formation is generally considered an aquitard, it is actually a local groundwater source in some places. The Chicot outcrops in western Wharton County and Colorado County, and the Evangeline outcrops in Fayette County. Wells in Matagorda and Wharton Counties typically reach depths of 300 to 1000 feet from the land surface in order to tap these confined aquifers. In reference to Table 6.2, nearly all of the groundwater used in Matagorda and Wharton Counties is pumped from the Chicot Aquifer. In Colorado County, about half of all the groundwater used is pumped from the Chicot Aquifer and one half comes from the Evangeline Aquifer.[15]

Prior to widespread pumping in the region (perhaps 1930), hydraulic head ranged from zero feet along the coastline to 300 feet in northwest Colorado County.[16] In many places, the head was above the land surface so that artesian wells existed. Broad valleys in the head distribution generally paralleled the rivers. This implies that the rivers recharged the aquifers where they outcrop, and the aquifers discharged to the rivers near the coast. The mean observed transmissivity of the Chicot and Evangeline Aquifers is approximately 7400 square feet per day, and the mean value of hydraulic conductivity is about 50 feet per day.[17] Figures 6.3 and 6.4 show the areas of highest transmissivity which are best suited for groundwater development.

Since about 1930, significant over-drafting of all three water-bearing units has occurred. While the Chicot and Evangeline units each contain about 70 to 80 million acre-feet of water in storage, their annual "firm yield" (annual recharge) in Wharton and Colorado counties is estimated at only 78,000 and 38,000 acre-feet, respectively.[18] In Matagorda County, the combined annual recharge is estimated to be 110,000 acre-feet per year.[19] Although the total of these recharge estimates exceeds current estimated pumping, water also discharges naturally from the aquifers (via return flow to streams, discharge to the Gulf of Mexico) and moves toward other high pumping regions such as the City of Houston.

Along with groundwater mining comes the danger of land subsidence and salt water intrusion. As of 1982, subsidence in the vicinity of the irrigation districts was not too great: a maximum subsidence of 0.5 to 1.0 foot was estimated in parts of the Gulf Coast District, and subsidence throughout Wharton and Colorado Counties was estimated to be less than 0.5 foot.[20] Salt water intrusion has yet to be detected, but the potential certainly exists. The hydraulic head of the Chicot and Evangeline Aquifers is now below sea level in parts of Matagorda County.[21]

In assessing the availability of groundwater, the effects of individual wells should be considered. Local interference of wells (i.e., the influence of drawdown "cones") is not important in regional studies, but it is important in cost considerations since the cost is directly related to the height which the water must be lifted. For example, one study was done using a continuous pumping rate of five cubic feet per second, a transmissivity of

20,000 square feet per day, and a storativity of 0.001, which are reasonable values for the Gulf Coast Aquifer. Figure 6.5 shows the drawdown cone at various times throughout the growing season. One should note that drawdown is linearly related to the pumping rate, so that a ten cubic feet per second pump causes a drawdown twice as deep as a five cubic feet per second pump, holding all other variables constant. A more realistic scenario for rice irrigation, though, is that heavy pumping would not be continuous. Perhaps pumps would run only a few days a week and during some periods of the year water levels would "recover" somewhat.

Groundwater Quality

The quality of water in the Chicot and Evangeline Aquifers is generally quite good while water quality in the Beaumont formation is marginal. In Colorado and Wharton Counties, water in the Chicot and Evangeline formations ranges from fresh to slightly saline except where local contamination from oil wells has occurred. In Matagorda county, these formations are prone to salt water intrusion, but still contain freshwater (total dissolved solids < 1000 milligrams per liter) to depths of 500 to 1000 feet.[22] Table 6.2 shows some typical results of chemical analyses of these waters.

Sodium chloride has been identified as a constituent, and commonly accepted rice tolerances are shown in Table 6.3. High rainfall in the region (averaging about 42 inches per year) and the fact that rice fields typically lie fallow for two years between crops further decrease the likelihood of soil salinization.[23]

Groundwater Modeling

The computer code USGS MODFLOW,[24] a pre-processing program, and a complete, calibrated data set for the Gulf Coast Aquifer were used for this study.[25] The computer model was run on a SUN SPARC workstation in the Civil Engineering Department at The University of Texas at Austin. On this platform, the program ran in about 10 to 15 minutes depending on the output and number of time steps specified. It would have been desirable to run the program on an IBM-PC, but there were some difficulties with this. LCRA staff have been unable to run the program on a PC, and they believe that an extended memory version of MODFLOW is required.[26] Also, computational efficiency was a consideration; a TWDB model of similar size has taken nearly five hours to run on an IBM-386 at The University of Texas at Austin.

The pre-processing program included two different sets of predicted pumping data, one from the LCRA and one from the TWDB, which were entered into a *Lotus-123* spreadsheet. A FORTRAN program was then run to read data from the spreadsheet and output it to a file which can be used by MODFLOW. This pumping file was then edited to simulate well fields in Lakeside and Gulf Coast Districts.

The numerical finite-difference model consists of three layers: Layer 1 represents flow in the Beaumont formation, Layer 2 represents flow in the Chicot formation, and Layer 3 represents flow in the Evangeline Aquifer. These layers and their corresponding boundary conditions are summarized in Figure 6.6. In the model, flow between formations is controlled by the difference in hydraulic head between the layers and the vertical hydraulic conductivity.

The finite-difference block of each layer contains 56 rows and 50 columns. Block faces range from 1.5 miles to 2.5 miles wide. Not all of the blocks in the grid are active. Some are outside of the model domain or represent no-flow boundaries. The active blocks for each layer are shown in Figure 6.7.

Areal aquifer recharge and discharge is modeled by the assignment of a head-dependent flux boundary to the active blocks in Layer 1. Leakage between rivers and the uppermost layer is simulated in a similar manner. A summary of the hydrologic parameters used in the numerical model is given in Table 6.4.

Pumping is also simulated at nearly all of the nodes in Layers 2 and 3, though pumping from Layer 1 is neglected. Pumping rates are assigned by county and are distributed according to the estimated water use for the period from 1971 to 1975.[27] That is, the 1992 pumping rate for a given block is calculated by the relative use rates, as:

$$Q(i,j,k)_{92} = Q(i,j,k,)_{71\text{-}75}[(\text{Cnty} - \text{use}_{92})/(\text{Cnty} - \text{use}_{71\text{-}75})] \qquad \text{(Eq. 6.1)}^{28}$$

where,

Q = the pumping rate in cfs for block (i,j) during period k

i,j = spatial indices (row, column) of model grid

k = a temporal index (stress period)

Cnty = country

use_{92} = water use in 1992

$\text{use}_{71\text{-}75}$ = estimated water use from 1971 to 1975

In the pre-processing program, two sets of pumpage predictions are given: one from the LCRA and one from the TWDB. Dutton and Richter used the projections provided by the LCRA in order to represent the "high demand" case. However, it is important to note that the projections given by the LCRA are about *twice* as high for some counties as those given by the TWDB.

Model calibration was based upon observed hydraulic head at a number of observation wells during the period from 1940 to 1985. The range of 1985 simulated drawdowns relative to pre-pumping conditions is shown in Table 6.5. Maximum drawdowns occurred in southeastern Wharton County.

Dutton and Richter also simulated future conditions (1990 to 2030), and their results are shown below in Table 6.6. There were three other important findings. First, the hydraulic head surface for each layer in the year 2030 was significantly below sea level over much of the modeled area, implying a risk of saltwater intrusion. Also, the hydraulic head in Layer 2 fell below the top of the aquifer, showing a change from confined to unconfined conditions. Second, due to increased drawdown, additional water is recharged to Layer 1 from the rivers. The amount of river seepage losses (aquifer recharge) nearly doubles from 85,501 acre-feet per year in 1985 to 167,684 acre-feet per year in 2030. Third, a maximum subsidence of 2.5 feet is predicted in Matagorda County by 2030. However, computations for 1985 over-estimated subsidence by more than one foot in parts of Matagorda County.[29]

Dutton and Richter then showed how their model could be used to evaluate water-resources projects. First, a well-field producing about 30,000 acre-feet per year was simulated near the northwest end of the Gulf Coast Irrigation District. By 2030, the well-field caused an additional drawdown of 10 to 80 feet and increased local subsidence potential by as much as 1.6 feet. Second, an artificial recharge pond (modeled as an isolated river reach) was simulated at the same location as the well-field. The 2.5 acre, 5-foot deep pond could recharge as much as 8,200 acre-feet during the first year, but would decrease to about 2,000 acre-feet per year thereafter.[30] Adding a recovery well to maintain a large hydraulic head difference between the pond and the uppermost aquifer was shown to increase recharge, but effective operation of such a system could prove to be difficult. Clearly, more site-specific research is needed to evaluate the full potential of artificial recharge.

There are some limitations of the model that Dutton and Richter have noted. One weakness is the use of no-flow boundaries to the east and the south. The no-flow boundary to the east diminishes the effects of Houston pumping, and the no-flow boundary for Layers 2 and 3 along the Gulf prevent the estimation of sea water intrusion. Another complication may be the hydraulic connections between each of the layers and between the river and the aquifer. More research is needed to determine the conductance value to be entered into the model. Finally, the influence of clay beds in the aquifer has been de-emphasized. Thus, the Chicot Aquifer probably would not become "unconfined," but strong vertical gradients could exist which would induce recharge from the Beaumont formation. Also, where clay beds occur, local drawdowns and subsidence may be significantly greater than predicted.[31]

As mentioned, Dutton and Richter used the LCRA's high case pumping predictions to represent a worst-case scenario. To determine the sensitivity of model results to pumping uncertainty, another simulation was run using the TWDB pumping predictions for 1985 to 2030. As previously mentioned, these predictions are significantly lower (about 30 percent) than the LCRA's. A summary comparison (average annual volumetric budgets for 1985 to 2030) of the two simulations is given in Table 6.7.

As expected, using the TWDB pumping predictions for future simulations also results in considerably less drawdown for all three layers. The minimum head values for the three layers are: Layer 1, -35 feet; Layer 2, -84 feet; and Layer 3, -60 feet. When comparing the drawdowns of the two simulations, one should note that in the model run at The University of Texas at Austin, drawdown is relative to the 1985 simulated head rather than to the steady-state, pre-pumping head as in Dutton and Richter's report. Table 6.8 therefore bypasses Dutton and Richter's reported results and compares the maximum drawdowns for each layer in reference to 1985 simulated head as simulated at The University of Texas at Austin. One concern, however, is that the hydraulic head contours for Layer 3 shown in Figure 57 of Dutton and Richter's report (p. 87) do not agree with the drawdowns in the output file from the model run at The University of Texas at Austin. Since the drawdowns given by the model at The University of Texas at Austin are reduced by a factor of ten, it is suspected that a constant has been changed in the block-centered flow (BCF) package input file.[32] This deserves further investigation but does not affect the results given in this report since conjunctive use simulations will include pumping only from Layer 2.

Simulation of Conjunctive Use

The groundwater model developed by Dutton and Richter was used to simulate conjunctive use in the LCRA irrigation districts. Upon reviewing historical water use, it was decided that providing 25 percent of total irrigation demand from groundwater would reduce the amount of stored water required. This amounts to pumping of about 46,000 acre-feet per year of water for the Gulf Coast District and about 30,000 acre-feet per year for the Lakeside District. The computer software package *PROPS*, an optimization module for *Lotus 1-2-3*, was used to determine the groundwater pumping capacity required to meet peak demands. Probability distributions of daily river flow and daily water demand at the Gulf Coast District[33] were entered into the spreadsheet, and a Monte Carlo simulation was run to determine the pumping capacity needed. The result was that a 97 percent reliability (meaning that only three percent of the time demands would not be fully met) required a capacity of 560 cubic feet per second. Thus, 70 wells with capacities of eight cubic feet per second each were specified.[34] Probability distributions of daily water demand at the Lakeside District were not available, so similar peak demands were assumed, resulting in the specification of 45 wells, with a capacity of eight cubic feet per second each.

Since the modeling results show that the groundwater in the study area is being mined, a sustainable conjunctive use operation must include facilities for artificial recharge. Artificial recharge, however, can greatly complicate management decisions. Research has been done to identify the factors affecting artificial recharge[35] and to develop some design recommendations and operating procedures for spreading basins and injection wells.[36] In general, basin recharge is influenced by the depth of water in the basin, soil type and layering, depth to groundwater, water quality, and operating procedure. Recharge through injection wells is most influenced by pumping rate, aquifer material (horizontal permeability and the presence of clays), water quality, and operating procedure.

Though much site-specific research is needed to determine the best location and method of recharge to the Gulf Coast Aquifer, this analysis assumed that dual-purpose wells located along the main canals of each district would be used. It was estimated that 18 wells operating in the dual-purpose mode in the Gulf Coast District could inject about

23,000 acre-feet of water during the off-season (i.e., about one half of what was extracted during the growing season). In the Lakeside District, 12 wells would be required to inject approximately 15,000 acre-feet of water each year.[37]

Using Dutton and Richter's model with the above pumping and injection rates, five simulations were run for the period from 1995 to 2010 in order to represent a 20-year planning period. Thus, simulated heads at 2010 would be used as average, though somewhat pessimistic, water levels in a cost analysis. Pumping rates and locations for these simulations are summarized in Tables 6.9 and 6.10, respectively. Model results are shown in Figures 6.8 through 6.12 and summarized in Table 6.12.

Economic Feasibility of Conjunctive Use

Preliminary benefit-cost analysis for the Gulf Coast District and the Lakeside District are shown in Tables 6.13 and 6.14, respectively. Though these analyses assess only the benefits and costs to the LCRA if it develops conjunctive use facilities, it should be noted that as much as one-third of all farmers have private wells. Farmers can typically extract groundwater at an operating cost of $10 to $20 per acre-foot if their wells are operating properly.[38]

Discussion of Cost Estimates

The capital costs of installing wells and pumps may be estimated from various information. The cost of drilling and completing an irrigation well is generally estimated at $75 to $100 per foot.[39] Pump prices can, of course, be obtained from suppliers, and an estimate of $20,000 per pump was given by a sales representative of the Oslin-Nation Company in Dallas, Texas.[40] Alternatively, the cost records for the wells used in the Lakeside District could be adjusted to reflect current dollar prices using a construction cost index.

Determining the capital cost of treatment facilities is more difficult since few systems like the one considered have been constructed. One similar facility (a sand filter bed for a five cubic-foot per second injection well) was designed by Jobaid Kabir of the LCRA, and he estimated the cost to be $35,000.[41] As the Kabir well was installed in a residential area, land costs may make construction of a similar well much cheaper in the irrigation districts. Other calculations of cost values could be obtained from the literature. For instance, a groundwater recharge facility in Orange County, California reported an amortized capital cost for filtration of about $6.00 per acre-foot per year, based on an amortization period of 20 years using seven percent discount rate.[42] For the LCRA districts, this rate would amount to a total capital cost of approximately $40,000 per well. Texas irrigation district land is likely to be much cheaper than land in Orange County, California.

Operating costs, primarily power costs, for the extraction of groundwater were estimated using cost information from the Lakeside District. Lakeside District well cost data from 1988 to 1992 are plotted in Figure 6.13. The y-intercept of the regression represents the monthly base charge during the growing season assessed by the utility company according to the pump's peak power demand. The slope of the line represents the marginal cost of pumping. This plot illustrates that a base charge of \$660 and marginal pumping cost of about \$10 per acre-foot are typical values for Lakeside District pumps with 5 to 8 cubic foot per second capacity. Although this marginal cost of pumping is directly related to the lift required, no well logs were available for study. However, solving the following equation for power costs with variable values as shown results in a lift of approximately 54 feet:

$$\text{Cost}(\$/\text{AF}) = \$10 = [\text{SW}(h)(c)/\text{eff}]\ (1{,}234\text{m}^3/\text{AF}) \qquad \text{(Eq. 6.2)}$$

where,

SW = specific weight of water (9.81 kg/m^3)

h = lift required (m)

c = cost of electric energy (\$.044/kWh, or \$1.22x10^{-5}/kg-m)

eff = wire-to-well efficiency (0.8)

Equation 6.2 can be used with hydraulic heads from Figures 6.12 (simulation 4) and estimates of local drawdown from Figure 6.5 to estimate future power costs. From this information average operating costs of \$19 per acre-foot and \$17 per acre-foot were generated for the Gulf Coast and Lakeside Districts, respectively, for the period 1995 to 2015.

The operating costs of injecting water can be approximated in a similar manner. Except for the case of injecting water, the equation is modified as follows:

$$\text{Cost}(\$/\text{AF}) = [\text{SW}(h - h_o)(c)/\text{eff}] \times \text{Factor} \qquad \text{(Eq. 6.3)}$$

where,

$h - h_o$ = the head minus the initial head (before injection begins)

eff. = 0.60 (generally less efficient than extraction)

Assuming that an injection "mound" forms proportionally to the pumping rate (like an inverse drawdown cone) and assuming that each injection well pumps at an average rate of 5 cubic feet per second and operates for four months each year, a maximum mound height of 41 feet is calculated. Assuming the average mound height over the four-month period is 25 feet, an injection cost of \$1.90 per acre-foot is calculated.

Maintenance costs for the system are also more difficult to estimate than capital costs. The LCRA estimates that current maintenance costs are \$350 per year for each groundwater pump and \$1,200 per year for each river pump.[43] In a conjunctive use system, groundwater pump maintenance would probably be somewhere between these two values. Malfunctioning injection wells could increase the cost and sand filter beds would need to be cleaned and repaired periodically. Thus, maintenance costs of $500 per year for each extraction well and $1000 per year for each dual-purpose well and filter bed seem reasonable.

The benefit of stored water savings ($5.27 per acre-foot) is considered a negative cost to the LCRA, though it could also be considered a direct benefit to the farmers. With conjunctive use, the farmers could receive the same amount of water without being charged the stored water fee. Alternatively, farmers could pay the same amount as they currently do if the LCRA were to charge an extra $5.27 per acre-foot for water which is pumped from the ground. Thus, the LCRA could justify charging $5.27 per acre-foot for groundwater to help recover conjunctive use capital and operating costs.

According to these calculations, as shown in Tables 6.12 and 6.13, a potential customer must be willing to pay about $25 to 35 per acre-foot (neglecting transportation costs) for water in order for conjunctive use to be feasible economically for the LCRA. This value is consistent with what the LCRA currently charges for water sold to municipalities on a year-to-year basis, and it is considerably less than the cost of many municipal water supply alternatives such as new reservoirs. Moreover, this price does not account for the value of decreased risk to the rice farmers. Thus, rice farmers should be willing to pay a higher price for water they receive from conjunctive use compared to the rates for interruptible water supplies that the LCRA can now market to municipalities.

To this point, the chapter has focused nearly exclusively on the LCRA's motivation and ability to plan and implement conjunctive use. However, many farmers already have private wells, and others might be encouraged to develop their own groundwater resources.

Assessment of Socioeconomic Feasibility

Any conjunctive use plan will be more successful if it is supported by the farmers who stand to benefit from it. Some results from the farmer survey conducted by the LBJ School of Public Affairs may provide insight to the socioeconomic feasibility of conjunctive use. First, it was found that 33 percent of all respondents use some groundwater. Of the respondents, the mean groundwater usage constitutes 42 percent of total water use. Moreover, 17 percent of all respondents rely on groundwater for at least 50 percent of their total water supply. If the survey is representative, approximately 15 percent of all water used in the districts comes from the ground. Unfortunately, data are not available on overall pumping capacities, well locations, or well depths; such, information would be useful in conjunctive use planning.

Farmers' attitudes regarding groundwater management through regulation were confirmed by their responses indicating that only 5.5 percent of respondents feel that public authorities should be able at any time to regulate groundwater use. About 40 percent believe that public authorities should be able to regulate groundwater during severe drought or when demand exceeds supply. Almost 55 percent, though, feel that public authorities should never be able to regulate groundwater.

A third relevant question addressed the use of holding streams in response to concerns regarding surface water delivery. Twenty-two percent responded that they use holding streams because the lead time on orders is too long, 19 percent responded that they fear water will not be delivered when ordered, and about 35 percent use holding streams only during "extreme heat waves," presumably because they are concerned with the dependability of the surface water supply.

Though the percentage of farmers using groundwater is surprising, it appears that even more would use groundwater if it were economically feasible and viewed as being more convenient and dependable than surface water. Theoretically, farmers should be able to pump groundwater for about the same cost as the LCRA. However, many farmers do not have operating wells, perhaps reflecting the high capital cost of drilling and completing a well or the land tenure relationship of the farmer. The potential for high maintenance costs dissuades many land owners from investing in wells.[44] Thus, it may be informative to compare groundwater use as indicated by the survey with the respondent's relationship to the land they farm (i.e., owner, tenant, co-op).

Conjunctive use may also raise some interesting legal and institutional questions. For instance, does the LCRA lose "ownership" of the recharge water once it is injected into the ground? Does the LCRA have any right to manage groundwater use in the area of the irrigation districts so as to reap the benefits of injection (i.e., higher water levels and lower operating costs)? What would happen in the event of the creation of a groundwater conservation district? It is obvious that current water laws and institutional arrangements do not adequately address conjunctive use issues. Rather, surface and groundwater in Texas are managed as separate and independent resources; surface water is allocated through a water rights system while groundwater is almost totally unregulated. The survey responses indicate that any type of groundwater management through regulation will be slow in coming.

Conclusions and Recommendations

In assessing the potential of conjunctive use, the LCRA's goal regarding conservation should be kept in mind:

> ...[to] promote the development and application of practices and technologies that improve water use efficiency, increase the beneficial reuse and recycling of water, and minimize the waste of water such that water supplies are extended (the LCRA Board Policy WFC 509.00).[45]

With the projected increase in water demand in the Lower Colorado River Basin in the future and the low likelihood of new surface water supplies due to economic and environmental concerns, conjunctive use may be essential to improving water use efficiency and extending water supplies in the Lower Colorado River Basin. A sustainable conjunctive use system could be hydrologically, economically, and socially feasible if the following conditions are met: (1) artificial recharge is employed to prevent excessive drawdowns; (2) the LCRA enters into a regional water supply plan in which a large part of the cost of the conjunctive use system is recovered through the sale of water to a municipality; and (3) farmers contribute according to the value of having reduced risk in the event of a drought.

To further investigate the potential of conjunctive use, a number of steps could be taken. A sensitivity analysis should be performed on the existing model of the Gulf Coast aquifer.[46] The results of recent studies by the US Geological Survey should also be reviewed, and pumping rates and distribution near the irrigation districts updated if possible. Vertical conductances between layers and between the top layer and the river should be studied further in order to better estimate induced recharge. Also, the localized effects of clay beds should be studied further.

Although the Gulf Coast Aquifer model is adequate for assessing regional groundwater availability, a more finely discretized model will be needed if the LCRA is to embark upon conjunctive use planning for the irrigation districts. Since pumping costs are so dependent on lift, the conjunctive use model should simulate individual drawdown cones.

Methods of artificial recharge need further investigation. Site-specific research will be needed to determine the best location for recharge facilities. Pilot tests should also be performed to ensure that recharge water is of suitable quality to prevent basin or well clogging. A much more detailed cost/benefit analysis (with respect to the LCRA, the farmers, and potential LCRA customers) is needed before any specific recommendations can be made. A final area for future research is to evaluate the willingness of farmers to cooperate and cost share. Farmer incentives to develop groundwater should be considered, and the value of reduced risk to the farmers should be quantified.

Notes

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[1] Greg Pierson, Lower Colorado River Authority, "Identification of Potential Groundwater Development for Conjunctive Water Use in the LCRA Irrigation Districts," (Austin, Tex., 1988).

[2] W. Viessman, Jr. and C. Welty, *Water Management: Technology and Institutions* (New York: Harper and Row, 1985); H.J. Morel-Seytoux and R.I. Restrepo, "SAMPSON: a Model for Conjunctive Operation of Surface and Groundwaters," in *Conjunctive Water Use*, ed. S.M. Gorelick, IAHS Publ. No. 156, 1985, pp. 415-424.

[3] Pierson, "Identification," p. 9.

[4] *Ibid.*, p. 17.

[5] Lower Colorado River Authority, "RESPONSE--LCRA Reservoir System Simulation Computer Program," (Austin, Tex., 1990) (program documentation).

[6] Lower Colorado River Authority, "Drought Management Plan for the Lower Colorado River," (Austin, Tex., 1990).

[7] Texas Department of Water Resources, "Water for Texas: a Comprehensive Plan for the Future," vol 1, (Austin, Tex., 1984), p. 16.

[8] Personal interview by David Watkins with Quentin Martin, Lower Colorado River Authority, Austin, Texas, November 1992.

[9] Quentin Martin, "Drought Management Plan for the Lower Colorado River in Texas," *Journal of Water Resources Planning and Management, 117* (6), 1991, pp. 645-660.

[10] Alan Dutton and Bernd Richter, Bureau of Economic Geology (BEG), "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water-Management Strategies," (Austin, Tex., 1990).

[11] Pierson, "Identification," p. 16.

[12] Dutton and Richter, "Regional Geohydrology."

[13] C.L. Loskot, W.M. Sandeen, and C.R. Follett, "Ground-water Resources of Colorado, Lavaca, and Wharton Counties," Texas Dept. of Water Resources Report 270 (Austin, Tex., 1982).

[14] Weldon Woolf Hammond, "Ground-water Resources of Matagorda County," (masters thesis, University of Texas at Austin, 1969).

[15] Dutton and Richter, "Regional Geohydrology," pp. 60-62.

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[16] *Ibid.*, pp. 63-65.

[17] *Ibid.*, p. 38.

[18] Loskot et al, "Ground-water Resources."

[19] Hammond, "Ground-water Resources."

[20] K.W. Ratzlaff, "Land-surface Subsidence in the Texas Coastal Region," Texas Dept. of Water Resources Report 272 (Austin, Tex., 1982).

[21] Dutton and Richter, "Regional Geohydrology."

[22] *Ibid.*, pp. 40-42.

[23] Hammond, "Ground-water Resources."

[24] M.G. McDonald and A.W. Harbaugh, "A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model," Chapter A1 of *Techniques of Water-Resources Investigations,* U.S. Geological Survey (Washington, D.C.: U.S. GPO, 1988).

[25] Programmed by Alan Dutton, BEG, Austin, Tex., 1992.

[26] Telephone interview by David Watkins with Steve Glenn, LCRA, Austin, Tex., November 1992.

[27] Dutton and Richter, "Regional Geohydrology," p. 54.

[28] *Ibid.*

[29] *Ibid.*, pp. 81-94.

[30] *Ibid.*, pp. 100-105.

[31] *Ibid.*, pp. 105-106.

[32] Telephone interview by D. Watkins with Alan Dutton, BEG, Austin, Texas, May 1993.

[33] Quentin Martin and Jobaid Kabir, "Preliminary Feasibility Analysis of Hydroelectric Power Generation at the Bay City Dam," (Lower Colorado River Authority, Austin, Tex., 1991) (working paper).

[34] Telephone interview by D. Watkins with Quentin Martin, LCRA, Austin, Texas, March 1992.

[35] H.M. Bouwer, "Effect of Water Depth and Groundwater Table on Infiltration from Recharge Basins," in *Irrigation and Drainage Proceedings*, ed. S.C. Harris, (New York: ASCE Publishers, 1990), pp. 377-384.

[36] V. Hauser, "Groundwater Recharge Through Wells," in *Artificial Recharge of Groundwater: Proceedings of the International Symposium*, eds. A.I. Johnson and D.J. Finlayson, (New York: ASCE Publishers,

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1987), pp. 97-106; J.W. Franson, "Evaluating Potential Artificial Recharge Projects," in *Artificial Recharge of Groundwater: Proceedings of the International Symposium* (1987), pp. 43-53.

[37] Telephone interview with Quentin Martin, March 1992.

[38] Telephone interview by David Watkins with Walter Garrett, Soil Conservation Service, Wharton County, Tex., December 1992.

[39] Ibid.; Personal interview with Quentin Martin, November 1992.

[40] Telephone interview by D. Watkins with sales representative, Oslin-Nation Company, Dallas, Tex., April 1993.

[41] Personal interview by D. Watkins with Jobaid Kabir, LCRA, Austin, Texas, March 1993.

[42] D.G. Argo and N.M. Cline, "Groundwater Recharge Operations at Water Factory 21, Orange County, California," in *Artificial Recharge of Groundwater*, ed. Takashi Asano (Boston: Butterworth, 1986), pp. 359-396.

[43] Telephone interview by D. Watkins with Ralph Johnson, LCRA, Eagle Lake, Tex., November 1992.

[44] Telephone interview by D. Watkins with Mr. Cosper, Wharton County Agricultural Extension Service, November 1992.

[45] Mike Personett, "Growing Rice with Less Water," (Lower Colorado River Authority, Austin, Tex., 1991) (working paper), p.1.

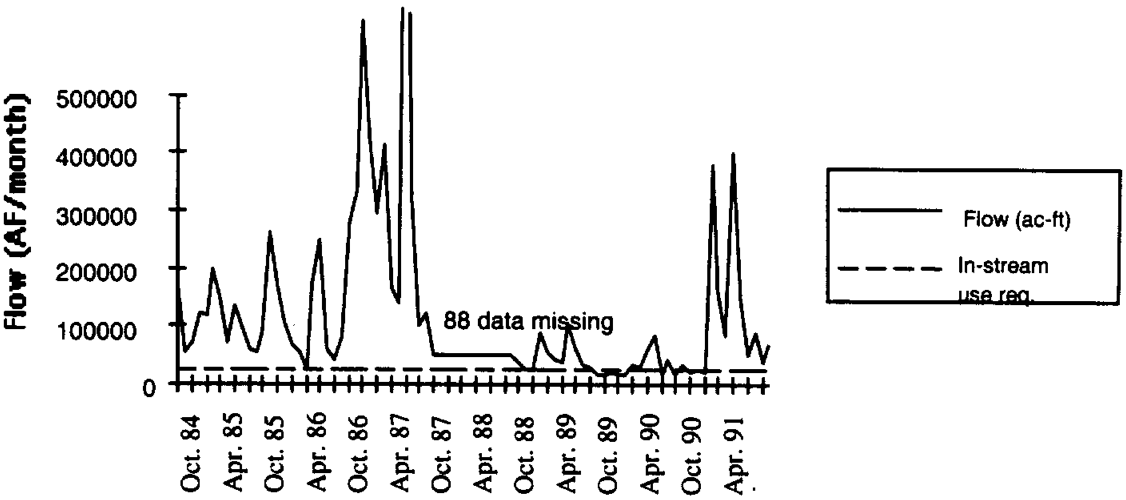
[46] Dutton and Richter, "Regional Geohydrology."

Table 6.1
LCRA Lakeside Irrigation District Irrigation Pumps

	No. Extraction Units	Capacity per Unit (cubic feet/second)	Total Capacity (cubic feet/second)
Surface Water:			
River Plant	5 pumps	54-175	700
Relift Plants (2)	7 pumps	55-133	635
Groundwater:	5 wells	5.24-8.35	32.3

Source: Lower Colorado River Authority, Lakeside Irrigation District, Eagle Lake, Texas, 1992.

Figure 6.1
River Flow and Average In-stream Use Requirement



Source: US Geological Survey. *Water Resources Data for Texas,* vol. 3, (Austin, Texas, 1984-1991).

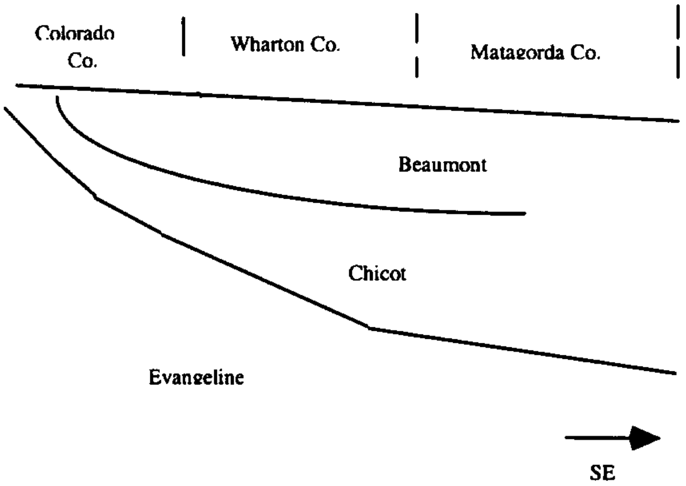
Table 6.2
Groundwater Use in the Three-County Region

Years	Matagorda	Wharton	Colorado
1900-45	4 059	26,701	8,970
1946-60	16,367	93,915	28,569
1961-70	22,656	147,166	45,880
1971-75	32,048	186,299	68,329
1976-85	33,125	121,330	32,875
1986-2030	42,003	199,973	48,659*
1986-2030	23,902	127,971	21,061**

Source: Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water-Management Strategies," Bureau of Economic Geology, Austin, Texas, 1990, p. 59.

Notes: Groundwater use in acre-feet per year. *LCRA projections. **Texas Water Development Board projections (averaged over time period).

Figure 6.2
Hydrostratigraphy of the Region



Source: Adapted from Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water Management Strategies." Bureau of Economic Geology, Austin, Texas, 1990, p. 47.

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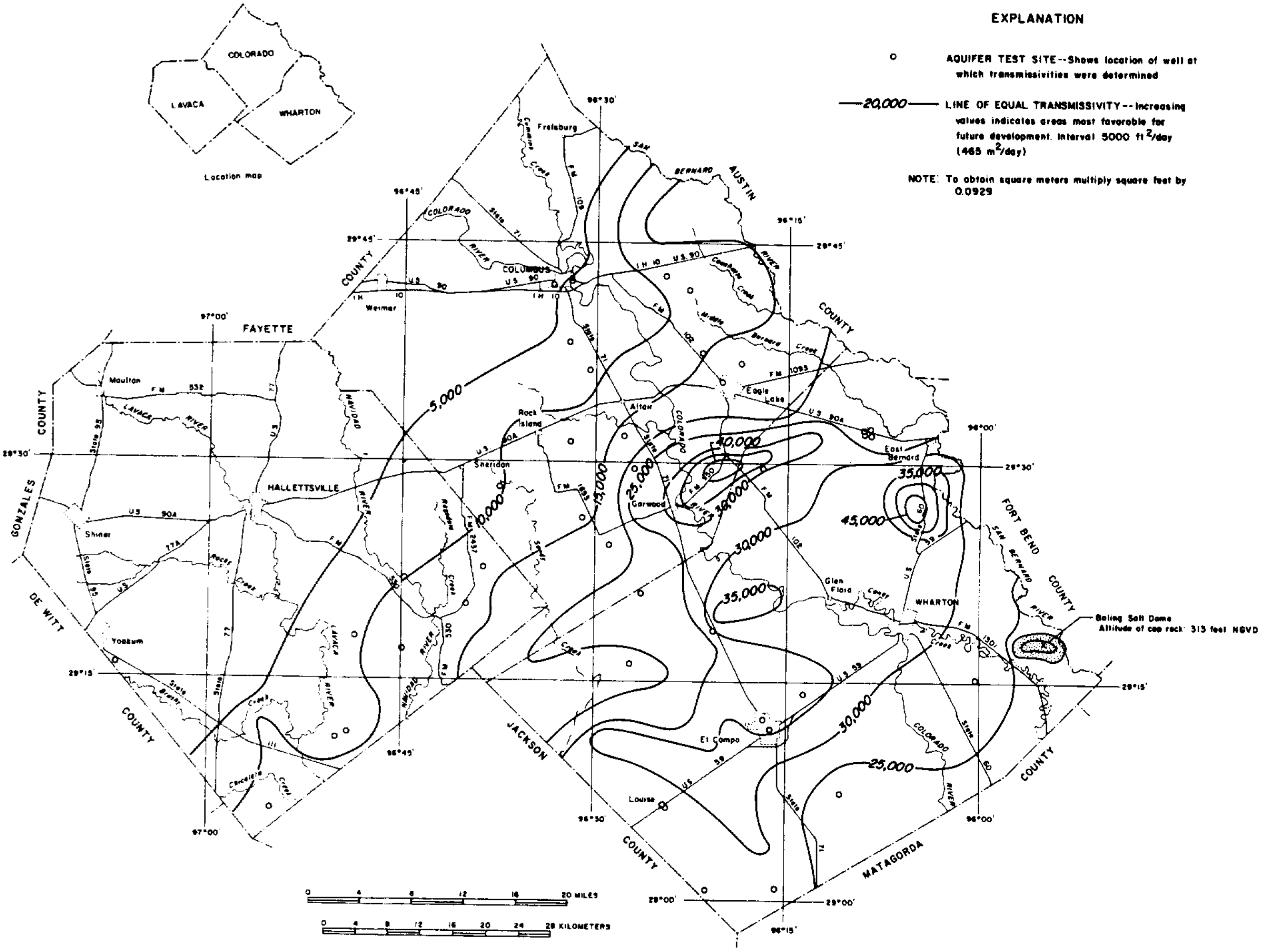
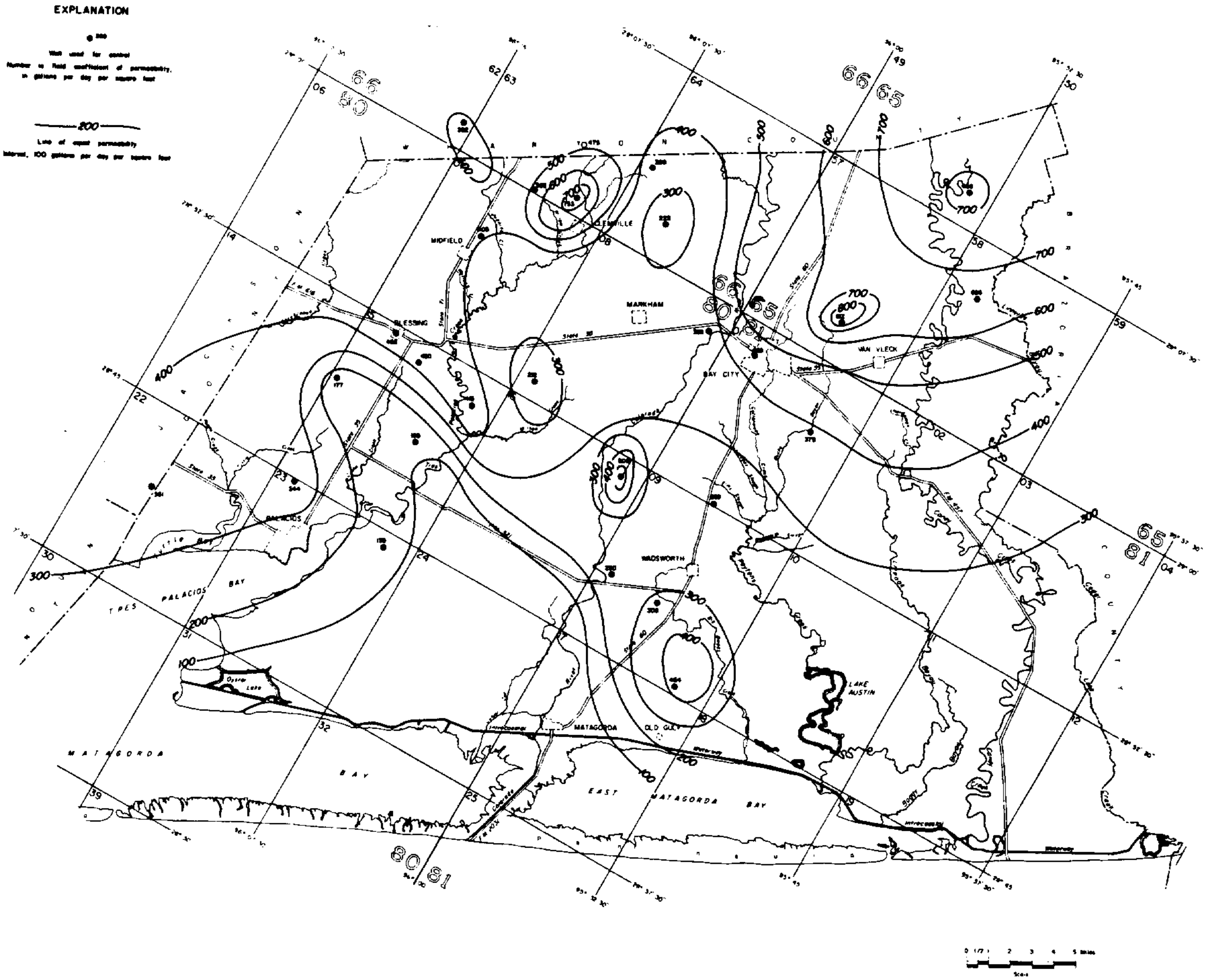
Figure 6.3
Transmissivity of the Chicot Aquifer in Colorado and Wharton Counties



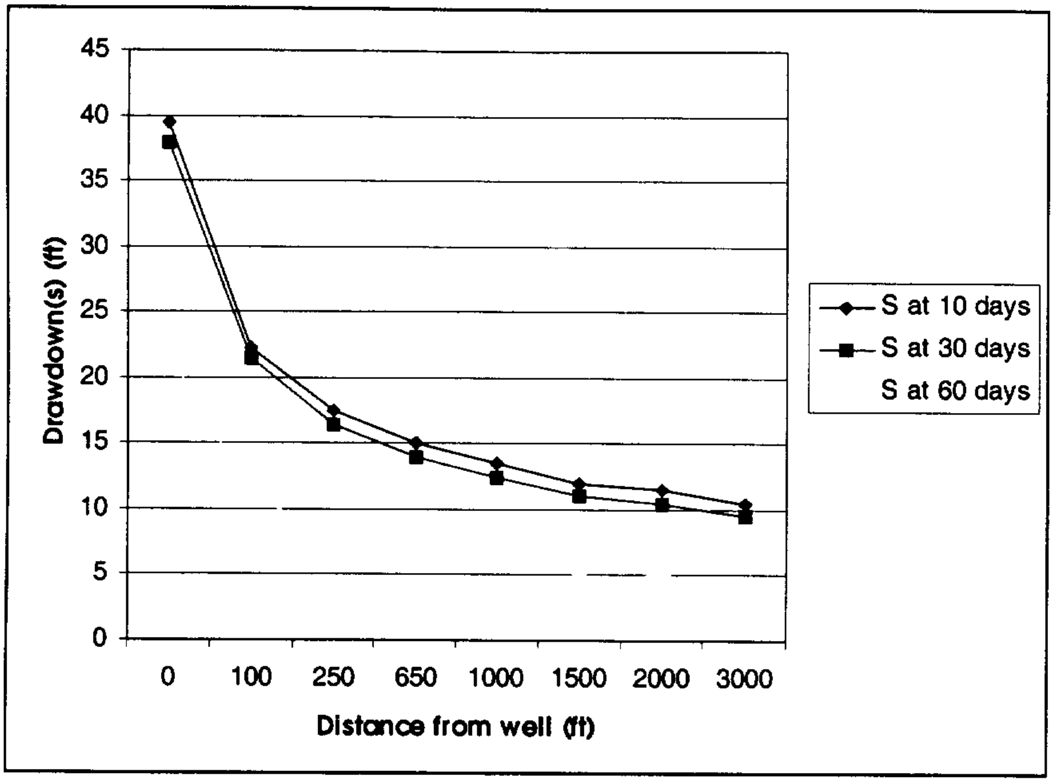
Source: C.L. Loskot *et al*, "Groundwater Resources of Colorado, Lavaca, and Wharton Counties," Texas Department of Water Resources Report 270, (Austin, Texas, 1982), p. 76-77.

Figure 6.4
Transmissivity of the Chicot Aquifer in Matagorda County



Source: Weldon Woolf Hammond, "Groundwater Resources of Matagorda County, Master's Thesis, The University of Texas at Austin, 1969, p. 35.

Figure 6.5
Drawdown Due to a Single Pumping Well



Source: Unpublished data, LCRA.

Note: Calculated from the Theis equation, assuming a transmissivity of 20,000 ft^2/day and a storage coefficient of 0.01.

Figure 6.6
Layers and Corresponding Boundary Conditions

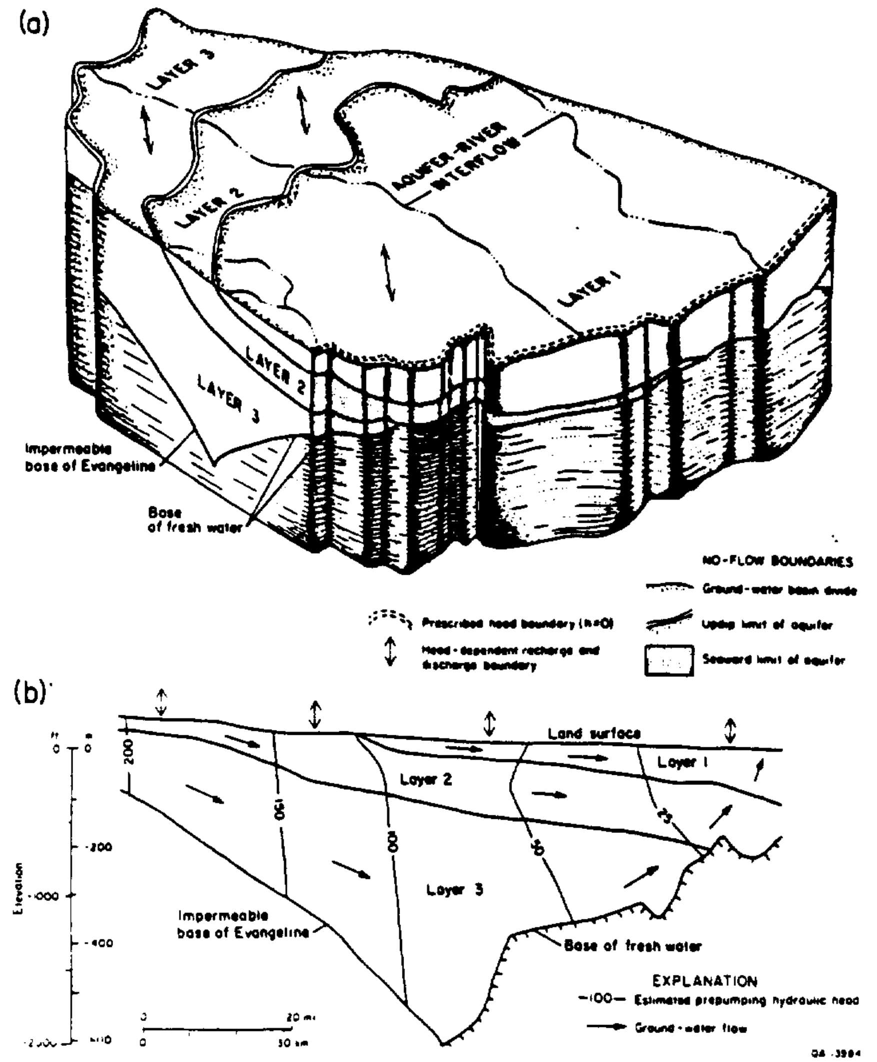


Figure 31. Schematic block diagram (a) and cross section along line A-A′ (b) illustrating layers and boundary conditions included in the conceptual model of the ground-water flow system.

Source:Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water Management Strategies." Bureau of Economic Geology, Austin, Texas, 1990, p. 47.

Table 6.3
Typical Water Quality Analysis Results

Well #	Hydrologic Unit	Depth	Chloride	Hardness
TA-66-xx-101	Chicot	479	33	150
TA-66-xx-701	Chicot	212	94	380
TA-65-57-801	Chicot & Evangeline	530	126	332
TA-80-08-801	Evangeline	750	63	74

Source: C.L. Loskot *et al*, "Groundwater Resources of Colorado, Lavaca, and Wharton Counties," Texas Department of Water Resources Report 270, (Austin, Texas, 1982).

Figure 6.7
Active Blocks by Layer

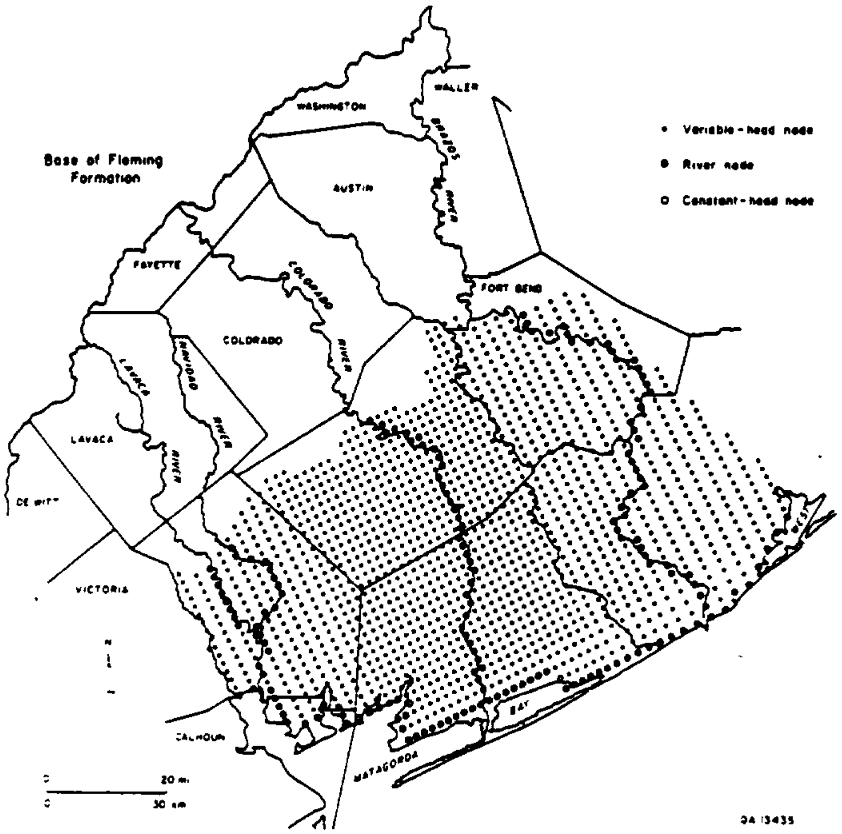


Figure 34. Plan-view location of the 1588 nodes of active blocks in layer 1 of the finite-difference grid.

Source: Adapted from Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water Management Strategies." Bureau of Economic Geology, Austin, Texas, 1990, p. 49-51.

Figure 6.7 (cont.)
Active Blocks by Layer

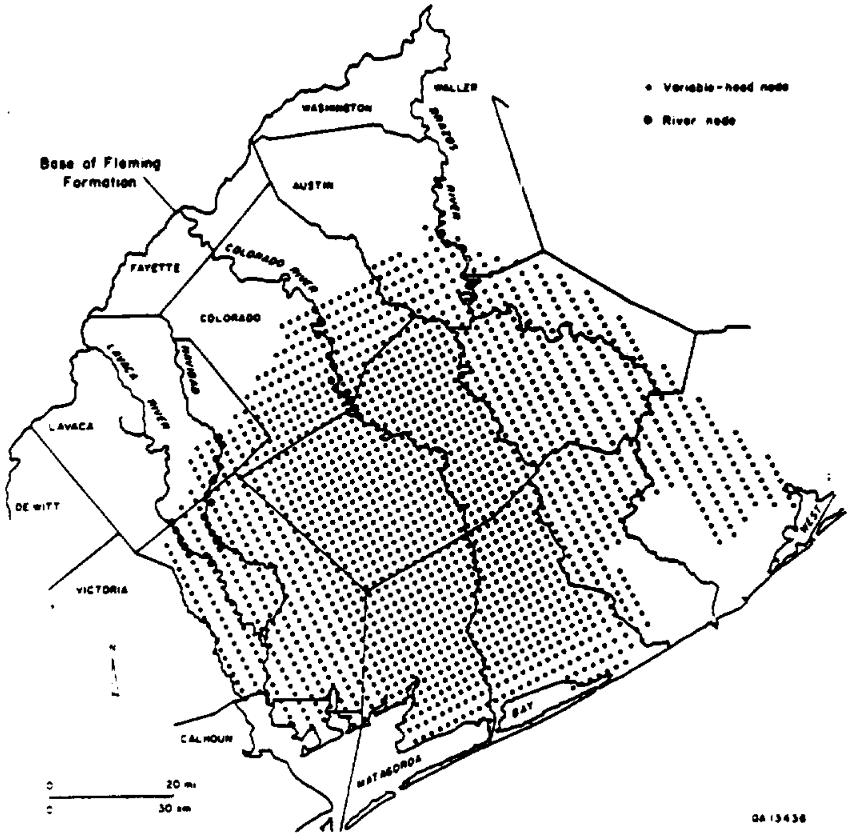


Figure 33. Plan-view location of the 1892 nodes of active blocks in layer 2 of the finite-difference grid.

Source: Adapted from Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water Management Strategies." Bureau of Economic Geology, Austin, Texas, 1990, p. 49-51.

Figure 6.7 (cont.)
Active Blocks by Layer

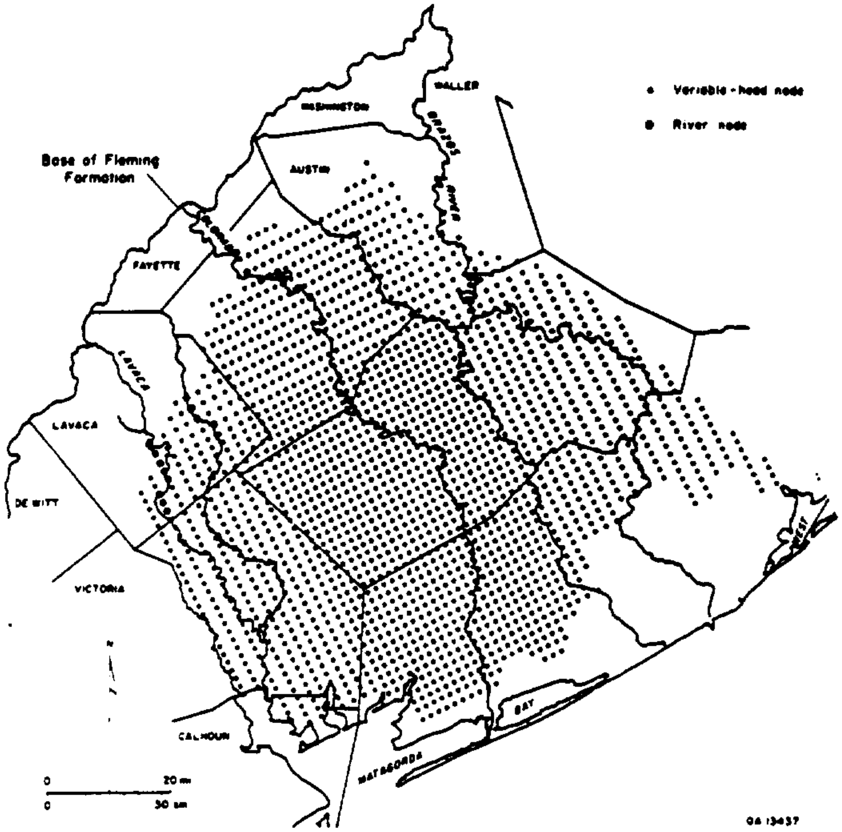


Figure 32. Plan-view location of the 1974 nodes of active blocks in layer 3 of the finite-difference grid.

Source: Adapted from Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water Management Strategies." Bureau of Economic Geology, Austin, Texas, 1990, p. 49-51.

Table 6.4
Salinity Tolerance of Rice

Concentration of NaCl	Tolerance
600	Tolerant at all stages
1300	Harmful to seedlings in dry, hard soil
1700	Harmful before tillering; tolerable from jointing to heading
3400	Harmful before booting; tolerable from booting to heading
5100	Harmful at all stages

Source: C.L. Loskot, W.M. Sandeen, and C.R. Follett, "Groundwater Resources of Colorado, Lavaca, and Wharton Counties," Texas Dept. of Water Resources Report 270, Austin, Texas, 1982; Counties, "Texas Dept. of Water Resources Report 270," Austin, Texas, 1982.

Table 6.5
Parameters Used in Model

Parameter	Layer 1	Layer 2	Layer 3
Mean vertical hydraulic conductivity (ft/day)	0.0048	0.0024	0.0006

Source: Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water-Management Strategies," Bureau of Economic Geology, Austin, Texas, 1990, p. 37.

Table 6.6
Drawdown for 1985 Simulated Conditions

Layer	Regional Drawdown (feet)	Drawdown Within Lakeside (feet)	Drawdown Within Gulf Coast (feet)	Max. Rate of Drawdown (feet/year)
1	0-50	5-10	10-15	1.5
2	0-90	10-20	20-50	1.7
3	20-100	20-40	20-50	3.7

Source: Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water-Management Strategies," Bureau of Economic Geology, Austin, Texas, 1990, pp. 78-80, 82.

Note: Drawdowns are relative to steady-state, pre-pumping conditions.

Table 6.7
Drawdown for 2030 Simulated Conditions

Layer	Regional Drawdown (feet)	Drawdown Within Lakeside (feet)	Drawdown Within Gulf Coast (feet)	Max. Rate of Drawdown (feet/year)
1	20-90	10-30	20-40	1.3
2	20-170	20-40	40-100	8.8
3	20-320	40-80	60-100	2.6

Source: Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water-Management Strategies," Bureau of Economic Geology, Austin, Texas, 1990, pp. 82, 89-91.

Note: Drawdowns are relative to steady-state, pre-pumping conditions.

Table 6.8
Average Annual Volumetric Budgets for Future Simulations

Flow Component	LCRA (ft^3/yr)	TWDB (ft^3/yr)
Pumping	2.81×10^{10}	2.07×10^{10}
River leakage	0.55×10^{10}	0.47×10^{10}
Flow from boundaries	0.18×10^{9}	0.16×10^{9}
Storage	-2.09×10^{10}	-1.47×10^{10}

Source: Adapted from the Gulf Coast Aquifer model, developed in Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water-Management Strategies," Bureau of Economic Geology, Austin, Texas, 1990.

Table 6.9
Comparison of Maximum Simulated Drawdowns

	LCRA's pumping (feet)	TWDB's pumping (feet)
Layer 1	63.4	49.8
Layer 2	97.4	74.2
Layer 3	37.8	20.8

Source: Results from running the Gulf Coast Aquifer model developed in Alan Dutton and Bernd Richter, "Regional Geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a Numerical Model to Estimate the Impact of Water-Management Strategies," Bureau of Economic Geology, Austin, Texas, 1990.

Note: Drawdowns are relative to the 1985 conditions simulated by Dutton and Richter, 1990.

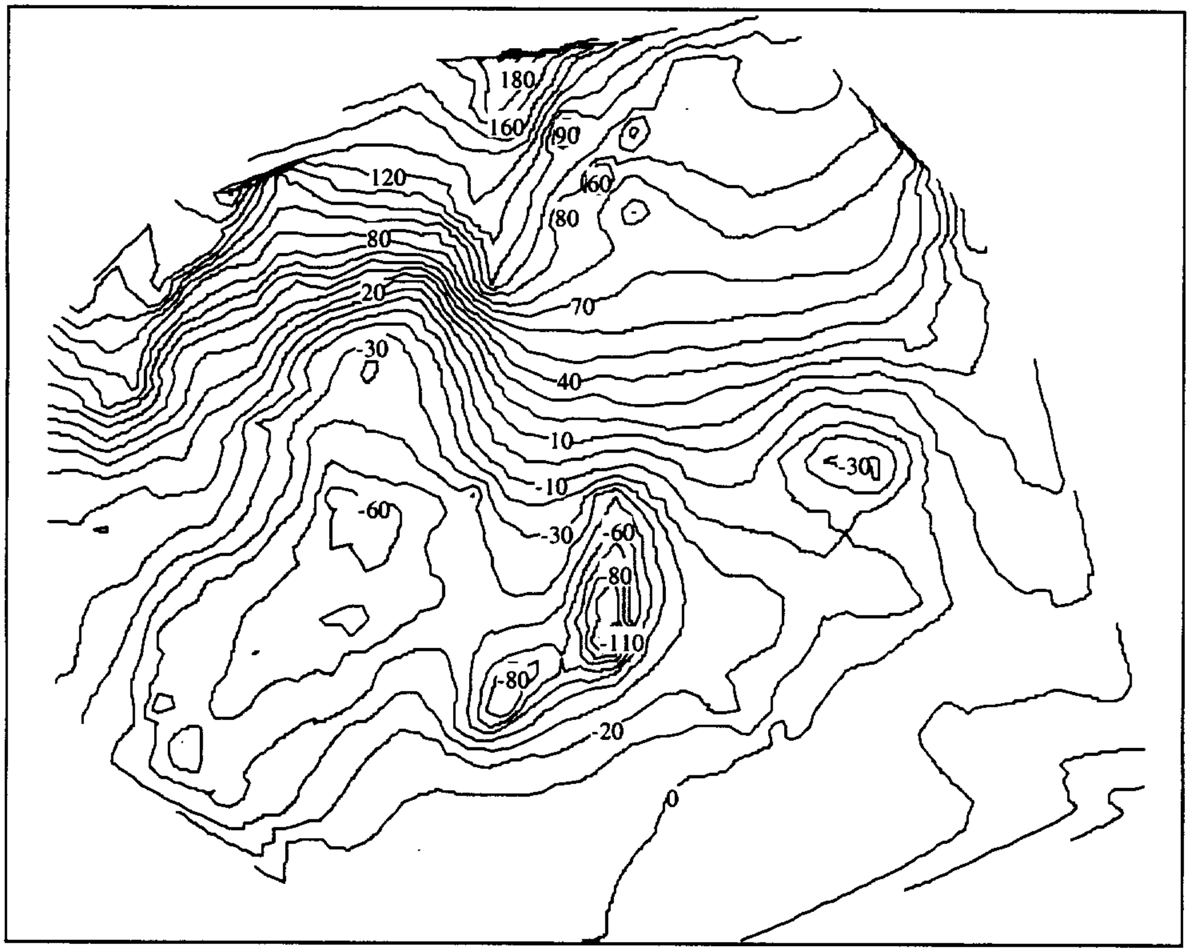
Table 6.10
Pumping Rates for Conjunctive Use Simulations

No.	Simulation	Lakeside District Rates	Gulf Coast District Rates	Background Rates
1	25 percent demand met by groundwater, no artificial recharge	5 ft^3/second (30,000 acre-feet/year)	3 ft^3/second (49,500 acre-feet/year)	TWDB projections
2	25 percent demand met by groundwater + artificial recharge	2.5 ft^3/second (15,000 acre-feet/year)	1.5 ft^3/second (23,000 acre-feet/year)	TWDB projections
3	25 percent demand met by groundwater, no artificial recharge	5 ft^3/second (30,000 acre-feet/year)	3 ft^3/second (45,900 acre-feet/year)	LCRA projections
4	25 percent demand met by groundwater + artificial recharge	2.5 ft^3/second (15,000 acre-feet/year)	1.5 ft^3/second (23,000 acre-feet/year)	LCRA projections
5	50 percent demand met by groundwater, no artificial recharge	10 ft^3/second (60,000 acre-feet/year)	6 ft^3/second (92,000 acre-feet/year)	LCRA projections

Source: Simulation conducted at The University of Texas at Austin.

Note: Background pumping projections provided by Alan Dutton, Bureau of Economic Geology, Austin, Texas, 1992.

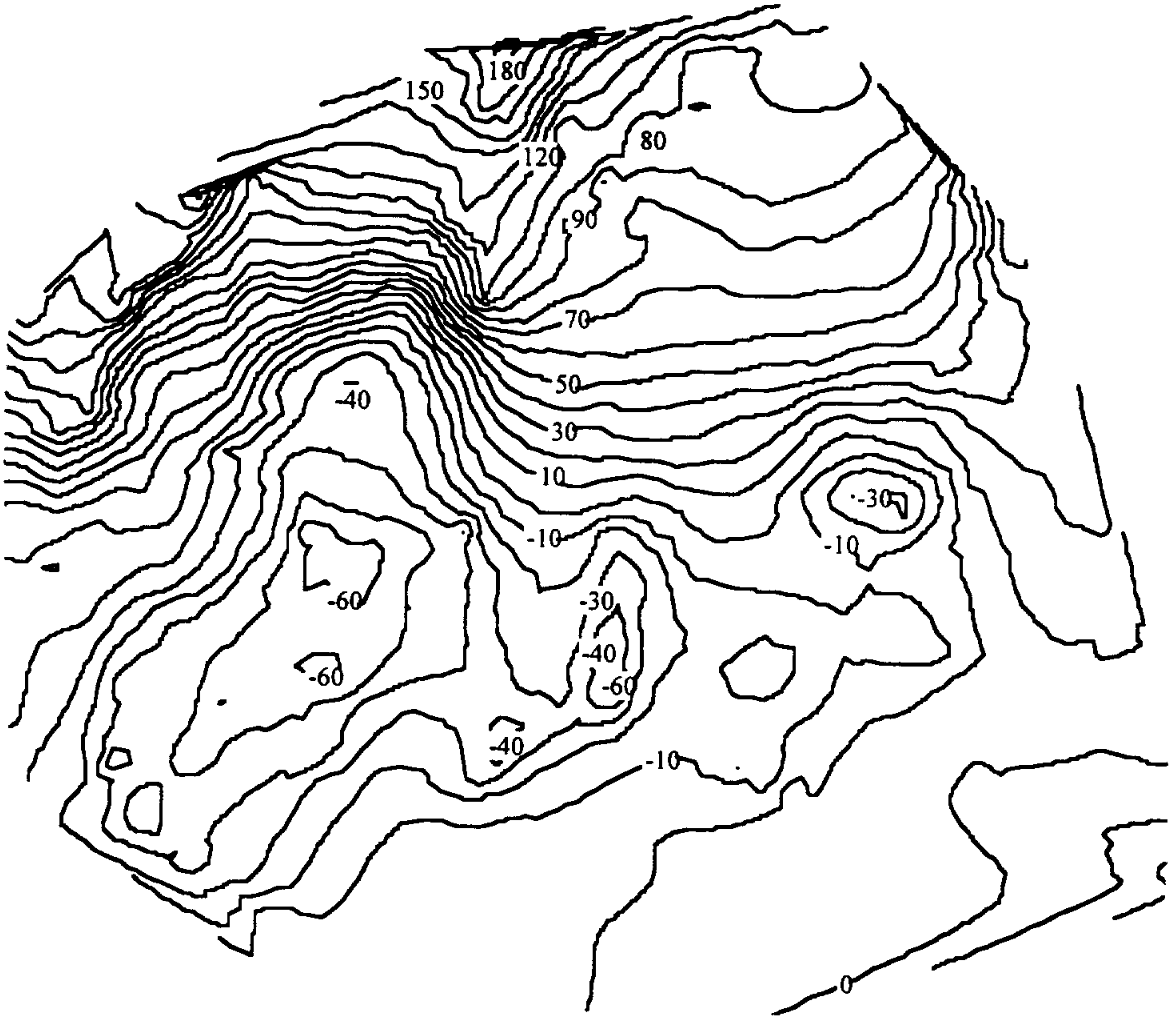
Figure 6.8
2010 Hydraulic Head in Layer 2; Predicted by Simulation 1



Source: Simulation conducted at The University of Texas at Austin.

Note: 25% of demand met by groundwater, no artificial recharge; Lakeside District rates of 5 ft^3/second (30,000 acre-feet/year); Gulfcoast District rates of 3 ft^3/second (45,900 acre-feet/year); background rates, TWDB projections.

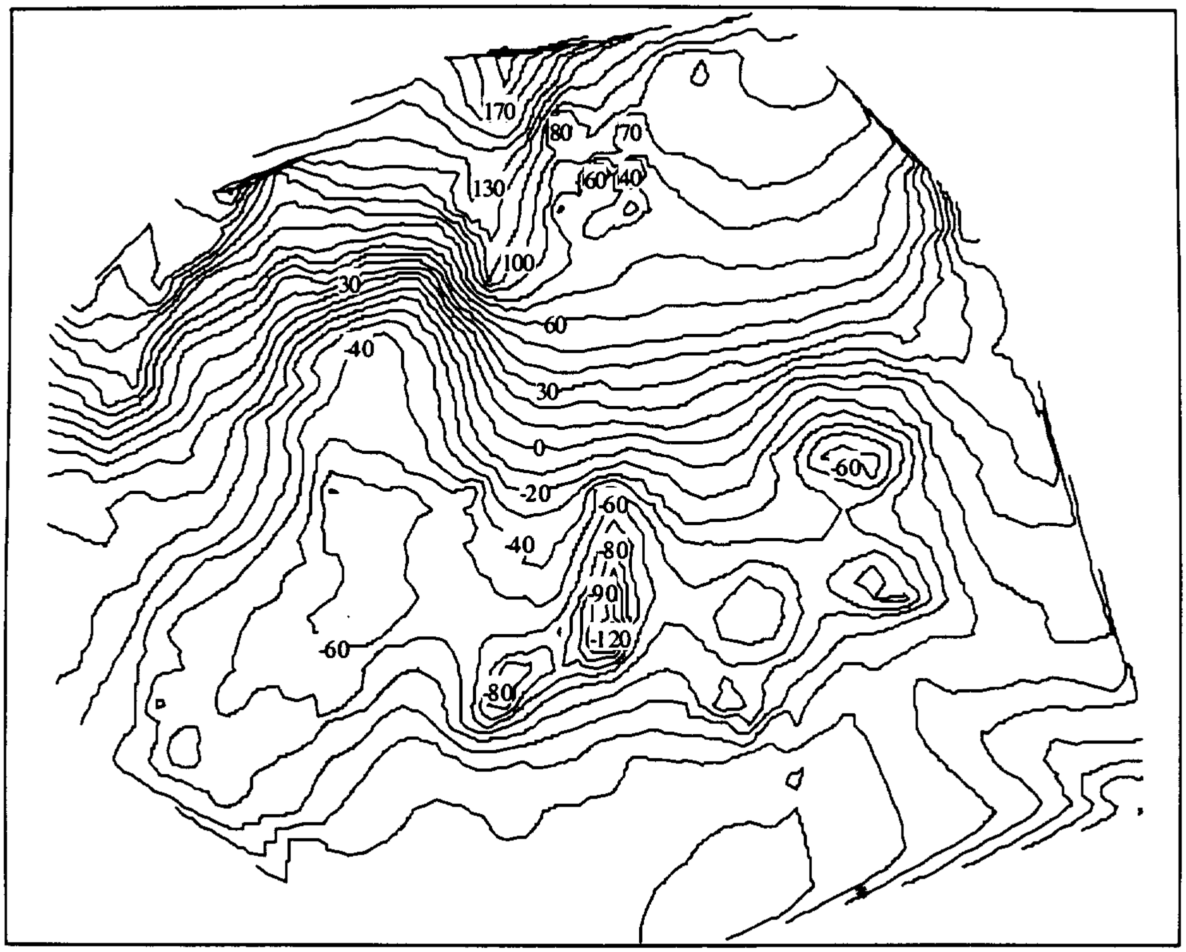
Figure 6.9
2010 Hydraulic Head in Layer 2; Predicted by Simulation 2



Source: Simulation conducted at The University of Texas at Austin.

Note: 25% of demand met by groundwater, no artificial recharge; Lakeside District rates of 2.5 ft^3/second (15,000 acre-feet/year); Gulfcoast District rates of 1.5 ft^3/second (23,000 acre-feet/year); background rates, TWDB projections.

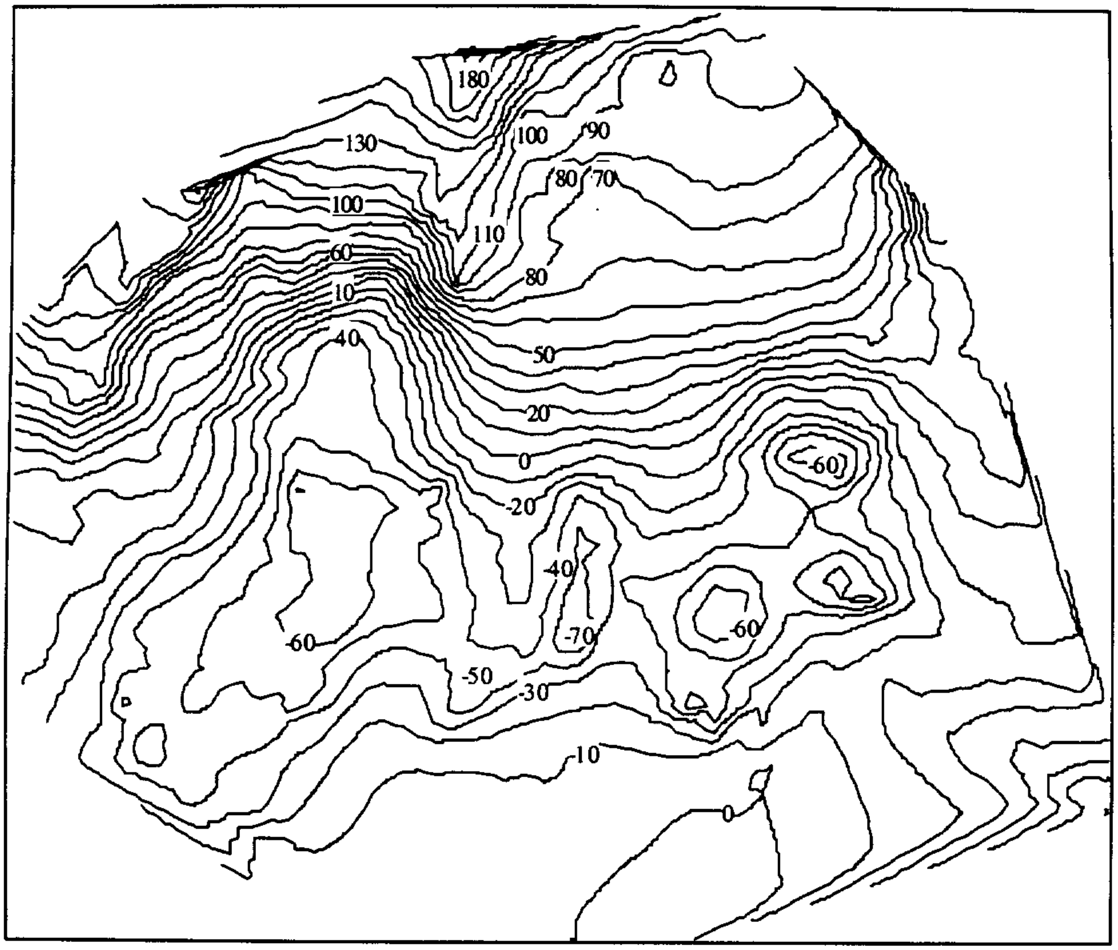
Figure 6.10
2010 Hydraulic Head in Layer 2; Predicted by Simulation 3



Source: Simulation conducted at The University of Texas at Austin.

Note: 25% of demand met by groundwater with artificial recharge; Lakeside District rates of 5 ft^3/second (30,000 acre-feet/year); Gulfcoast District rates of 3 ft^3/second (45,900 acre-feet/year); background rates, LCRA projections.

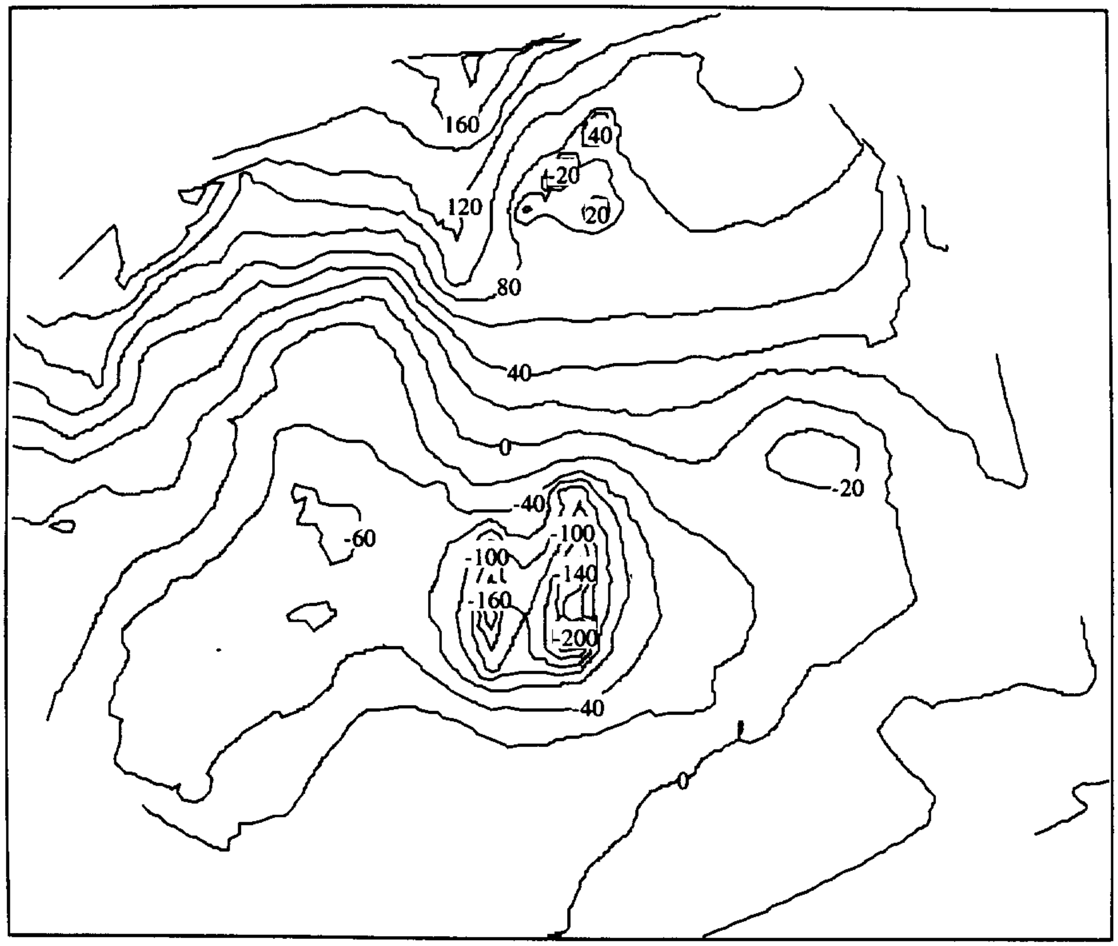
Figure 6.11
2010 Hydraulic Head in Layer 2; Predicted by Simulation 4



Source: Simulation conducted at The University of Texas at Austin.

Note: 25% of demand met by groundwater with artificial recharge; Lakeside District rates of 2.5 ft^3/second (15,000 acre-feet/year); Gulfcoast District rates of 1.5 ft^3/second (23,000 acre-feet/year); background rates, LCRA projections.

Figure 6.12
2010 Hydraulic Head in Layer 2; Predicted by Simulation 5



Source: Simulation conducted at The University of Texas at Austin.

Note: 25% of demand met by groundwater, no artificial recharge; Lakeside District rates of 10 ft^3/second (60,000 acre-feet/year); Gulfcoast District rates of 16 ft^3/second (92,000 acre-feet/year); background rates, LCRA projections.

Table 6.11
Model Nodes at which Pumping was Increased

District	(column, row)
Lakeside District	(26,12) (26,14) (26,16) (28,14) (28,17) (30,12) (30,14) (30,16)
Gulf Coast District	(21,46) (22,45) (22,44) (23,42) (23,43) (23,44) (24,42) (25,41) (28,32) (28,37) (28,38) (28,39) (28,40) (29,32) (29,33) (29,34) (29,35) (29,36) (29,37) (29,38) (29,39) (29,40)

Source: Simulation conducted at The University of Texas at Austin.

Note: Node (0,0) located in northwest corner of model. Center of model (28,25) located near center of Wharton County.

Table 6.12
Summary of Conjunctive Use Simulation Results

	Minimum Head (MSL) (feet)		Avg. Annual Volumetric Budget Terms for Entire Model (1000 acre-feet/year)		
Simulation Number	Lakeside District	Gulf Coast District	Pumping	River Seepage	Storage
1	60	-110	545	120	386
2	80	-60	505	116	350
3	40	-120	696	134	516
4	70	-70	656	130	483
5	20	-200	772	140	535

Source: Results obtained from running the Gulf Coast Aquifer model developed by Dutton and Richter, 1990.

Table 6.13
Preliminary Benefit-Cost Analyses for Gulf Coast District

Capital Cost Item	Cost per Unit	Amortized Capital cost[e]	Number	Total Annual Capital Costs
Well drilling/completing	$60,000/well[a]	$6,111	70	$427,779
Pumps	$20,000 ea.[b]	$2,037	70	$141,593
Treatment facilities	$30,000 ea.	$3,056	18	$55,000
				$624,372

O&M Cost Item	Annual Cost Per Unit	Number	Total Annual O&M Costs
Electricity: Base charge	$5,000/pump	70	$350,000
Electricity: Extraction	$19/acre-foot	45,9 acre-feet (105 ft. avg. lift)	$872,100
Electricity: Injection	$1.9/acre-foot[c]	23,000 acre-feet (25 ft. avg. head change)	$43,700
Extraction pump maintenance	$500/pump[d]	52	$26,000
Injection pump maintenance	$1,000/pump	18	$18,000
			$1,309,800

Benefit Item	Annual Cost per Unit	Number	Total Annual Benefit
Stored water savings	$5.27/acre-foot	45,900 acre-feet	$241,893
		Annual Net Cost	**$1,693,280**
		Net Cost/acre-foot	**$36.89**

Notes: [a] Telephone interview with Walter Garrett, Soil Conservation Service, Bay City, Texas, 1992.

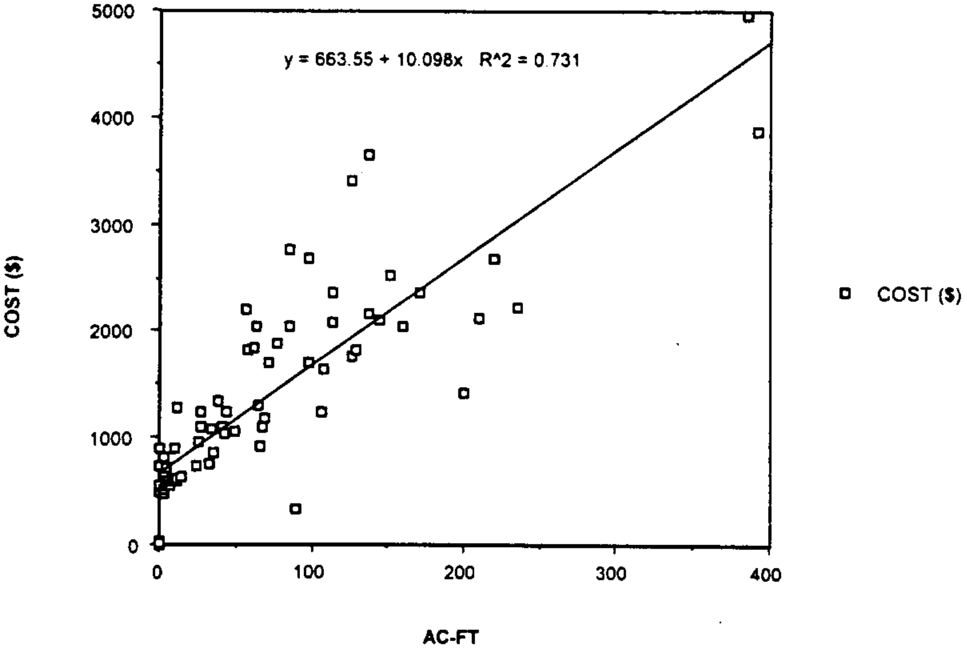
[b] Telephone interview with sales representative, Oslin-Nation Co., Dallas, Texas. Price quoted for Bell &Gossett pump, 4000 gpm, 200 hp., 1750 rpm.

[c] Assuming 80 percent motor/pump efficiency for extraction, 60 percent for injection

[d] Based on telephone interview with Ralph Johnson, LCRA, Eagle Lake, Texas, 1992.

[e] Discount rate of 0.08 percent, repayment period of 20 years

Figure 6.13
Monthly Pumping Cost Data for the LSWD, 1988-1992



Source: Adapted from cost data obtained from LCRA, Eagle Lake, Texas, 1992

Note: Pumping cost equals a base charge plus the cost of power used.

Table 6.14
Preliminary Benefit-Cost Analyses for Lakeside District

Capital Cost Item	Cost per Unit	Amortized Capital cost[e]	Number	Total Annual Capital Costs
Well drilling/completing	$60,000/well[a]	$6,111	45	$275,001
Pumps	$20,000 ea.[b]	$2,037	45	$91,667
Treatment facilities	$30,000 ea.	$3,056	12	$36,667
				$403,335

O&M Cost Item	Annual Cost Per Unit	Number	Total Annual O&M Costs
Electricity: Base charge	$5,000/pump	45	$225,000
Electricity: Extraction	$17/acre-foot	30,000 acre-feet (90 ft. avg. lift)	$510,000
Electricity: Injection	$1.9/acre-foot[c]	23,000 acre-feet (40 ft. avg. head change)	$28,500
Extraction pump maintenance	$500/pump[d]	33	$16,500
Injection pump maintenance	$1,000/pump	12	$12,000
			$792,000

Benefit Item	Annual Cost Per Unit	Number	Total Annual Benefit
Stored water savings	$5.27/acre-foot	30,000 acre-feet	$158,100
		Annual Net Cost	**$1,037,235**
		Net Cost/acre-foot	**$34.57**

Notes: [a] Telephone interview with Walter Garrett, Soil Conservation Service, Bay City, Texas, 1992.

[b] Telephone interview with sales representative, Oslin-Nation Co., Dallas, Texas. Price quoted for Bell &Gossett pump, 4000 gpm, 200 hp., 1750 rpm.

[c] Assuming 80 percent motor/pump efficiency for extraction, 60 percent for injection

[d] Based on telephone interview with Ralph Johnson, LCRA, Eagle Lake, Texas, 1992.

[e] Discount rate of 0.08 percent, repayment period of 20 years

Chapter 7. Salinity of East Matagorda Bay

Introduction

East Matagorda Bay (EMB, the bay) is a nearly land-locked estuary that lies between Matagorda Peninsula and the Intracoastal Waterway (ICWW) near the mouth of the Colorado River. The bay is approximately twenty miles long, 3.5 miles wide, and one to two meters deep (Figure 7.1). Like many estuaries along the ICWW, the bay is characterized by poor circulation. Most water flows in and out of the bay through Brown Cedar Cut, a small channel leading to the Gulf of Mexico. Big Boggy Cut and several other channels also communicate with the ICWW. The bay supports 110 vertebrate and 34 invertebrate species, and is an economically important resource for the local fishing industry.

Like most estuaries, the bay is susceptible to gradual environmental change. The management of water resources in the lower Colorado River Basin could influence environmental quality and the stability of the ecosystem in the bay. At present, there is only a limited exchange of water between the river and the bay. Inflows to the bay have been further reduced by the closing of several locks on the ICWW. The purpose of this chapter is to assess the effect water management decisions in the lower Colorado River Basin might have on water quality in the bay.

For the purpose of this study, changes in salinity provide a yardstick for measuring water quality within the estuary. Other measures, such as dissolved oxygen, water temperature, alkalinity, chemical oxygen demand, or turbidity might also serve as indicators of water quality. However, salinity has been selected as the most appropriate measure for this study because this characteristic often directly affects species composition and productivity in a brackish water estuary. Gradual or sharp changes in salinity might undermine species diversity in the ecosystem.

This report investigates factors that affect salinity in the bay and discusses the use of a mathematical model to predict the combined effect of river flows and precipitation on changes in salinity. This model is based on historical observations of salinity, river flows, and precipitation. Model results provide recommendations for managing salinity levels in the bay.

Model results indicate that rainfall is the predominant factor controlling salinity in the bay over the period in which water samples were taken. Results also indicate that salinity levels are relatively homogenous throughout the bay. These results imply that management decisions regarding river flows and the allocation of water for environmental uses in the lower Colorado River Basin may have little effect on water quality in this estuary. This conclusion is based on salinity measurements between 1982 and 1991, and it is not known whether or not long term changes in water quality occurred prior to 1982 or after 1991 as a result of water management decisions.

The Lower Colorado River Authority provided historical data on salinity levels within the bay for the years 1982 through 1991. Each observation includes information on the sampling date, the location of the sample (longitude and latitude), and the salinity levels. Samples are clustered in space and time. LCRA personnel sampled the water at various locations in the bay over a two-day period, but there are several weeks between sampling periods. Figures 7.2 and 7.3 display the temporal and spatial distributions of the water samples respectively. Additional data used to model salinity levels includes river flows and precipitation. River flows were measured at the USGS gaging station at Bay City, 9 miles north of EMB. The National Weather Service collected data on rainfall at the East Matagorda II station at Matagorda, Texas.

This chapter reports both a spatial and a temporal analysis of salinity measurements. For spatial analysis, sampling points are identified by latitude and longitude to the nearest minute. This grid is further sectioned into seven zones that account for hydraulic characteristics of the bay (see Figure 7.4). These seven zones may be used to infer whether or not differences in salinity between samples can be attributed to the location at which the sample was taken.

A time-series analysis is presented to determine the effect of river flows and precipitation on daily salinity levels, and to estimate the effect of management decisions in the river basin on changes in salinity between days. Because the spatial analysis indicates that salinity levels within the bay are relatively homogenous, the location of samples is not considered a factor in the time-series analysis.

Spatial Analysis of Salinity Measurements in East Matagorda Bay

As shown in Figure 7.1, several inlets lead from the bay to the ICWW, and the ICWW has connections to the Colorado River. Therefore, it may be that the northern-most portion of the bay is more heavily influenced by river flows. In addition, the surface area of the drainage flowing into the northern portion of the bay is larger than the surface area of the drainage from Matagorda Peninsula into the southern portion of the bay. To evaluate these hypotheses, the bay was divided into four zones in the north, and 3 zones in the south.

Figure 7.5 shows the relationship between salinity levels in all zones of the bay, rainfall intensity, and river flows. Figure 7.6 shows the relationship between these variables and salinity measurements taken in the northern portion of the bay, zones 1 to 4. Figure 7.7 shows the relationship between these variables and those salinity measurements taken in the southern portion of the bay, zones 5 to 7.

This result suggests that salinity levels are relatively homogenous throughout the bay. However, there are differences in salinity levels between the northern and the southern portions of the bay that occur after sudden drops in salinity. Figures 7.6 and 7.7 illustrate such differences during the periods late 1984, early 1985, early 1987 and early 1991. These periods typically last one to two months and correspond to high river flows. Similar analysis was carried out by sectioning the bay into an eastern portion, a central portion, and a western portion (plot not shown). Again, there appears to be no difference in salinity levels between portions of the bay when salinity measurements were organized in this manner. These results suggest that water flowing from the river into the bay travels through the inlets leading to the ICWW. After river flows decrease, the mixing of water within the bay causes salinity levels to move towards an equilibrium.

The zones in the bay might also be analyzed from a different perspective. For example, water in Zone 2 flows from the ICWW through the Big Boggy Cut inlet, suggesting a relatively high level of exchange between the two bodies of water at this point. Zones 3 and 6 are at the eastern end of the bay where there is apparently little inflow from any source other than precipitation and runoff. In contrast, zones 4 and 7 are close to the Colorado River; therefore they might be affected by flooding when the flow of water in the river is particularly high, but otherwise receive little inflow from any source other than rainfall. Figures 7.6 and 7.7 show the comparison of these zones. It is difficult to detect any difference in salinity levels among these seven zones.

The spatial analysis suggests three conclusions about salinity and mixing in the bay. One is that salinity levels are relatively homogeneous throughout the bay except after sudden drops in salinity. The second is that salinity levels in the northern portion of EMB remain lower than those in the southern portion after sudden drops in salinity during periods that continue for less than a few months. The third conclusion is that there are no apparent significant differences in salinity levels between the eastern and western portions of the bay.

Although the spatial analysis shows some differences between the salinity levels in the northern portion and the southern portion of EMB, these results generally support the conclusion that salinity may be estimated using only one equation for the entire bay. That conclusion, and salinity equation for the bay, is utilized in developing the time series models discussed below.

A Time Series Model of Salinity Levels in EMB

Because inorganic salts are stable compounds in water, salinity in the EMB changes only as a result of mass exchanges of water between EMB and adjacent bodies of water. Possible pathways for mass exchange between the bay and adjacent waters include: precipitation in the bay; evapotranspiration from the bay; runoff from precipitation north of the bay; the intrusion of fresh or brackish groundwater; discharge of freshwater from the Colorado River through ICWW or through flooding of the river; the flow of water from the bay into the Gulf of Mexico; and the intrusion of sea water from the Gulf of Mexico.

With the exception of hydrologic data on river flows and precipitation, no quantitative data exist on the mass exchange of water between the bay and adjacent waters. However, this chapter shows that it is possible to estimate salinity levels from data on precipitation and river flows alone. There are three components of the model used to estimate salinity. The first component describes the effect of rainfall intensity and runoff.

Rainfall and Runoff Component

Given the available information, data on precipitation at the East Matagorda II weather station (used as a proxy for precipitation) and runoff into the bay, salinity can be estimated by considering the mass balance of water. Equation 7.1 states that salinity is a function of the initial salinity level, and a coefficient describing the rainfall intensity, duration of rainfall, and surface area to volume ratio of the bay:

$$S = S_o*(1 + I*t*(A/V))^{-1} \qquad \text{(Eq 7.1)}$$

where the variables are defined in Table 7.1.

If the surface area to volume ratio is rewritten as 1/d, or (length *width) /(length *width *depth) equals 1/depth, then equation 3.1 becomes:

$$S = S_o*(1 + (I*t)/d)^{-1} \qquad \text{(Eq. 7.2)}$$

If α replaces duration/depth, then equation 7.2 can be rewritten as:

$$S = S_o*(1 + \alpha *I)^{-1}$$

Table 7.1
Table of Variables for Equation 7.1

Variable	Definition	Units
S	Salinity before rainfall (ML^{-3})	Grams per liter, parts per million
S_o	Salinity after rainfall (ML^{-3})	Grams per liter, parts per million
I	Rain fall intensity (LT^{-1})	Inches/day
t	Duration of rainfall (T)	Days
A	Surface area of bay (L^2)	Length x width
V	Volume of bay (L^3)	Length x width x depth
d	Average depth of bay (L)	Depth
α	A constant, ($L^{-1}T$)	Days/depth

The average depth of water within the bay is approximately one meter. If precipitation is defined in inches per day, and the time span between S and S_0 set to be a one-day time unit, then α can be computed to be 0.025 (this is converted by dividing one day by 39.37 inches/meter).

The relationship between rainfall and surface water runoff into the bay is probably nonlinear. Runoff is influenced by soil type, soil moisture content, and the topography of the land north of the bay. However, because there is insufficient information to incorporate these factors into the model, the assumption used in this preliminary research is that runoff has a linear relationship to rainfall intensity; specifically, runoff is assumed to be proportional to precipitation measured at the East Matagorda II station. Therefore, the α used in this model is an empirically determined variable reflecting the combined effect of precipitation and runoff.

River Flow Component

There is probably a complex hydraulic relationship between fresh water flow and salinity that is difficult to determine to describe the flow of water from the Colorado River into the bay. Although the volume of river flows into the bay are not known, flows at Bay City provide a proxy for this variable. To reflect the complexity of factors influencing the flow of river water into the bay, this model uses an exponential relationship:

$$q = \beta \text{ x } Q^{n} \qquad \text{(Eq. 7.3)}$$

where

q = flow from the Colorado River into the bay ($L^3 T^{-1}$), volume/day

Q = Colorado River flows at Bay City measured in ($L^3 T^{-1}$), volume/day;

β and n = empirically determined coefficients ($L^{3(1-n)} T^{-(1-n)}$); dimensionless.

If n is greater than unity, the relationship between the volume of fresh water entering the bay from the river and river flows at Bay City is concave. This result would indicate that when river flows are high, the amount of water flowing into the bay increases in proportion to the volume of river flows. However, if n is less than unity, this indicates that the curve is convex, and suggests that as river flows increase, the proportion of river flows entering the bay decreases. For example, perhaps the water has a greater tendency to flow towards the west side of the river during times of flood. In the case that n is equal to unity, there is a constant, directly proportional relationship between q and Q.

On the basis of the assumptions expressed in the exponential equation, attenuation of the discharge of freshwater inflows within the bay may be calculated in the same manner used to describe the effect of rainfall on salinity levels. The equation states that salinity levels are a function of the initial salinity times a coefficient that describes the volume of water entering the bay, or

$$S = S_o*(1 + q*t/V)^{-1} \qquad \text{(Eq. 7.4)}$$

Multiplying q by t/V eliminates the units associated with q, so S becomes:

$$S = S_o*(1 + \beta' *Q^n)^{-1} \qquad \text{(Eq. 7.5)}$$

if the right-hand side of equation 7.3 is substituted for q

where,

β' is an empirically determined coefficient ($L^{3(1-n)} T^{n}$)

The parameter β' is an empirically determined coefficient that accounts for the volume of water in the bay and the time span during the salinity change. For the purposes of this chapter, the time span is defined as one day. The definition of n is identical to that in equation 7.

Aggregate Variable Component

Several other factors affect salinity levels in the bay. For example, groundwater intrusion may occur. Some exchange of water between the Gulf of Mexico and the bay probably occurs. In addition, evaporation of water from the bay can also cause increases in salinity. However, the influence of these factors on salinity levels in the bay could not be estimated with the available data. For the purposes of this model, these factors are aggregated into one constant. The equation states that the salinity is equal to the initial salinity plus the aggregate effect of groundwater and or saltwater intrusion, and evaporation:

$$S = S_o + \gamma \qquad \text{(Eq. 7.6)}$$

where,

γ is an empirically determined constant ($M\ L^{-3}$).

The parameter γ, the empirical constant, represents the change in salinity that may be attributed to those factors for which there were no data. The effect of these factors is additive rather than multiplicative because salinity levels in the bay appeared to increase in a linear fashion in the absence of increases in rainfall intensity and river flows.

A Time Series Model for Estimating Salinity from River Flows and Precipitation

The three model components discussed above may be combined into one equation to estimate salinity:

$$S = (S_o + \gamma)*(1 + \alpha *I)^{-1}*(1 + \beta *Q^n)^{-1} \qquad \text{(Eq. 7.7)}$$

Multiple regression methods can be used to determine the four empirical constants γ, α, β, and n. First, a series of daily salinity values is estimated using hypothetical values for the parameters to be estimated, the initial salinity value, and daily observations of rainfall and river flow. The "Solver tool" in Microsoft Excel™ may then be applied to solve for the value of the four constants that minimizes the sum of squared error between the estimated and observed salinity values.

Because the model does not account for the lag time between changes in the salinity level and rainfall, surface runoff, or river flows at Bay City, the estimated coefficients do not reflect the fact that runoff and the complete mixing of water in the EMB takes place over a period of several days to several weeks.

Field observations of salinity levels are plotted in Figure 7.6 along with daily precipitation and river flows. For purposes of graphical clarity, river flows are upside down. The graph shows that salinity decreases after periods of high precipitation and/or high river flows. For example, in 1987 the graph also shows that salinity decreases when both precipitation and river flows decline. This suggests the existence of a fairly strong relationship between precipitation, river flows, and salinity levels.

There may be some correlation between river flows at Bay City and rainfall at the East Matagorda II weather station. If there is a causal connection between these two variables, incorporating both variables into the equation will not improve the parameter estimates. Figure 7.8 shows the relationship between rainfall and river flow. A wide range of river flows occur regardless of the amount of rainfall. This result tends to support the use of both variables in the equation.

For computational simplicity in determining parameter estimates, the size of the dataset was reduced by averaging all measurements taken within a three-day period. Because there is a period of several weeks between brief sampling periods, the data for each sampling period are reduced to one observed mean salinity value for every period of several weeks. Although the number of observations used to calculate the mean observed value differed between sampling periods, the least square regression analysis was conducted without weighting mean observed values according to the relative number of observations used to obtain that mean. To confirm that these changes did not affect the results, a least square regression analysis was conducted using the full dataset.

Table 7.2
Results of Parameter Optimization – Precipitation Only

	Precipitation Only
α (day/in)	0.03179
β (cfs^{-n})	0
n (dimless.)	-
γ (g/L)	0.0765
Σres^2	5477

Note: Original data were used. The squared sums of residuals are not comparable when the number of independent variables differs between alternative models. β and n are empirically determined coefficients ($L^{3(1-n)} T^{-(1-n)}$) and are dimensionless. n represents the relationship between the volume of fresh water entering the bay from the river and river flows at Bay City. β accounts for the volume of water in the bay and the time span during the salinity change. The parameter γ is an empirical coefficient ($M\ L^{-3}$)and represents the change in salinity that may be attributed to those factors for which there were no data

Table 7.3
Results of Parameter Optimization – Precipitation and River Flow

	Precipitation and River Flow				
α (day/in)	0.03841	0.03745	0.03605	0.03444	0.03264
β (cfs^{-n})	3.61E-4	4.36E-5	4.63E-6	1.60E-7	2.73E-9
n (dimless.)	0.3	0.5	0.7	1	1.3
γ (g/L)	0.1517	0.1195	0.1006	0.0881	0.0798
Σres^2	5231	5172	5209	5254	5370

Note: Original data were used. The squared sums of residuals are not comparable when the number of independent variables differs between alternative models. *β* and *n* are empirically determined coefficients ($L^{3(1-n)}T^{-(1-n)}$) and are dimensionless. *n* represents the relationship between the volume of fresh water entering the bay from the river and river flows at Bay City. β accounts for the volume of water in the bay and the time span during the salinity change. The parameter γ is an empirical coefficient ($M L^{-3}$)and represents the change in salinity that may be attributed to those factors for which there were no data

Table 7.4
Results of Parameter Optimization – Best *n*

	Best *n*	
α (day/in)	0.03814	0.03814
β (cfs^{-n})	1.10E-4	1.11E-4
n (dimless.)	0.4203	0.4203
γ (g/L)	0.1338	0.1338
Σres^2	5161	*

Note: Original data were used. The squared sums of residuals are not comparable when the number of independent variables differs between alternative models. *β* and *n* are empirically determined coefficients ($L^{3(1-n)}T^{-(1-n)}$) and are dimensionless. *n* represents the relationship between the volume of fresh water entering the bay from the river and river flows at Bay City. β accounts for the volume of water in the bay and the time span during the salinity change. The parameter γ is an empirical coefficient ($M L^{-3}$)and represents the change in salinity that may be attributed to those factors for which there were no data

Table 7.2 lists the results of the multiple least squared regression analyses. Column 1 shows parameter estimates from the analysis using only the precipitation variable; the values of β and n were fixed at zero. The results of this analysis are shown in Figure 7.9. There was some systematic deviation of salinity estimates from observed values in mid-1987 and mid-1989, but the results seem to provide an adequate estimate of salinity levels. The value of α, 0.03179, is only slightly higher than the preliminary estimate of 0.025. If B and n are 0, then the only difference in the equations is inclusion of the term ($S_0 + \gamma$); alpha is 27 percent larger than the initial estimate. A similar analysis was also conducted in which the precipitation variable was excluded by fixing α at zero. The results from the regression of salinity as a function of inflow were low enough to have no explanatory power; this suggests that rainfall is more important than river flows in determining the salinity levels in the bay.

Multivariate least squared regression analysis, under hypothetical values of n, can simultaneously optimize the values of α, β, and γ and separate the effect of the value of n on model results. The explanatory power which results is similar to the model that included only the precipitation variable, again supporting the inference that rainfall has a relatively larger effect on salinity levels in the bay than river flows. The parameter values obtained when all three variables were estimated simultaneously are listed in the second to last column of Table 7.2. The results are also displayed in Figure 7.9, along with the results from the model with precipitation only. Of interest is the fact that the value of α increased when estimated along with the parameter for river flows. When more variables are included in the model, the relationship between rainfall and salinity becomes more clear. In contrast, the value of γ decreased as *n* increased.

To determine whether or not the use of mean observed salinity values affected the value of parameter estimates, parameters were optimized again (see the last column of Table 7.2). With the exception of β and n, all values are similar to those estimates based on mean observed salinity values. The difference in the β values between models is 1 percent, and the difference in n between models is 10^{-6} percent.

These results support the inference that rainfall is a more important factor affecting salinity levels in the bay than is river flow. The relative contribution of each factor to the attenuation of the bay may be seen in Figure 7.10. The y-axis shows α*I and β*Q^n for each day in the sampling period. In Figure 7.10, the contribution of river flow to the attenuation of the bay is smaller, but more consistent than the contribution of precipitation. The average contribution of river flows on each day may be compared with the average contribution of precipitation. The average contribution of river flows is approximately half the contribution of rainfall.

It may also be stated that rainfall was the predominant factor controlling salinity in the bay over the period in which the samples were taken. This is supported by the fact that the two variables, river flows and precipitation, are independent of each other and that the value of α is physically meaningful. The least squared results imply that rainfall is the best predictor of bay salinity.

Conclusions and Recommendations

This chapter has sought to explain patterns of salinity within East Matagorda Bay. Storms and floods of fresh water can reduce the level of salinity in the bay. Under non-storm, non-flood conditions, salinity levels do not seem to vary spatially within the East Matagorda Bay. High river flows appear to cause spatial variation in salinity levels, and such flows create spatial differences in salinity between different zones for a period of several months. This chapter developed a semi-empirical mathematical model to predict the salinity level of EMB:

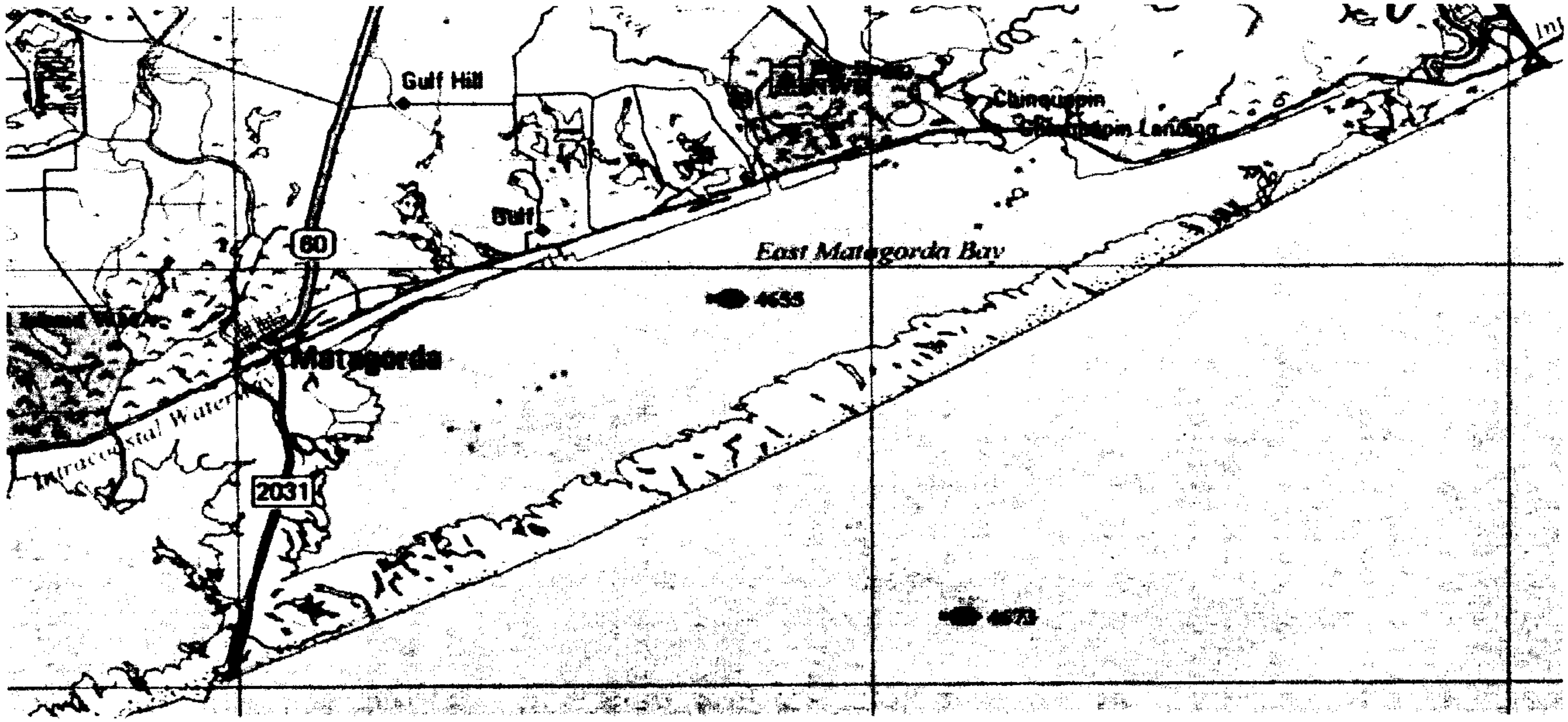
$$S = (S_0 + \gamma) \times (1 + \alpha \times I)^{-1} \times (1 + \alpha \times Q^{n})^{-1} \qquad \text{(Eq. 7.8)}$$

The variables S and S_o are salinity (g/l) on a given day, I is daily average rainfall intensity (in./day), as measured at East Matagorda II station, Q is the volume of water (cfs) in the Colorado River at the Bay City USGS hydrologic gauging station, and α, β, γ, and n were parameters to be estimated. These values are listed in the last column of Table 7.2. A simplified model (predicting bay salinity as a function of precipitation alone) that omits river flow showed similar performance. The parameters for this model can be found in the first column of Table 7.2. Precipitation has a larger effect on salinity levels than river flows. The contribution of river flows to the attenuation of the bay is half of that of precipitation.

In conclusion, it remains difficult to evaluate quantitatively the relative contribution of precipitation and river flow. Based on this analysis, under current hydrologic conditions, any attempt to manage salinity levels in the bay by manipulating the flow of water in the Colorado River alone would probably be ineffective. If a water management strategy should warrant dilution of the bay, some hydraulic structure that diverts water more effectively to the bay than the existing channels could be considered. Before attempting such a project it would be useful to first assess the impact of those changes. An adequate assessment of how such changes could affect salinity levels might include a determination of whether or not the river flow will be sufficient to dilute the bay, particularly during periods of low precipitation. Any assessment of bay water quality characteristics other than salinity should evaluate changes in water temperature, dissolved oxygen levels, nutrient content, and turbidity levels within the bay.

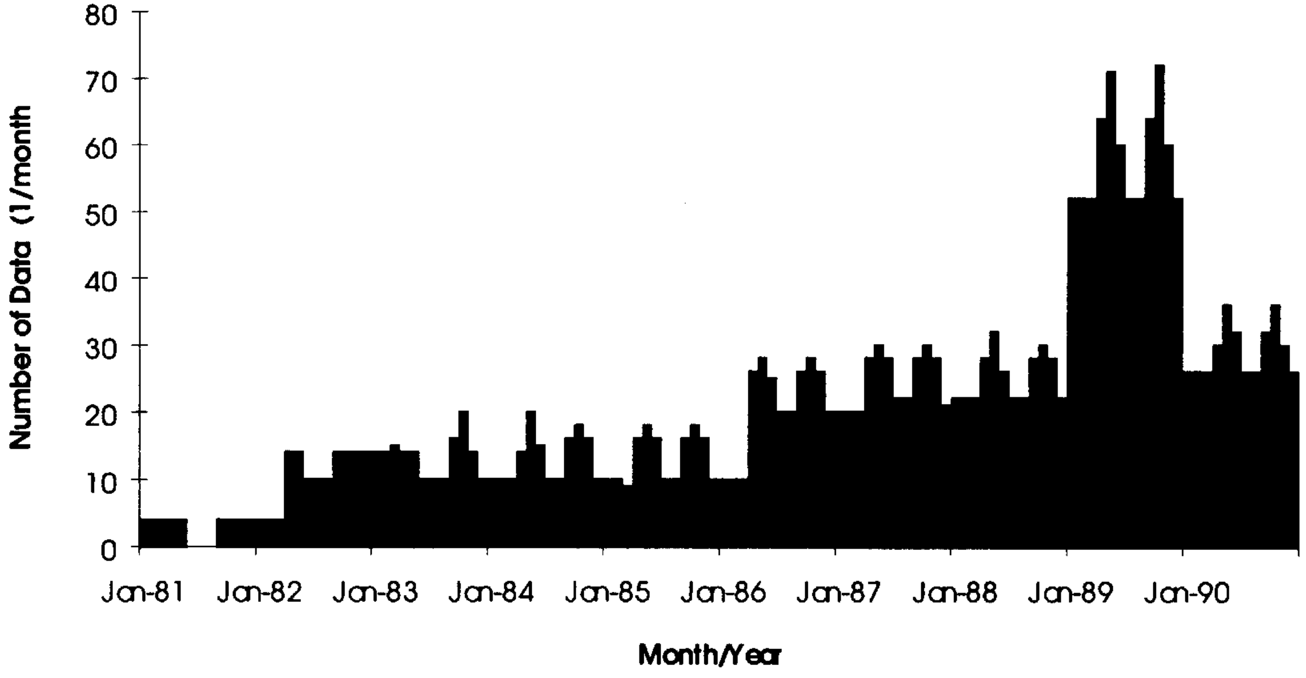
This chapter has demonstrated that a methodology for assessing salinity change due to alternative fresh water inflows is possible. There remains much uncertainty about its practical use.

Figure 7.1
East Matagorda Bay



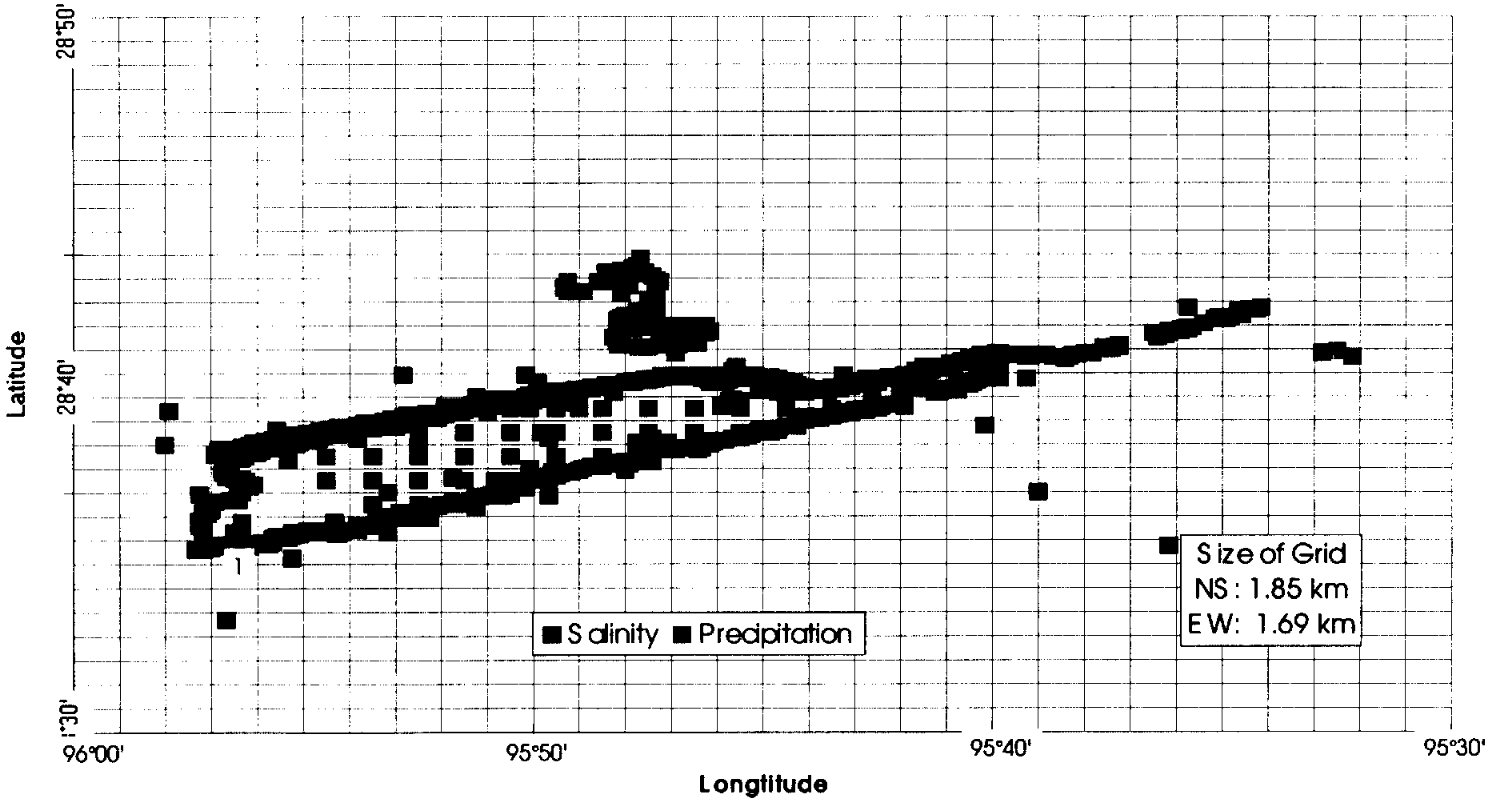
Source: *Texas Atlas and Gazetteer* (Freeport, Maine: DeLorme, 1995). Note that this is a copyrighted source. The published version of this report will contain a public domain map from the LCRA.

Figure 7.2
Temporal Distributions of the Water Samples



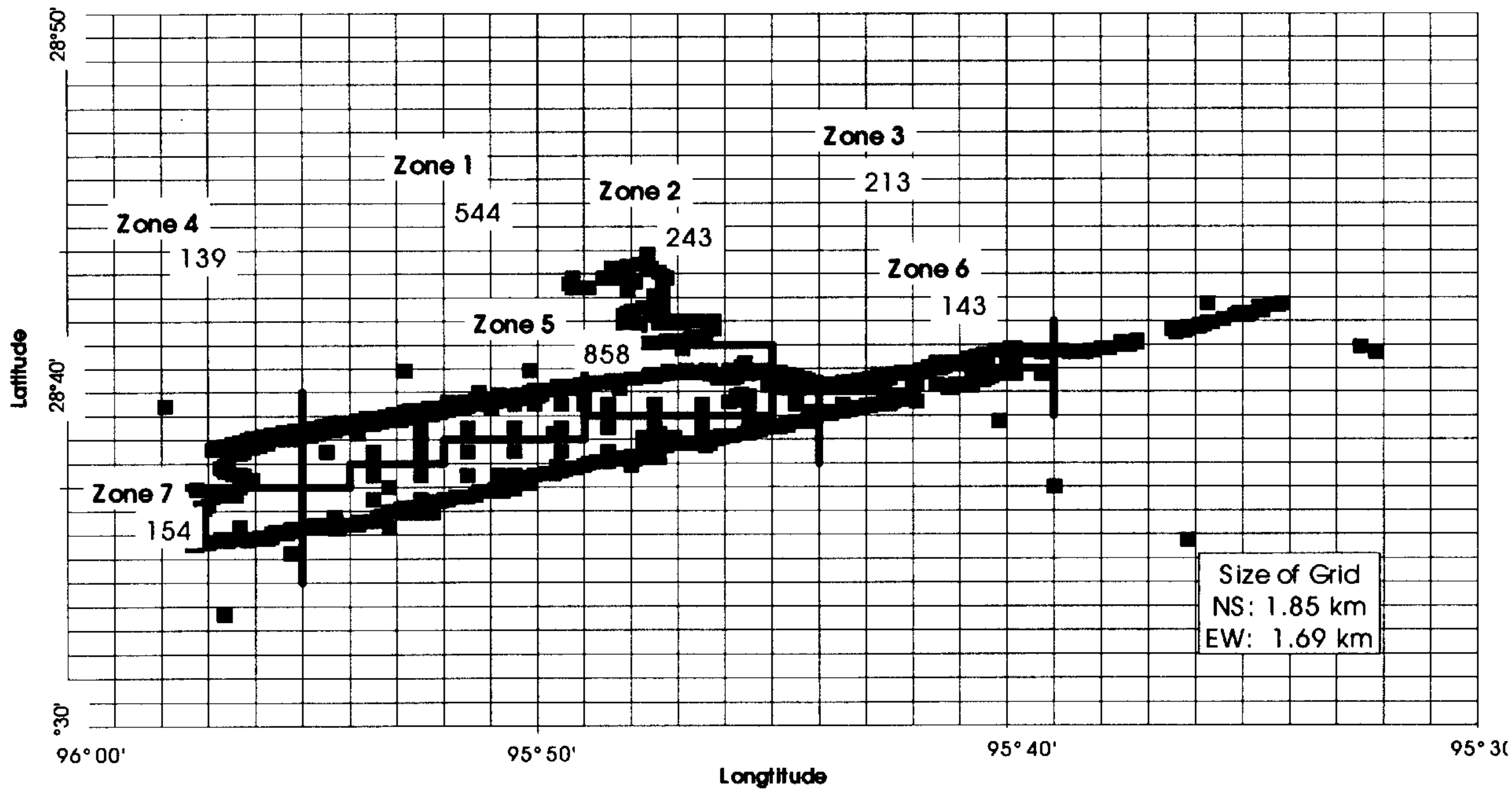
Source: Unpublished data provided by the Lower Colorado River Authority.

Figure 7.3
Spatial Distributions of the Water Sample



Source: Unpublished data provided by the Lower Colorado River Authority.

Figure 7.4
Hydraulic Characteristics of the East Matagorda Bay

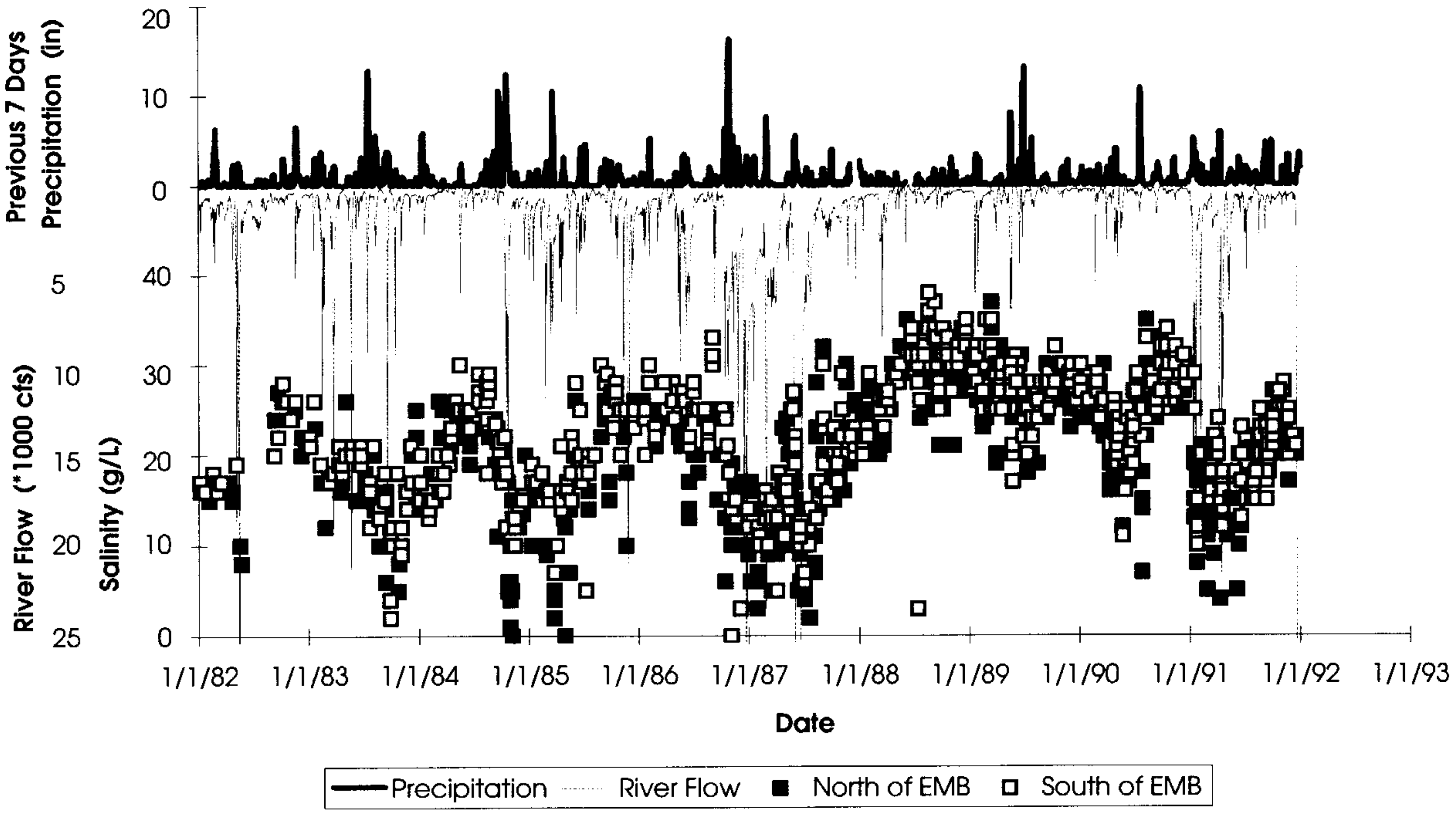


Source: Unpublished data provided by the Lower Colorado River Authority.

Note: Numbers indicate the number of data distributed in each zone

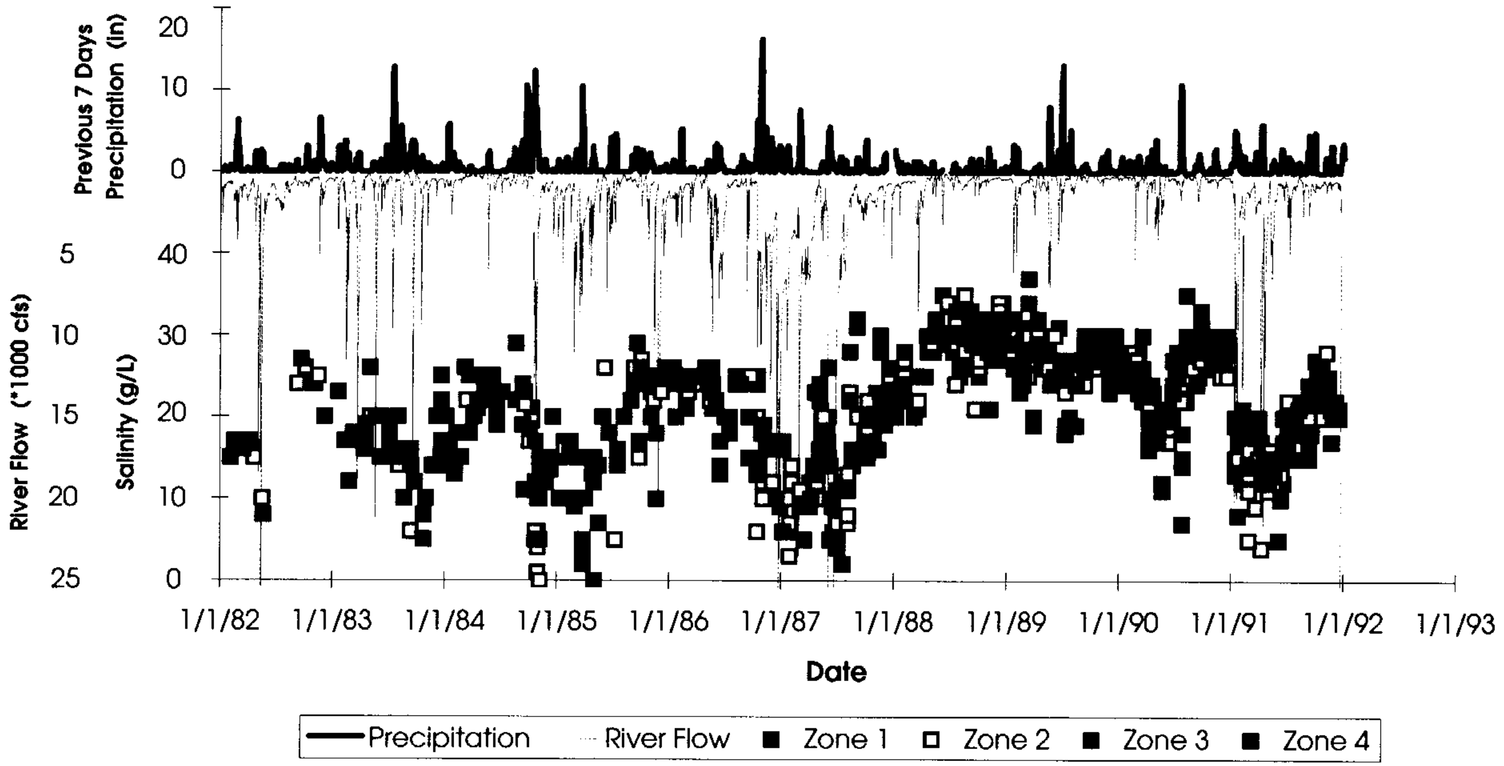
Figure 7.5

Relationship between Salinity Levels in the Bay, Rainfall Intensity and River Flows



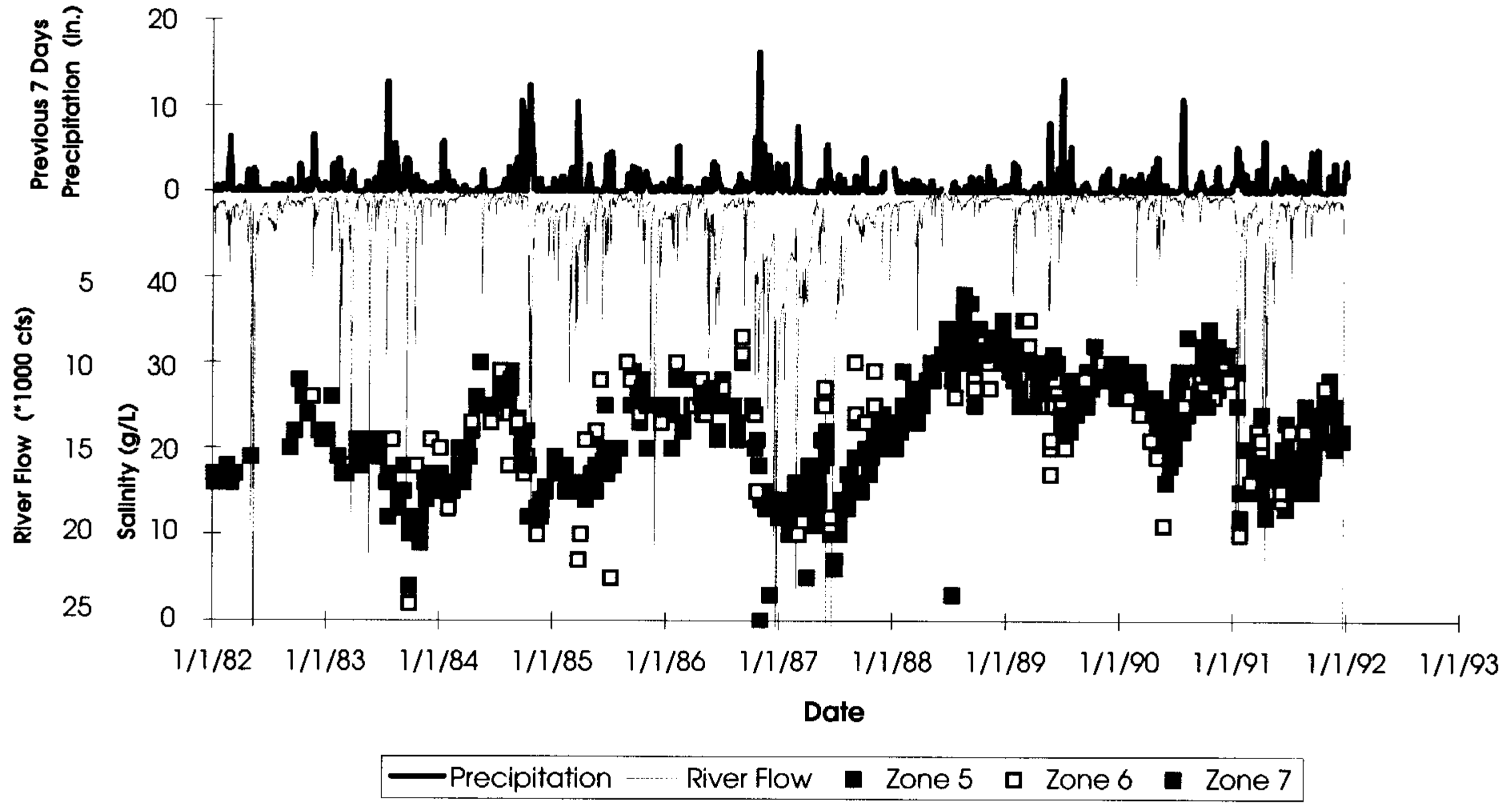
Source: Unpublished data provided by the Lower Colorado River Authority.

Figure 7.6
Relationship between Salinity Levels in the Bay, Rainfall Intensity and River Flows, Zones 1 to 4



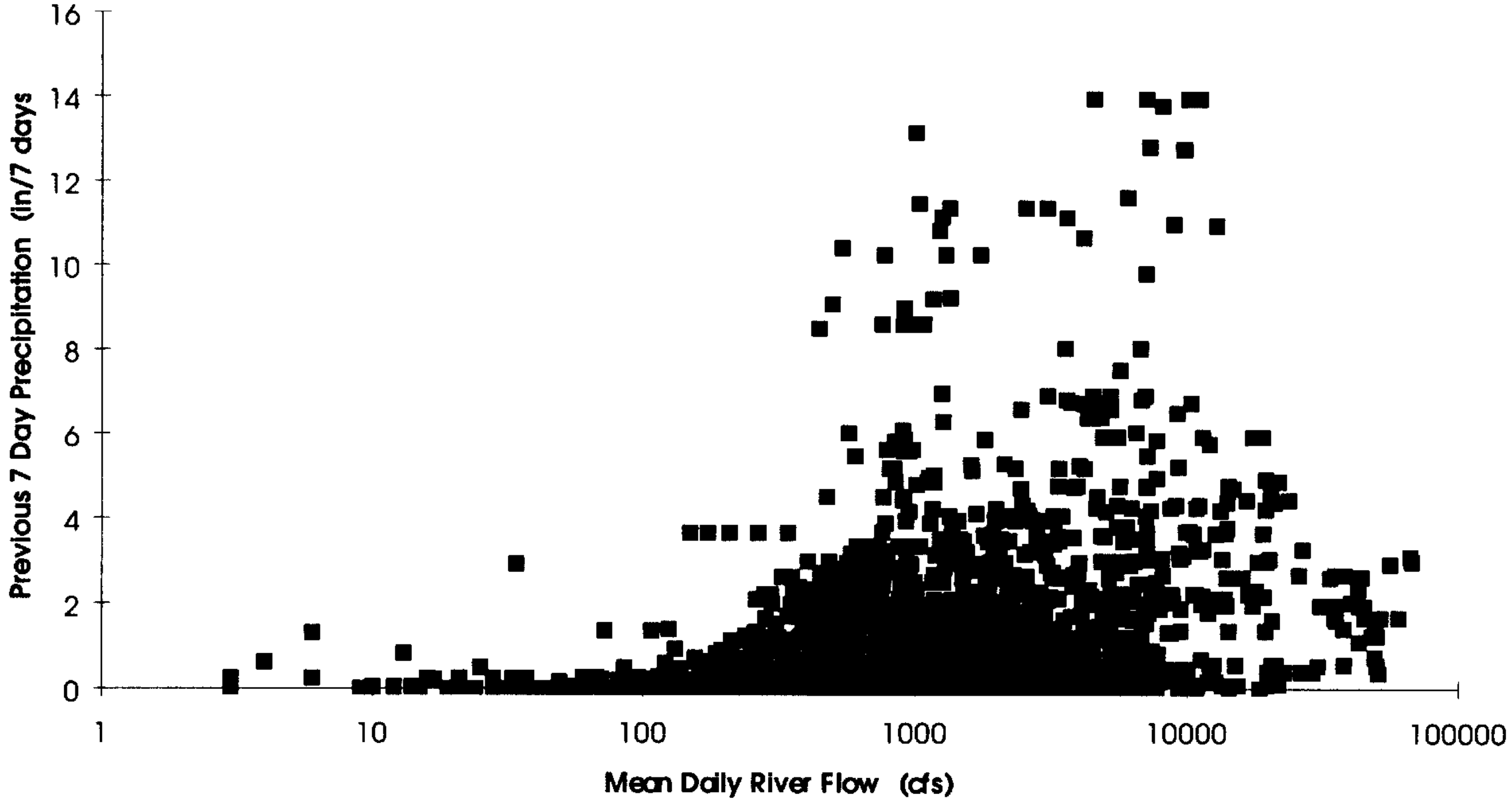
Source: Unpublished data provided by the Lower Colorado River Authority.

Figure 7.7
Relationship between Salinity Levels in the Bay, Rainfall Intensity and River Flows, Zones 5 to 7



Source: Unpublished data provided by the Lower Colorado River Authority.

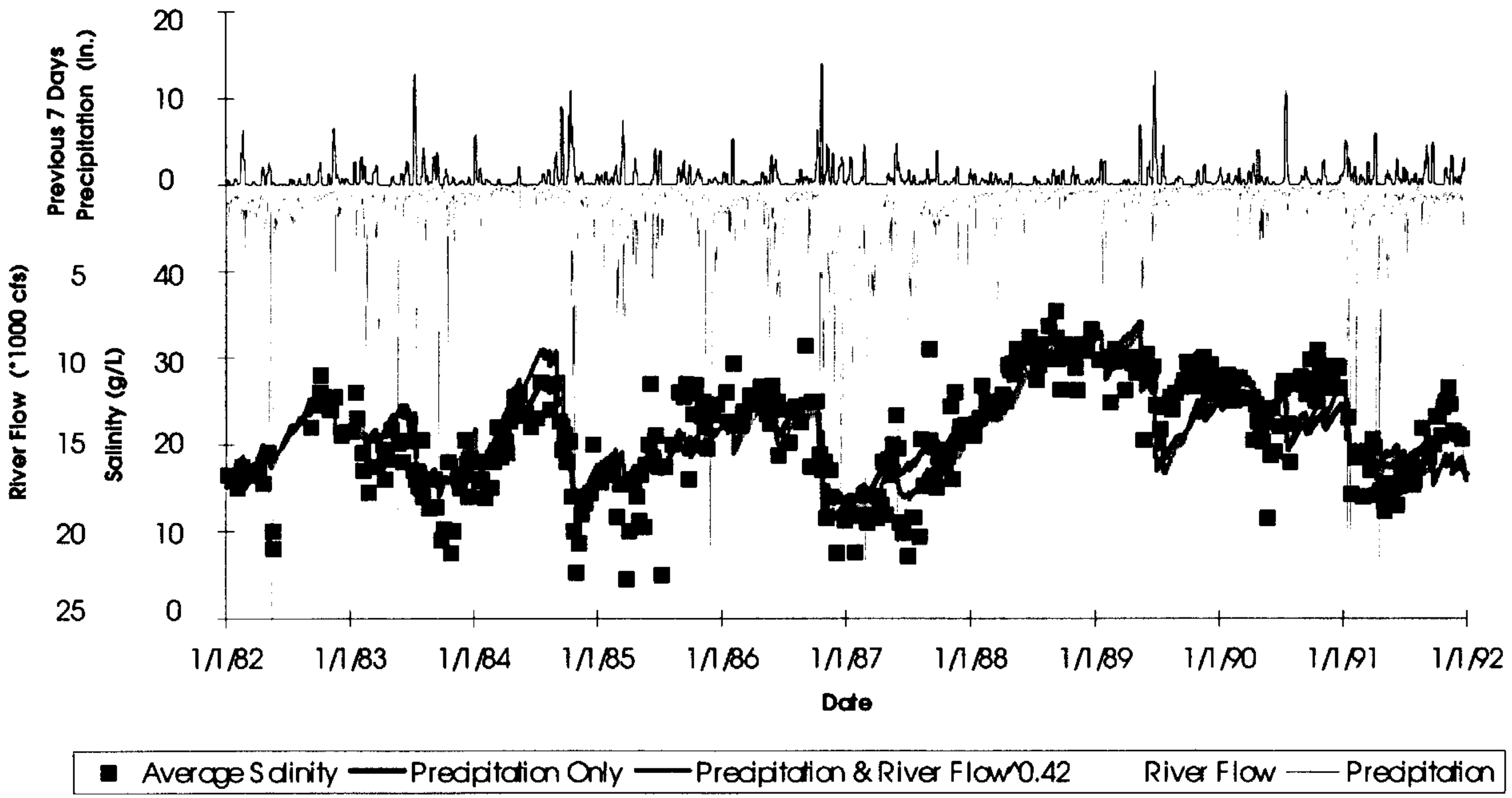
Figure 7.8
Relationship Between Rainfall and River Flow



Source: Unpublished data provided by the Lower Colorado River Authority.

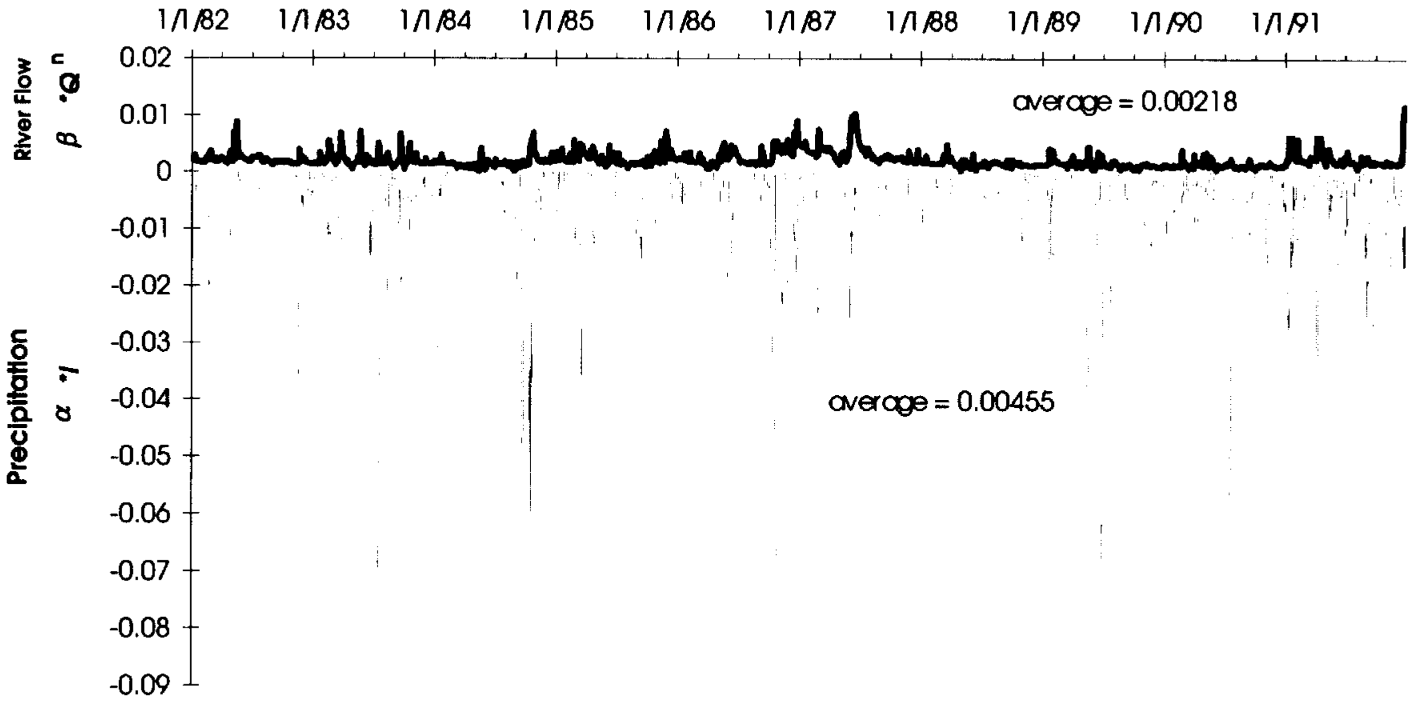
Figure 7.9

Multiple Least Squared Regression Analyses Parameter Estimates



Source: Unpublished data provided by the Lower Colorado River Authority.

Figure 7.10
Relative Contribution of Factors to the Attenuation of the Bay



Source: Unpublished data provided by the Lower Colorado River Authority.

Chapter 8. An Opinion Survey of Rice Farmers

Introduction

Water measurement, volumetric pricing, and technology transfer will not be successful in promoting water conservation in agriculture without the active support and involvement of farmers. One way to assess the attitudes and knowledge of farmers who work the land in the Gulf Coast and Lakeside Irrigation Districts is to survey them directly. This chapter describes the development, implementation, and results of a survey of rice irrigators who had active water accounts during the 1992 crop season.

Survey results may be applied to evaluate farmer knowledge and attitudes toward irrigation water conservation. Survey results may allow the LCRA to gauge farmers' opinions about how well the irrigation districts perform and can assist the LCRA in allocating its resources and implementing its water conservation programs. The survey also may indicate areas in which communication between the LCRA and the farmer might be improved. Finally, this survey can also serve as a means by which farmers might influence the water conservation and irrigation operations in the districts.

A third party survey is a potentially more accurate method of obtaining information about farmers' concerns and attitudes towards the LCRA, the irrigation districts, and the water conservation programs. There are at least two alternatives to an independent survey that might be used to gather this information from farmers. The first might be to rely on farmers' initiative in contacting the agency regarding specific concerns. However, such a method tends to bias results and would leave many questions unanswered. Farmers' phone calls, letters, and visits to the LCRA offices are not necessarily representative of the concerns in the farmer population as a whole. Another method might be a direct survey conducted by the irrigation districts themselves. This method is also inferior to an independent survey because farmers' responses to the LCRA might be biased. A third party survey can obtain representative responses from the population as a whole and eliminate bias associated with political motives or sampling methods.

Development of the Survey

This section describes the development of the survey instrument. A mail survey, rather than telephone interviews or personal interviews, was determined to be the most appropriate in this situation. Like most sampling methods, mail surveys have distinct advantages and disadvantages. Mail surveys can be more cost-effective and less time-consuming than other methods. In addition, mail surveys allow respondents to remain anonymous, so they may feel more freedom to express their views. One disadvantage of a mail survey is that the respondent is unable to ask clarifying questions. To some extent, this problem can be controlled by ensuring that survey questions are as clear and concise as possible. This survey attempted to achieve such clarity. However, some responses indicate that not all farmers understood questions in the same way.

Before designing questions, it was first necessary to become familiar with the operations of the irrigation districts. Several meetings were held with personnel from the LCRA in both Austin and Bay City. Documents were obtained from the LCRA and Texas A&M University Rice Experiment Station staff and at an LCRA-farmer meeting in Bay City. Each of these sources of information provided an understanding of the issues involved in rice farming, best management practices, and the water conservation program. Finally, officials from both the Austin and Bay City offices were asked to review the final draft survey to suggest improvements. The text of the final survey and other materials that were sent to farmers can be found in Appendix A. The gathered data are reported in Appendix B.

The survey contained four sections. The first section included questions about individual farming operations, such as the number of acres irrigated and the use of farming techniques. The second section contained questions about the personal characteristics of the respondent such as age and education. Section three included questions about farmer relations with and opinions of the LCRA, and farmers' opinions about the proposed volumetric rate structure. The final section was an open-ended question allowing respondents to express any concerns not addressed in other parts of the survey. Forty two of the seventy-nine respondents, or 54 percent, expressed their thoughts in this section.

In January 1993, 230 farmers received postcards informing them of the coming survey. This sample included the entire population of rice irrigators in both districts. One week later, farmers received the survey instrument, a postage-paid return envelope, and a postage-paid postcard with which to request survey results. Postcards were intentionally separate to ensure anonymity. Farmers also received a cover letter describing the purpose of the survey and to explain that the LBJ School, not the LCRA, was responsible for initiating and conducting the survey.

Survey Results

Farmer Response Rate

Three aspects of this survey enhanced the response rate and the quality of results: a sampling set consisting of all farmers, an independent survey, and farmer anonymity. The entire population of farmers was sampled on both districts. This eliminated any potential bias associated with sampling subsets of the population. The second factor contributing to the relatively high response rate was its direction by an independent third party. Finally, the survey ensured anonymity for those farmers responding to the survey. Respondents could feel free to express any positive or negative opinions about the LCRA and its programs without fear of jeopardizing their relationship with the agency.

Table 8.1 lists farmer response rates for each district. Farmers in the Lakeside District returned 40 of 102 surveys, or 39 percent. Farmers in Gulf Coast Districts returned 38 of 128 surveys, or 30 percent. Overall, the response rate was 79 of 230 surveys, or 35 percent. Lakeside responses accounted for 51 percent of all responses. The results of the survey will be discussed based on the combined results from the two districts. Only when there are significant differences in responses between districts will a distinction be made between the two farmer groups. The following discussion concerns farmer practices, farmer relations with the LCRA, and opinions about the proposed volumetric rate structure that was introduced in 1993.

Analysis of Survey Results

Statistical analyses of survey results, including frequencies, percentages, cross tabulations, and chi-square tests executed in Lotus 1-2-3 and SPSS software packages. Several issues should be discussed regarding the validity of these survey results. This survey sought to avoid bias by including all farmers in this sample. However, as with any kind of mail survey, farmers themselves decided whether or not to respond to the survey. If any systematic relationship exists between a farmer's decision to respond to the survey and farmer attributes, the results could be biased through the self-selection process. Other researchers conducting mail surveys have shown that it is possible to obtain representative results from mail surveys even with a high rate of non-response.[1] In this survey, there was a very high participation rate, a 35 percent response to the survey. This level of participation reduces the likelihood that a significant bias existed between survey participants and non-respondents.

Another practical problem in mail surveys is item non-response. Item non-response occurs when an individual respondent does not answer one or more questions in the survey. There are several reasons respondents might decline to answer a question. The respondent may feel that the question invades his or her privacy. The respondent may not understand the question or may otherwise be unable to answer the question on the basis of information available to him. It may also be that the question does not apply to the respondent. For example, one question asked farmers about the benefits of water conservation demonstration projects and the effectiveness of LCRA-sponsored farmer meetings. If a farmer did not visit the demonstration project or did not attend the farmer meetings, he is not qualified to answer the question. Under these circumstances, most respondents would probably skip this question. Several questions on the survey had particularly high non-response rates. A question that asked about how helpful the LCRA staff were in handling inquiries about water deliveries had a 15.2 percent non-response rate. The question regarding the benefits associated with LCRA-sponsored farmer meetings had a 16.5 percent non-response rate. The question regarding the benefits of water conservation demonstration projects had a 33 percent non-response rate. The item non-response rate for remaining questions was less than or equal to 10 percent.[2] It is not easy to assess whether the higher non-response rate to such questions reflects the validity of the results.

Another weakness of the survey relates to the phrasing of response choices. For example, in those questions for which the responses were: "very helpful," "helpful," or "not helpful," it might have been better to replace the choice "helpful" with "somewhat helpful." Use of the word "helpful" as the middle response forces respondents to make a binary choice regarding the level of helpfulness. It is hard to assess how the use of such qualitative measures affects the validity of results.

Farming Practices

Crop Mix and Farm Size. All farmers responding to the survey indicated they irrigated rice on their farms. On Gulf Coast District, 9 percent of farmers indicated they also raised non-rice crops. Few farmers on Lakeside District indicated that they also raised non-rice crops (Figure 8.1). The average size of rice farms on the two districts was 554 acres. In Lakeside District, the average size of rice farms was 744 acres and in Gulf Coast District, the average size of rice farms was 356 acres. The average size of farms on the two districts when acreage planted in non-rice crops is included in the estimated was 636 acres. Figure 8.2 displays the responses to the questions regarding farm size.

Land Tenure. Land ownership patterns may influence farmer's decisions to implement farming practices or make capital investments that might increase irrigation efficiency. In these irrigation districts, farmers own, lease, and sharecrop the land on which they irrigate rice. Because the benefits associated with infrastructural improvements becomes capitalized into the sale price of the land, farmers that sharecrop or cash-rent their lands may not be willing to make capital improvements. The only remaining incentive for a farmer who does not own the land he irrigates to make capital improvements is the potential cost-savings associated with water conservation. Under a fixed, per-acre irrigation rate structure, landowners have little incentive to make improvements. Under the volumetric rate structure, it may be that landowners will have an incentive to make such infrastructural improvement. A landowner might recoup his investment by charging a higher rental rate based on the increased water efficiency in a field. However, it may also be that farmers could implement water conservation measures without making capital improvements to the land. If so, they may be unwilling to pay a higher rental rate as long as alternatives exist. Under the traditional pricing system, the farmer could not save money by using less water. The new volumetric pricing system should give both landowners, sharecroppers, and cash-renters some evident incentives to invest in improving water efficiency through either improvements in infrastructure or management practices. In order to understand the relative importance of land ownership, the survey asked farmers about land ownership (Figure 8.3). Only 28 percent reported that they owned between 81 to 100 percent of the land they farmed. A majority of 56.5 percent reported that they owned between zero to 20 percent of the land they farmed. Of those who did not own land that they farmed, 85 percent reported that they leased it (see Figure 8.4). Thirteen percent reported that they were in a cooperative arrangement with the owner of the land.

Use of Holding Streams. One water-intensive farming practice employed by some farmers is known as a holding stream. The practice enables the farmer to keep a steady stream of water flowing through field at all times and reduces the labor cost associated with tending fields. This survey attempted to determine the percentage of farmers using a holding stream and their motivations for doing so. A knowledge of these factors could assist the LCRA and the farmers to reduce the use of holding streams. Fifty-five percent of the farmers reported using a holding stream. Figure 8.5 shows the reasons given by the farmers for their use of the stream. The most frequently reported reason for using a holding stream was that it takes too long for the water to arrive at the field once the farmer places an order for water. Thirty percent of the farmers who use holding streams gave this as their reason for implementing the practice. It may be that if LCRA addresses the problem of the waiting time for water, farmers will have less incentive to use holding streams.

Distance to Fields. The number of miles a farmer travels each day to manage the fields may be related to the number and location of fields farmed. These factors could have an impact on the quality of management at individual fields. It is more difficult to manage many small fields scattered over large distances that it is to manage a few relatively large fields. If a farmer must travel long distances between fields, it follows that it is more difficult to implement labor-intensive water management practices. To determine whether or not this is an important factor affecting water management practices, farmers were asked for information regarding the distance between fields. In spite of the "logical" connection, no correlation between the number of fields farmed, the distance between fields, and water management practices was found in the survey based on cross-tabulations.

Water Conservation Techniques. A variety of farming practices can increase irrigation efficiency and reduce water use. These practices include both labor-intensive management techniques and capital-intensive infrastructural improvements. Labor intensive techniques require the farmer's time and effort but are less expensive than infrastructural improvements.

In contrast, capital-intensive water management practices require a large investment but may actually reduce labor costs. Examples of capital intensive techniques include precision-leveling and the construction of in-field laterals. Given a list of possible water conservation techniques, farmers were asked to identify those that they currently use. This information may help to determine which water conservation methods future policies should emphasize. Figure 8.6 shows the response frequency for each technique listed in the survey.

In the Lakeside District 80 percent of farmers reported using multiple delivery points. In Gulf Coast District, 60 percent of farmers responded that they used multiple delivery points. Of the respondents on Lakeside District, 57.5 percent reported having used precision-leveling while 26 percent in Gulf Coast District reported having used precision levelling. In the Lakeside District, 30 percent of farmers reported using underground pipes while in Gulf Coast District, 13 percent of farmers reporting using underground pipes. For the two districts combined, the most frequently reported practices were: canal maintenance, 72.2 percent; levee improvement, 72.2 percent of farmers; and multiple delivery points, 70.9 percent. The least popular practice was the use of underground pipes, 21.5 percent. Respondents were given an opportunity to report water conservation technologies they implement that were not listed. 5.1 percent of respondents listed additional technologies. Perhaps the biggest surprise was that only 41.8 percent of the farmers reported using field records. Field records will not save as much water as techniques such as precision leveling and underground pipelines, but they are inexpensive and can assist the farmer in examining his practices in a systematic manner. The greatest percentage of farmers reported using four water conservation techniques. The average number of techniques employed was 4.2. The difference between the number of reported conservation techniques in use on each district was not statistically significant, but there seems to be a difference in which techniques farmers select between the two districts.

Precision-Leveling. The farmers were asked to provide the acreage of fields that had been precision-leveled (Figure 8.7). Counting both districts, 41.8 percent indicated that they had precision-leveled the land. This leaves 58.2 percent who do not use this technique. Twenty-three percent of the farmers indicated they had between 50 and 300 acres of land precision-leveled. Twenty-three percent also said they had over 300 acres of land that had been precision-leveled. Farmers appear to fall into three categories: those with no acres precision leveled; those with relatively few acres precision-leveled; and those with many acres precision leveled. The last two groups are the same size and added together just about equal those in the first group.

Conjunctive Use. The potential for conjunctive use of groundwater and surface water was examined in chapter 6 of this report. To understand current groundwater use, the farmers were asked to estimate the portion of their irrigation water that comes from surface sources (the LCRA canal system) and the portion that comes from groundwater wells. Overall, 32.9 percent of the farmers reported using at least some amount of groundwater to irrigate crops. Of those who did report the use of groundwater, the average amount as a percentage of total water usage was 41.6 percent. The most common portion reported was 50 percent. Therefore, of those who do use groundwater, 23.1 percent use it for half of their water supply. This represents 7.6 percent of all farmers.

LCRA Response to Inquiries. A large portion of the survey was designed to assess farmers' attitudes toward the LCRA. Most of the questions in this section deal with the performance of the LCRA as perceived by the farmers. Farmers were asked to evaluate LCRA staff's response to their concerns about billing for irrigation water (Figure 8.8). Roughly 97 percent of the farmers reported that the LCRA was "helpful" in regards to such questions with 35.2 percent reporting that the LCRA was "very helpful." Only 2.8 percent rated the staff as "not helpful." The farmers were also asked to rate the LCRA's response to their questions about water conservation (Figure 8.9). A combined 89.6 percent said the LCRA was at least "helpful" and 17.9 percent reported the LCRA was "very helpful." LCRA staff were described as "not helpful" in answering such questions by 10.4 percent of respondents. On questions about water deliveries, a combined 94.4 percent felt the LCRA was at least "helpful" with 26.4 percent feeling the LCRA was "very helpful" in answering such questions (Figure 8.10). Only 5.6 percent reported the LCRA was "not helpful" in answering questions about water deliveries.

Water Deliveries. Although most farmers felt that the LCRA did a good job in answering questions about water deliveries, many farmers were uncertain about the ability of LCRA to measure water deliveries. Figure 8.11 shows that while a combined 54.2 percent felt the deliveries were "accurate," 45.8 percent felt that they were "not accurate." This question takes on greater significance with the introduction of the new volumetric pricing system for water. For the new rate structure to be fair, the amount of water delivered must be measured accurately. Farmers concerns over the accuracy of water measurement are addressed in the following section.

Farmer Meetings with LCRA. Farmers were asked a series of questions about LCRA-sponsored farmer meetings. One question was whether they had been invited to a farmer meeting in the past year (Figure 8.12); 97.4 percent of farmers reported receiving invitations to these meetings and 2.6 percent reported that they had not been invited. The LCRA appears to have done a good job informing the farmers of the meetings. The farmers were then asked about meeting attendance. The majority of farmers reported attending at least one of the meetings (Figure 8.13) and 80.3 percent of the farmers reported having attended a meeting in the past year. Farmers in Lakeside District were more likely than farmers on Gulf Coast District to have attended at least one meeting.[3] In the Lakeside District, 89.5 percent of the farmers reported attending a meeting. In the Gulf Coast District, 71.1 percent attended. This result indicates that farmers in the Lakeside District are more involved with the LCRA than farmers in the Gulf Coast District. The LCRA may need to give special attention to motivating Gulf Coast farmer involvement. The greater the number of farmers that work closely with the LCRA, the greater the chance the LCRA has of achieving its water conservation objectives. Farmers were asked to evaluate the meetings that they attended. As Figure 8.14 shows, 81.8 percent of the farmers felt that the meetings were at least "useful." 18.2 percent felt that they were "not useful."

Water Conservation Demonstration Projects. The LCRA has conducted water conservation demonstration projects in the area. The farmers were asked whether or not they had been invited to observe the demonstration project and whether or no the demonstration was of any value. Figure 8.15 shows that 88.2 percent of farmers reported having been invited to demonstration projects. Three-quarters (75.4 percent) of the farmers who attended these demonstrations gave them favorable ratings; 9.4 percent of farmers even rated them as "very helpful." Some farmers reported that they found the demonstrations "not helpful" (see Figure 8.16). These results indicate that the LCRA should continue to implement conservation demonstration projects.

Technical Advice. In a question related to the conservation projects, farmers were asked whether the LCRA had offered them any technical advice in the past year (Figure 8.17). One half (50.7 percent) of the farmers reported receiving technical advice from the LCRA in the past year. There is no information on whether or not the farmers implemented any of this advice. The question stated, "did the LCRA offer you any technical[4] advice . . .?", so the advice may have been offered as a response to questioning by the farmer and was not necessarily instigated by the LCRA.

Attitudes Toward Regulation. The survey also attempted to gain insight into farmers' attitudes toward the regulation of both surface water and groundwater. It may be that LCRA's attempts to implement on-farm water conservation programs are confounded by a strong bias against the regulation of water. Only a small percentage of farmers felt that both groundwater and surface water should "always be regulated" (Figure 8.18). However, 69.4 percent felt that surface water should be regulated under conditions of drought, when the demand for water exceeded the supply, and 22.2 percent of respondents felt that surface water should "never" be regulated. More than one-third of the farmers (39.7 percent) felt that groundwater should be regulated under drought conditions. This is an unexpected result because groundwater is not regulated *per se* by the state in Texas. In Texas, landowners have a right to access groundwater supplies that may be pumped from wells located on their property. As was expected, a large percentage of farmers (54.8 percent) felt that groundwater should "never" be regulated.

To determine whether farmers were consistent in their responses to questions regarding the regulation of groundwater and surface water supplies, responses were cross tabulated to determine whether or not there was a statistical significant correlation between responses (Table 8.2). Results showed a statistically significant correlation between responses.[5] The largest group of respondents were those who felt that both groundwater and surface water should "never" be regulated. An even 50 percent of the farmers felt that even in situations when demand exceeds supply, neither groundwater nor surface water should be regulated.

General Attitude Toward LCRA. To get an impression of the overall relationship between the farmers and the LCRA, the farmers were asked whether they felt that, in general, the LCRA was helpful to rice farmers. Most of the farmers or 84.4 percent felt that the LCRA was at least "helpful" to the farmers (Figure 8.19). The LCRA was identified as "very helpful" by 14.7 percent of respondents. An equal number, 14.7 percent, felt that LCRA was "not helpful" to rice farmers. This indicates that, overall, the LCRA has a good reputation with the farmers although one-seventh (14.7 percent) are unhappy with the organization. It is not certain how much of this sentiment was specifically associated with implementation of the volumetric rate structure. It is possible that some farmers judge the LCRA's entire operations on this basis. However, it is also possible that this small but statistically significant number of farmers have a poor opinion of the LCRA regardless of the volumetric rate structure.

New Rate Structure

Access to Information on the New Rate Structure. The volumetric rate structure represented a major departure from the past. Beginning in 1993, the farmers would reduce their water bill if they use less water. Conversely, water bills could go up if the farmers use more water. An important factor in obtaining farmer support for the new plan was to educate them about its design, purpose, and function. Over 90 percent of the farmers felt that LCRA had done at least an "adequate" job of informing them about the new rate structure (Figure 8.20); 12.3 percent even felt the LCRA had done a "very adequate" job of informing them of the new rate; and 9.6 percent felt that the LCRA had done an "inadequate" job. Given the reservations farmers have about the new rate structure, it was interesting that over 90 percent report LCRA has done an adequate job informing them about it. This seems to indicate that most farmers understand the principles behind the new rate structure, but disagree with its implementation.

The Accuracy of Water Measurements and Changes in the Cost of Water. Much of the opposition to volumetric water pricing appears to be associated with potential changes in the cost of water. Slightly less than half (45.1 percent) of respondents reported that their water cost would increase as a result of the new rate structure (Figure 8.21), 33.8 percent predicted that there will be no change in their water cost, and 21.1 percent of respondents predicted that their water cost would decrease. A major concern among respondents is that the methods used to measure water are not accurate: 45.8 percent of respondents responded LCRA's water measurements were inaccurate. Responses on the accuracy of water measurement and the effect of the volumetric billing on the cost of water were cross tabulated. The results show a strong correlation.[6] Farmers who believe that water measurements are inaccurate also believe that the new rate structure will increase their water cost. It is not clear whether or not they just "fear" it will increase their water cost or they actually believe it will increase their water cost. If water measurements are inaccurate, but not systematically biased, it is possible that mis-measurements could also reduce their water cost by underestimating water deliveries. However, many farmers apparently feel that the water measurements will be systematically biased towards over-estimating water deliveries. The most common correlation (33.8 percent) was found among those respondents who felt that water measurements were not accurate, and that the new rate structure would increase their water cost. The next largest group (26.8 percent) were those who believed the water measurements would be accurate and there would be no change in their water cost.

When were asked if they felt the new rate structure was fair, 63.7 percent of respondents felt that the new rate structure was at least "fair," 7.2 percent felt it was "very fair," and 36.2 percent felt that the new rate structure was "unfair" (see Figure 8.22). A cross tabulation was run on the questions of fairness and the predicted effect on water bills (see Table 8.4); responses were correlated strongly.[7]

Farmers who believed that the new rate structure would increase their water cost felt that the rate structure was unfair. This represented the single largest group of responses at 30.9 percent of the total. The second largest group believed their water cost would not change and considered the rate structure fair. More than one-eighth (13.2 percent) felt that their water cost would increase and yet still considered the new structure to be fair.

Questions about the fairness and accuracy of water measurement were cross-tabulated to determine the existence of any correlation between responses (Table 8.5). Results show a statistically significant correlation.[8] The largest group (35.3 percent) thought that water measurements were accurate and considered the new rate structure fair. The second largest group (26.5 percent) felt that water measurements were inaccurate and that the new rate structure was unfair.

Incentive for Water Savings. Farmers were asked whether the new rate structure provided an incentive to save water (Figure 8.23). Of the respondents, 58.3 percent thought that the new rate structure provided an incentive to conserve water, 20.8 percent felt that it did not promote water conservation and 20.8 percent of respondents expressed no opinion in response to the question. Cross tabulations among responses to questions about whether or not the new rate structure provided an incentive to save water and whether or not LCRA's method of water measurement was accurate were not statistically significant. However, results showed the largest group (30 percent) felt that water measurement was accurate and that the new structure provided an incentive to save water. The second largest group (22.9 percent) felt that water measurement was not accurate but that the new structure did provide an incentive to conserve water. This result is somewhat surprising because one might expect that if water measurements were not accurate, then a volumetric rate structure would not provide an incentive to save water.

Responses to questions about whether or not the new structure provided an incentive to save water and the farmers perception of its effect on water cost were also cross tabulated (Table 8.6). The results from these tests showed a statistically significant correlation.[9] Twenty percent of the farmers believed that the new structure did provide an incentive to save water but that it would also increase their water cost. An equal number also felt that the new structure provided an incentive to conserve water but that it would not alter the cost of water. The third largest group (18.6 percent) also felt that the new structure provided an incentive to save water but that it would result in a reduction in their water cost.

Essay Responses

Farmers were given the opportunity to respond to an open-ended question regarding the LCRA. The response rate to this question was 53 percent. The most frequent comments were in regard to the accuracy of water measurements and the operations of the LCRA. Many farmers expressed an opinion that the LCRA is an inefficient bureaucracy.

Farmers cited water measurement as their biggest concern (Figure 8.11). Many farmers remain unconvinced that LCRA can measure water and charge them on a volumetric basis. The farmers' main concern appears to be that fluctuating canal depths prevent the flow of water through the delivery structures from remaining constant between measurement. As one farmer states:

> Without an actual gear driven counter, the volumetric rate structure will be inaccurate. This is because the canal level fluctuates up and down, and at times (up to 36-48 hours) no water is flowing through the water box, but the clock is still ticking indicating how much water should be flowing through the opening in the water box.

Of the farmers responding in this section of the survey, 30 percent commented about this issue. Several of these respondents noted that they agreed with the theory of volumetric pricing but felt that in practice it would not be fair since the accuracy of the water measurement was in question.

The second most commonly identified issue in the essay section was the feeling that the LCRA was inefficient in its use and management of water. Many respondents expressed an opinion that the LCRA was an inefficient bureaucracy, that it had become a self-serving organization, and that it was not responsive to the farmers' needs.

Farmers suggested that LCRA could save large amounts of water by improving its canal system. (LCRA has implemented an ongoing capital improvement project for canal rehabilitation since 1988.) This would include better maintenance of the levees as well as removal of vegetation from the canals. Several farmers also suggested that, while on-farm water use had decreased in recent years, LCRA had increased water prices. The comments reflected a view that much of the inefficiency of water use had already been removed, but farmers had not benefited financially from this savings; they are paying more money for less water. The argument continued that now, when increases in irrigation efficiency are harder to realize, the LCRA is implementing a volumetric rate structure.

Several other farmers did remark in the essay section that volumetric pricing was a good thing and should account for a larger portion of the total water bill. While they welcomed the opportunity to save money by conserving water, they also argue that the cost-savings will be insufficient to merit investment in capital-intensive water conservation technologies such as underground pipelines and precision leveled fields. Some farmers indicated that a greater incentive to save water would occur if the flat fee was reduced and the volumetric fee increased.

Some farmers also expressed frustration over their perceived lack of input about issues on the irrigation districts that affect them. Although questions regarding the effectiveness of farmer meetings received a generally positive response (Figure 8.14), several farmers remarked that they had been "taken out of the decision-making loop." Generally, these types of opinions were associated with the perception that LCRA has become a self-serving bureaucracy that LCRA is not concerned about working with the farmers. However, many farmers also made positive comments. The most frequent comment was that the LCRA and the farmers need to work together more. The farmers noted that they are not the only ones benefiting from rice farming, as they represent a large segment of the economy in their areas and support many local businesses. The LCRA also derives income from the farmers.

Conclusions

One finding of the survey is that only 42 percent of farmers are currently maintaining any type of field records. Field records provide an economical means of improving water management. The use of field records may also assist in changing farmer attitudes. Keeping records of field conditions and problems aids in the solution of problems and promotes a more systematic approach to the practice of farming. A more systematic approach may help many farmers improve their irrigation efficiency and become more receptive to new technology.

Farmers indicated there is concern over the accuracy of the water measurements. Some farmers responded positively to the idea of volumetric pricing but did not endorse the program because of perceived inaccuracies in water measurement methods. Farmers might be more willing to accept volumetric pricing if the LCRA can assuage concerns with the issue of accuracy of irrigation water measurement. For example, if a third party, selected by farmers on the irrigation districts, could take measurements independently at several delivery structures, over an extended time period, farmers could observe the correspondence between water use and measure watered use. Such an approach could deal with the issue of measurement accuracy due to fluctuations in the depth water in the canal between measurements.

Many farmers indicated that communication between the LCRA and farmers could be improved. Improving communications with farmers could help convince farmers that the LCRA's water measurements are accurate and the districts are interested in the farmers' welfare.

Although many farmers expressed a generally positive attitude toward the LCRA, others felt that their concerns were not being given enough weight. The farmers want to feel that they are a part of the decision-making process. In light of the fact that a majority of farmers indicated that farmer meetings were of value, LCRA should continue to hold meetings regularly.

The excellent response rate to this survey indicates that the farmers appreciate the opportunity to express their views. Future surveys could continue monitoring the farmers' water management practices and their opinions. The fact that this survey, conducted by a third party, received an excellent response rate suggests that future surveys also be conducted by third parties. This fact apparently convinced the farmers that their opinions would be considered fairly.

Notes

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[1] Paul O. Erdos, *Professional Mail Surveys* (New York: McGraw-Hill Book Company, 1984).

[2] The number and percentage of farmers who did not respond to any question, along with all raw survey data, can be found in the raw data presented in Appendix B.

[3] Pearson chi-square significance is 0.04.

[4] The term "technical" was not defined in the survey and may have been misunderstood.

[5] Pearson chi-square significance is equal to 0.01.

[6] Pearson chi-square significance is 0.0001.

[7] Pearson chi-square significance is 0.0001.

[8] Pearson chi-square is 0.0002.

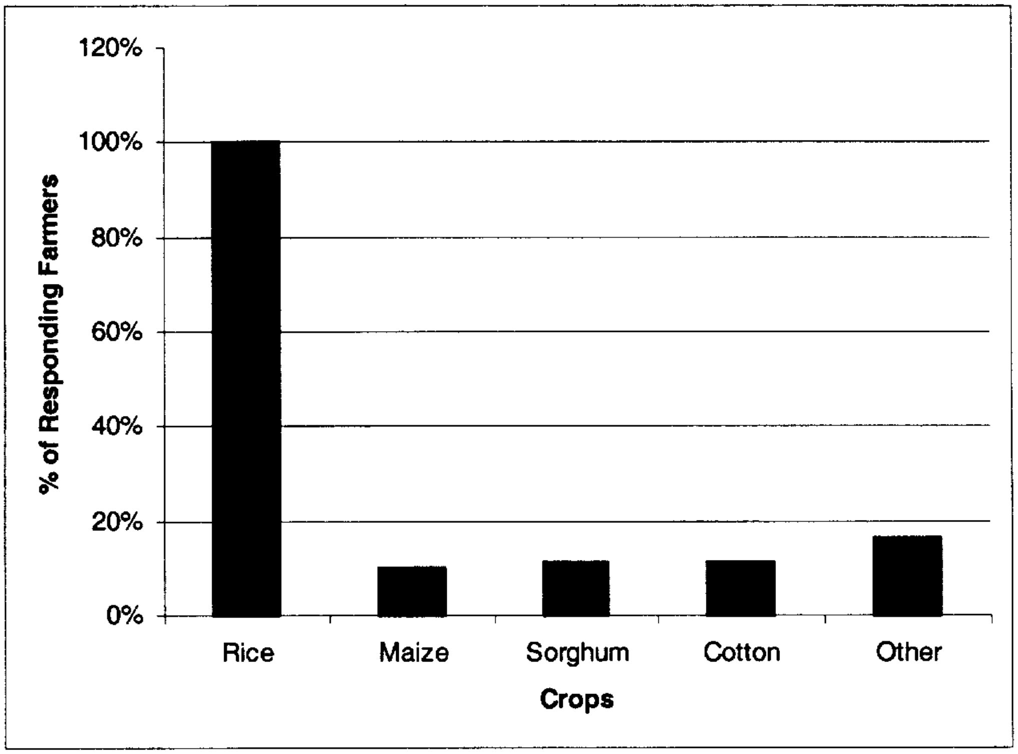
[9] Pearson chi-square significance is 0.004.

Table 8.1
Response Rate for Survey

District	Response Rate	Percent of Farmers
Gulf Coast	38/128	30
Lakeside	40/102	39
Total	**79/230**	**35**

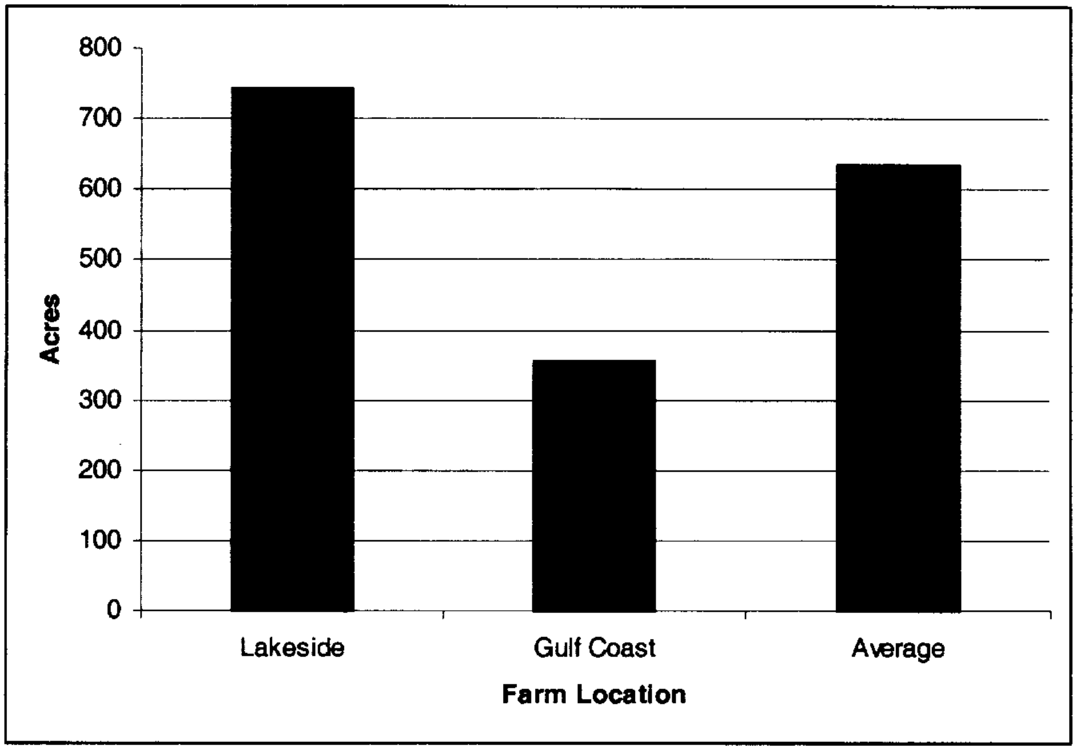
Note: All tables and figures derived from LBJ Policy Research Project survey.

Figure 8.1
Percentage of Farmers Who Grow Crops Other than Rice



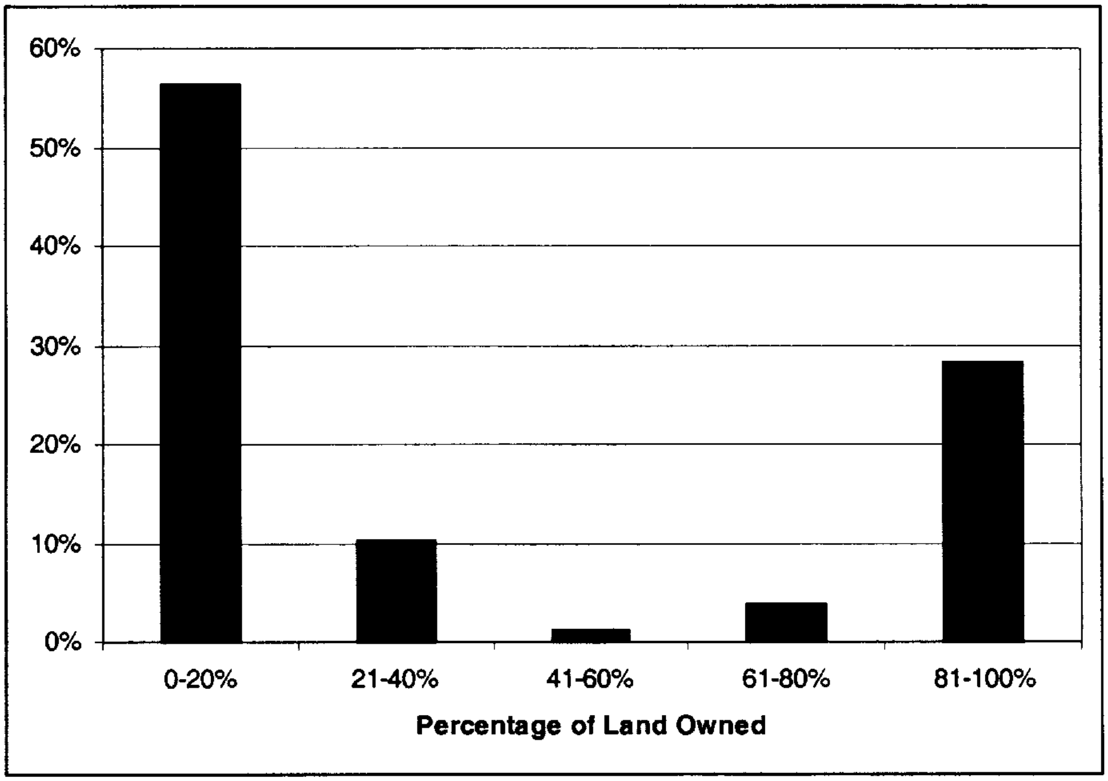
Source: LBJ School Policy Research Project survey.

Figure 8.2
Size of Farms in Study Area



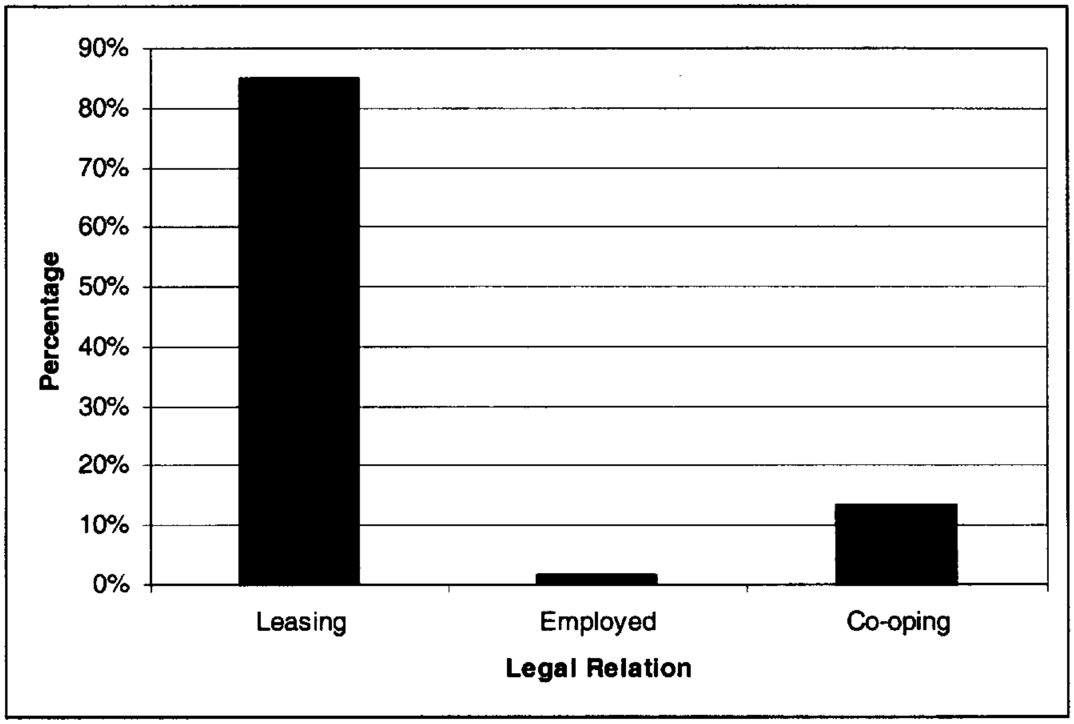
Source: LBJ School Policy Research Project survey.

Figure 8.3
Percentage of Land that is Owned by Farmer



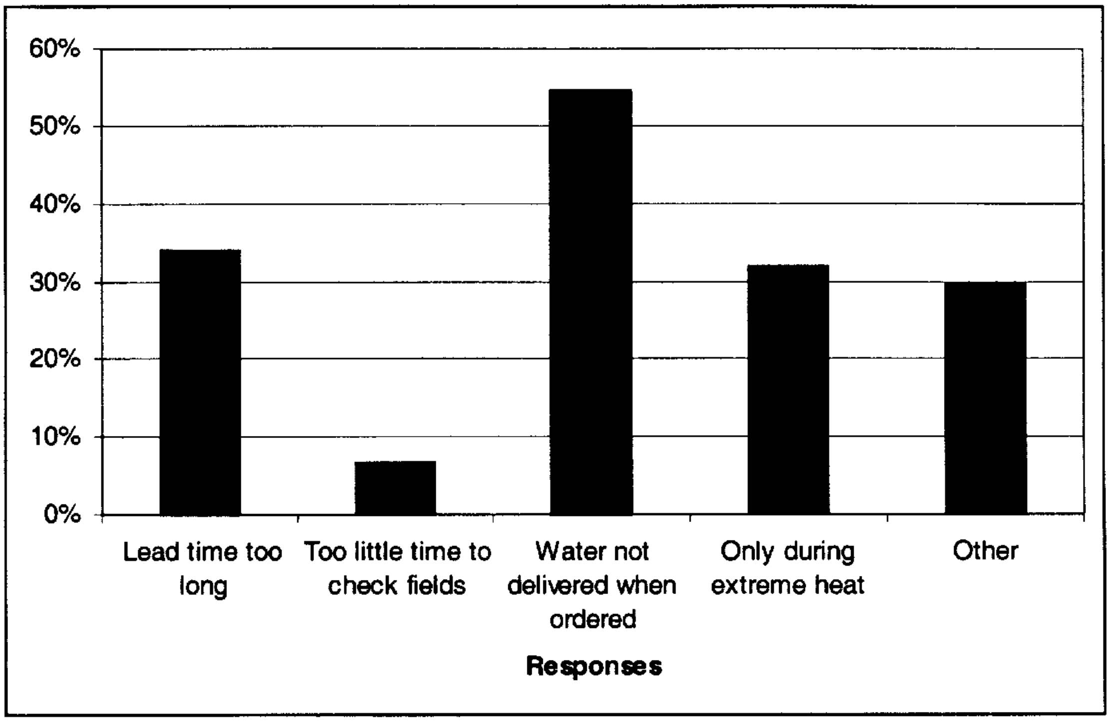
Source: LBJ School Policy Research Project survey.

Figure 8.4
Legal Relation to Land Farmed but not Owned



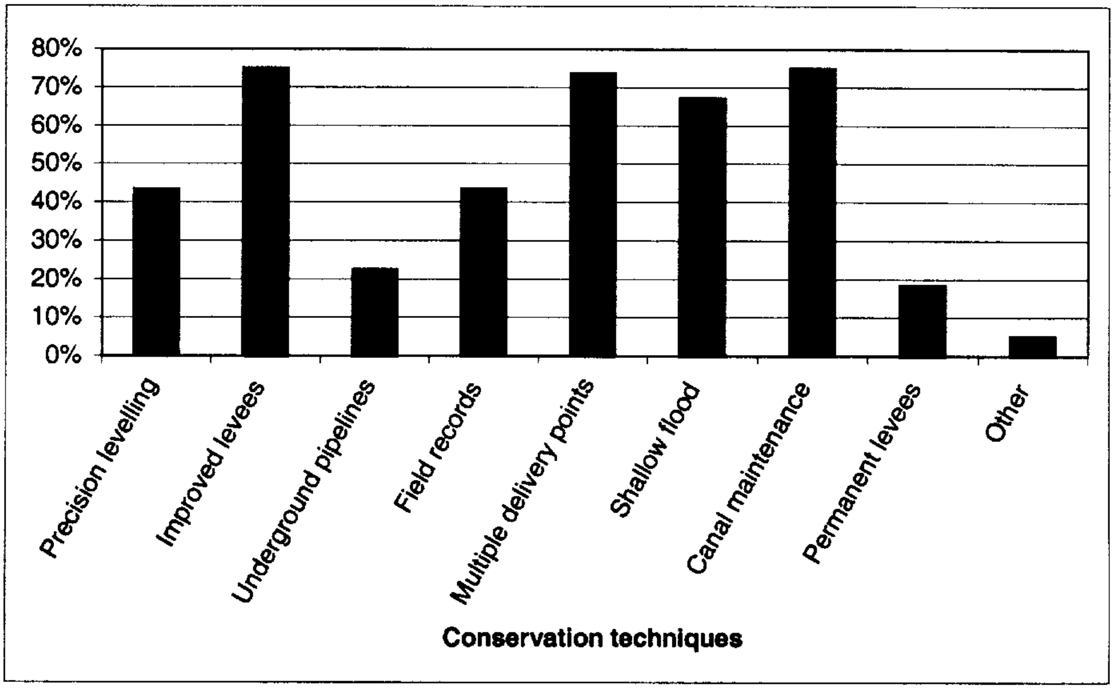
Source: LBJ School Policy Research Project survey.

Figure 8.5
Farmers' Reasons for Using a Holding Stream



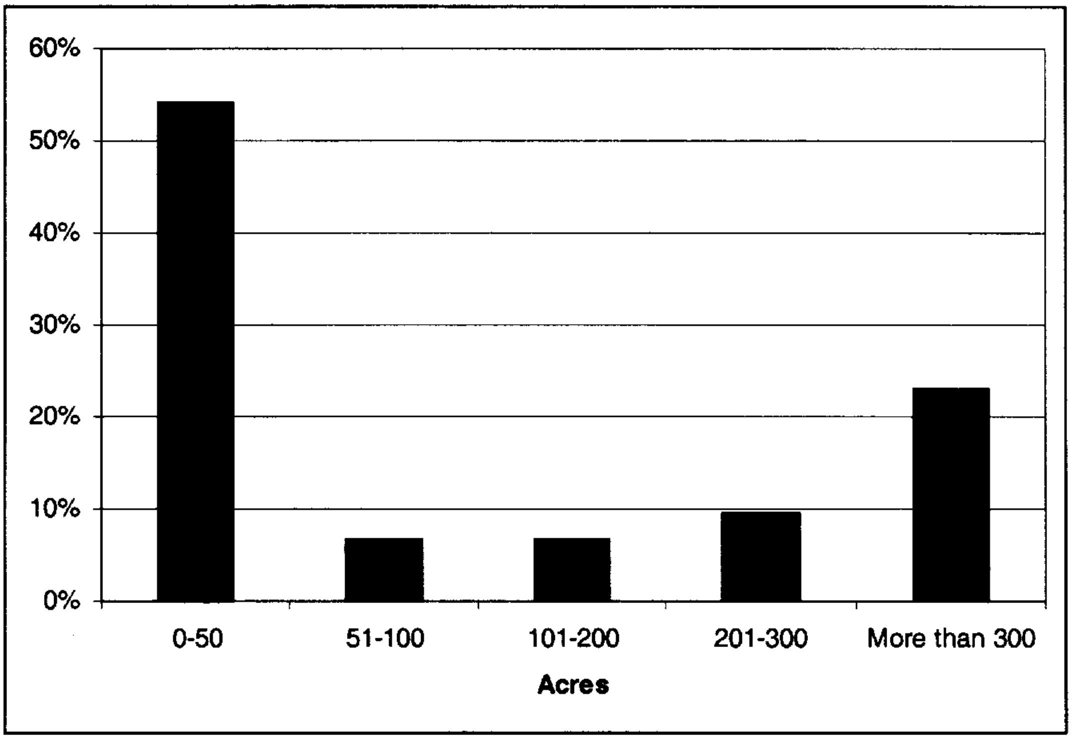
Source: LBJ School Policy Research Project survey.

Figure 8.6
Farmers Using Specific Water Conservation Techniques



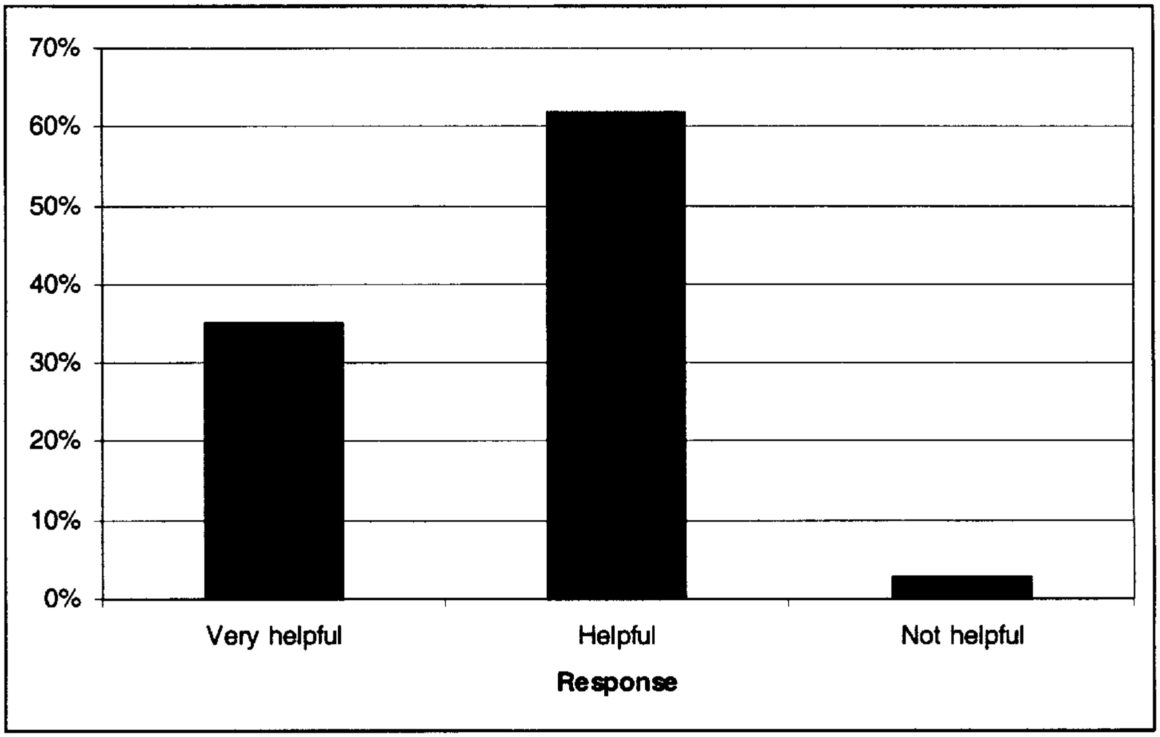
Source: LBJ School Policy Research Project survey.

Figure 8.7
Number of Acres Precision Leveled



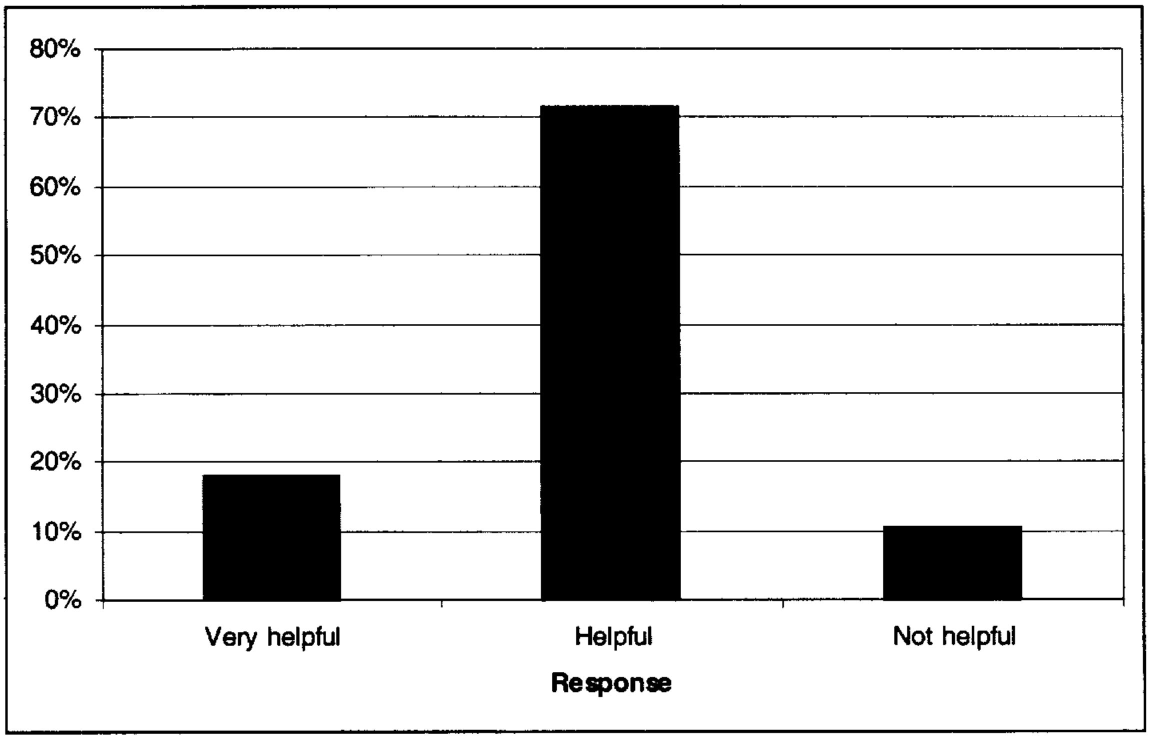
Source: LBJ School Policy Research Project survey.

Figure 8.8
Farmers' Evaluations: LCRA's Response to Billing Questions



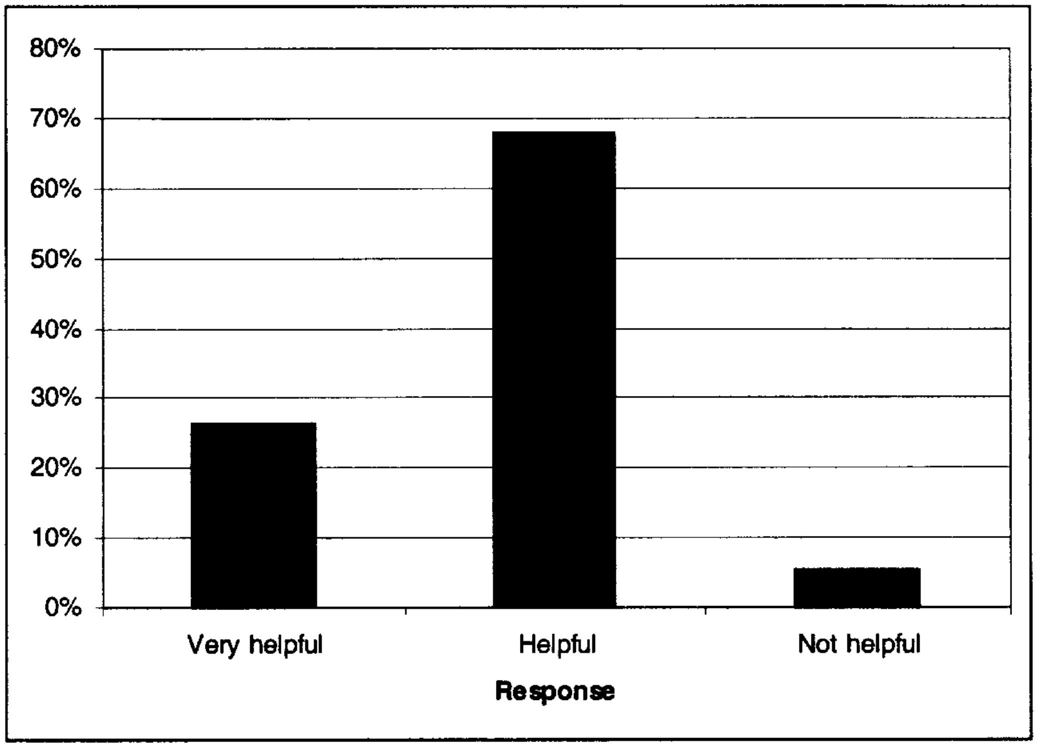
Source: LBJ School Policy Research Project survey.

Figure 8.9
Farmers' Evaluations: LCRA's Response to Water Conservation Questions



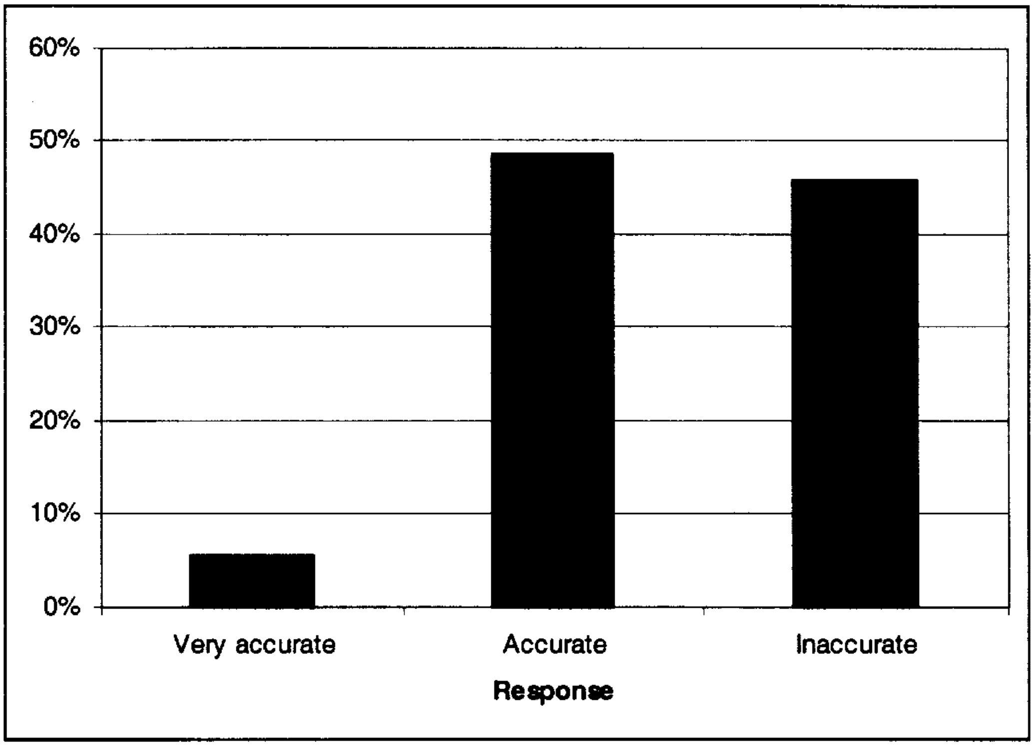
Source: LBJ School Policy Research Project survey.

Figure 8.10
Farmer's Evaluations: LCRA's Response to Water Delivery Questions



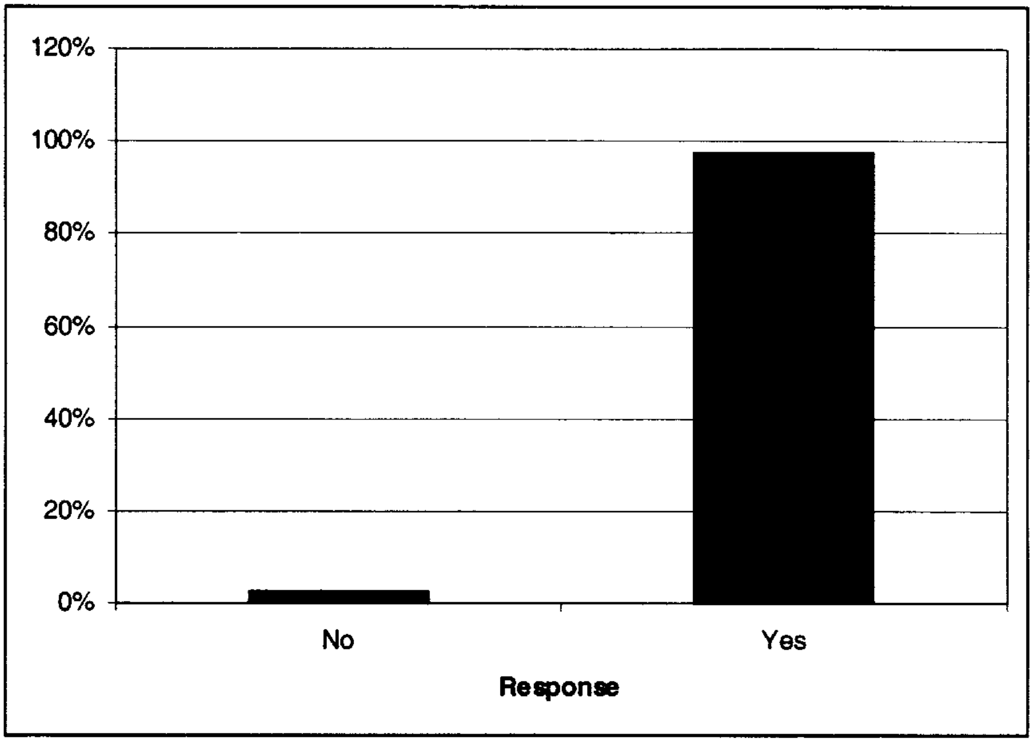
Source: LBJ School Policy Research Project survey.

Figure 8.11
Farmers' Evaluations: Accuracy of LCRA's Water Deliveries



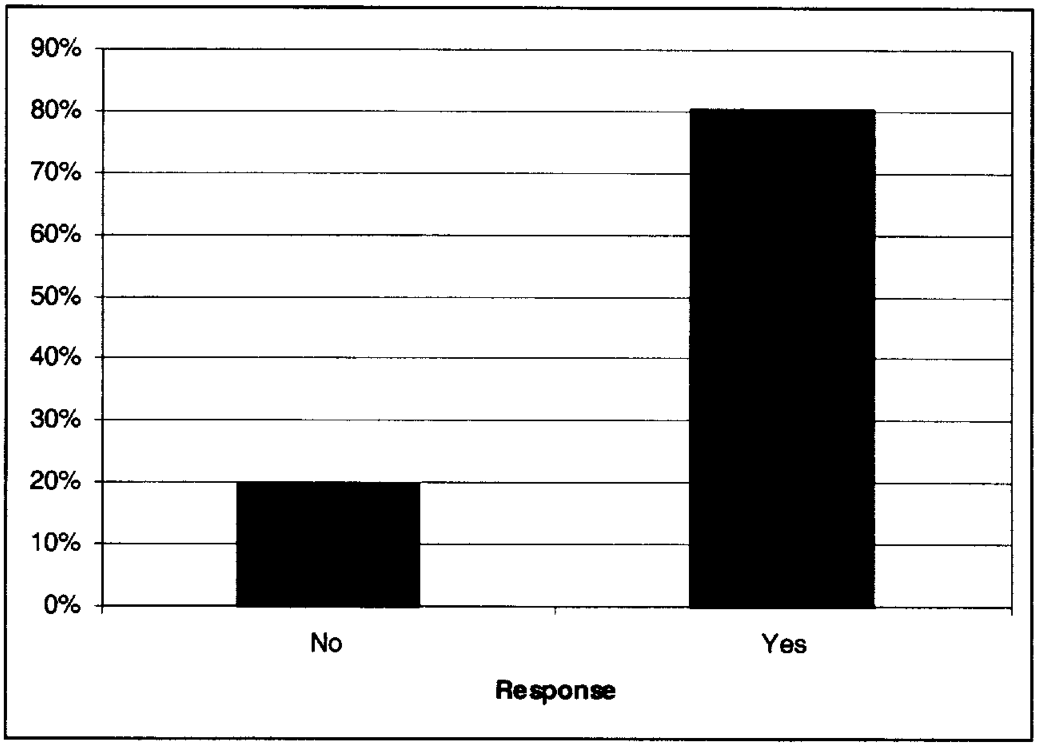
Source: LBJ School Policy Research Project survey.

Figure 8.12
Percentage of Farmers Invited to Farmer Meetings



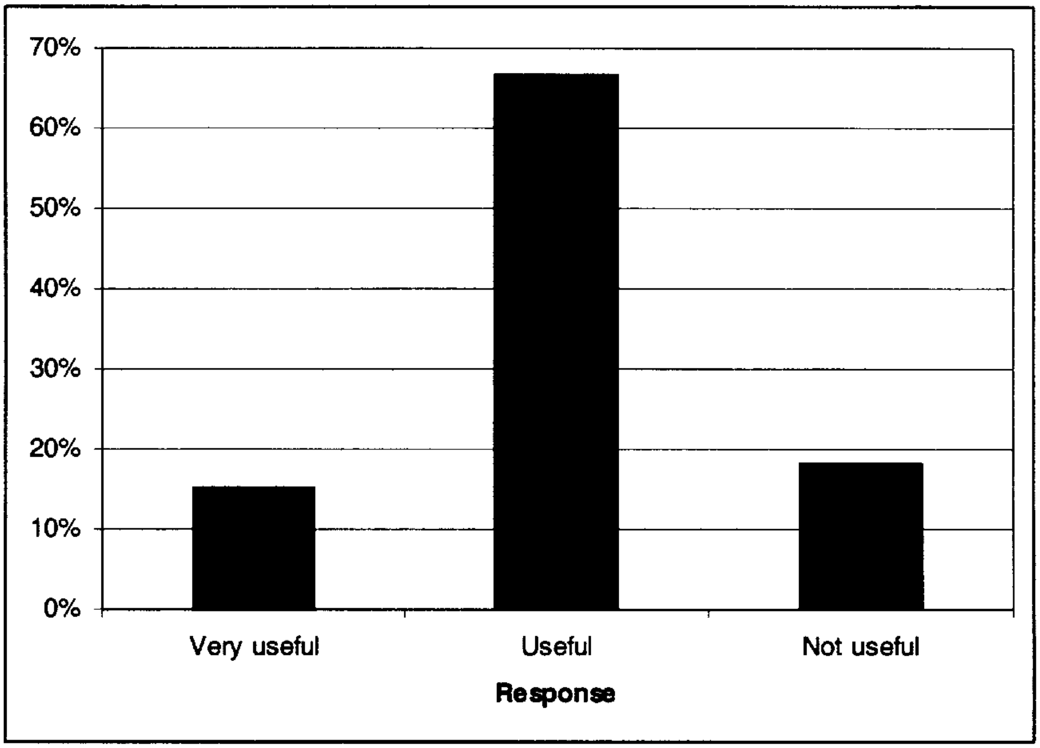
Source: LBJ School Policy Research Project survey.

Figure 8.13
Farmers who Attended Meetings



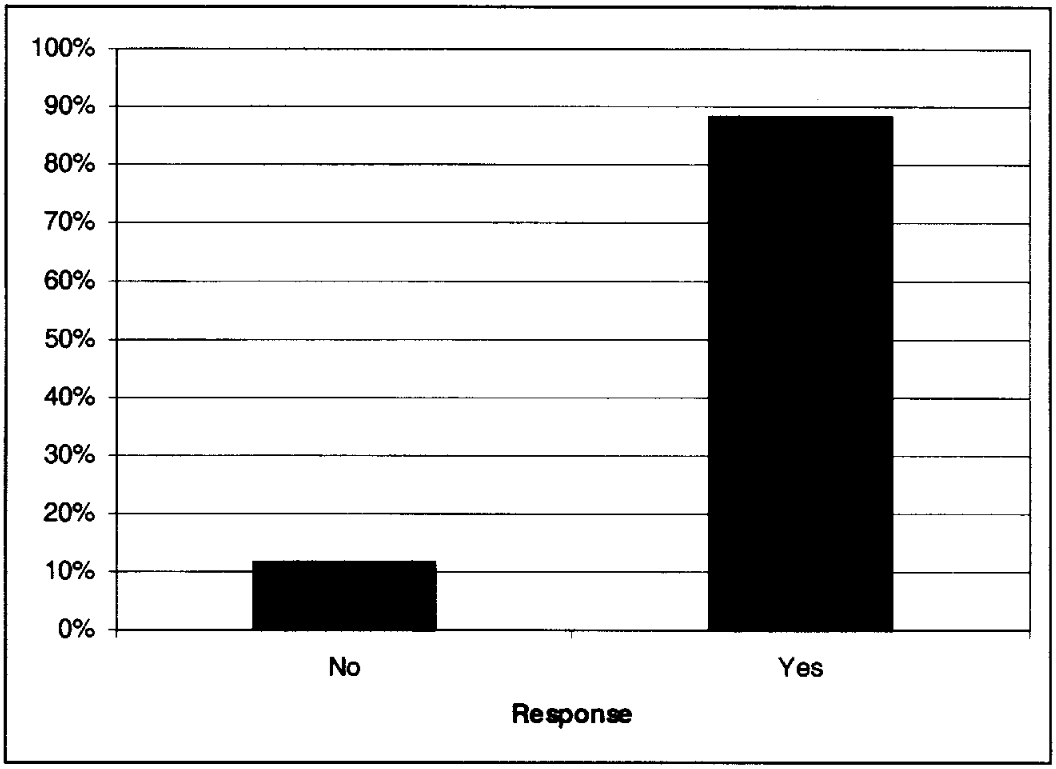
Source: LBJ School Policy Research Project survey.

Figure 8.14
Farmers' Evaluation: Usefulness of Farmer Meetings



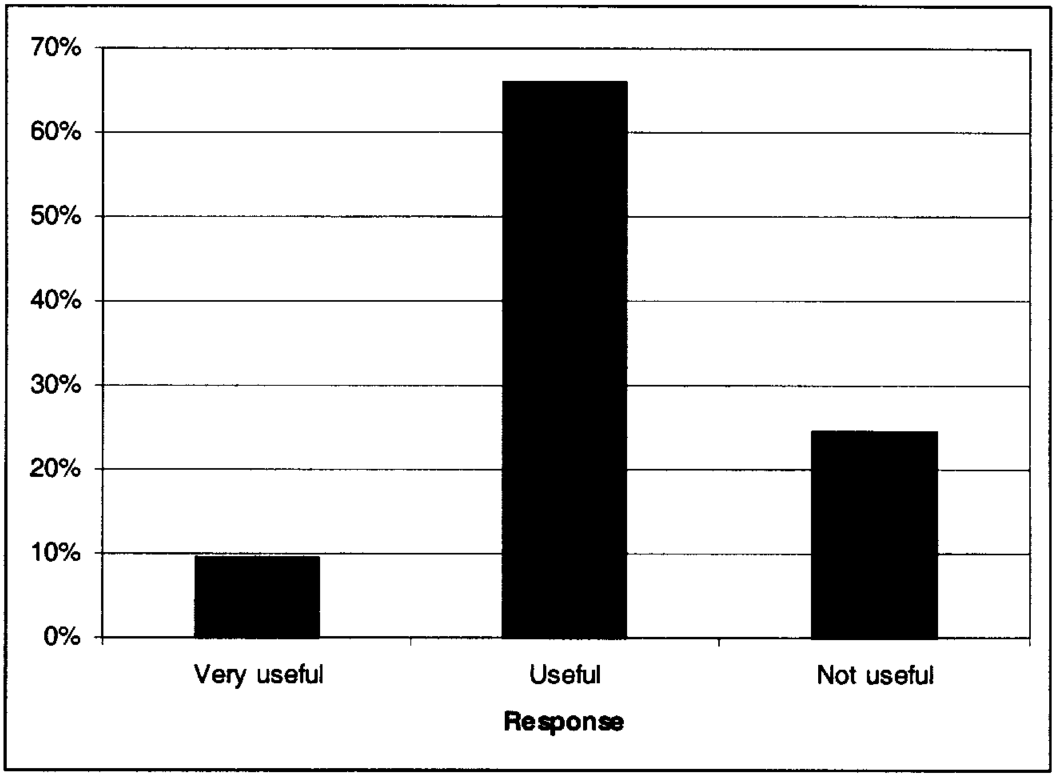
Source: LBJ School Policy Research Project survey.

Figure 8.15
Percentage of Farmers Invited to Water Conservation Demonstration Projects



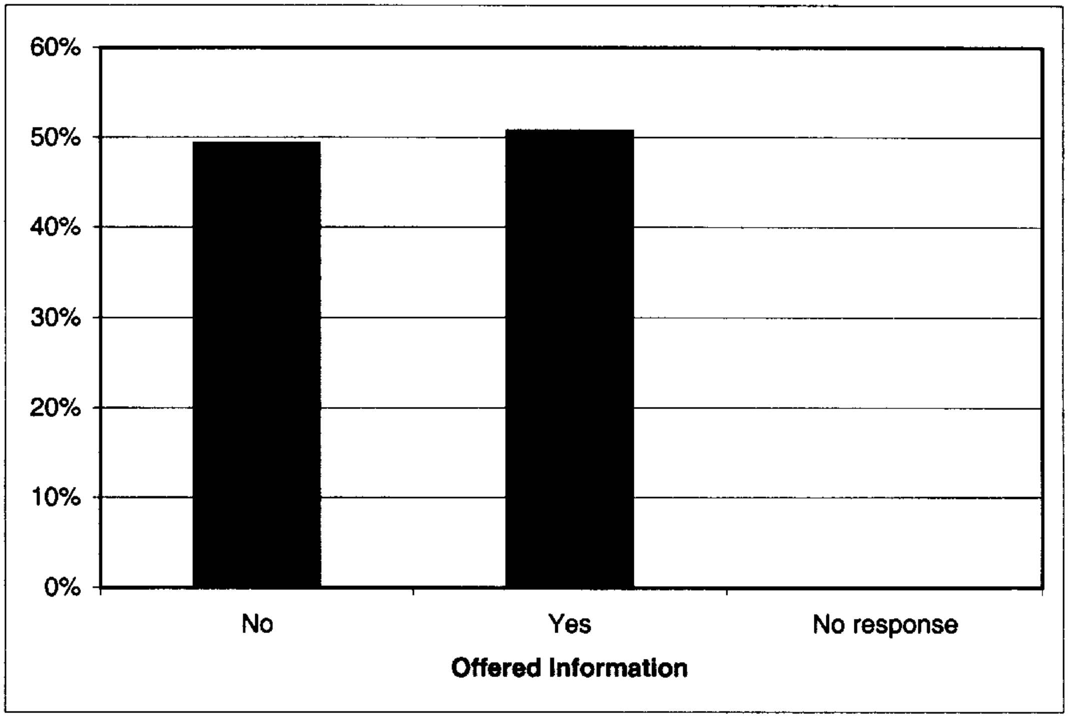
Source: LBJ School Policy Research Project survey.

Figure 8.16
Farmers' Evaluations: Value of Water Conservation Demonstration Projects



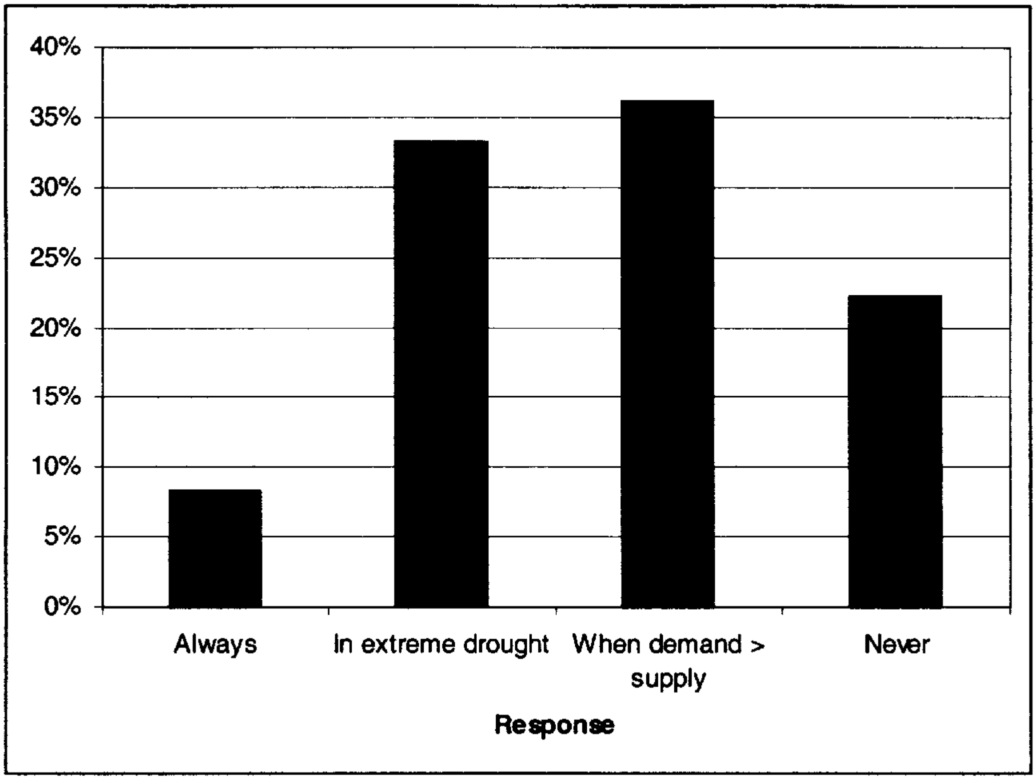
Source: LBJ School Policy Research Project survey.

Figure 8.17
Farmers Offered Technical Information by the LCRA



Source: LBJ School Policy Research Project survey.

Figure 8.18
Farmers' Opinions: When Should Water Supplies be Regulated?



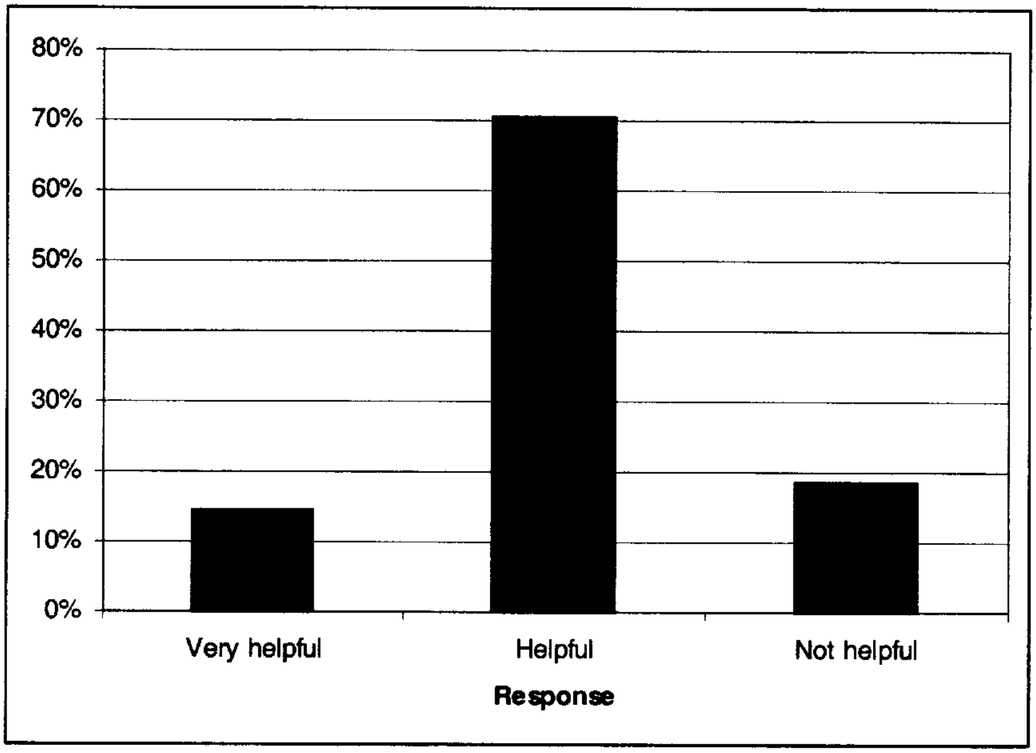
Source: LBJ School Policy Research Project survey.

Table 8.2
Cross Tabulation: Farmers' Attitudes Towards Regulation for Groundwater by Surface Water

Surface Regulation			**Groundwater Regulation**		
	Always	*During Drought*	*When Demand > Supply*	*Never*	*Total*
Always	0 (0%)	2 (2.9%)	2 (1.3%)	2 (1.3%)	6 (8.6%)
During Drought	2 (2.9%)	9 (12.9%)	3 (4.3%)	9 (12.9%)	23 (32.9%)
When Demand > Supply	2 (2.9%)	2 (2.9%)	9 (12.9%)	12 (17.1%)	25 (35.7%)
Never	0 (0%)	2 (2.9%)	0 (0%)	14 (20%)	16 (22.9%)
Total	4 (5.7%)	15 (21.4%)	14 (20%)	37 (52.9%)	70 (100%)

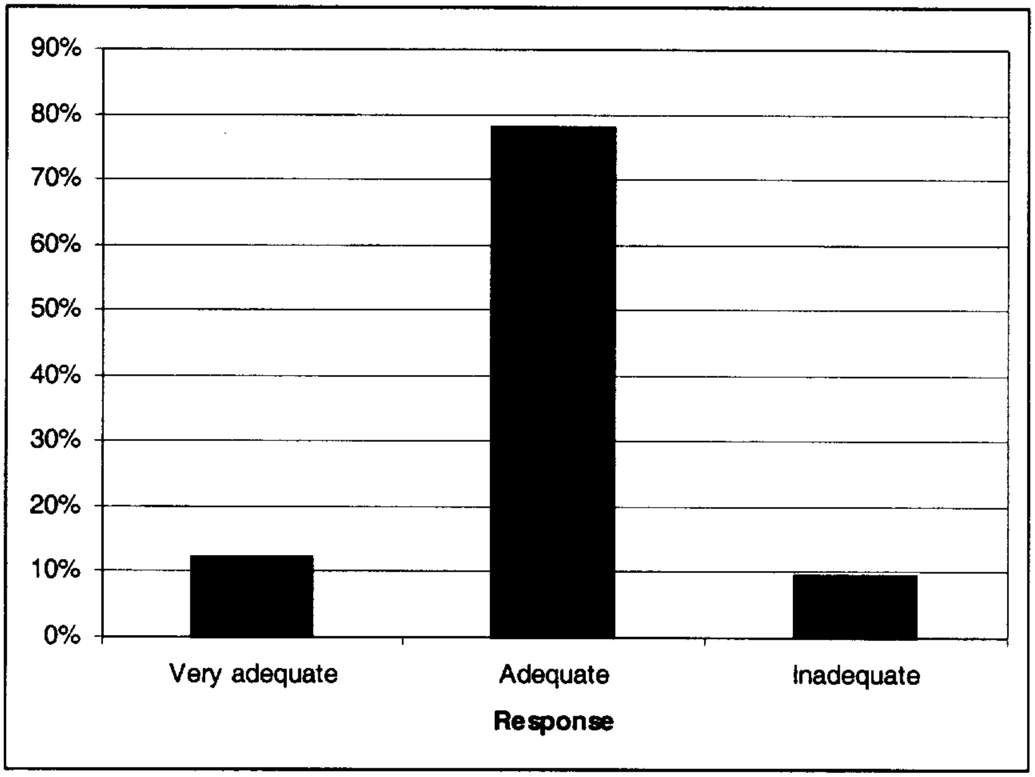
Source: LBJ School Policy Research Project survey.

Figure 8.19
Farmers' Evaluations: LCRA's Helpfulness to Farmers



Source: LBJ School Policy Research Project survey.

Figure 8.20
Farmers' Evaluations: LCRA's Attempts to Inform Farmers of New Rate Structure



Source: LBJ School Policy Research Project survey.

Table 8.3
Cross Tabulation: Accuracy of Water Deliveries and Effect on Water Bill of New Rate Structures

Accuracy of Deliveries	**Effect on Water Bill**			
	Increase	***No Change***	***Decrease***	***Total***
Very Accurate	1 (1.4%)	1 (1.4%)	2 (2.8%)	4 (5.6%)
Accurate	7 (9.9%)	19 (26.8%)	8 (11.3%)	34 (47.9%)
Inaccurate	24 (33.8%)	4 (5.6%)	5 (7.0%)	33 (46.5%)
Total	32 (45.1%)	24 (33.8%)	15 (21.1%)	71 (100%)

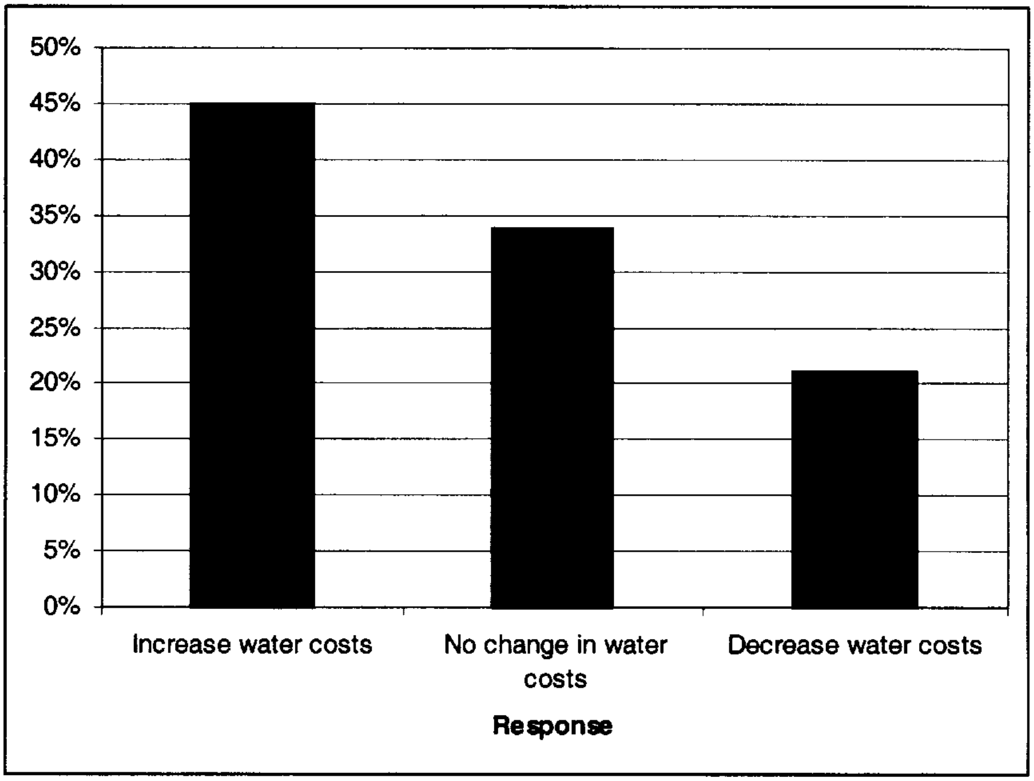
Source: LBJ School Policy Research Project survey.

Table 8.4
Cross Tabulation: Effect on Water Bill of New Structures and Fairness of New Structure

Fairness of New Structure	**Effect on Water Bill**			
	Increase	***No Change***	***Decrease***	***Total***
Very Fair	1 (1.5%)	1 (1.5%)	3 (4.4%)	5 (7.4%)
Fair	9 (13.2%)	19 (27.9%)	11 (16.2%)	39 (57.4%)
Unfair	21 (30.9%)	2 (2.9%)	1 (1.5%)	24 (35.3%)
Total	31 (45.6%)	22 (32.4%)	15 (22.1%)	71 (100%)

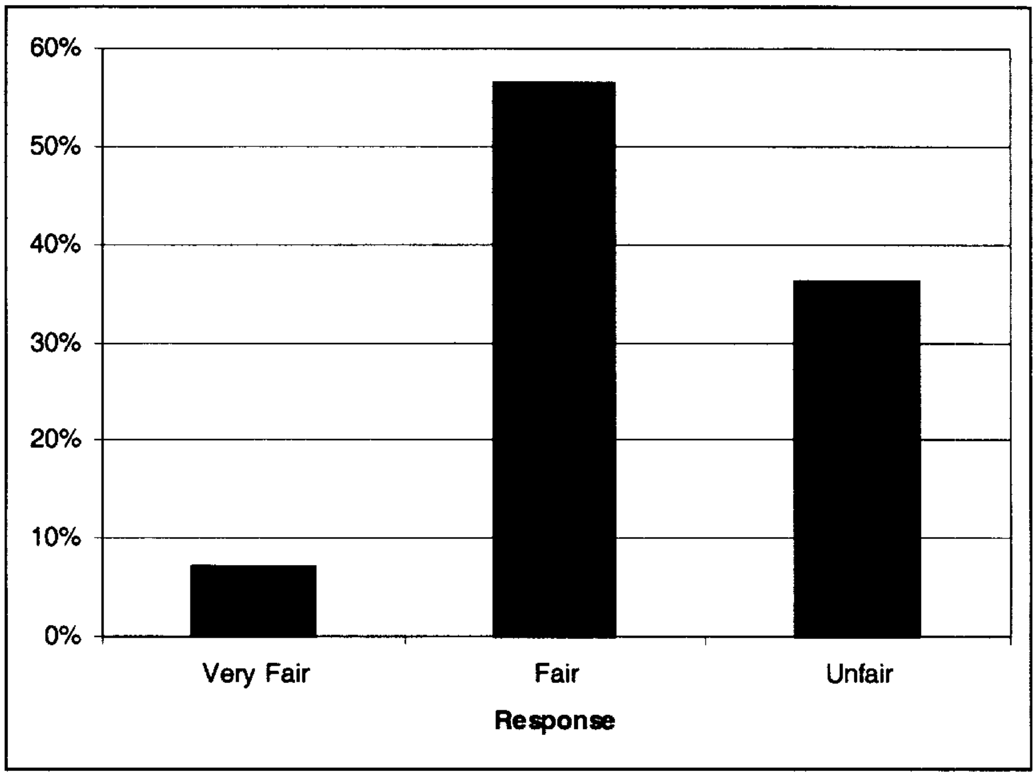
Source: LBJ School Policy Research Project survey.

Figure 8.21
Farmer's Opinions: Effect of New Rate Structure on Water Bill



Source: LBJ School Policy Research Project survey.

Figure 8.22
Farmers' Opinions: Fairness of New Rate Structure



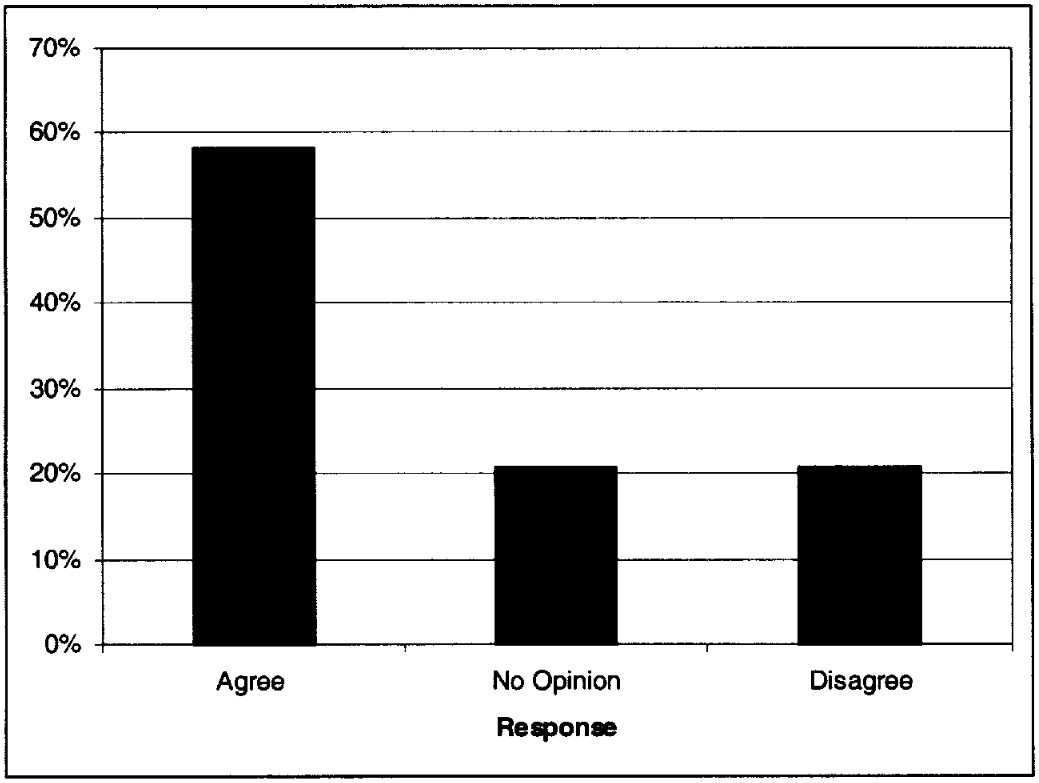
Source: LBJ School Policy Research Project survey.

Table 8.5
Cross Tabulation: Accuracy of Water Deliveries and Fairness of New Structure

Accuracy of Deliveries	**Fairness of Structure**			
	Very Fair	*Fair*	*Unfair*	*Total*
Very Accurate	2 (2.9%)	2 (2.9%)	0 (0%)	4 (5.9%)
Accurate	2 (2.9%)	24 (35.3%)	6 (8.8%)	32 (47.1%)
Inaccurate	1 (1.5%)	13 (19.1%)	18 (26.5%)	32 (47.1%)
Total	5 (7.4%)	39 (57.4%)	24 (35.3%)	68 (100%)

Source: LBJ School Policy Research Project survey.

Figure 8.23
Farmers' Opinion: Will new Rate Structure Provide Incentive to Save Money?



Source: LBJ School Policy Research Project survey.

Table 8.6
Cross Tabulation: Effect on Water Bill of New Structure and "Does New Structure Provide Incentive to Save Water?"

Effect on Bill	**Agree with Statement**			
	Yes	*No Opinion*	*No*	*Total*
Increase	14 (20%)	8 (11.4%)	10 (14.3%)	32 (45.7%)
No Change	14 (20%)	6 (8.6%)	3 (4.3%)	23 (32.9%)
Decrease	13 (18.6%)	0 (0%)	2 (2.9%)	15 (21.4%)
Total	41 (58.6%)	14 (20%)	15 (21.4%)	70 (100%)

Source: LBJ School Policy Research Project survey.

Appendix A
Pump Ratings at LCRA Irrigation District Pumping Stations

The following two tables provide information on recent pump ratings which were conducted by the LCRA. Pump ratings reflect the volume of water (in gallons per minute) that each unit is able to pump. Some pumps are used to divert water from the river and some are used between canal segments to relift the water to higher elevations. Because the pumps do not have variable speeds, the ability of the districts to vary the rate at which they supply water through the canal systems is limited. The districts are further limited by the possible combination of available pumps.

Table A1
Lakeside Water District

Plant	Pump Rating (thousand gallons per minute)
River Plant	
Pump #1	79
Pump #2	74
Pump #3	73
Pump #4	67
Pump #5	24
Prairie Relift Plant	
Pump #1	29
Pump #2	55
Pump #3	24
Lake Relift Plant	
Pump #1	26
Pump #2	59
Pump #3	57
Pump #4	33
Groundwater Pumps	
Pump #2	3
Pump #4	3
Pump #5	3
Pump #6	3
Pump #8	3

Source: Memorandum from Sean Maijala, Lower Colorado River Authority (LCRA), to Bruce Hicks, Manager, Irrigation Operations, LCRA, July 26, 1991; Henry Bradford, District Superintendent, Gulf Coast Irrigation District, LCRA, Bay City, Texas, interview by Martin Schultz, November 17, 1992.

Table A2
Gulf Coast Water District

Plant	Pump Rating (thousand gallons per minute)
Lane City Plant	
Pump #1	40
Pump #2	50
Pump #3	50
Pump #4	60
Pump #5	60
Office Plant	
Pump #1	40
Pump #2	40
Plant #3	
Pump #1	40
Pump #2	60
Pump #3	70
Pump #4	70

Source: Memorandum from Sean Maijala, Lower Colorado River Authority (LCRA), to Bruce Hicks, Manager, Irrigation Operations, LCRA, July 26, 1991; Henry Bradford, District Superintendent, Gulf Coast Irrigation District, LCRA, Bay City, Texas, interview by Martin Schultz, November 17, 1992.

Appendix B
Survey Instrument

The following pages contain the survey document used in this report.

I. We want to start by thanking you for your valuable participation in this survey. Section I focuses on your field(s) and farming practices.

Please do not write in this column

1. Which crops did you farm last year? (Please check all that apply)
____rice ____maize ____sorghum ____cotton
____Other (please specify)________________________________
_/_/_/_/_
_/_/_/_/_

2. How many acres of each crop did you farm last year? (Please write in the appropriate number)
______rice ______maize ______sorghum ______cotton
____Other (please specify)________________________________
_/_/_/_/_
_/_/_/_/_

3. Do you rotate crops?
____yes (within same year) ____yes (year to year) ____no
_/_/_

4. Please estimate the percentage of irrigation water you use from surface and groundwater sources.
______ % surface water ______ % groundwater
_/_/_/_

5. How many separate fields did you farm last year?
____1 ____2 ____3 ____4 ____5 or more
_/_/_/_/_

6. How would you describe the soil types of your field(s)? (Please check all that apply)
____ silty sand ____ sandy clay ____ sandy clay loam ____ loam
____ silt loam ____ sandy loam ____ clay ____ sand
_/_/_/_/_
_/_/_/_/_

7. Of the land you farmed last year, what percentage do you own?
____0-20% ____21-40% ____41-60% ____61-80% ____81-100%
_/_/_/_/_

8. On the land you farmed that you do not own, were you
____leasing? ____employed? ____co-oping?
_/_/_

9. Do you employ any field hands?
________yes (give number) ____no
_/_/_/_

10. Do you live next to the land you farm?
____yes ____no
_/_

11. How many miles do you travel each day during the growing season to tend your fields (average)?
____0-10 ____ 11-30 ____ 31-50 ____more than 50
_/_/_/_/_

12. Which of the following water conservation methods are you currently using? (Please check all that apply)
____ precision leveling ____ multiple delivery points
____ improved levees ____ shallow flood
____ underground pipelines ____ canal maintenance
____ field records ____ permanent levees
____Other (please specify)________________________________
_/_/_/_/_
_/_/_/_/_

13. How many acres of your farm land has been precision leveled?
____0-50 ____50-100 ____100-200 ____200-300 ____ more than 300
_/_/_/_/_

14. How many flushings did you use last year?
____1 ____2 ____3 ____more than 3 (please write in the number)__________
_/_/_/_/_

15. If you use a feeder stream to maintain the water level on your field(s), please check the reasons as they apply to your situation.
____ lead time on orders is too long ____ water may not be delivered when ordered
____ too little time to check every field ____ used only during extreme heat waves
____Other (please specify)________________________________
_/_/_/_/_
_/_/_/_/_

II. Section II covers personal characteristics. We would like to know this information to help us with our analysis. If you do not wish to answer a question in section II, please feel free to skip it.

Please do not write in this column

16. What is your age?
____less than 30 ____31-40 ____41-50 ____51-60 ____more than 60
_/_/_/_/_

17. In which irrigation district do you farm?
____Gulfcoast ____Lakeside
_/_

18. Are you a native of this area?
____yes ____no
_/_

19. How many years have you been farming in this district?
____0-5 ____6-10 ____11-15 ____16-20 ____more than 20
_/_/_/_/_

20. What is the highest level of education that you have completed?
____8th grade ____high school ____college ____graduate school
_/_/_/_

21. Is your formal education related to your success in farming?
____ very important ____ related ____ not related
_/_/_

22. How many persons are there in your household?
____1 ____2 ____3 ____4 ____5 ____6 ____more than 6
_/_/_/_/_
_/_/_/_/_

23. Which of the following comes closest to your total family income?
____ 0-$10,000 ____ $10,000-$20,000 ____ $20,000-$30,000
____ $30,000-$40,000 ____ $40,000-$60,000 ____ over $60,000
_/_/_/_/_
_/

III. Section III is the last section. It deals with your interaction with the LCRA, your opinions on water conservation, and the proposed rate structure. We really appreciate your time and effort.

Please do not write in this column

24. Who do you most often contact at LCRA?
____water boss ____district manger ____secretary ____ supervisor
____Other (please specify)________________________________
_/_/_/_/_

25. How do you most often communicate with this person?
____ by telephone during the working day ____ by telephone in the evening
____ by coincidental meeting in the field ____ by planned meeting
____Other (please specify)________________________________
_/_/_/_/_
_/_/_/_/_

26. How frequently do you communicate with LCRA?
____more than once per month ____about once per month ____less than once per month
_/_/_

27. Approximately how many times did you order water from LCRA during last year's growing season?
1st crop: ______1 ______2 ______3 ______4 ______more than 5
2nd crop: ______1 ______2 ______3 ______4 ______more than 5
_/_/_/_/_
_/_/_/_/_

28. Has LCRA invited you to any farmer meetings during the last two years?
____yes ____no
_/_

29. Have you attended any of these LCRA farmer meetings?
____yes ____no
_/_

30. If you attended any farmer meetings, how useful was the information you received from them?
____ very useful ____ useful ____ not useful
_/_/_

31. Has LCRA informed you about its water conservation demonstration projects?
____yes ____no
_/_

32. If you have observed these demonstration projects, how would you assess their value to you?
____ very helpful ____ helpful ____ not helpful
_/_/_

33. Did LCRA offer you any technical information last year?
____yes ____no
_/_

34. Do you ever experiment with new or different farming techniques?
____yes ____no
_/_

35. How helpful are LCRA staff when you have questions about water deliveries?
____ very helpful ____ helpful ____ not helpful
_/_/_

36. How helpful are LCRA staff when you have questions about water conservation techniques?
____ very helpful ____ helpful ____ not helpful
_/_/_

37. How helpful are LCRA staff when you have questions about your irrigation water bill?
____ very helpful ____ helpful ____ not helpful
_/_/_

38. How would you rate the accuracy of LCRA's water deliveries?
____ very accurate ____ accurate ____ inaccurate
_/_/_

39. How would you rate LCRA's attempts to inform you of its proposed volumetric rate structure?
____ very adequate ____ adequate ____ inadequate
_/_/_

40. In your opinion, the proposed volumetric rate structure is:
____ very fair ____ fair ____ unfair
_/_/_

41. In your opinion, how will the proposed volumetric rate structure affect your bill?
____ increase in water costs ____ no change in water costs ____ decrease in water costs
_/_/_

42. What is your position on this statement, "LCRA's proposed rate structure will provide incentives to save water"?
____ agree ____ no opinion ____ disagree
_/_/_

43. From which of these sources have you gotten most of your farming knowledge? (Please check all that apply)
____parents/relatives
____other farmers
____practice/experience
____agricultural extension service
____Other (please specify)____________________
____school
____trade magazines
____LCRA
_/_/_/_/_
_/_/_/_/_

44. Of the sources you checked above in # 43, which one is most related to your farming success? (Please check only one)
____parents/relatives
____other farmers
____practice/experience
____agricultural extension service
____Other (please specify)____________________
____school
____trade magazines
____LCRA
_/_/_/_/_
_/_/_/_/_

45. When LCRA develops its water conservation policies, whose interests do they have in mind? (Please check all that apply)
____farmers' interests
____state government
____other (please specify) ____________________
____LCRA's own interest
____municipalities
_/_/_/_/_
_/_/_

46. In your opinion, which of these options should be most important in the development of water conservation programs for rice farming? (Please check only one)
____farmers' interests
____state government
____other (please specify) ____________________
____LCRA's own interest
____municipalities
_/_/_/_/_
_/_/_

47. When should public authorities have the right to regulate surface water use?
____ all the time
____ in periods of extreme drought
____ only when there are more demands than supply
____ never
_/_/_/_/_

48. When should public authorities have the right to regulate groundwater use?
____ all the time ____ only when there are more demands than supply
____ in periods of extreme drought ____ never
_/_/_/_/_

49. Do you believe that LCRA helps rice farmers?
____ very helpful ____ helpful ____ not helpful
_/_/_

50. Please add your comments about any issues not addressed in the questionnaire.

Thank you for your cooperation. Please return the questionnaire in the postage-paid envelope as soon as possible.

If you would like a free copy of the survey results please fill out the enclosed postage-paid postcard and send it to us.

Dear LCRA Customer,

As part of a graduate course at the LBJ School of Public Affairs at The University of Texas, my students are conducting an evaluation of the LCRA's water conservation program. An important part of this evaluation will be a survey. We will be asking farmers who use LCRA water for irrigation about their opinions on the LCRA and its water policies.

The survey should be arriving shortly. Please watch for it.

Thank you.

David J. Eaton
Beth Harris Jones Centennial
Professor in Natural
Resource Policy Studies

Dear LCRA Customer,

If you would like to receive a copy of the survey results, please check the box below and return this card with your name and address.

☐ Yes, I would like to be sent a copy of the survey reuslts.

Return address: ______________________________
____
____

Appendix C
Survey Data

This appendix contains the raw data response for each question on the survey administered to the rice farmers. Following each response is the number of farmers who marked that particular response. To the right of this number is the percentage of total responses represented by this number. The total of all percentages for each question may not add up to 100. This may be due to any combination of two reasons. One reason is the rounding of percentages. The second reason is that several questions contain multiple responses. As an example of the latter, a question may ask a farmer to "check all answers that apply." In this case, the recorded data will indicate the percentage of farmers who "checked" a particular response, not a particular response's percentage out of all possible responses.

Surveys mailed	230
Surveys returned	79 (35%)
Surveys not returned	151 (65%)

Question 1 — "Which crops did you farm last year? (Please check all that apply)"

No response	0	
Rice	79	(100.0%)
Maize	8	(10.1%)
Sorghum	9	(11.4%)
Cotton	9	(11.4%)
Other	13	(16.5%)

Question 2 — "How many acres of each crop did you farm last year?"

(Average acreage for those who farm each respective crop)

No response	1
Rice	554.3 acres
Maize	190.3 acres
Sorghum	557.8acres
Cotton	327.3 acres
Other	244.1 acres

(Average total acreage cultivated by each farmer for 1992)

Total	636.2 acres

Question 3 — "Do you rotate crops?"

No response	0	
No	16	(20.3%)
Yes (within same year)	5	(6.3%)
Yes (year to year)	58	(73.4%)

Question 4 — "Please estimate the percentage of irrigation water you use from surface and groundwater sources."

(Average responses)

No response	7
Surface Water	86.8%
Groundwater	41.6%

Question 4 — "Please estimate the percentage of irrigation water you use from surface and groundwater sources."

No response	2	
1	7	(9.1%)
2	11	(14.3%)
3	7	(9.1%)
4	11	(14.3%)
5 or more	41	(53.2%)
Average	3.9 fields	

Question 6 — "How would you describe the soil types of your field(s)? (Please check all that apply)"

No response	0	
Silty Sand	3	(3.8%)
Sandy Clay	23	(29.1%)
Sandy Clay Loam	30	(38.0%)
Loam	1	(1.3%)
Silt Loam	6	(7.6%)
Sandy Loam	38	(48.1%)
Clay	17	(21.5%)
Sand	4	(5.1%)

Question 7 — "Of the land you farmed last year, what percentage do you own?"

No response	1	
0-20%	44	(56.4%)
21-40%	8	(10.3%)
41-60%	1	(1.3%)
61-80%	3	(3.8%)
81-100%	22	(28.2%)

Question 8 — "On the land you farmed that you do not own, were you..."

No response	19	
Leasing	51	(85%)
Employed	1	(1.7%)
Co-oping	8	(13.3%)

Question 9 — "Do you employ any field hands?"

No response	0	
No	36	(45.6%)
1	23	(29.1%)
2	8	(10.1%)
3	5	(6.3%)
4	3	(3.8%)
5	1	(1.3%)
6	2	(2.5%)
7	0	(0.0%)
8	1	(1.3%)

Question 10 — "Do you live next to the land you farm?"

No response	1
No	60 (76.9%)
Yes	18 (23.1)

Question 11 — "How many miles do you travel each day during the growing season to tend you fields? (Average)"

No response	3
0-10	12 (15.8%)
11-30	24 (31.6%)
31-50	20 (26.3%)
More than 50	20 (26.3%)

Question 12 — "Which of the following water conservation methods are you currently using? (Please check all that apply)"

No response	3
Precision leveling	33 (41.8%)
Improved levees	57 (72.2%)
Underground pipelines	17 (21.5%)
Field records	33 (41.8%)
Multiple delivery points	56 (70.9%)
Shallow flood	51 (64.6%)
Canal Maintenance	57 (72.2%)
Permanent levees	14 (17.7%)
Other	4 (5.1%)

Question 13 — "How many acres of your farm land has been precision leveled?"

No response	5	
0-50	40	(54.1%)
51-100	5	(6.8%)
101-200	5	(6.8%)
201-300	7	(9.5%)
More than 300	17	(23.0%)

Question 14 — "How many flushings did you use last year?"

No response	7	
0	24	(33.3%)
1	32	(44.4%)
2	11	(15.3%)
3	5	(6.9%)
More than 3	0	

Question 15 — "If you use a feeder stream to maintain the water level on your field(s), please check all reasons as they apply to your situation."

No response	35	(44.3%)
Lead time on orders is too long	15	(19.0%)
Too little time to check every field	3	(3.8%)
Water may not be delivered when ordered	24	(30.4%)
Only during periods of extreme heat waves	14	(17.7%)
Other	13	(16.5%)

Question 16 — "What is your age?"

No response	1	
Less than 30	6	(7.7%)
30-40	18	(23.1%)
41-50	22	(28.2%)
51-60	18	(23.1%)
More than 60	14	(17.9%)

Question 17 — "In which irrigation district do you farm?"

No response	1	
Gulf Coast	38	(48.7%)
Lakeside	40	(51.3%)

Question 18- — "Are you a native of this area?"

No response	1	
No	9	(11.5%)
Yes	69	(88.5%)

Question 19 — "How many years have you been farming in this district?"

No response	2	
0-5	7	(9.1%)
6-10	15	(19.5%)
11-15	9	(11.7%)
16-20	13	(16.9%)
More than 20	33	(42.9%)

Question 20 — "What is the highest level of education that you have completed?"

No response	1	
8th grade	0	
High school	29	(37.2%)
College	41	(52.6%)
Graduate school	8	(10.3%)

Question 21 — "Is your formal education related to your success in farming?"

No response	2	
Very important	14	(18.2%)
Related	42	(54.5%)
Not related	21	(27.3%)

Question 22 — "How many persons are there in your household?"

No response	2	
1	3	(3.9%)
2	23	(29.9%)
3	18	(23.4%)
4	20	(26.0%)
5	10	(13.0%)
6	3	(3.9%)
More than 6	0	(0.0)
Average	**3.2 people**	

Question 23 — "Which of the following comes closest to your total family income?"

No response	6	
$0-$10,000	2	(2.7%)
$10,000-$20,000	6	(8.2%)
$20,000-$30,000	6	(8.2%)
$30,000-$40,000	14	(19.2%)
$40,000-$60,000	26	(35.6%)
Over $60,000	19	(26.0%)

Question 24 — "Whom do you most often contact at the LCRA?"

No response	2	
Water boss	69	(89.6%)
District manager	2	(2.6%)
Secretary	4	(5.2)
Supervisor	0	(0.0)
Other	2	(2.6)

Question 25 — "How do you most often communicate with this person?"

No response	1	
By telephone during the working day	62	(79.5%)
By coincidental meeting in the field	8	(10.3%)
By telephone in the evening	1	(1.3%)
By planned meeting	3	(3.8%)
Other	4	(5.1%)

Question 26 — "How frequently do you communicate with this person?"

No response	3	
More than once per month	60	(78.9%)
About once per month	4	(5.3%)
Less than once per month	12	(15.8%)

Question 27 — "Approximately how many times did you order water from the LCRA?"

1st Crop

No response	9	
1	1	(1.4%)
2	9	(12.9%)
3	6	(8.6%)
4	11	(15.7%)
5 or more	43	(61.4%)
Average	4.2 times	

2nd Crop

No response	25	
1	5	(9.3%)
2	15	(27.8%)
3	12	(22.2%)
4	7	(13.0%)
5 or more	15	(27.8%)
Average	3.3 times	

Question 28 — "Has the LCRA invited you to any farmer meetings?"

No response	2	
No	2	(2.6%)
Yes	55	(97.4%)

Question 29 — "Have you attended any of these meetings?"

No response	3	
No	15	(19.7%)
Yes	61	(80.3%)

Question 30 — "If you attended any farmer meetings, how useful was the information you received from them?"

No response	13	
Very useful	10	(15.2%)
Useful	44	(66.7%)
Not useful	12	(18.2%)

Question 31 — "Has the LCRA informed you about its water conservation demonstration projects?"

No response	3	
No	9	(11.8%)
Yes	67	(88.2%)

Question 32 — "If you observed these demonstration projects, how would you assess their value to you?"

No response	26	
Very Helpful	5	(9.4%)
Helpful	35	(66.0%)
Not Helpful	13	(24.5%)

Question 33 — "Did the LCRA offer you any technical information last year?"

No response	8	
No	35	(49.3%)
Yes	36	(50.7%)

Question 34 — "Do you ever experiment with new or different farming techniques?"

No response	6	
No	16	(21.9%)
Yes	57	(78.1%)

Question 35 — "How helpful are the LCRA staff when you have questions about water deliveries?"

No response	7	
Very helpful	19	(26.4%)
Helpful	49	(68.1%)
Not helpful	4	(5.6%)

Question 36 — "How helpful are the LCRA staff when you have questions about water conservation techniques?"

No response	12	
Very helpful	12	(17.9%)
Helpful	48	(71.6%)
Not helpful	7	(10.4%)

Question 37 — "How helpful are the LCRA staff when you have questions about your irrigation bill?"

No response	8	
Very helpful	25	(31.6%)
Helpful	44	(55.7%)
Not helpful	2	(2.5%)

Question 38 — "How would you rate the accuracy of the LCRA's water deliveries?"

No response	7	
Very accurate	4	(5.6%)
Accurate	35	(48.6%)
Inaccurate	33	(45.8%)

Question 39 — "How would you rate the LCRA's attempts to inform you of its proposed volumetric rate structure?"

No response	6	
Very adequate	9	(12.3%)
Adequate	57	(78.1%)
Inadequate	7	(9.6%)

Question 40 — "In your opinion, the proposed volumetric rate structure is..."

No response	10	
Very fair	5	(7.2%)
Fair	39	(56.5%)
Unfair	25	(36.2%)

Question 41 — "In your opinion, how will the proposed volumetric rate structure affect your bill?"

No response	8	
Increase in water costs	32	(45.1%)
No change in water costs	24	(33.8%)
Decrease in water costs	15	(21.1%)

Question 42 — "What is your position on the statement, 'the LCRA's proposed rate structure will provide incentives to save water'?"

No response	7	
Agree	42	(58.3%)
No opinion	15	(20.8%)
Disagree	15	(20.8%)

Question 43 — "From which of these sources have you gotten most of your farming knowledge? (Please check all that apply)"

No response	4	
Parents/relatives	51	(64.6)
Other farmers	62	(78.5)
Practice/experience	63	(79.7)
Agricultural extension service	41	(51.9)
School	11	(13.9)
Trade magazines	15	(19.0)
LCRA	5	(6.3)
Other	2	(2.5)

Question 44 — "Of the sources checked above in #43, which one is most related to your farming success? (Please check only one)"

No response	7	
Parents/relatives	25	(34.7%)
Other farmers	13	(18.1%)
Practice/experience	27	(37.5%)
Agricultural extension service	6	(8.3%)
School	0	
Trade magazines	0	
LCRA	0	
Other	1	(1.3%)

Question 45 — "When the LCRA develops is water conservation policies, whose interests do they have in mind? (Please check all that apply)"

No response	4	
Farmer's interest	29	(36.7%)
State Government	19	(24.1%)
LCRA's own interest	49	(62.0%)
Municipalities	36	(45.6%)
Other	9	(11.4%)

Question 46 — "In you opinion, which of these options should be most important in the development of water conservation programs for rice farming? (Please check only one)"

No response	6	
Farmer's interest	67	(91.8%)
State Government	1	(1.4%)
LCRA's own interest	1	(1.4%)
Municipalities	0	
Other	4	(5.5%)

Question 47 — "When should public authorities have the right to regulate surface water use?"

No response	7	
Always	6	(8.3%)
In periods of extreme drought	24	(33.3%)
Only when more demands than supply	26	(36.1%)
Never	16	(22.2%)

Question 48 — "When should public authorities have the right to regulate groundwater use?"

No response	6	
Always	4	(5.5%)
In periods of extreme drought	15	(20.5%)
Only when there are more demands than supply	14	(19.2%)
Never	40	(54.8%)

Question 49 — "Do you believe that the LCRA helps rice farmers?"

No response	4	
Very helpful	11	(14.7%)
Helpful	53	(70.7%)
Not helpful	11	(14.7%)

Question 50 — "Please add your comments about any issues not addressed in the questionnaire."

Written responses were given by 42 of the 79 respondents. Note that the symbols "----" indicate writing on the survey form that could not be read.

Respondent 1:

LCRA wastes more water than any farmer ever thought about. They never patrol their canals to look for leaks. They often leave canals leaking all season, resulting in pastures being flooded and roads washed out. The volumetric billing is simply LCRA figuring a way to make the farmers pay for their incompetence. The extra charge for purchase of stored water is unfair. The farmer cannot pass extra and unexpected costs through to his customer and LCRA should not either. There should be one price for water no matter where it comes from.

Respondent 2:

(questions) # 40, 41, 42: Cannot express an opinion at this time because it has not been in practice long enough or on enough fields to determine its efficiency.

Respondent 3:

How about the price of LCRA water compared to others in the state and other states? One, in my opinion, to be higher than any other.

Respondent 4:

We have farmed rice for only one year, therefore, our answers are limited in value to you. At a recent Rice Growers' Seminar in Bay City, it was shown that we are the high cost producers of rice in the nation. Water is a big part of that cost. This puts a premium on LCRA to provide lower cost water to rice farmers or lose the customers.

Respondent 5:

I can pump groundwater cheaper than I can buy from LCRA.

Respondent 6:

I think the LCRA needs to pay more attention to the quality of water being dumped into the river by cities and towns up the river.

Respondent 7:

The metering system of measuring water flowing into fields is not accurate when pushing water to high points. Canals are not checked for trash or ---- in them. Canals are not held at regular levels.

Respondent 8:

I believe LCRA, like most other public utility companies, spends too much money on new equipment. If farmers had new trucks, backhoes, tractors, etc., we wouldn't be able to afford them. I believe the average tractor in the U.S. is 19 years old. I wonder what the average price of equipment of LCRA is. Also I believe we should have a lower flat rate for water and a higher charge for the amount of water that we really use. This would make farmers conserve more water.

Respondent 9:

Any regulations placed on water that is used by the agricultural community or farmers would only lead to further regulations, to which my tax dollars, as well as other farmers, would be used to fight these usually very unfair regulations.

Respondent 10:

I believe the metering of our water is needed and has been needed in the past. There are a lot of people in Texas today and water will become a very important and costly commodity. Hopefully we will be able to answer the challenge. The only way we will be able to compete with cities for water is by using up to date methods of conserving water. This will come with the implementation of volumetric metering of our usage of water. Farmers must curtail the way they use in every way and every phase of the crop during the year. But LCRA needs to make these efforts worthwhile to the farmer. Incentive is going to have to play a big part in this project. This will have to come from LCRA. Hopefully the process of metering will also improve in 1993 over 1992. Too much difference from field to field in '92. Hope you can get something out of this. Thank you for your efforts.

Respondent 11:

LCRA has done a very good job through the years. My biggest concern is on the new measuring system that we are going to be charged by in 1993. I think there has not been enough studies done on the system for enough years to start charging us by this method, although it has been said there will be adjustments made if there is a large amount of difference in the normal amount of water used. I just think this program needs a few more years and different weather conditions in these years, such as a drought or two, to come up with fair rates to both LCRA and the farmer.

Respondent 12:

Surface water belongs to everyone, but the people in the Colorado River Water Shed should have priority. Here we share the concerns of floods, droughts, or any environmental or industrial disaster that may occur on the River or Highland lakes. The rice farmer pays for water used in the irrigation of their crops that support their families, cities, counties, and businesses along the Colorado River. Without our water so goes the rice farmer and everyone connected, including LCRA. I also feel that ground water should be regarded as a mineral and should be handled in this manner. The land owner should have some consideration in this, an important issue as well. I support a volumetric metering concept for conservation and billing purposes, but I feel that inconsistencies in canal levels, high rainfall amounts, debris in delivery points add to the problem with the method and type of metering equipment available for an accurate delivery measurement, plus or minus 10%, at this time. This is the only opposition I have, as well as many of my cohorts. Higher irrigation cost is a fear shared by all farmers. The incentive for better water conservation needs to be addressed further, the proposed Rate Tariff does not make it feasible or profitable to invest in the enormous expense involved in precision land leveling and or underground pipelines. Perhaps, lower per acre charges and higher diversion charges, and/or discounts for precision leveled land, along with higher rice prices could help enhance these incentives. We all need each other, to work together, to achieve our goals, and make this program profitable for all of us.

Respondent 13:

Thank you for this opportunity to share my thoughts and feelings regarding LCRA and the proposed water conservation program. As rice farmers dependent on water from the Colorado River we realize that we are forced to deal with, yea - at the mercy of a bureaucracy. A bureaucratic organization with little interest in irrigation. In my small farming operation, water costs have increased 21.12% in three years. In a dry year this could increase another 10% as projected by the LCRA stored water charge ($5.27 per acre foot). At each meeting for farmers and the LCRA which I have attended some farmer has asked "Are you attempting to shut down irrigation and put farmers out of business?" Volumetric billing is sound, however three boards and a yardstick in a silted lateral do not a meter make. Our water costs go up - then there is an announcement that "LCRA has frozen electric rates until the turn of the Century." AND another – "LCRA announces with pride the winning of $1.5 million in grants for Environmental Purposes" including $414,000 in fact gathering and report preparation for the Colorado River under Clean Rivers Act. Also $200,000 for solid waste management planning. Folks, what are we dealing with here? Oh yes, BUREAUCRACY. A far better question - Would not LCRA employees and customers all be far better served should these assets become part of a well managed and for profit business? Again, thank you.

Respondent 14:

LCRA is a state agency - it pays no taxes - generates 0 jobs in the private sector, but can greatly effect jobs in the private sector by its decisions and policy making.

Respondent 15:

#48 - Water usage policy must be developed in a rational and objective atmosphere and environment and not as a "knee jerk reaction". The establishment of policy for water is critical and should be openly debated.

Respondent 16:

The LCRA makes no attempt to listen to, or implement any of our ideas. Sure, they have meetings down here but they are only to pacify us. It's obvious because of their attitude and we see nothing coming back our way at all. We used to have local farmers on some committee that went to Austin from time to time to voice our concerns and give suggestions to help us and LCRA see things eye to eye but this committee has not met in 2 years. We as farmers have been taken out of the decision making loop. We just do and pay as we are told with no input. Six or eight years ago we in Matagorda County were using approximately 8 to 9 acre feet per acre (AFPA). This past year I think we used an average of approximately 4.5 to 5 AFPA. We as farmers in the field are the ones for this decrease in usage by our hard work and our willingness to be conservative for environmental reasons. LCRA is getting and gladly taking all of the credit and in return we farmers are getting to pay approx. 45% more in rates. Times as they are in the rice farming business, it has become apparent that something has got to change for the better or we will be out of business soon, real soon. We have got to all work together because without us we take down lots of other businesses with us. This includes a lot of jobs employed by LCRA.

Respondent 17:

Person in charge of water, water boss: isn't working with the farmer like he should, in the last 3 year this is a little better than year ago. LCRA needs the rice farmer and rice farmer need LCRA. Some of your personnel is hard to get along with.

Respondent 18:

No one with LCRA has ever actually watered rice. They do not understand a lot of the many problems the farmer faces in his day to day watering process. This in turn costs the farmer alot of time, money, and stress. There needs to be more understanding and cooperation between the farmers' everyday needs and LCRA's employees handling the water distribution.

Respondent 19:

LCRA is becoming a self-servicing organization.

Respondent 20:

The only revenue that I can remember to pay for the dams was from the rice farmer for many years. I know it is going to cost more to meter and keep back then the small amount of water saved. It will create new jobs and cost.

Respondent 21:

Without an actual gear driven counter, the volumetric rate structure will be inaccurate. This is because the canal level fluctuates up and down, and at times (up to 36-48 hours) no water is flowing through the water box, but the clock is still ticking indicating how much water should be flowing through the opening in the water box. In other words - we are being charged for the hole in the water box and nothing is passing through it but air. Unfluctuating canal depths to maintain constant pressure is extremely important.

Respondent 22:

This is an estate (family) operation. We have a tenant farmer, therefore cannot answer all the questions.

Respondent 23:

Thank you for giving us the opportunity to make comments on the LCRA. It is our opinion that the LCRA is working for the good of all in their attempt at volumetric metering, but there are many problems that must be worked out if it will be successful and have the approval of farmers. Two problems that have already surfaced at Gulfcoast are:

A. inaccuracies in measurement

B. lack of incentive in curtailment of usage

The LCRA staff has attempted over the last several years to obtain a better working relationship with its customers. They have organized two different "Farmer Advisory Groups", the first met only once or twice. The second group was formed only shortly before the first of the year. For the most part, members of the group feel that their opinions and suggestions fall on deaf ears with the staff at Austin. The staff uses the "Farmer Advisory Groups" to add to their recommendations to the LCRA board. At a recent board meeting in Austin the staff stated that over 50% of their irrigation customers were in support of a rate change. This could not be farther from the truth. Nearly all Texas rice farmers are feeling the effects of higher inputs and lower prices from the mills.

Respondent 24:

I believe that the volumetric rate system will not be an accurate way to charge for water use.

Respondent 25:

Re: Volumetric Rate Structure. The method of measurement is unfair. The system used is accurate when the water level in the canal is constant. Unfortunately, the water level fluctuates and therefore true water use is not fairly determined.

Respondent 26:

Out of the 650 ac. of rice, only 250 ac. on LCRA. The remainder of the rice and soybeans are irrigated by a private irrigation well.

Respondent 27:

Questions #47 and #48 need one more choice - that being a water commission of equal representation from each water user in the river basin. This is a nice questionnaire, but what is its purpose? LCRA has a monopoly and our only choice is to pay their proposed rate or do without the water, in other words, don't grow a crop that depends upon the use of irrigation water. LCRA could provide the same or better service to our area by cutting overhead, staff, ----------, etc.

Respondent 28:

The G&A <u>cost</u> factored into the water division of the LCRA continued to grow as the LCRA Bureaucracy grows. This monster has grown exponentially since 1980 to date. This growth has been by Management, Board of Directors, Legislated Mandates, etc. The farmers and Water division of LCRA have taken a lot of flack from the Board and Lake People because we are not a profit center with the huge G&A expense in our budget. Which by the way continues to grow annually.

Respondent 29:

Your survey is not applicable in several ways to us as we are landowners who lease their land for a share of crop and for cash. For crop share leases for rice, we provide land, water and seed plus a portion of the other crop inputs, however the lessees provide the labor and equipment. Also the land is owned and operated by partnerships of six people so the personal questions are answered only by one partner, the managing partner. W.R.T. LCRA meetings — they are generally on short notice and in conflict with other important meeting and at a distance. (In fact it seems that LCRA schedules meetings in conflict with some obvious events.)

Respondent 30:

Some rice farmers have abused their water rights. They were inattentive to their watering practices and did not care about using water conservatively - I appreciate the method that if a farmer conserves and manages his water he will be billed accordingly.

Respondent 31:

LCRA is overstaffed and overpaid. Too much emphasis put on recreation. Environmental input is great. Farmers will soon be priced out of business per acre ft. costs will soon outgrow our income.

Respondent 32:

The volumetric measurement was inaccurate. I had two fields side by side. One read 1.5 feet difference. It will be very good to help conserve water when it is perfected. If the water Boss would spend a little more time on the canal he could do a better job. They don't have the experience the older water bosses had.

Respondent 33:

Water is becoming a bigger farming issue every year. A farmer's conservation practice is becoming more important and mandatory. We cannot afford to experiment with too radical a farming techniques so the information LCRA and extension services provide can be very helpful.

Respondent 34:

In my opinion LCRA needs a more accurate way to measure water discharged into fields. The way water is measured to date is not accurate enough to allow them to fairly charge farmers for usage.

Respondent 35:

I have been farming rice since 1976. Water is absolutely necessary in growing rice. Since '76 LCRA has more than doubled, in fact almost tripled, the rate they charge me for water. Yet with practically no change in services - except for now a metering system which in "theory" is great but in "practice" is terribly inaccurate! Personally, I feel LCRA is selling water to the highest bid which would be municipalities and leaving the farmers hung out to dry because of the prohibitive cost of LCRA water. I think it's terrible and I can't stop it and will merely become a victim of the system.

Respondent 36:

Four years ago rates were increased by 28% spread over a four year period at 7%/year actually compounded to a 35% increase. At the same time water use by LCRA's own numbers have decreased in Gulf Coast from over 9 acre feet/acre to under 6 acre feet/acre. Actually 5.25 acre feet/acre. Over 30% savings in water usage. We were also promised there would be no more rate increases for 4-5 years after this. Now to get around a rate increase they come up with a new system of billing - volumetric rates - which in most of the farmer's opinion a very poor method of measurement. Wildly fluctuates between fields. So you tell me - do you believe that LCRA helps rice farmers? Sadly most of us feel that we will be paying 10-25% more within 2-3 years and the low prices of rice will not sustain this increase.

Respondent 37:

As a rice producer I feel like the municipalities and recreational interests have tried to take away water rights from the farmers. As a whole the farmers have cut way back on the amount of water used in the last 10 years. But every year we pay more and more for water. While the price we receive for our crop decreases every year. I sometimes feel people are more concerned about the water level of the lake, that was built for irrigation purposes, than the crops that produce food to feed them. I also feel that after studies have been completed they will show water coming <u>out</u> of our rice fields are cleaner than the water we are putting <u>in</u> the top of our fields.

Respondent 38:

LCRA does not spend enough time or energy conserving water within their system, i.e., main canals.

Respondent 39:

Best relations between water boss and farmer in my 50 years of farming. Note I own $100,000.00 LCRA bonds.

Respondent 40:

The accuracy of LCRA measurements of water concerns me greatly. They need an independent measuring service consisting of farmers and LCRA employees that are educated in the practice of measuring water so that this will be fair for everybody. Hand held meters should be thrown away. This is not in my opinion an accurate way to measure water, especially when you are farming on the end of the canal because of canal level fluctuations. Accuracy above all is my main concern. Send me this survey a year from now and I will be able to answer your questions more accurately.

Respondent 41:

Water rate is too high in comparison to the prices we receive on our rice.

Respondent 42:

LCRA is a bureaucracy with too many folks trying to run other people's business to impress the folks above them. The water districts and their local management should be left alone to do their jobs without Austin breathing down their necks. This survey just seems to me to be another attempt by bureaucrats to look impressive. There is a point at which information becomes futile. LCRA is not and will not every be one of the rice farmers' main sources of information. That is not and should not be LCRA's responsibility except where it pertains to water conservation.

Appendix D
GIS Maps

Figure D1
Lakeside Irrigation District - 1992

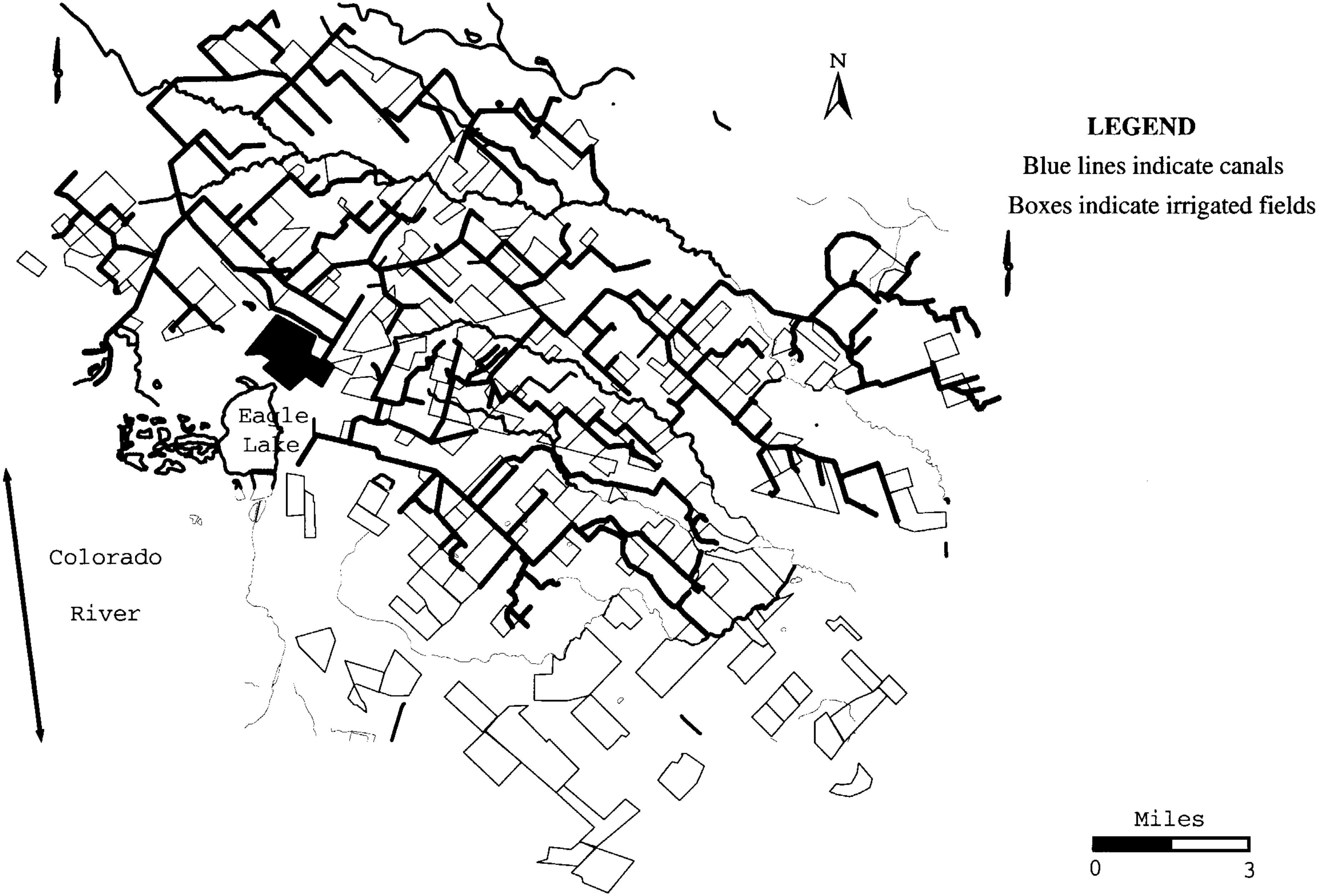


Figure D2
Magnified View, Eagle Lake Area

Figure D3
Lakeside 1992 First Crop Water Use, Small Fields

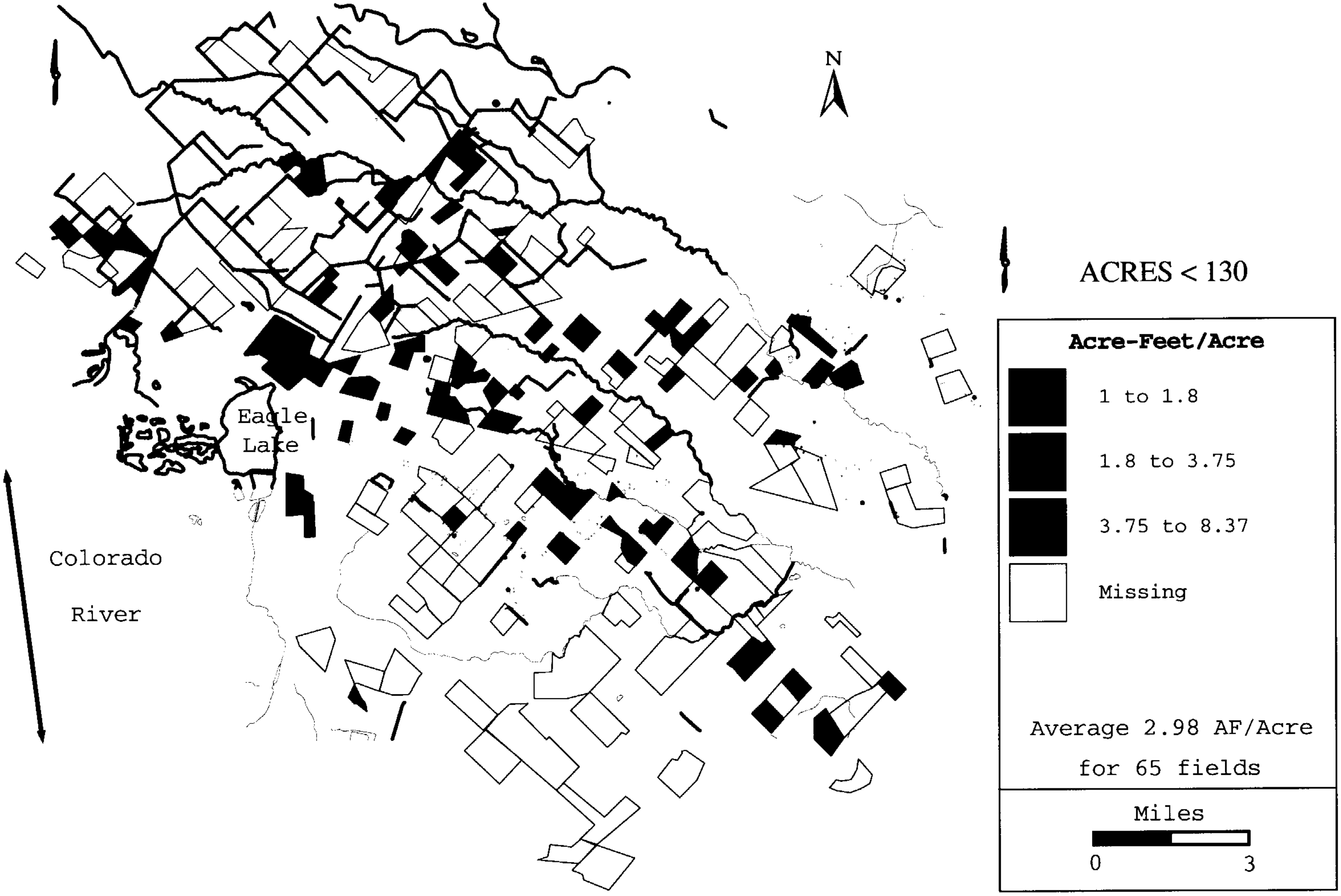


Figure D4
Lakeside 1992 Second Crop Water Use, Small Fields

Figure D5
Lakeside 1992 First Crop Water Use, Large Fields

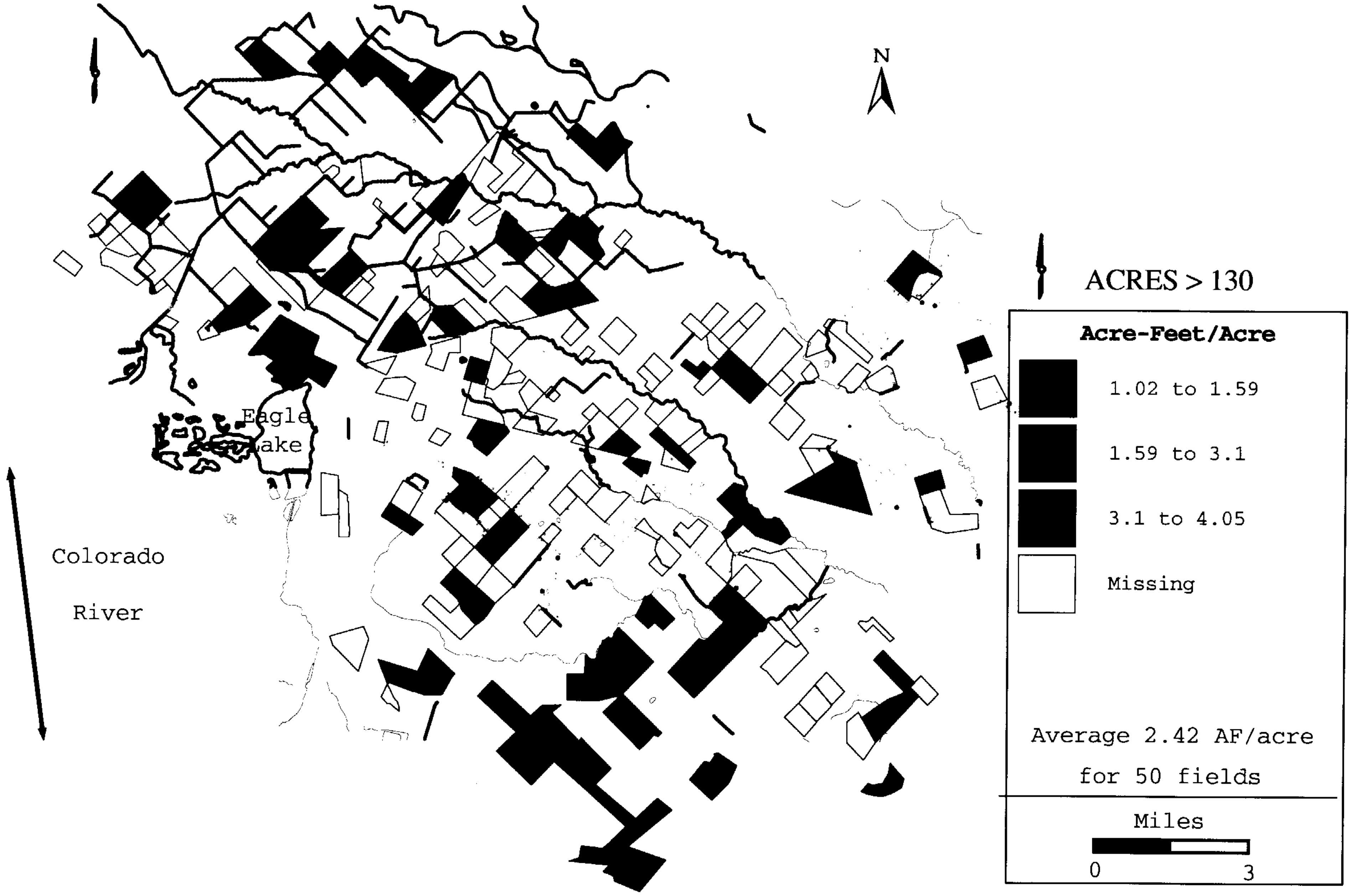
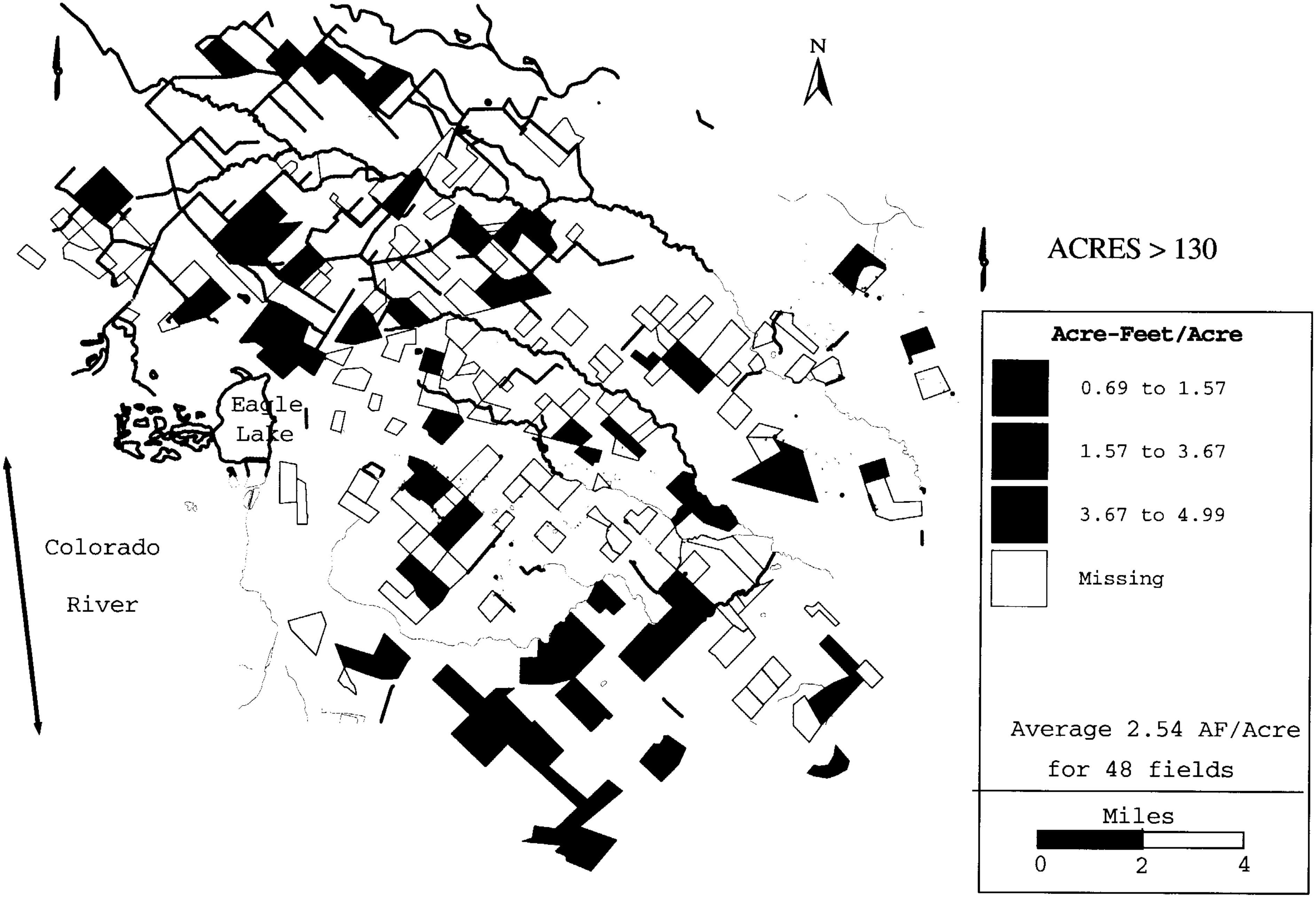


Figure D6
Lakeside 1992 Second Crop Water Use, Large Fields



Appendix E
Administrator's Comments

ATTACHMENT 1
TEXAS WATER DEVELOPMENT BOARD

Attachment 1
Texas Water Development Board
Review Comments – Contract No. 92-483-330
University of Texas at Austin

Attachment 1
Texas Water Development Board
Review Comments – Contract No. 92-483-330
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1. Report title "South Texas Rice Fields" should be more specific. Since the report only addresses rice fields within LCRA's jurisdiction, not all of the South Texas rice growing areas. Please consider changing the title to better portray the project's scope, for example, "Rice Water Irrigation Conservation in LCRA Irrigation Districts".

2. The two volumes should be labeled clearly as: "Volume I of II" and "Volume II of II"

3. Maps would be easier to interpret in color. Consideration should also be given to enlarging maps using smaller icons so that they are not so congested with information. Should review tables and figures for completeness and accuracy.

4. An Executive Summary should be included at the beginning of the report that concisely describes what work was performed, who sponsored the project (LCRA), why the work was needed and the findings of the report.

5. A reference on the report "Policy Research Project Participants" face sheet should note Jobaid Kabir's affiliation with the LCRA.

6. Page xv, "Acknowledgements"; Mike Personett, Turner, Collie and Braden Inc., formerly an employee of the Texas Water Development Board and the Lower Colorado River Authority. Please correct this reference.

Chapter 1

7. First sentence; please rewrite to read "In recent years, LCRA <u>has</u> owned and . . ."

8. Page 1, third paragraph; different years are chosen to represent the various characteristics of water use and volume instead of a single set of, say 5 years. By choosing different years for different statistics it makes it difficult to compare data. Please standardize to 1992 data.

9. Page 1, fourth paragraph; first sentence, please change program to programs.

10. Page 2, fourth paragraph, last sentence "If the natural run-..." Please correct this statement to reflect operating and water right practices more appropriately. In the case of a drought, for example, LCRA will probably not release water downstream to meet junior water right needs even though the river flow may be low.

11. Page three is missing from the report.

12. Page 6, second to last paragraph, last sentence: "In addition..." How did the coordinators actually "measure" this quantity for each farmer? Please describe the methodology that LCRA irrigation managers used to estimate or measure the water used by "each farmer."

13. Page 6, last paragraph, first sentence; Measuring water flows can be very complicated depending upon the means of measurement. Explain why measurements were straightforward. This conflicts with later statements on page 9, paragraph two where "measurements" are actually described more like averages of estimated flows. Again, how are these "measurements" taken?

14. Page 7, second to last paragraph, first paragraph; "In the Lakeside..." Refers suddenly to the "Water Management Project". The Water Management Project is not described until page 10.

15. Page 9, second paragraph "Farmers ordered..." Explain terminology (e.g. "undershot") and describe ordering units in a clearer manner. If a box is equivalent to 3,000 gpm then what constitutes one box (i.e. 3,000 gpm for how many minutes)?

16. Page 9, it is not a "paradox" that an ordering unit does not arrive in strict adherence to its title. "The farmer does, however, receive..." is vague. Please rewrite sentence to provide more meaningful content within the report context.

17. Page 11, third paragraph; the report refers, intermittently, to various measurement techniques as proposed or used. There is no reference to the actual number of the "global flow meters" or whether each farmer had one assigned to them. Please give numbers of meters used and cost of an example meter.

18. Figure 1.2 reflects number of acres irrigated since 1968. Text stated table was to reflect 1960 as starting period.

Chapter 3

19. Page 54, second paragraph, first sentence, recommend removing "the water" from the sentence.

Chapter 4

20. Page 68, first paragraph, first sentence states that environmental and economic considerations make construction of new water supply projects "unlikely". Recommend changing "unlikely" to "more challenging".

21. Page 70, "Summary of Results". Suggest that section come after the "Methods" section.

    Farmer's attitudes resulting from the legal and political changes along with other behavioral variables do not appear to be addressed in Chapter 4.

    Page 80, fourth paragraph, first sentence. "The parameter estimate for the acreage variable [Beta], purifies the meaning of average water use per-acre on each district. The use of "purifies" is questionable.

22. Page 84, second paragraph, second sentence: recommend changing "that" determining to "in" determining, for grammatical correctness.

    Page 84, second paragraph, fourth sentence, "This is an unexpected result". That water is used more efficiently as a field size increase should be expected. Also, the paragraphs use of the term "water use" here is vague. Per acre? Total?

Chapter 5

23. Page 5, first paragraph, sixth sentence: recommend changing "included" to "include."

Chapter 6

24. Cost estimates ignore many associated costs such as project costs and piping. Chapter 6 does not address third party impacts or costs.

25. Page 19, second paragraph, seventh line: recommend adding "be" between "flows to" and "available".

26. Page 23, third paragraph, second line: recommend changing "represented" to " represent"

27. Page 27, paragraph 4, line 5, the phrase "when supply exceeds demand . . . " is reversed. It should be "when demand exceeds supply.

28. The report is missing figures, entire pages, and has notes such as "Where did data come from?" (see figure 6.5) and Vol. II, page 66. The source(s) of all data should be identified.

29. Chapter 6 does not adequately address subsidence problems or the issue of increased use of surface water as pumping draws down water tables. Socioeconomic feasibility analysis consisting of surveys and five paragraphs of text seem inadequate.

Chapter 7

30. Please include a conclusion section.

31. Page 59, line 6, and page 60, line 23: A reference is made to Figure 7.1 as showing East Matagorda Bay. The figure shows Matagorda Bay and only a tiny portion of the western tip of East Matagorda Bay. There is not enough of East Matagorda Bay in the figure to allow the reader to see several inlets that connect the ICWW with the bay even though the figure is specifically referenced to show that on page 60.

32. Page 61, line 8. There is a reference to zones 3 and 6 being at the "western end of the bay." In fact, they are at the eastern end of East Matagorda Bay.

33. Page 62, line 27: The paragraph ends with the statement "then [Greek letter alpha] can be computed to be 0.025." How this constant is calculated is not clear unless the reader understands that the preliminary value is merely 1 day divided by 39.37 inches per meter. An additional phrase to the sentence would clarify the calculation.

34. Page 62, line 32: The next-to-last sentence on the page states "the sum of rainfall intensity and runoff is proportional to precipitation measured at the East Matagorda II station." The previous sentence in the paragraph states "runoff has a linear relationship to rainfall intensity." These sentences imply that the sum of rainfall intensity and runoff, which is a linear function of rainfall intensity, are proportional to rainfall intensity: (Intensity + (a +b * Intensity)) is proportional to Intensity. What is the importance of this? It is not clear why the sum of rainfall intensity and runoff as a value is important. Some clarification of the importance of this statement is needed.

35. Page 64, lines 3-4: The last sentence of the paragraph states "The definition of n is identical to that in equation 7.2." Equation 7.2 does not have "n" in it. Do the authors mean equation 7.3?

36. Page 65, lines 24-25: These lines are the descriptions of the columns of values in Table 7.2. It is not clear what some of the columns of values mean. Some do not appear to be discussed in the text and it is not clear what they show.

37. Page 66, lines 17-18: The last sentence of the paragraph reads "the value of [Greek letter gamma] decreased relative to its value in the model with precipitation only." The entries for [Greek letter gamma] in Table 7.2 for precipitation had the lowest (0.0765) and highest (0.1517) values in the table. It is unclear how this conclusion was reached; it does not seem to agree with information in the table.

38. Page 67, lines 12-14: Suggest that the last sentence of the paragraph be deleted. The greater relative importance of runoff versus river flow seems clearly demonstrated in the analysis. It is not clear why this sentence is introduced.

39. Page 74: The draft copy of the report contained two copies of Page 74, Figure 7.6.

LYNDON B. JOHNSON SCHOOL OF PUBLIC AFFAIRS

Policy Paper No. 3

Estimation of Derived Demand for Surface Water on Two Rice Irrigation Districts in the Lower Colorado River Basin, Texas

Martin T. Schultz

THE UNIVERSITY OF TEXAS AT AUSTIN

Paper Series

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Acknowledgements

The author appreciates the many individuals and organizations that provided assistance in the npletion of this project. Four individuals served as readers and worked with the author throughout preparation of this report: David Eaton of the Lyndon B. Johnson School of Public Affairs (LBJ ool), The University of Texas at Austin (UT/A), Peter Wilcoxen of the Department of Economics, /A, and Quentin Martin and Jobaid Kabir of the Lower Colorado River Authority (LCRA). Chandler lp of the LBJ School introduced the author to data envelopment analysis and discussed its application l interpretation.

This project would not have been possible without the support of Bruce Hicks and his staff on LCRA irrigation districts, Mike Shoppa, Henry Bradford, Thomas Pivonka, Larry Harbers, Kelly ber, and district water coordinators. These individuals spent many hours with the author over a two- ar period discussing operations and management on the irrigation districts and rice farming.

Several other individuals assisted the author with specific issues at various times during the mpletion of this report. Angie Taylor and Alan Faries of the LCRA Rates Management Division ovided information on the development of irrigation water rates. Garry McCauley of Texas ricultural Experiment Station, Texas A&M University, shared his extensive knowledge of rice ming and provided data from the Less Water-More Rice Research Project. James Engbrock and Rick hn of the Texas Agricultural Extension Service offices in Matagorda and Colorado Counties discussed al conditions and provided the author with farm budgets.

The author is solely responsible for any errors, interpretations, or omissions.

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Chapter 1
Summary of Results

Introduction

Property rights in surface water ensure that water is adequately distributed throughout a river basin. In addition, the assignment of private property rights to common property resources can lead to economic benefits by reducing investment risks. However, when water supplies become limiting and water is inefficiently allocated among users there are suboptimal economic returns. Agricultural interests have had and continue to have preferential access to water supplies. In the process of promoting agricultural development by the assignment of water rights, the state has failed to ensure that agricultural interests develop water-saving technologies in response to water shortages. As a result, the economic returns from limited supplies of water have not reached their potential.

This paper analyzes the allocation of water within the Lower Colorado River Basin and measures the economic impact of water rights. This is accomplished by estimating the derived demand for water on two rice irrigation districts that account for most water diversions. The demand for water and the value of water in its assigned use are determined through farm budget analysis and linear programming methods common in agricultural economics. The benefits of agricultural water use are then assessed against the cost of obtaining alternative supplies of water within the river basin. Results show an economic cost associated with the allocation of water.

The approach used to evaluate the allocation of water is to measure the benefits of water used on the irrigation districts against what less-senior owners of water rights are willing to pay for water. The reallocation of water for storage in the Highland Lakes is not considered itself to be a productive use of run-of-river water that is not diverted by the irrigation districts. The economic rationale for reduced downstream consumption of Highland Lakes water is that if water is reallocated from the irrigation districts, and reduces the cost of stored water for less-senior water rights holders, the benefits to the basin could exceed the costs. Although there may be various environmental benefits associated with reducing water diversions on the irrigation districts, the assumption is that these are satisfied by existing institutional constraints.

If water is not a limiting resource, there is no need to allocate it among users and there are no costs or subsidies associated with its use. Once water is allocated by water rights, and market transfers of water that would occur in a competitive market do not occur, the allocation of water becomes inefficient. Market efficiency is defined as the condition in which water is freely traded among parties so that the productive output of water is maximized. Inefficiencies arise when water rights and state regulations obstruct price signals between buyers and sellers that indicate water might be more productive in another use.

This paper considers whether economic principles could support a transfer of water, and not how a transfer should take place. In the absence of market mechanisms, an efficient transfer of resources is still possible. Efficient transfers meet the conditions of Pareto efficiency. That is, a trade occurs such that one party is better off, and the other party is at least no worse off. In the case that a transfer of resources represents a tradeoff between the well being of two parties, there is yet another indicator of whether or not that transfer is efficient. The Kaldor-Hicks standard of efficiency assesses whether or not those who gain from the transfer **could** compensate those who lose from the transfer.

Diversions of water for irrigation account for the vast majority of consumptive water diversions from the lower Colorado River (Table 1.1). Agricultural water diversions, in particular those for rice irrigation, dominate all other uses. Although agriculture is an important part of the regional economy, the allocation of a substantial portion of the regional water resources to agriculture has a significant burden on the economy as whole. This allocation of water increases the cost of water to other users. Others who seek to divert run-of-river water under their own water rights, but cannot do so, must purchase relatively expensive stored water supplies from the Highland Lakes. An economic argument to reallocate run-of-river water to other uses can be made if the value of water in irrigation is less than the value of water in alternative uses.

Table 1.1
Water Consumption, Lower Colorado River, Texas, 1980 - 1989
(Acre-Feet)

Year	Municipal	Industrial	Mining	Irrigation	Total
1980	90,005	38,844	2,242	605,075	736,166
1981	84,935	24,070	2,123	573,732	684,860
1982	97,243	26,524	2,082	607,873	733,722
1983	91,874	49,710	1,571	410,779	553,934
1984	114,106	41,600	1,893	580,497	738,096
1985	116,248	82,381	2,035	447,677	648,348
1986	118,497	38,419	1,795	441,265	599,984
1987	114,101	26,362	1,576	432,590	574,637
1988	122,300	89,293	3,800	568,971	784,372
1989	138,527	105,816	2,519	488,415	735,277

Source: Texas Water Commission (TWC). 1993. "Reported Surface Water Use For Colorado River Basin, All Rights and Claims," Austin, Texas. (Computer Printout.)

Note: Does not include non-consumptive diversions for recreational uses, industrial uses, or hydro-electric power generation. Irrigation water uses include agricultural and non-agricultural water diversions.

Chapter 2 presents a normative framework for evaluating the allocation of water in a river basin. The results of this project are interpreted in terms of the economic efficiency criteria established in that section of the paper. Economic efficiency is not and should not be the only basis for evaluating the allocation of water. Social or non-economic policy goals may indicate that an uneconomical allocation of water is a legitimate or a preferred outcome. Chapter 2 also discusses the use of crop production functions and farm budget analysis to estimate the marginal benefit of water in crop production. In competitive markets, resources are allocated according to the value of their marginal product.

It is not possible to determine the demand for water directly because no competitive market for water exists. Derived demand is a method of estimating the value of water based on the demand for farm outputs. One complication with this approach is that there is an artificial demand for farm output. The market for rice is subsidized through Agricultural Stabilization and Conservation Service (ASCS) farm programs. Therefore, the demand for farm outputs is not an entirely accurate measure of the value of farm outputs.

Chapter 3 systematizes information about the irrigation districts so that farm budget methods and linear programming may be applied to estimate the value of water. Chapter 4 assesses the potential for water conservation in rice irrigation. This is an application of data envelopment analysis to data collected at sample farms during the Texas A&M University's Less Water-More Rice research project. Chapter 5 follows with a description of the linear program and a discussion of model assumptions. Model results are presented and interpreted in Chapter 6.

Research Results

Research results include:

- a model for predicting district rice acreage in the upcoming season based on ASCS program parameters;
- a model for estimating reductions in per-acre on-farm water use in response to LCRA's introduction of volumetric pricing;
- an estimate of the crop-water production frontier;
- derived demand functions for irrigation water.

Predicting district rice acreage in the upcoming season based on ASCS program parameters:

Chapter 3 presents a regression model for forecasting each districts' rice acreage in the upcoming season using information about ASCS program parameters. The model predicts rice acreage on the basis of historical acreage levels, maximum planting rates, and advance deficiency payment rates. ASCS program parameters for an upcoming crop season are made public in January. Rice acreage and crop prices affect estimates of the value of water. Using these acreage estimates in the linear programmming model incorporates these factors into derived demand estimates and makes the model more suitable as a planning tool.

Formerly, LCRA required information on farmers planting intentions to forecast rice acreage. This information is not available until just before planting begins in March. This regression model lengthens LCRA's planning horizon by approximately three months because estimates are available beginning in January.

Estimating reductions in per-acre on-farm water use in response to volumetric pricing:

Chapter 3 also discusses a model for estimating decreases in on-farm water use that resulted from LCRA's introduction of volumetric water pricing in the 1993 crop season. Results are interpreted in terms of on-farm water savings during the first crop period in Chapter 3 and short-run elasticity estimates in Chapter 6.

Estimating the crop-water-production frontier:

Chapter 4 applies data envelopment analysis to estimate the production frontier for irrigation water as an input in the production process. Data envelopment analysis (DEA) is a non-parametric method of estimating a technically efficient level of input use. Model results could be used to establish field-specific irrigation water standards, and to estimate the potential water savings associated with on-farm water conservation programs. These results suggest more analysis is needed to develop a uniform irrigation standard.

DEA results reveal a significant water savings potential associated with on-farm water conservation that are distinct from efforts such as canal improvement and volumetric pricing. On-farm water conservation programs emphasize the introduction of water-saving technologies in rice farming. The potential water savings associated with an on-farm water conservation program during the first crop period on Lakeside District is 24 percent of 1993 irrigation inflows during that period. Similarly, the potential water savings is 51 percent of 1993 first crop irrigation inflows on Gulf Coast District.

Estimating and using derived demand functions for irrigation water:

Chapter 5 presents the linear program and discusses model assumptions. Chapter 6 presents and interprets derived demand functions based on linear program and farm budget analysis results. Derived demand functions may be interpreted to estimate the:

- collective value of water delivered to the farm gate;
- short-run average value of water delivered to the farm gate;
- short-run average value of land during the crop season;
- marginal value of successive units of water on the districts;
- value of the subsidy to farmers associated with LCRA's irrigation district water right;
- cost to others associated LCRA's irrigation district water right;
- equilibrium price for water under an average cost per acre-foot pricing strategy;
- decrease in rice acreage resulting from implementation of an average cost pricing strategy.

Linear program results should be interpreted with a knowledge of the limits of the linear programming model. In general, the linear programming method requires a rigid specification of conditions on the irrigation districts and the results will be sensitive to year-to-year changes in these conditions. For example, changes in crop price and farm acreage will affect estimates. On the other hand, this model is easily updated to reflect changing conditions. This report presents a detailed review these assumptions.

The collective value of water delivered to the farm gate:

The total value represents that portion of profit on the irrigation districts specifically associated with farmer's access to irrigation water. It is a collective value of water based on agricultural markets, alternative crops, farming costs, on-farm water use and water prices during the 1993 crop season. On Lakeside Irrigation District, the collective value of on-farm water deliveries to 26,221 acres at an effective price of $11.11 is approximately $4.133 million. On Gulf Coast Irrigation District, the value of on-farm water deliveries to 25,371 acres at an effective price of $6.55 is $4.198 million. For reasons discussed later in this report, these are modelled acreage values, not actual acreage values. Total values will be sensitive to the acreage assumptions used in the linear program. As rice acreage and water deliveries increase, so will the total value of water.

The value of water will decrease as the price of water increases. The effective price used in making these estimates represents the expected price of one acre-foot of water on the district plus the expected cost of stored water. The districts also charge farmers on a per-acre basis. To account for this cost, payments made by farmers to the LCRA have been subtracted from estimates of the total value.

The short-run average value of water delivered to the farm gate

When the collective value of water is averaged over the volume of water delivered to farmers, the result is an average value per acre-foot. Individual farmers might place more or less value on the water they use depending upon their range of crop alternatives and their farming practices. Unlike collective values described above, average values are not sensitive to acreage assumptions.

Estimates of the average value of water are short-run values. They represent the value of water during the 1993 crop season only. Short-run estimates are based on variable costs of farming. Long-run values are a function of the farmer's perception about the market for irrigated crops in the future, and both the capital cost and the variable cost of farming. Economic theory suggests that long-run values are generally lower than short-run values. Estimates represent the value of water, not the value of water rights. The rationale for this approach is those who use the water rights on these districts do not own them and therefore have no right to sell them.

The short-run average value of one-acre foot of water represents the price that the average farmer would be willing to sell his right to *use* one acre-foot of water if that farmer stopped raising irrigated crops, switched to dryland farming where possible, and sold *all* of his water. Table 1.2 presents estimates of the short-run average value of water. The average value of water over the full crop season (first and second crop periods combined) is $37.95 on Lakeside District and $32.80 on Gulf Coast District.

In general, the value of water will be higher during the first crop period than the second crop period because yields are higher. In 1993 the short-run value of one acre-foot of water delivered to fields on Lakeside District was $61.44 during the first crop period, and $7.41 during the second crop period. On Gulf Cost District, the average values are $41.47 and $13.15 for first and second crop periods respectively.

The short-run average value of land during the crop season:

It has been suggested that transfer payments might be used to reduce rice acreage by paying farmers to farm non-irrigated crops. Table 1.2 presents estimates of the value of one irrigated acre used in rice production. This may be interpreted as the expected cost of paying the average farmer to raise a non-irrigated crop during the 1993 crop season. For example, on Lakeside District, the average value of one irrigated acre is $144.26. The average value of one second crop acre is $13.38. The total cost of such a program, $1.22 million, can be estimated by multiplying first crop acreage by the value of second crop acreage.

The marginal value of successive units of water on the districts:

This paper also estimates the marginal value of successive units of water on the irrigation districts. Marginal values are more useful in allocating water between users, but are of little use without comparable information on the marginal value of water in alternative uses. No estimates are presented for instream values because reliable estimates of canal losses are unavailable. Because canal losses are part of the cost of transferring water from the river to the farm gate, instream values would be lower.

The value of the subsidy to farmers associated with LCRA's irrigation district water right:

Estimates of the value of water developed in this paper suggest that the current allocation of water in the Lower Colorado River Basin is inefficient. Model results show that the volume of water inefficiently allocated is 49,929 acre-feet on Lakeside District and 42,122 acre-feet on Gulf Coast District. This inefficiency may be characterized as a cost to those who must purchase alternative supplies of water in the Highland Lakes, or as a benefit to those who have access to the water. The approach used in this paper is to characterize the inefficiency as a benefit.

The benefit is an indirect subsidy. It arises from farmers' access to water that would not be available if water were allocated on the basis of economic efficiency criteria. The indirect subsidy to farmers on Lakeside District is approximately $395,249. The indirect subsidy to farmers on Gulf Coast District is approximately $561,895. Results of the model in Chapter 6 indicate that the value of the indirect subsidy to farmers and the cost associated with the current allocation of water rights are a function of second crop acreage. One assumption implicit in these estimates is that other users that currently purchase water from the Highland Lakes would use all of the water the districts did not divert.

The cost to others associated LCRA's irrigation district water right:

Although the benefit farmers receive is small, the cost to others who must obtain alternative supplies of water may be much larger. The cost to others can be estimated as farmers' cost of replacing the volume of water that is inefficiently allocated with stored water from the Highland Lakes. Farmers could not afford to do this, but if they did, the cost on Lakeside District would be $2,521,380 and the cost on Gulf Coast District would be $2,127,208. Thus, the total cost associated with LCRA's ownership of water rights on the irrigation districts in 1993 was approximately $4.65 million.

The equilibrium price for water under an average cost per acre-foot pricing strategy:

Estimates of the value of water are followed by a review of the potential for average cost pricing. Average cost pricing is the practice of pricing water so that LCRA's cost of operating and maintaining the irrigation districts is fully recovered. Until 1993, LCRA averaged its cost over acreage and charged farmers only for the number of acres irrigated, not the volume of water used. Under that system there was no cost associated with water and no incentive for farmers to reduce water use.

Economic theory suggests that if the marginal cost of water is high, farmers will use less water. This concept is reflected in the price elasticity of water demand, the percent change in on-farm water use relative to a percent change in price. Implementation of an average cost per acre-foot price requires an understanding of how much less water farmers would use as the price increases. If not, there is a risk LCRA would not recover its cost of supplying water. This report evaluates the elasticity estimates implicit in the linear programming model. Assumptions used in developing the model may have resulted in artificially low elasticity estimates. Relaxing these assumptions provides a maximum elasticity value. Chapter 6 provides details of this aspect of the study.

Table 1.2
Short-Run Average Value of Water on LCRA Irrigation Districts in 1993

Description		**Lakeside District**	**Gulf Coast District**
Average Value of Water:			
(Value per acre-foot)	Full Crop*	$37.95	$32.80
	First Crop	61.44	41.47
	Second Crop	7.41	13.15
Average Value of Irrigated Land:			
(Value per-acre)	First Crop	$144.26	$145.16
	Second Crop	13.38	33.85

Source: Calculated by the author based on data generated by the linear program using XA Software.

Note: Values based on 1993 agricultural markets, farming costs, and on-farm water use. (*) The average value during the full crop period is the average value of water in the first and second crop periods combined.

The decrease in rice acreage resulting from implementation of an average cost pricing strategy:

Linear programming results show that average cost pricing would not substantially reduce first crop acreage, and would have only a small effect on first crop water diversions. Under an average cost pricing system, the price of one acre-foot of water on Lakeside District would be approximately $36.42. First crop acreage would decrease 220 acres and all second crop acreage would go out of production. Similarly, on Gulf Coast District the price of one acre-foot would be approximately $26.05. First crop acreage would decrease 1,848 acres and all second crop acreage would go out of production.

How These Results May be Used by Affected Agencies

Results contained in this report have many applications for the planning and management of water resources. Some of these have already been discussed. Results may be directly applied within the Lower Colorado River Basin to:

- evaluate water conservation benefits;
- evaluate water conservation program alternatives;
- establish water conservation targets;
- evaluate costs and benefits of water rights;
- evaluate economic impacts of alternative drought management policies;
- establish volumetric water prices in accordance with state law.

This report demonstrates how results can be obtained using derived demand functions developed in this paper. Any agency interested in pursuing an evaluation of water conservation benefits on the LCRA districts may adapt the models accordingly. Cost and benefit estimates will be specific to 1993 unless the model is updated. However, exact estimates may not be as important as the magnitude and sign of model results. For example, the exact estimate of costs associated with LCRA irrigation district water rights within the basin will vary from year to year, but the magnitude of costs will not likely change much. This demonstration of cost should be sufficient to evaluate policy options unless specific decisions require more exact estimates.

Throughout this paper, there are discussions of the potential water savings associated with price increases and on-farm water conservation. On-farm water savings might occur when farmers voluntarily adjust technology and input ratios in response to volumetric pricing. Extension efforts can also educate farmers and encourage them to adopt water-saving technologies. Regulations can produce water savings by either prohibiting certain practices or requiring farmers to adopt specific technologies as a condition of service. This report reveals substantial on-farm water savings that are yet un-tapped on the LCRA districts.

Water conservation estimates are not additive. For example, it would not be reasonable to implement an on-farm water conservation program and increase the variable price of water with the goal of achieving the maximum potential savings associated with each of these programs individually. Finally, all estimates are made under the assumption that there is no change in the conditions on which the model is based. Despite this sensitivity of results, these models provide insights into irrigation district water rights and tangible lessons for regional water policy that are not available elsewhere.

This report develops a methodology for addressing each of these tasks and demonstrates how conclusions can be drawn from the linear programming models. The report also demonstrates how management and policy alternatives may be evaluated using this information. The methods can be applied in other areas of the state as well, but adjustments may be needed to accomodate differences in the availability of data and local conditions. The emphasis this report places on clarification and validation of model assumptions should be useful to any agency interested in applying linear programming and farm budget analysis to specific problems.

Chapter 2
Methods Estimating the Value of Water

Economic theory provides a window through which to view and understand issues associated with the allocation of water in a river basin. The assignment of water rights has caused an inefficient distribution of water among users and a net economic cost in the river basin. The cost is increasing as the demand for water increases due to population pressures and economic growth. The purpose of this chapter is to present a normative theoretical framework for interpreting the effect of LCRA irrigation district water rights on the economy in the Lower Colorado River Basin, and to present analytical methods for evaluating that effect. This analysis also provides a tool for estimating the subsidy associated with the allocation of water rights and for determining an appropriate price for water on the LCRA irrigation districts.

Water has been the subject of much theoretical and applied research because its availability can make or break a regional economy. Economic theory of perfectly competitive markets suggests the most efficient allocation of water occurs when those willing to pay the most have access to water. If economic efficiency is a goal, knowledge of water's value indicates how to distribute access to limited water supplies. For example, this information could be used to determine the optimum placement of water development projects. Knowledge of the value of water also provides information on how much to charge those who use the water, and whether or not water development projects are cost effective.

The Value of Water in Competitive Markets

Consumptive uses of water are often allocated according to the category of use. Typical categories include municipal, commercial, industrial, agricultural, and environmental uses. With the exception of environmental uses, the value of water is equal to the consumer's willingness to pay. In municipal uses, water is an end product from which consumers derive direct utility. The value of a unit of water in municipal uses is equal to the utility consumers derive from the use of that unit of water. In commercial, industrial and agricultural uses, water is a factor in the production process. The value of a unit of water is equal to the marginal contribution of that unit of water in production. The value of water in environmental uses is more difficult to evaluate, although several methods exist (Gibbons, 1986). For the purposes of this paper, water allocated to environmental uses is considered unavailable. This is consistent with previous studies which focus only on the portion of water which regulations allow to be allocated among users (Yaron, 1967; Gisser, 1970).

If water is a commodity, the value of water is equal to the consumers willingness to pay, and each consumer is willing to pay more for the first unit of water than for additional units. This pattern of diminishing marginal value of water exists in all categories of water use. A marginal value product curve describes the change in consumers willingness to pay for water. Figure 2.1 provides an example of what hypothetical marginal value product curves might look like in a typical river basin. Any point along the line of the curve represents the maximum amount that any user in that category would be willing to pay for that water. Figure 2.1 also displays an aggregate marginal value product curve. This is the horizontal sum of all three category-specific curves. For example, if the marginal value of water is MV2, and if Q2 units of water are available, municipal users will value Q1 units of water more highly than industrial users. Industrial users will value Q2 - Q1 units of water more highly than the remaining municipal users. Therefore, municipal users will get Q1 units of water, and industrial users will get Q2 - Q1 units of water. Agricultural users do not value water at a level above MV3, and therefore receive no water. In a competitive market, these curves relate directly to the value of any one unit of water.

Figure 2.1 describes how water might be allocated in a competitive market. Other investigators have documented that municipal users place the highest value on the first few units of water (Gibbons, 1986). One reason may be that water is a life requisite, no other activities are possible without it. Agricultural users of water place the lowest value on their first few units of water. The reason is that the economic returns from water are lower in agriculture than in commercial and industrial uses (Kelso *et al.*, 1973). Figure 2.2 displays the aggregate demand curve for water in the same hypothetical river basin. P1, P2, and P3 are possible prices of water. Given a price of P1, industrial and agricultural users would not purchase water because the marginal value product of water in those uses is less than its value in domestic use. Similarly, at price P2, some industrial and most agricultural users would still not purchase water. At price P3, most possible uses are satisfied.

In a perfect market, the equilibrium price is a function of the availability of water and the cost of supplying that water to users. Price will equal the marginal value product of the last unit of water used in each category. The value of water is given by the area above the price line and below the demand curve.

Figure 2.2 shows that if water price in a competitive market is equal to P2, then the value of Q2 - Q1 units of water is equal to the shaded area beneath the demand curve and above the price line. Another perspective can reveal the value of water in a particular use. If water price is P3, and the maximum volume of water available to all users of water is Q3, then the value of water in agricultural uses is equal to the crosshatched area beneath the demand curve and above the price line.

If the price of water rises due to competition among users during a water shortage, marginal users would be the first to loose access to water. In their study of the economic impact of water shortage in Arizona, Kelso *et al.* (1973) found that marginal users in the agricultural category were most critical because, in relation to other users, the volume of water they use is large and the marginal productivity of water is low. In many cases, it is possible to focus an analysis of regional water demand exclusively on this marginal user group because a reallocation of water among users will occur in this portion of the demand curve.

A normative demand function reveals problems associated with the allocation and management of surface water in practice. Price serves as a mechanism for allocating resources to their highest valued use. When surface water is allocated among end users through non-market mechanisms, the allocation is potentially inefficient. When water rights specify the use, the point of diversion, the location of use, and the priority of right, they create a barrier through which price signals cannot travel. As long as sufficient quantities of water are available to satisfy all water rights, no inefficiency exists.

There is a cost associated with any inefficient allocation of water. This may be characterized as either a subsidy to those who use the water in ways that are less productive than the market value of the water, or a cost to others who would have used the water but were deprived of that use. The value of a subsidy is equal to the difference between the price of water in a perfect market, and the productivity of that unit of water. The cost is equal to the difference between the water price and either the potential productivity of a unit of water, or the cost of obtaining alternative supplies of water.

There can be only one efficient price for a certain quantity of water. This price is equal to the marginal value of the last available unit of that water in any category of use. If some users are granted access to water at an artificially low price, they receive an indirect subsidy. Figure 2.3 shows how to evaluate this subsidy. The demand function for water in agriculture has a positive slope rather than a negative slope. This is accomplished by expressing the quantity of run-of-river water available to group 2 as a function of the quantity of water available in the river basin that is not allocated to group 1. Suppose the maximum quantity of run-of-river water available to those that own water rights is Qmax. If all run-of-river water is available, Qmax = (Q1 + Q2), and Q2 = (Qmax - Q1). The variables Q1 and Q2 represent the volume of water allocated to group 1 and group 2 respectively.

Maximum willingness to pay is a function of the quantity of water available. Suppose that group 1 consists of municipal, commercial, and industrial users of water. Their maximum willingness to pay is $P = f(Qmax - Q2) = f(Q1)$. Group 2 consists of agricultural interests. Their maximum willingness to pay is $P = f(Qmax - Q1) = f(Q2)$. At the price P*, water will be allocated so that group 1 receives Q* units of water and group 2 receives (Qmax - Q*) units of water. P* is the efficient price at which the two groups' maximum willingness to pay is equal. The maximum price each group is willing to pay is a function of both the amount of water available and competing demands.

The price P* is the market clearing price for water. At this price, all water in the river basin is allocated to its most highly valued use. However, if agricultural interests have preferential access to water at some below market price, there will be an inefficient allocation of water. The degree of inefficiency will be a function of the marginal cost of diverting that water for irrigation, Pa. Agricultural interests will demand (Qmax - Q1) units of water, and their maximum willingness to pay, Pa, will equal the cost of diverting water. The result is a net loss to the economy in the river basin, and an indirect subsidy to agricultural interests.

The economic cost is given by the shaded area D that is associated with the lost productivity of water. The indirect subsidy to agriculture is given by the sum of the shaded areas A and B. The shaded area A is associated with the benefit of access to an additional (Q* - Q1) units of water that would have been allocated to others in a competitive water market. The shaded area B is the benefit to farmers associated with paying less than the competitive market price for water that would have been used for agricultural purposes anyway.

Inefficiencies can still occur if both groups of users pay only their individual costs of diverting water. For example, if group 2 has a senior water right that allows it to divert water first, and the cost of diverting water is Pa, then the group will divert (Qmax - Q1) units of water. Water users in group 1 will use the remaining Q1 units of water and the preceding evaluation of inefficiencies is still valid. If group 1 has access to stored water supplies at a price above P*, it can be shown that stored water supplies mitigate the inefficiency represented by area D that is associated with group 2's preferential access to water. However, if the cost of the stored water is above the market clearing price P*, there will still be a net loss to the economy in the river basin.

Figure 2.4 displays the demand curve for on-farm irrigation water on a hypothetical irrigation district where farmers have no individual water rights. Suppose this public irrigation district possesses a senior water right within a river basin where river flows are limiting. Also suppose that this irrigation district determines its price on a cost of service basis. P3 is the unit price of water, and Q3 is the quantity of water farmers currently use. P2 represents the highest price farmers would be willing to pay for an additional unit of water at Q2. It is the price they would be willing to pay if they adopted irrigation technologies that increased the value of water in response to local water shortages. For example, if water were distributed among farmers on the irrigation district on the basis of their willingness to pay, rather than the cost of service, farmers would adopt technologies and find substitutes in response to the localized scarcity of water. The point P1 is the highest price that municipal and industrial water consumers would be willing to pay the irrigation district not to divert water under its water rights, therefore making Q1 units of water available for themselves.

When the allocation of water encourages technological inefficiency, the subsidy to irrigators can be divided into two parts. Shaded areas in the Cartesian plane reflect key values of subsidies associated with irrigation district water rights. The sum of shaded area represents the total indirect subsidy to farmers as a result of the current system of water rights and district pricing strategies. The gray shaded portion of the subsidy is due specifically to district ownership of water rights. The crosshatched portion of the subsidy is due specifically to a price for water which is less than the maximum willingness to pay if the quantity of water available were restricted to Q2. As water becomes increasingly scarce this area increases and the total value of the subsidy increases. Similarly, if the price of water on the irrigation district decreases, the area within the crosshatched portion of the subsidy increases; therefore, the value of the subsidy to farmers increases.

Economic Inefficiencies Related to Water Markets in Practice

In practice, the State of Texas does not allocate water rights and water development projects on the basis of economic criteria. With certain exceptions, the state allocates water administratively on a first-come, first-serve basis. To understand how this allocation can be economically inefficient, it is first necessary to understand how the state manages its water resources.

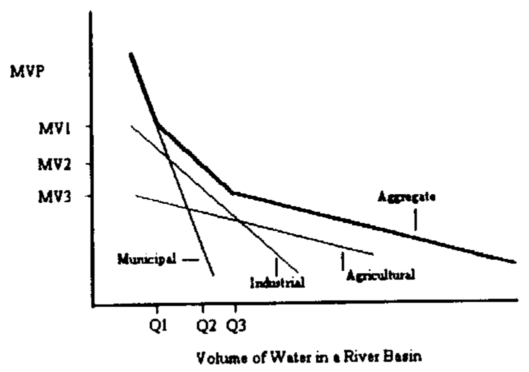
In Texas, water is a commodity. Water rights and water itself may be bought and sold. Water rights allow an owner to divert surface water from a stream, subject to limitations on the volume, the rate of diversion, the purpose, and the location of use. For that individual, the cost of a unit of water is the cost of delivering it to the point of use. Those who do not own water rights must purchase their water from those who own water rights. For these individuals, the cost of a unit of water is the rental rate of that portion of the water right, plus the cost of delivering it to the point of use. In Texas, the Texas Natural Resource Conservation Commission (TNRCC) administers water rights, and monitors the transfer of water rights between individuals. Because the transfer of water rights can have negative impacts on other water rights owners, the TNRCC must approve all market transfers (Griffin and Boadu, 1992).

Access to water under a water right is restricted by the prior appropriation doctrine. This doctrine states that owners of water rights may divert water only if the needs all other water rights owners with a more senior (earlier) priority date have been satisfied. The priority date is the date on which the state granted those water rights. When water is scarce, those users who would apply water to more highly valued uses might be required to defer to those applying water to less valued uses, if the latter user has an earlier priority date.

As a rule of thumb, the State of Texas grants water rights when the flow of water at the point of diversion is sufficient to supply the applicant with at least 75 percent of the volume he requests at least 75 percent of the time (Evans, Interview, January 20, 1994). It follows that if the state has allocated all of the water rights within a river basin, 25 percent of those who own water rights will not have access to water 25 percent of the time. During drought periods, when river flows are lower than normal, those with less-senior water rights will have even less access to surface water. Storage facilities can help alleviate this problem by making water available when it is needed. However, water rights do not typically extend to stored water supplies, and water rights owners must purchase stored water just like those users without water rights.

It is important to distinguish between water rights and water itself. A water right is a capital good that guarantees access to water when it is available. Because in theory a water right is valid in perpetuity, it may be valued in either the short or the long run. When the use of water diverted under those rights is specified, it is possible to calculate and compare the long-run value of water rights in a river basin. However, water rights are not a substitute for water in municipal, industrial, or agricultural uses. When the value of water in environmental uses is excluded from the analysis, water that is not diverted from the stream has no value. Unless a unit of water is stored for future use, its value is a short-run value because any unit of water is only available temporarily as it flows downstream.

Figure 2.1
Hypothetical Marginal Value Product Curves in a Typical River Basin



Note: MVP is the marginal value product of water.

Figure 2.2
Hypothetical Demand Curve for Water in a Typical River Basin

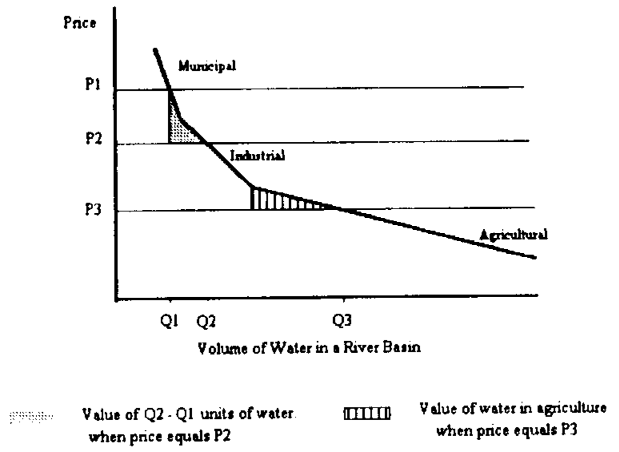


Figure 2.3
Value of a Subsidy in an Efficient Water Market

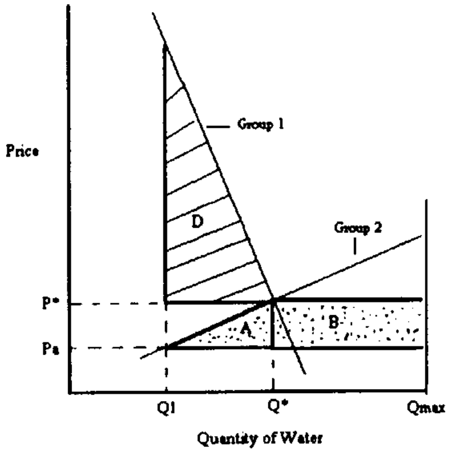
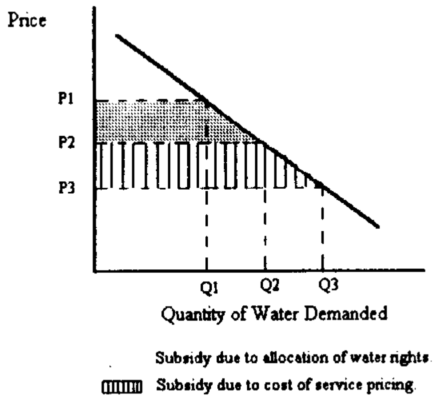


Figure 2.4
Hypothetical Demand Curve for Water on a Public Irrigation District



Methods of Estimating the Value of Water

Gibbons (1986) provides a good summary of techniques for determining the value of water and water demand in municipal, industrial, agricultural, and environmental settings. This discussion will focus on methods of determining the value of water in agricultural uses, and deriving water demand functions from non-market sources.

There are two methods of deriving the demand for irrigation water from non-market sources. Crop-water production functions measure the contribution of water to agricultural production. Farm budget analysis measures the farmers willingness to pay for water. Table 2.1 provides a brief outline of the advantages and disadvantages of each method. Estimates of the value of water may be either average or marginal values, and may be estimated in the short-run or the long-run. In general, those studies which resort to the use of the average value of water do so in response to a lack of information. Marginal values provide more information on how best to allocate water among users. The decision whether or not to calculate short- or long-run values of water is slightly more complex. In the context of a farmer's irrigation and planting decision, short-run values provide a more meaningful measure of the value of water in any one crop year. When making long-term decisions about how to allocate water rights among municipal, industrial, and agricultural uses in the future, or where to construct reservoirs and pipelines, long-run values are more meaningful.

Demand curves appear to provide a simple mechanism for determining the quantity of water farmers in an irrigation area would use at any particular water price. In planning water projects, public agencies and private suppliers of irrigation water can ensure that water sales will cover project costs. Private water suppliers can adjust their prices to maximize profits and state agencies charged with funding irrigation projects can allocate their funds more efficiently if they know the relationship between inter-regional water values.

Several caveats accompany the conceptual simplicity of these models. There is rarely good information on how consumers respond to different water prices because competitive markets for water are uncommon. In the context of agricultural production, water is an intermediate good. As such, its value may only be derived in terms of its marginal value product which is a function of the crop price (Young and Gray, 1982, p.1820). Whether or not the estimated value of water is derived through a crop production function or through farm budget analysis, the value of water and the elasticity of demand will change in response to changing crop prices.

Farmers subjective estimates of what crop prices will be in the future will usually differ from those specified in the model. In addition, farmers will differ in their decisions about what proportion of inputs to use in production, and each farmer will achieve different levels of production. These factors will result in deviations from the projected demand in any one crop season (Flinn, 1969, p.140). Projections of the demand for water are also susceptible to changes in technology, environmental conditions, and institutional factors. These changes will result in year to year deviations from the projected demand.

Within a given season, the demand for irrigation water may be nearly inelastic because farmers have already made their planting decisions. In the face of increasing water prices, farmers will be reluctant to make large adjustments in irrigation intensity or abandon their crops. Therefore, demand models based on crop production functions or farm budgets may be more useful in predicting the effect of changes in the price of water on short-run planting decisions, or on changes in the year-to-year demand for water.

Table 2.1
Methods of Estimating Derived Demand: Advantages and Disadvantages

Model	Advantage	Disadvantage
Production Functions		
Quadratic specification	Models the relationship between water input and yield as determined in experimental fields.	Requires experimental or field data on water inputs and crop yields. Regression line underestimates the production frontier. Underestimates the elasticity of water demand when crop alternatives are present.
Product method	Models the relationship between water input and yield as determined in experimental fields. Incorporates additional information on the sensitivity of yields to the timing of irrigation.	Requires experimental or field data on water inputs and crop yields. Underestimates the elasticity of water demand when crop alternatives are present.
Cobb-Douglas specification	Gives the partial elasticity of output with respect to farm inputs directly and allows calculation of the returns to scale. May be applied to data on either physical farm inputs or on farm production costs. May be applied to individual fields, individual farms, or to farming regions.	Form is inconsistent with the negative marginal product of water observed at high irrigation intensities in experimental settings. Underestimates the elasticity of water demand when crop alternatives are present. Regression line underestimates the production frontier.
Farm Budget Analysis		
Static budget valuation	Computationally simple method of estimating the average value of water.	The crop water requirement is fixed in the farm budget. Provides only a static average value.
Linear programming	Provides a means of estimating either average or marginal values of water. Crop water requirements and water prices need not be fixed in the budget. Incorporates information about crop alternatives, risk, and farmer's reactions to changing farm input or output prices.	Requires detailed knowledge about the irrigation area. Provides marginal values of water on individual farms, but not by crop type if there is more than one irrigated crop on the farm.

There are several examples of attempts to estimate the long-run value of water using derived demand curves (Gisser, 1970; Shumway, 1973; Kulshreshtha and Tewari, 1991). However, there is not much conceptual support for concluding that a static derived demand curve based on a rigid input-output model can adequately capture future changes in technology, input prices, crop prices, environmental conditions, or institutional factors. The fact that many farmers actually make their planting decisions on the basis of anticipated crop prices provides an additional argument for interpreting these models on a short-run basis.

The most reliable interpretation is in the short-run, during which all conditions are relatively predictable. However, even in the short-run, derived demand models may not be useful in predicting farmers immediate reactions to abrupt changes in the price of water or abrupt changes in crop price. In any one year, farmers subjective estimates and farming decisions may be different from those specified in the model. In recognition of this problem, Moore and Hedges (1963, p.131) conclude that, over a longer time span, farmers will adjust to what they should do according to a short-run model as long as the model parameters remain constant. Lacewell and Condra (1976, p.16) came to the same conclusion in their work on the Texas High Plains.

Estimates of the demand for water are location specific. Environmental conditions vary between sites and farmers have different crop alternatives. As a result, farmers' planting decisions and crop production levels will vary, even within a small geographic boundary. Choosing the size of the area under analysis is perhaps more important when using farm budget methods than crop production functions. In general, farm budget methods include assumptions about a larger number of variables, and attempt to model the behavior of farmers on individual farms. Crop production functions only reflect the biological demand for water in relation to crop productivity.

Crop Water Production Functions

Both marginal and average values of water may be measured in terms of water's contribution to crop production. Because these functions are not related to the economics of production, but to the physical demands of the plant, they may not be defined in terms of the short- or the long-run (Gibbons, 1986, p.28). In dryland farming, plants depend on soil moisture and rainfall to meet their evapotranspiration requirements. When these two factors are limiting, the plant suffers from water stress which in turn reduces crop production. Irrigation can boosts production by satiating this demand. For many years, agricultural scientists assumed that each plant's water requirement was fixed (Flinn, 1969, p.128). But small amounts of water stress may have only a negligible impact on yields, and at near optimum levels of irrigation, the demand for water may be near perfectly elastic. As the supply of water decreases, the demand for water becomes increasingly inelastic.

Production functions can assist the farmer in achieving both economic efficiency and irrigation efficiency, but efficiency is a complex variable that consists of several economic and technical factors. Moreover, statistically derived production functions and most derived demand functions do not adequately account for these factors. Therefore, the results have limited usefulness in terms of improving the on-farm irrigation efficiency on either a technical or an economic basis.

When estimating the crop water production frontier from sample farms, the implicit assumption is that farmers *operate* on the production frontier, and that farmers are acting rationally (maximizing profits) with complete information. However, most farms are inefficient and therefore do not operate on the production frontier (McGuckin *et al.*, 1992). Figure 2.5 shows a production frontier and describes each of these inefficiencies. A farm is technically inefficient if the combination of inputs does not achieve the appropriate production level on the frontier.

In Figure 2.5, farm A is both technically inefficient and price inefficient. However, given a technical inefficiency constraint, farm A can still maximize its profits if it meets price efficiency criteria. The farmer must adjust his use of water so that the marginal product of water equals a ratio of water prices to other input prices. He must also produce at a marginal cost that is equal to the crop price. These conditions are referred to as allocative efficiency and scale efficiency respectively. In Figure 2.5, farm B is price efficient, but remains technically inefficient. Farm C is technically efficient because its yields are precisely on the production frontier, but it is economically inefficient. Farm D is both technically and economically efficient.

According to this analysis, the optimum use of water is not the volume of water that maximizes yield, but rather the volume of water that produces a marginal benefit equal to the marginal cost of supplying that water. For the purposes of modelling irrigation water demand, most researchers assume that farmers internalize this condition as a constraint in making their irrigation water management decisions.

Experimental evidence has been used to argue that, within a region, the slope of the crop-water production function is constant across experimental fields with different levels of soil fertility, and across years with different environmental conditions, including weather and pest infestation. Within a region, quadratic production functions will vary in their elevation on the y-axis (crop production), but not in the slope of the parameter estimates (Yaron, 1967). This stable parameter simplification allows farmers to optimize production if they know how much water is needed, and use the appropriate combination of farm inputs. Given an optimum volume of water, production across farms will still vary as a result of differences in the input mix.

Marginal values of successive units of water plotted against volume is a demand curve for water. However, deriving the demand function from the production function directly assumes that farmers have no crop alternatives. The existence of crop alternatives will increase the elasticity of demand within a region. If the existing crop mix is known, the appropriate production functions may be weighted and added to represent the on-farm demand for irrigation water for that growing season.

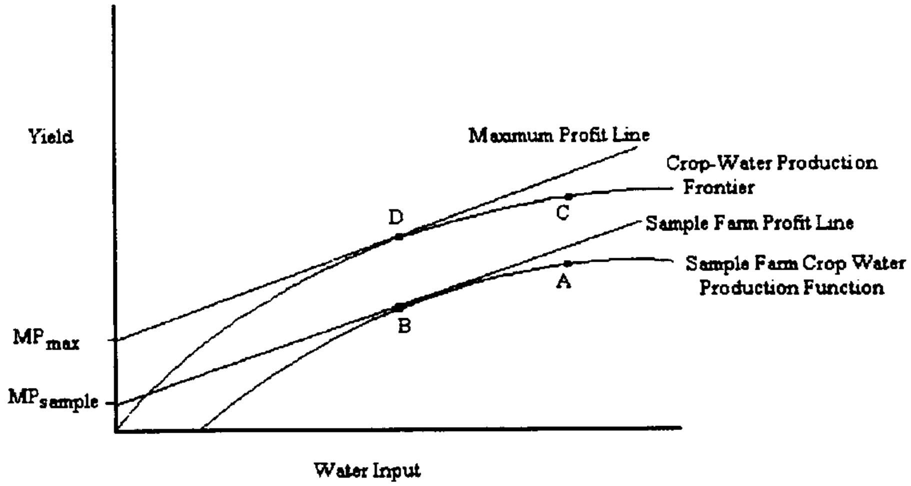
Equation 2.1 presents a simple crop water production function. The model states that yield (crop production per acre of land under cultivation) is a function of the amount of water the farmer applies to the field:

$$Y_k = \beta_0 + \beta_1 W_k + \beta_2 W_k^2 \qquad \textbf{(Eq. 2.1)}$$

Y	expected yield
W	crop water requirement
k	an index of crop type
β	parameters estimated by regression

In practice, the variable W represents either actual evapotranspiration divided by potential evapotranspiration or the total volume of water used in production. In many cases, these functions include other variables related to plant growth such as fertilization and weather. Those equations based solely on evaporation ignore the concept of irrigation efficiency and are therefore less useful in estimating water values (Gibbons, 1986).

Figure 2.5
The Relationship Between Economic and Technical Efficiency on Hypothetical Farms



A	Technically and economically inefficient
B	Technically inefficient
C	Economically inefficient
D	Technically and economically efficient

MPmax	Maximum marginal product
MPsample	Sample farm marginal product

Since the timing of water applications is often a critical factor in production, more sophisticated analyses incorporate information on both the time and volume of water applied relative to growth stages. Equation 2.2 presents a Jensen growth-stage production function in which a shortage of water in one period can have differential effects on production (Water Resources Management Incorporated, 1992). The model states that yield is a product of the ratio of actual evapotranspiration to potential evapotranspiration in defined growth stages.

$$\frac{Y}{Y_m} = \prod_{i=1}^{s} \left(\frac{W_i}{W_{m\,i}} \right)^{\lambda_i} \qquad \textbf{(Eq. 2.2)}$$

Y	the total yield for all growth stages
Y_m	the maximum yield under full irrigation
W_i	water applied in growth stage i
W_m	the water requirement under full irrigation in growth stage i
i	an index of growth stage
s	the number of growth stages
λ_i	an empirical water-response sensitivity coefficient specific to growth stage i

One drawback to the quadratic and product methods is that both require data from experimental or field observations. These data are rarely available. Some researchers have resorted to estimates of the ratio of actual to potential evapotranspiration to explain the ratio of actual to potential yields. Kulshreshtha and Tewari (1991) used the sum of residual soil moisture and the volume of irrigation water applied to estimate actual evapotranspiration. However, the authors used these estimates to establish the optimum volume of water required by crops, not as a means of imputing the marginal value of water directly. Nevertheless, the use of non-experimental data to estimate yields using crop water production functions reduces both the validity and the reliability of these estimates.

The Cobb-Douglas production function is an alternative to quadratic and product methods. The independent variables in the Cobb-Douglas equation are some substitutable combination of farm inputs. From the economist's perspective, this is a more intuitively satisfying alternative because it recognizes that water does more than satisfy evapotranspiration requirements. Water can serve as a substitute for other farm inputs, and this may be more efficient if the cost of the water is less than the alternative input. The Cobb Douglas production function is particularly useful because it provides information on the partial elasticity of yield with respect to individual farm inputs.

Ruttan (1965) modelled the demand for irrigated acreage for agricultural regions in an attempt to project future irrigation water demands in regions within the United States. Equation 2.3 presents his specification of the Cobb-Douglas production function. The equation states that irrigated crop yield within a region is equal to the area of land under irrigation times the operating expenses for farms in that region.

$$Y = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \qquad \textbf{(Eq. 2.3)}$$

Y	value of farm products sold in the region
X_1	number of acres irrigated in the region
X_2	regional farm operating expenses
β	parameters estimated by regression

Equation 2.3 may be transformed to a linear equation and estimated by ordinary least squares regression. By themselves, the parameters β_1 and β_2 represent the partial elasticity of yield with respect to inputs. The sum of the parameter estimates β_1 and β_2 gives the total elasticity of yield with respect to all inputs. The elasticity of yield is the proportional change in yield with respect to a proportional change in inputs. A sum of parameter estimates greater than one suggests increasing returns to scale and a sum less than one suggests decreasing returns to scale.

Equation 2.4 shows how to derive the marginal physical product of inputs from equation 2.3 once the parameter estimates are known. The equation states that the marginal physical product of irrigated land is equal to the yield per-acre times the partial elasticity of yield with respect to acreage:

$$\lambda_L = \left(\frac{Y}{X_1}\right) \beta_1 \qquad \textbf{(Eq. 2.4)}$$

λ_L	marginal physical product of irrigated land (unrelated to λ in Eq. 2.2)

In this model, the water requirement is fixed on each acre. The variable λ can be converted to the marginal physical product of water by substituting the total water requirement for the number of irrigated acres:

$$\lambda_W = \left(\frac{Y}{\psi X_1}\right) \beta_1 \qquad \textbf{(Eq. 2.5)}$$

λ_W	marginal physical product of irrigation water
ψ	crop water requirement on one acre

Ruttan's Cobb-Douglas model is appropriate if irrigation water is a strict complement to irrigated land, and the researcher assumes a fixed water requirement. However it provides no information on what might happen to crop yield if the level of irrigation intensity were altered. Economic theory and empirical field observations suggest that water has a diminishing marginal value in production. Because the model provides no indication of what an optimum level of irrigation intensity might be, and crop yields vary with irrigation intensity, the demand for water is a function of the demand for crop output, not the demand for land (Ruttan, 1965, p.73-5). Furthermore, this production function relies on financial data on farm production, and does not describe the physical relationship between farm inputs and farm outputs. Therefore, it requires assumptions about farmer behavior (Moore *et al.*, 1992, p.17).

Moore *et al.* (1992) developed an alternative Cobb-Douglas specification using cross-sectional data from the Department of Agriculture's Farm and Ranch Irrigation Survey. This model states that crop yield is a function of the amount of water applied, rainfall, cooling degree days, and the amount of land area under cultivation:

$$Y = \beta_0 X_1^{\alpha} X_2^{\beta_1} X_3^{\gamma} X_4^{\delta} e^{\sum_{i=1}^{n} \rho_i z_i + \epsilon_1} \qquad \textbf{(Eq. 2.6)}$$

Y	output per-acre
X_1	volume of irrigation water used in production
X_2	rainfall per-acre of irrigated land

X_3	cooling degree days
X_4	area of land under irrigation
$\alpha, \beta, \delta, \gamma, \rho$	parameters estimated by regression

The equation is linear in the logarithms. The parameter β_0 is the y-intercept, α is the partial elasticity of yield with respect to irrigation water inflows, β_1 is the partial elasticity of yield with respect to rainfall, and γ is the partial elasticity of yield with respect to cooling degree days. The parameter estimate δ is the returns to scale with respect to farm size. The variable z_i in the exponential function is a vector of n qualitative variables representing irrigation technology, water management, farm structure, climate, and soil quality. It is accompanied by a vector of parameter estimates, ρ_i. Qualitative variables are specified as an exponential series because they are not variable inputs in the short-run context of this model. The value of the parameter estimate ρ_i indicates the marginal contribution of farm characteristic z_i on crop yield.

Because the per-acre specification is algebraically derived from farm-level data, the parameter estimate for land, δ, measures returns to scale rather than the partial elasticity of yield with respect to land, ϕ. By definition, returns to scale is equal to the sum of all partial elasticities:

$$1 + \delta = \alpha + \beta_1 + \gamma + \phi \qquad \textbf{(Eq. 2.7)}$$

ϕ	partial output elasticity of land

All other parameters are as previously defined. From this it can be seen that the output elasticity of land is contained in the returns to scale term. The output elasticity may be isolated by rearranging equation 2.7 so it expresses the output elasticity of land (Moore *et al.*, 1992, p.18):

$$\phi = -\alpha - \beta_1 - \gamma + 1 + \delta \qquad \textbf{(Eq. 2.8)}$$

The Cobb-Douglas specification is useful because it provides information on both returns to scale and output elasticities of farm inputs. The authors note that for most crops the returns to scale, δ, are consistently close to 1.0. These conclusions support the use of a constant returns to scale assumption in many econometric models of irrigation water demand. Knowledge of the output elasticities of different farm products enables the researcher to calculate the marginal rate of technical substitution (MRTS) between farm inputs.

Equation 2.9 defines the MRTS between land and water. Farmers may optimize their combination of farm inputs if the prices are known. Equation 2.9 states that the tradeoff between the water land is equal to the irrigation intensity (acre-feet of water per-acre of land) times a ratio of the output elasticities:

$$\mathrm{MRTS} = \left(\frac{-\phi}{\alpha}\right)\left(\frac{X_1}{X_4}\right) \qquad \textbf{(Eq. 2.9)}$$

MRTS	marginal rate of technical substitution
ϕ	output elasticity of land
α	output elasticity of water
X_1	amount of water used in irrigation
X_4	amount of land irrigated

When specified on a per-acre basis, equation 2.6 describes how much additional land a farmer would need to cultivate in order to maintain his total yield if he were required to reduce his irrigation intensity.

Despite its advantages, the Cobb-Douglas specification does not fully describe agricultural principles of irrigation. Unlike the quadratic specification, the Cobb-Douglas never reaches a maximum, and there is no negative marginal product for irrigation water. This is important because experimental evidence shows too much water can reduce yields. However, when the researcher's objective is to evaluate economic rather than biological parameters, and the assumption is that farmers maximize profits, this problem is irrelevant because maximum profits will not occur in the range of negative marginal product (Moore *et al.*, 1992, p.27). For example, Figure 2.5 shows a stylized quadratic production function. All farmers could apply more water to their crops. However, this would cause them to move along the production function and away from the point of tangency with the profit line. As the amount of water applied to the field increases, yield decreases. No rational farmer would apply water to a crop if it would reduce yield.

Farm Budget Analysis

When field data on the crop-water relationship are not available, farm budget analysis provides an alternative to statistical production functions. Farm budgets include information on the cost and combination of inputs required to achieve a certain level of production, and the returns from farming activities. Farm budgets are in essence a static production function. When all farm inputs other than water are valued at their marginal value product, the difference between variable production costs and farm revenue is a measure of the value of water applied (Young and Gray, 1985). This value is referred to as the farm budget residual, and may be used to calculate the average value of water when the quantity of water is known. The returns to farming activities represent the farmer's maximum ability to pay, and can be interpreted as willingness to pay. Linear programming methods, discussed below, provide a means of determining the marginal value of water from farm budgets.

Farm budgets may be used to determine short-run and long-run values of water. When the budgets include both variable and fixed costs, the estimate is a long-run value of water. The estimate is a short-run value when the budget includes only variable costs (Shumway, 1973; Kulshreshtha and Tewari 1991). Some authors regard short-run values as more appropriate in the context of estimating irrigation water demand because changing crop prices, irrigation technologies, and environmental conditions make statements about the future questionable (Flinn, 1969).

Farm budget estimates may overstate the value of water because they include no information on technical or economic efficiency (Kulshreshtha and Tewari, 1991). Young and Gray (1985) also caution that the residual method of valuing water may result in an overestimate of water's true value when the opportunity costs of unpriced factors of production such as labor and capital are excluded from farm budgets. Gisser (1970) suggests that excluding these costs from the analysis may be justified when estimating an extremely short-run value for water because the value of land in farming regions and the availability of alternative employment for farm managers is low.

Shulstad et al. (1982) used the farm budget residual to estimate the relative value of water among farming regions in Arkansas. They conclude that the difference between the residual for irrigated and dryland farming operations, divided by the amount of water used in irrigation, represents the average value of water. For crops such as rice dryland farming is not an alternative means of production. In these cases, profits from the most remunerative non-irrigated crop alternative to rice represent returns to dryland farming. The authors conclude that these estimates of water value may be used to allocate water among farming regions, evaluate the potential transfer of water from one region to another, and locate water development projects.

Linear programming methods estimate the static normative demand for irrigation water. The model is static because farm inputs are fixed in the model budgets, and is normative because the budgets reflect what farmers should do to maximize profits, not what they actually do. It expands on the concepts of the value of water by allowing the researcher to vary the price of water, and estimate water use under specified conditions. In contrast, Shulstad's average values discussed above say nothing about how farmers will alter water use in relation to changing water prices.

Linear programming methods optimize farm profit by adjusting crop mix subject to farming constraints. Given a single farm with fixed water requirements and fixed production levels for each crop, the quantity of water used is a function of crop mix. As the price of water increases, the farmer chooses an appropriate crop mix to maximize profits. Biological and economic considerations can be incorporated into the model by limiting the maximum acreage of individual crops within the farm.

The water requirement for each crop may be either fixed or variable. If the crop-water relationship is known, the model may incorporate crop response to different levels of irrigation intensity (Flinn, 1969). When this information is not available, the average value of water is fixed in the farm budget residual, and the volume of water and level of production remain constant for each crop. As the price of water increases, crops go out of production if more remunerative crop alternatives are available. The result is a stepped demand curve over a range of water volume. Each transition point is a corner on the demand schedule, and represents the highest possible water cost for an individual crop.

The constraints in the linear programming model should reflect the actual conditions in the study area. If a study area is homogenous, the model need not distinguish between farms and analysis can be done on an acre-by-acre basis (Gisser, 1970). Farms may vary in size, but will exhibit constant returns to scale and a fixed proportion of inputs for each crop.

Models of heterogenous farming areas are more complex and it is rarely feasible to analyze and model each individual farm within a diverse irrigation area. In this case, farms may be grouped into farm types by physical characteristics such as soil type, farm size, and preferred crop mix as well as characteristic differences such as cultural orientation and farming practices between farmers. For a heterogeneous farming region, demand schedules are estimated for each farm type and weighted in terms of the prevalence of that farm type in the region. The horizontal sum of all these demand schedules represents the demand schedule for the region as a whole.

Three sources of error can bias linear programming results. These are specification error, sampling error, and aggregation error (Flinn, 1969, p.130). Specification error results from problems in adequately describing the conditions faced by farmers in the region, the objectives of each farm firm, and the potential decisions of each farmer. Sampling error refers to problems in collecting information on the conditions faced by each farm firm in the region. Aggregation error refers to the difference in the horizontal sum of demand functions for individual farm units and the sum of demand functions for model farm types.

Aggregation error is probably the most difficult problem with respect to linear programming estimates because each farm faces a unique set of conditions, and each operator makes individual decisions about farm management. Flinn (1969, p.130) suggests two ways of minimizing aggregation error. First, farms should be grouped in terms of the most limiting resource in the production process, and second, farms with similar patterns of output response to price change should be grouped together.

Common assumptions of linear programming models are that the market for farm products is perfectly elastic, and that the factor input ratios do not change in response to changes in the price of water. A perfectly elastic market for farm products indicates that crop prices do not change as crop production decreases with acreage in response to increases in the price of water. This may not be an unreasonable assumption when working in small areas that serve much larger markets.

Constant factor input ratios reflect a much stronger assumption. Economic theory suggests that the input ratio will equal the ratio of the input prices. As the price of water increases, rational farmers should adjust by finding substitutes for water. However, input ratios are fixed in the budgets and farmers cannot adjust inputs within the model. If the price of farm inputs or farm products changes, the analysis may no longer be valid (Shumway, 1973; Lacewell *et al.*, 1974).

Applications of Linear Programming Techniques

Knowledge of irrigation water demand provides information on not only the economic efficiency of a particular water development project, but also on the viability of proposed water projects. From the variety of literature available, it is clear that many possible formulations of the problem exist, and such analyses may be either normative or positive. Moore and Hedges (1963) developed a linear programming model for irrigation water in Tulare County, California, to evaluate the feasibility of a proposed water development and to project revenues for the development. They also suggest that public and private water districts would find such a curve useful in establishing a variable price for water.

Yaron (1967) conducted a similar study in Israel in the attempt to estimate an efficient allocation of water which had not been previously assigned through water rights. He suggests that the larger the region under analysis, the more complex the objective function must be in order to meet the conditions of economic efficiency. He also stresses that, to be a useful tool, the analysis must focus only on that portion of the available water for which farmers actually compete. Institutional constraints, such as the prior allocation of water rights among farmers, must be incorporated in the model. Following the concept of diminishing marginal value of water, such considerations would result in lower estimates of the value of water, and perhaps even a tendency to allocate marginal water supplies among those farmers without existing water rights.

Flinn (1969) used linear programming procedures to estimate a demand function for the Yanco Irrigation Area in Australia. He notes that the crop water requirement varies over the growing season, and that the demand curve within a region will have different elasticities during different periods of the growing season. Accordingly, the author constructed separate demand curves for three periods during the growing season on each model farm. The horizontal sum of these curves represented the demand for water on that model farm over the entire growing season. The horizontal sum of seasonal demand for all farm models, when weighted appropriately, represents the demand for water in the region.

In his study of agriculture in the Pecos River Basin of New Mexico, Gisser (1970) used linear programming methods to estimate the future demand for imported water. His model incorporated the effects of both varying levels of irrigation intensity and water salinity on crop production. This study assisted policy-makers in determining the appropriate quantity of water to import and the appropriate price to charge while simultaneously maintaining efficient use of existing groundwater supplies.

Kelso *et al.* (1973) analyzed the effect of water shortage on the regional economy in Arizona by modelling agricultural water demand on irrigation districts within the state. Their primary assumption was that continued growth in the state's economy, and the difference in the marginal value of water between the non-agricultural and the agricultural sectors, would result in a transfer of water away from agriculture towards urban and industrial centers. Extensive research on the supply of water within the state, and the demand for water among different farms and farming regions provided the basis for estimating that impact.

Shumway (1973) estimated an optimum price for irrigation water on the west side of the San Joaquin Valley in California to meet regional crop production targets and reduce the total value of the state's subsidy to agricultural producers. In the Texas High Plains Region, Lacewell and Condra (1976) estimated the long-run demand for irrigation water. This analysis differs from others of its kind in that the authors considered the effect of projected changes in the price of agricultural inputs. Gisser et al. (1979) analyzed the effect of competition for water from hydro-electric power plants in New Mexico. Kulshreshtha and Tewari (1991) estimated both short-run and long-run values of irrigation water on an irrigation district in Saskatchewan, Canada, to assess the potential for future public investment in water development projects.

This project uses farm budget analysis and linear programming methods to derive the demand for irrigation water on two rice irrigation districts in the Texas Gulf Coast region. The objective is to estimate the subsidy to farmers which arises as a result of district ownership of senior water rights in the Lower Colorado River Basin. Since 1988, the Lower Colorado River Authority (LCRA) has implemented a water conservation program to reduce surface water diversions. Knowledge of the source of economic inefficiencies related to water diversions will assist LCRA in more efficiently distributing its water conservation effort between program components and in determining the benefits associated with its investment in water conservation. Knowledge of the demand for irrigation water on each district will also assist the LCRA in replacing its fixed per-acre irrigation rate with a volumetric rate structure. From the analysis presented in the following chapters, LCRA should be able to determine what price of water would both enable it to meet the fixed costs on the irrigation districts and encourage farmers to be conservative in their use of water.

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Chapter 3
LCRA Rice Irrigation Districts

This chapter describes the irrigation districts and factors that influence on-farm demand for water. The first section discusses the Lower Colorado River Authority and water management in the Lower Colorado River Basin. The following sections identify key factors that influence farm water requirements, and discuss the methods used to estimate their effect. Factors of water demand include climatological factors, physical factors, crop price, crop alternatives, water management practices, and second cropping rate. The data and estimates presented in this chapter are the parameters used in the linear programming model.

The Lower Colorado River Authority (LCRA) and county agents at Texas Agricultural Extension Service offices in Columbus, Wharton, and Bay City provided much of the data. Until 1992, LCRA collected information only on total water diversions, and first and second crop rice acreage on each district. In 1992, the LCRA also began collecting data on the volume of water deliveries to individual fields. This information provided data for calculating individual farm water requirements. The Texas Agricultural Extension Service (TAES), US Soil Conservation Service, and Texas A&M University provided the information needed to make statements about farm water requirements under different technological and economic conditions. Detailed information on the field characteristics, operations, and crop production on individual farms was not available for this study. However, TAES model farm budgets provided an approximation of farming operations and crop production in each county.

The Lower Colorado River Authority

LCRA is a state-owned river authority charged with managing land and water resources within the Lower Colorado River Basin, a ten county area in Central Texas. LCRA operates under the statutory authority of the Texas state administrative codes and the LCRA Act of 1934 which established the agency as a conservation and reclamation district. The agency manages a system of six reservoirs, the Highland Lakes, with a storage capacity of approximately 1.5 million acre-feet and a firm yield of approximately 445,000 acre-feet a year (LCRA, 1988). Although the LCRA receives revenues through stored water sales within the river basin, it depends mostly on revenues from its coal and hydroelectric power generation facilities that produce electricity for wholesale to other public utilities throughout Texas. Stored water supplies in the Highland Lakes are an important addition to the natural flow of the Lower Colorado River because the state has allocated all surface water rights within the basin, and run-of-river flows are not sufficient to meet municipal, industrial, and agricultural demands.

The LCRA owns and operates the Lakeside and Gulf Coast Irrigation Districts. The LCRA purchased the Lakeside District in 1983, and the Gulf Coast District in 1960. Both district own senior water rights to run-of-river water flows in the Lower Colorado River. The volume of Lakeside's water right is 131,250 acre-feet, and the volume of Gulf Coast District water rights is 262,500 acre-feet. The districts divert and sell water to farmers for rice irrigation. Each year, these two districts account for about half of all consumptive uses of surface water within the basin. Table 3.1 shows the total irrigation district diversions and the percent of total diversions within the river basin for each year since 1980. For example, in 1980, Lakeside District diverted 139,797 acre-feet of water from the river. This was 18.98 percent of all consumptive municipal, industrial, and agricultural water diversions from the river in 1980.

Lakeside and Gulf Coast Irrigation District water rights have priority dates of 1901 and 1900 respectively. Because their water rights possess a more senior priority date than most other water rights in the basin, the irrigation districts have preferential access to run-of-river water. When run-of-river flows cannot satisfy the total demand within the basin, those with less-senior water rights may not have access to run-of-river flows. Those who wish to divert water must purchase stored water from the Highland Lakes. For this reason, most major water rights owners maintain long-term firm water contracts with the LCRA. These contracts guarantee access to specified quantities of stored water supplies. In 1992, 76 percent of firm water supplies were committed under LCRA water contracts (Crittendon, Interview, January 25, 1993). The cost of maintaining these contracts is $50.50 per acre-foot per year, with an additional $50.50 for each acre foot which the contract holder actually diverts.

When the demand for water exceeds the run-of-river flow and the irrigation districts are unable to divert water under their own water rights, they also must purchase stored water from the Highland Lakes. However, the districts do not maintain firm-water contracts. Instead, each district has access to unspecified quantities of interruptible stored water with which to supplement water diverted under their own water rights. The districts purchase this water for $4.50 an acre-foot, which is LCRA's operational cost of supplying one acre-foot of interruptible water (Taylor, Interview, January 25, 1993). The cost of interruptible water is much less than firm water because LCRA does not guarantee its availability. During drought periods, when the level of water in the reservoirs drops below a certain point, the LCRA curtails its interruptible water sales.

The LCRA has operated under this system of firm water and stored water since 1989, but LCRA has never found it necessary to curtail the sale of interruptible water. As of 1993, LCRA only sells interruptible stored water for agricultural uses. While it is legally possible to deprive farmers of their long-established access to stored water during a drought period, the political difficulties associated with this decision might make implementation an unfeasible alternative for the LCRA board (McGarity, Interview, October 20, 1993). Therefore, it may not be possible to equate the discounted cost of interruptible water with the risk associated with its potential curtailment. Table 3.2 lists each irrigation districts' interruptible stored water diversions since 1989. For example, in 1989, Lakeside Irrigation District diverted 78,717 acre-feet of stored water. This was 59.4 percent of all surface water diversions on that district.

Although LCRA owns the irrigation districts and their water rights, those water rights do not include the authority to divert and use this water for non-agricultural purposes. In addition, LCRA may not market this water outside of the district boundaries. However, ownership of the districts gives LCRA the means to implement agricultural water conservation programs to increase the supply of water in the basin. Since 1988, LCRA has pursued a water conservation program to reduce the demand for water through education, canal rehabilitation, and water measurement. A 1993 study showed that, with the exception of canal rehabilitation on the Gulf Coast District, these efforts had not contributed to a measurable decrease in the total demand for water on the districts (Lyndon B. Johnson School of Public Affairs, 1995).

Operational water losses, leaks, and seepage of water from the unlined canal systems contribute to the total demand for water on the irrigation districts. Although both irrigation systems are about one-hundred years old, canal maintenance on Lakeside District has been more intensive than on Gulf Coast District. To address this problem on Gulf Coast District, LCRA began a canal rehabilitation program in 1988. Canal rehabilitation has succeeded in reducing the annual demand for water on Gulf Coast District by approximately 57,000 acre-feet (Lyndon B. Johnson School of Public Affairs, 1995).

Table 3.1
Total Water Diversions and Percent of Total Consumptive Uses

	Lakeside District Water Diversions		Gulf Coast District Water Diversions	
	(acre-feet)	(percent)*	(acre-feet)	(percent)*
Year				
1980	139,797	18.98%	236,801	32.17%
1981	116,735	17.05	302,364	44.15
1982	142,957	19.48	240,485	32.78
1983	108,019	19.50	186,389	33.65
1984	149,698	20.28	245,339	33.24
1985	109,809	16.94	179,766	27.73
1986	92,811	15.47	212,426	35.41
1987	115,825	20.15	187,657	32.66
1988	160,349	20.44	235,136	29.98
1989	133,186	18.11	199,522	27.14

Sources: Texas Water Commission. 1993. "Reported Surface Water Use for Colorado River Basin, All Rights and Claims," Austin, Texas. (Computer Printout.); and Lower Colorado River Authority. 1993. "Irrigation Water Diversions," Austin, Texas. (Photocopy.)

Note: (*) Percent of total consumptive uses of surface water in the Lower Colorado River Basin. Includes both run-of-river and stored water diversions.

Table 3.2
Interruptible Stored Water Diversions on LCRA Irrigation Districts

	Lakeside District Stored Water		Gulf Coast District Stored Water	
	(acre-feet)	(percent)*	(acre-feet)	(percent)*
Year				
1989	78,717	59.40%	71,920	36.15%
1990	64,163	43.18	71,229	45.83
1991	67,273	56.17	16,857	13.05
1992	15,748	11.61	0	0.00
1993	52,981	54.92	56,802	53.84

Source: Lower Colorado River Authority. 1993. "Total and Stored Water Diversions by Lakeside and Gulf Coast Irrigation Districts." Austin, Texas. (Computer Printout.)

Note: (*) Percent of total district diversions that are stored water.

Table 3.3
1993 Volumetric Irrigation Water Rates

	Lakeside District		Gulf Coast District	
	1993 Rate	1992 Rate	1993 Rate	1992 Rate
Variable Charges				
Volume Charge per acre-foot:	$9.25	-	$5.40	-
Stored Water Charge per acre-foot:	5.27	-	5.27	-
Fixed Charges				
Per-Acre Charge				
Irrigated Rice:	$42.50	$92.43	$49.50	$87.26
Irrigated Turf Grass:	N/A	N/A	22.20	29.30

Source: Lower Colorado River Authority. 1992. "Board Meeting Agenda." Austin, Texas. (December, 16.)

Under the water measurement program established in 1993, farmers must pay for both the volume of water they use and the number of acres they irrigate. Volumetric water pricing contrasts with the district's pre-1993 practice of charging farmers a fixed fee for irrigation based only on the amount of land they irrigate. LCRA designed the new rate structure on a cost-of-service basis. Table 3.3 displays the new rate structure for both districts. Farmers pay a diversion charge for each acre-foot of water that they use. This variable rate covers the marginal cost of supplying water. The difference in the volumetric rates between the two districts is due to the fact that Lakeside District must lift its water a second time in each of its main canals.

When farmers receive interruptible stored water from LCRA reservoirs, as determined by the LCRA's daily water allocation model, a $5.27 surcharge accompanies the diversion charge. The surcharge represents LCRA's standard interruptible stored water rate ($4.50) plus a cost factor of 17 percent of the interruptible stored water rate (Taylor, Interview, January 25, 1993). Operational water losses are those water losses which occur between the irrigation district's diversion point on the Colorado River and farm delivery structures. The 17 percent cost factor is not based on empirical estimates of canal efficiency, but rather, is LCRA's best estimate of canal efficiency.

The final element of LCRA's volumetric rate structure is a per-acre charge which, like the old rate, is based strictly on the number of acres a farmer irrigates. This charge reflects the fixed costs of operating the districts regardless of the actual amount of water delivered in any particular year. The lower per-acre charge on Lakeside District is due to the somewhat more efficient labor costs on that district.

LCRA does not calculate the stored water diversions until after the districts divert water from the river, and the irrigation districts charge farmers for stored water on the basis of the proportion of total diversions that LCRA determines are stored water. Because rainfall has a significant effect on the volume of run-of-river flows, the proportion of stored water which the districts divert varies from year to year. In addition, stored water diversions increase as the rice season progresses because run-of-river flows decline in response to decreases in the amount of rainfall between March and October. Because farmers make their water management decisions on the basis of the price of water, but do not know the actual volume of stored water they purchase, they must make their decisions on the basis of an anticipated water price. Historical data on the proportion of monthly diversions that LCRA determines are stored water provides a means of estimating the probability that a farmer will draw stored water.

Annual Rice Acreage Requirements

Rice is the principal crop on the irrigation districts, and is the only crop which farmers consistently irrigate. The standard practice among farmers is to rotate their rice crop among their fields on a three year basis. During the two year interim, farmers usually leave their rice fields fallow, but may also raise cattle on that land. Not all the land on the districts is used in rice production. Where possible, farmers also raise cattle, corn, cotton, sorghum, soybeans and, on Gulf Coast District, turf grass. With the exception of turf grass, these crops are normally grown under dryland conditions. Farmers choose to irrigate these crops only during extreme drought.

For farmers that participate in the Agricultural Stabilization and Conservation Service's (ASCS) price support programs, rice is the most remunerative crop alternative. Because rice prices fluctuate from year to year, farmers who do not participate in these programs take a considerable risk in terms of recovering the costs of production. In many cases, banks are reluctant to provide loans to farmers who do not participate (Humphrey, Interview, December 14, 1992). Farmers who participate in the programs are limited in the amount of land they can put into rice production by their base acreage allotments. ASCS establishes base acreage limitations on the basis of historical production records on the land.

Base acreage allotment are tied to specific land areas, not farming entities. In addition to base acreage allotments, the ASCS also uses mandatory and optional set-aside requirements to reduce the total area of land on which farmers plant rice. With limited exceptions, the variety of crops which farmers may plant on base acreage which they have set-aside is restricted by the ASCS. In choosing the proportion of their base acreage to set-aside, farmers respond primarily to the anticipated price of rice at the time of harvest relative to guaranteed deficiency payments from the ASCS (Engbrock, Interview, December 14, 1993).

Rice acreage on each irrigation district fluctuates because market prices and ASCS farm programs fluctuate. Therefore, it is not possible to make a year to year prediction of the exact rice acreage on each district. Table 3.4 lists the total amount of rice acreage planted on the irrigation districts in each year since 1968. For example, in 1968, farmers on Lakeside District irrigated 25.7 thousand acres of rice during the first crop period, and 23.4 thousand acres of rice during the second crop. The drop in rice acreage that occurred between 1980 and 1982 is the result of changes in ASCS farm programs.

Given the annual rice acreage on the districts in past years, and ASCS farm program parameters, ordinary least squares regression provides a means of estimating first crop acreage in the upcoming crop season. Estimates may be made in January when ASCS makes program parameters public. Equation 3.1 gives a time series model of first crop rice acreage on each district. The model states that first crop acreage is a function of the mandatory ASCS set-aside requirement and ASCS advance deficiency payments.

$$A_t = \beta_0 + \beta_1 Y_t + \beta_2 M_t + \beta_3 D_t \qquad \textbf{(Eq. 3.1)}$$

A	first crop acreage (thousand acres)
Y	a trend variable for crop year $Y = (1, 2, 3, ..., n)$
M	maximum fraction of base acreage allowed by ASCS in that year (a fraction)
D	advance deficiency payment that ASCS gives farmers at the time they state their planting intentions for the coming year (dollars per acre)
t	an index of crop year $t = (1, 2, 3, ..., n)$
β	coefficients estimated by ordinary least squares regression

For those years prior to 1982 when the current ASCS programs went into effect, the variable M equals 1 to indicate there was no limit on the acreage a farmer could plant, and the variable D equals zero, to indicate that farmers did not receive advance deficiency payments. Table 3.5 shows the regression results. Figures 3.1 and 3.2 graph the acreage predictions on Lakeside and Gulf Coast Districts respectively.

Table 3.4
Rice Acreage Irrigated with Surface Water on LCRA Districts
(Thousand Acres)

	Lakeside District		**Gulf Coast District**	
Year	**First Crop**	**Second Crop**	**First Crop**	**Second Crop**
1968	25.7	23.4	41.2	27.9
1969	25.7	23.2	38.8	34.7
1970	22.6	22.2	34.6	27.5
1971	24.0	22.2	35.0	30.2
1972	25.4	23.5	35.2	31.0
1973	26.1	15.7	42.5	22.8
1974	27.1	25.6	40.4	36.0
1975	26.1	24.9	41.6	38.5
1976	25.7	25.1	38.1	32.5
1977	26.2	25.4	36.2	30.1
1978	27.4	27.0	42.8	38.6
1979	26.7	24.7	40.9	35.2
1980	28.2	27.5	42.7	39.7
1981	28.3	27.2	41.7	40.8
1982	27.2	26.6	39.3	34.6
1983	21.0	20.2	21.7	16.1
1984	25.4	23.1	31.9	21.1
1985	23.3	17.0	24.4	8.4
1986	21.0	19.2	21.6	18.1
1987	18.6	18.1	21.1	16.2
1988	26.7	23.9	33.7	15.3
1989	25.1	23.2	25.8	16.9
1990	26.7	23.9	28.9	12.9
1991	26.7	26.0	28.2	9.3
1992	26.9	22.3	27.2	8.7
1993	21.3	12.7	21.7	4.2

Source: Lower Colorado River Authority. 1992. "LCRA Irrigation District Acreage and Water Use." Austin, Texas. (Computer File.); Lower Colorado River Authority. 1993. Irrigation District Water Accounting Database. Lakeside Irrigation District, Eagle Lake, Texas (Computer File.); Lower Colorado River Authority. 1993. Irrigation Water Accounting Database. Gulf Coast Irrigation District, Bay City, Texas. (Computer File.)

Parameter estimates measure the change in planted rice acreage associated with changes in ASCS program parameters. All else equal, first crop rice acreage is increasing on Lakeside District at a rate of 313 acres per year. An insignificant parameter estimate for the trend variable on Gulf Coast District indicates no long-term change in first crop acreage after controlling for ASCS program parameters. Interpretation of the parameter β_2 is that for every one percentage point increase in the maximum fraction of base acreage, planted acreage will increase 158.4 acres on Lakeside District, and 268.1 acres on Gulf Coast District. The smallest fraction of base acreage ASCS allowed in any one year was 0.65 between 1985 and 1987.

Parameter estimates for the advance payment variable are negative. Planted acreage decreases 638.1 acres on Gulf Coast District with every ten cent ($0.10) increase in the per-acre advance deficiency payment. This parameter estimate is insignificant on Lakeside District, suggesting advance deficiency payments have little effect on farmers planting decisions. The negative sign of this coefficient seems contrary to prior expectations of model results. However, advance deficiency payments may increase as anticipated crop prices decrease. This result indicates that increases in advance deficiency payments are not a substitute for the planting incentive generated by high anticipated crop prices.

The model predicts that, in 1993, farmers will irrigate 26,221 acres on the Lakeside District, and 25,371 acres on the Gulf Coast District. These figures overestimate actual 1993 rice acreage on both districts. Several factors contribute to this discrepancy. An unusually wet spring delayed planting for several weeks and at the time of planting, most farmers anticipated a low market price for rice. Also of interest are the rather low values for crop years 1984 through 1987. These are the result of lower than average ASCS acreage allowances.

Table 3.5
District Acreage Model Regression Results

Variable	**Coefficients**	**Lakeside District**	**Gulf Coast District**
Intercept	β_0	7.849	10.842
Trend (Y)	β_1	0.313	0.197
		(4.624)*	(1.497)
Maximum Base (M)	β_2	15.840	26.814
		(3.612)*	(3.132)*
Advance Payment (D)	β_3	-1.534	-6.3813
		(-1.801)	(-3.837)*
R-squared		0.665	0.865
Adj. R-squared		0.617	0.846
Model F		13.876	45.099

Source: Coefficients calculated by the author based on program provisions and payments rates data provided by the Agricultural Stabilization and Conservation Service, Columbus, Texas.

Note: T-statistics given in parenthesis. (*) Asterisks indicate significance at the 95% confidence level.

Figure 3.1
Actual and Estimated First Crop Acreage on Lakeside District

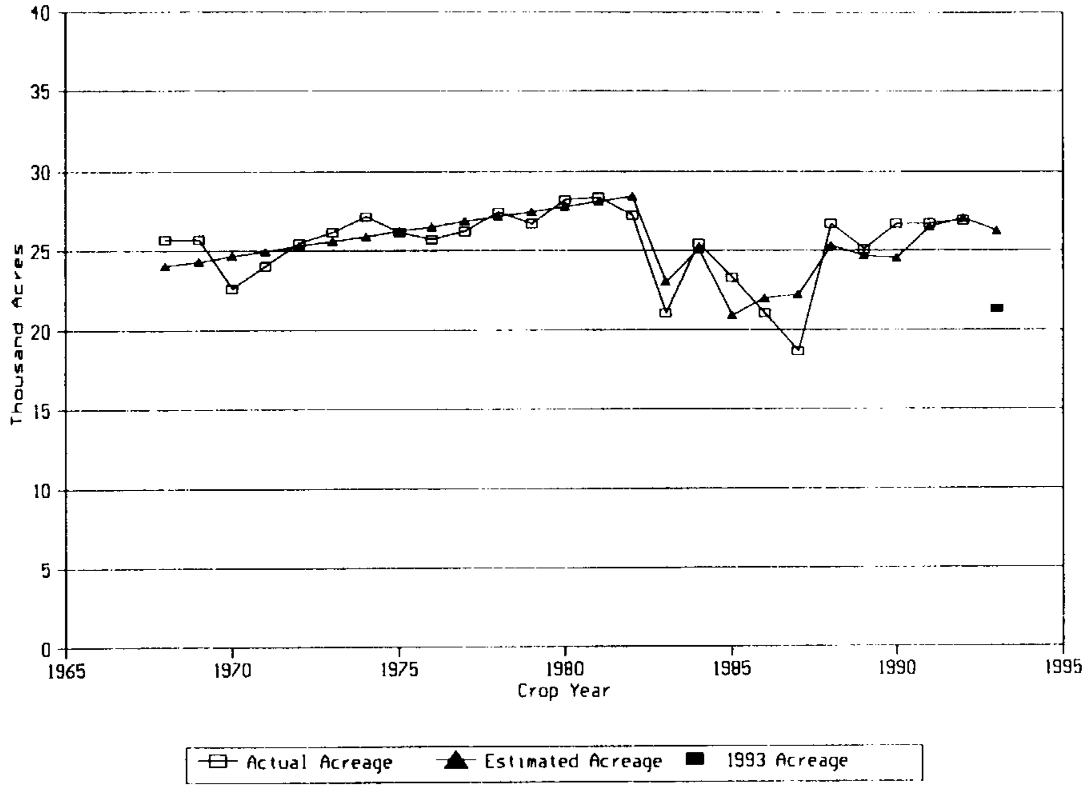
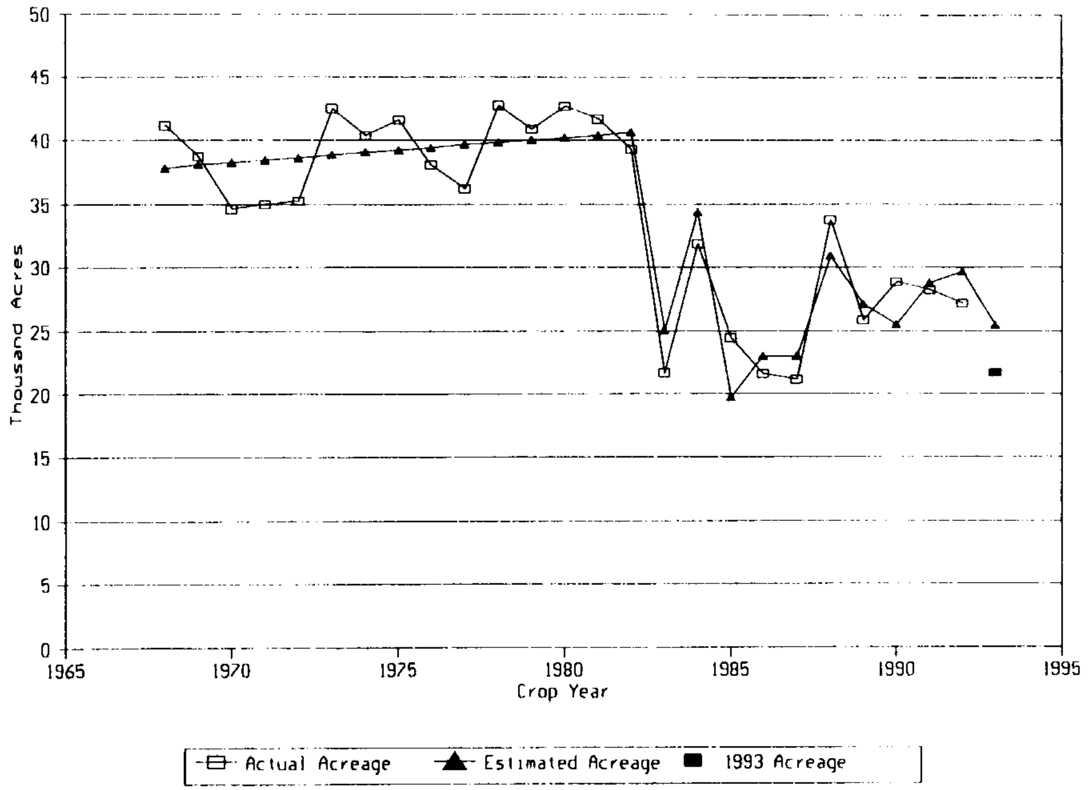


Figure 3.2

Actual and Estimated First Crop Acreage on Gulf Coast District



Since 1968, farmers on both districts have practiced double cropping of their rice fields. Farmers usually plant the first crop about mid-March and harvest the crop at the end of July. In August, they re-irrigate their rice fields to grow a second crop. Second crop yields are much lower than the first crop, but require little capital investment and few inputs. In addition, the second crop requires less water than the first crop because the rice plants are well established. The second cropping rate tends to be much lower and much more erratic on Gulf Coast District than on Lakeside District. The difference between the two districts is probably related to weather patterns and the date of first planting. Spring rains tend to last longer near the coast, and farmers on Gulf Coast District plant their fields slightly later than on Lakeside District. In addition, fall rains come earlier near the coast, and can make a second crop impossible to harvest. For this reason, these farmers are reluctant to invest in a second crop.

The amount of land that farmers irrigate each year and the second cropping rate are significant factors that affect irrigation water demand on the district, but many other factors can affect the demand for water both on the district as a whole, and between individual fields. Differences in rainfall between crop years can influence the total water diversions and crop water requirements (Martin, 1988). Relative differences in farming practices and water management styles between farmers can lead to differences in the demand for water. The field soil type, the variety of rice a farmer plants, and structural differences between fields may also lead to differences in irrigation water use. Some less obvious factors that influence the demand for surface water in the river basin are the crop price, the set of feasible crop alternatives, and the availability and relative cost of groundwater.

Water Management Practices

Water management practices can be evaluated using at least three measures that reflect water efficiency. A technical measure is the amount of water a farmer uses per acre of irrigated land (acre-feet per acre). Although often preferred because it is easily calculated, it provides only a weak basis for comparing efficiency between farmers because it ignores differences in production and net returns to farming. Water efficiency, a unit-less measure of the amount of water actually used in production (evapotranspiration) as a percentage of field inflows, may be a better measure of on-farm water management. However, differences in physical characteristics of fields cause non-crop water use to differ between fields. This measure more appropriately describes field efficiency rather than farmer efficiency. In the economic sense, irrigation efficiency might be measured by net returns per acre-foot of water (Small, 1992). The farmer who receives higher returns per acre-foot of water is more efficient. Although a technical measure of water management (acre-feet of water used per-acre of rice irrigated) may not be the best means of evaluating farmer's water management practices, information on which to base an alternative measure of on-farm water management is not available.

Water management practice refers to both farming methods and water management styles. Farming methods are fairly consistent on the irrigation districts. Among other things, farmers use continuous flood irrigation, and plant their crop by drill seeding. Alternative methods are available which might use more or less water, but farmers have adopted these practices on the basis of what works best in the area. In contrast, water management style, the active decision of when to use water and how much water to use, varies considerably between farmers that use the same farming practices. Farmers who use a high level of water management place a high emphasis on controlling the timing of water deliveries and the flow of water into the field.

Water coordinators, those responsible for operating the canal and making water deliveries, provided a subjective assessment of each farmer's relative water management style based on their knowledge of each individual's farming practices. They rated each farmer as one who uses high, medium, or low management. Water coordinators *did not* rate farmers on the basis of the volume of water used. All else equal, farmers that use high management should use water at a lower rate than farmers who use low management. Given the above definition of water management, water coordinators on both districts were given the opportunity to establish their own indicators of water management style.

On Lakeside District, water coordinators used three criteria to rate farmers. These included the frequency with which the farmer contacts the water coordinator, the quality of the farmer's field hands, and the emphasis the farmer places on field preparation before planting. On Gulf Coast District, water coordinators used two criteria. These included the frequency with which the farmer checks his levees for leaks and spills, and the frequency with which the farmer turns his water on and off.

Tables 3.6 and 3.7 show the proportion of farmers on each district that water coordinators placed in each management category, and the average water use among those farmers in 1993. For example, water coordinators on Lakeside District rated 26 percent of their farmers as using a high level of water management, and the average water use in the fields in which those farmers cultivated rice. First crop water use was 28.47 acre inches per-acre during the first crop, and 23.76 acre inches during the second crop. Regression of water use on dummy variables representing management styles showed little difference in irrigation efficiency between the management categories. The model used to test whether there were statistically significant differences in irrigation efficiency between farmers is given in equation 3.2. The model states that per-acre water use is a function of the amount of rainfall, the length of the growing season, farmers water management styles, and the crop type:

$$W = \beta_0 + \beta_1 R + \beta_2 D + \beta_3 H + \beta_4 L + \beta_5 S + S (\beta_6 H + \beta_7 L) \qquad \textbf{(Eq. 3.2)}$$

W	field-specific water use (acre-feet per-acre)
R	rainfall between first irrigation and last irrigation in that field (inches)
D	number of days between first irrigation and last irrigation
S	a dummy variable equal to one for observations from second crop fields
H, L	dummy variables equal to one for high and low management respectively
β	coefficients estimated by ordinary least squares regression

Data on rainfall were collected by the National Weather Service at Columbus and Bay City Waterworks for Lakeside District and Gulf Coast District respectively. For Gulf Coast District, the variables R and D were excluded from the model because, for many observations, the database did not include those dates on which the farmer either began taking water or stopped taking water.

Table 3.8 gives the parameter estimates. The intercept term is interpreted as mean per-acre water use during the first crop period among farmers using a medium water management style. This interpretation assumes no differences in these farmers' rainfall and irrigation period. On Lakeside District, every inch of rainfall during the crop period reduces inflows 0.067 acre-feet, or 0.804 inches. This is the trade-off between rainfall and irrigation inflows. Per-acre water use increases 0.021 acre-feet for each one-day increase in the irrigation period.

Parameter estimates for the second crop dummy variable (S) are negative. Negative values indicate farmers use less water per acre during the second crop relative to the first crop. All other variables equal, medium water managers on Lakeside District use 1.239 acre-feet per acre less water than 2.065 acre-feet during the second crop period. This comparison assumes constant values of rainfall and irrigation period variables between crop periods.

Most parameter estimates for water management variables are insignificant. Results show that farmers classified as "low" water managers on Gulf Coast District's East Side consistently use an additional 0.5 acre-feet per acre than medium water managers on Gulf Coast District during the first crop period. The insignificance of management variables are most likely related to the subjective method used to classify farmers by water management style.

Lakeside management variables are insignificant and contrary in sign to what would be expected. This might indicate that water coordinators assessments of each farmer's water management style was not accurate. It may also indicate that differences in water management style have little affect on water use on that district. Gulf Coast management variables are insignificant, but the ordinal arrangement of management groups based on predicted first crop per-acre water use is generally consistent with prior expectations. Results for the second crop are less consistent with priors than those for the first crop.

Table 3.6
Management Practices and Water Use on Lakeside District in 1993
(Acre-Inches per Acre)

		Water Use	
Management Style	Percent of Farmers	First Crop	Second Crop
High	26%	28.47	23.76
Medium	56	30.00	22.64
Low	18	27.86	23.37
Average		**29.27**	**23.06**

Source: Calculated by the author based on: Lower Colorado River Authority. 1993. Irrigation District Water Accounting Database. Lakeside Irrigation District, Eagle Lake, Texas. (Computer File.)

Note: Water use is the amount of water farmers use to irrigate one acre. Average water use is the average for all fields.

Table 3.7
Management Practices and Water Use on Gulf Coast District in 1993
(Acre-Inches per Acre)

	East Side			West Side		
		Water Use			Water Use	
Management Style	Percent of Farmers	First Crop	Second Crop	Percent of Farmers	First Crop	Second Crop
High	10%	43.38	22.83	43%	40.35	26.07
Medium	59	45.56	29.44	19	44.77	23.99
Low	31	51.70	31.38	38	46.27	24.89
Average		**47.14**	**28.63**		**43.58**	**25.33**

Source: Calculated by the author based on: Lower Colorado River Authority. 1993. Irrigation District Water Accounting Database. Gulf Coast Irrigation District, Bay City, Texas. (Computer File.)

Note: Water use is the amount of water farmers use to irrigate one acre. Average water use is the average for all fields.

Table 3.8
Parameter Estimates and T-Statistics for the Water Management Model (Eq. 3.2)

		Lakeside District	Gulf Coast District	
			East Side	West Side
Variable	**Coefficient**			
Intercept	β_0	2.065	3.7963	3.7306
Rainfall (R)	β_1	-0.067	-	-
		(-4.048)*	-	-
Days Watered (D)	β_2	0.0211	-	-
		(3.971)*	-	-
High Management (H)	β_3	-0.112	-0.1813	-0.3699
		(-0.728)	(-0.5432)	(-1.0220)
Low Management (L)	β_4	-0.215	0.5117	0.1254
		(-0.929)	(2.1755)*	(0.3423)
Second Crop (S)	β_5	-1.239	-1.3428	-1.7314
		(-4.729)*	(-3.2275)*	(-2.3331)*
Interaction Term (S*H)	β_6	0.036	-0.3699	0.5410
		(0.145)	(-0.5427)	(0.6005)
Interaction Term (S*L)	β_7	0.085	-0.3506	-0.0504
		(0.241)	(-0.5939)	(-0.0454)
R-squared		0.118	0.2280	0.1551
Adjusted R-squared		0.114	0.2015	0.1149
Model F		5.735	8.6245	3.8577

Source: Calculated by the author based on: Lower Colorado River Authority. 1993. Irrigation District Water Accounting Database. Lakeside Irrigation District, Eagle Lake, Texas. (Computer File.); Lower Colorado River Authority. 1993. Irrigation District Water Accounting Database. Gulf Coast Irrigation District, Bay City, Texas. (Computer File.)

Note: T-statistics given in parenthesis. Asterisks indicate significance at the 95 percent confidence level.

Other Factors Influencing Field-Specific Water Use

Differences in the water-holding capacity between soil types can influence irrigation water use between fields. However, the consensus among soil scientists in the Gulf Coast region is that differences in soil type do not cause differences in irrigation water use on these districts. After the soil becomes saturated during planting, there is little difference in the ability of different soils to maintain a flood on the surface. In addition, there is no deep percolation of water on the districts, so the soil remains saturated in the absence of evaporation. For this reason, differences in irrigation water use between soil types are the result of differences in the amount of water a soil needs to become saturated.

Differences in soil type do not cause more than a 3 to 5 acre-inch per-acre difference in field inflow between fields (Crenwelge, Interview, December 1, 1993; McCauley, Interview, October 29, 1993). A 1993 study that related irrigation water use in individual fields to soil types also showed no difference between soil types when fields were grouped according to high, medium, or low permeability of their respective soils types (Lyndon B. Johnson School of Public Affairs, 1995).

For the most part, farmers raise three varieties of rice on the irrigation districts. These are Gulfmont, Lemont, and Maybelle. Differences in the variety of rice a farmer plants may be the cause of some of the differences in irrigation water use between fields because the length of the growing season differs among the rice varieties. However, because most water use occurs during the first part of the growing season, differences in the water requirements among the varieties of rice do not cause more than a 2 to 3 acre-inch per acre difference in water use between fields (McCauley, Interview, October 29, 1993).

Adequate land preparation before planting can reduce irrigation water use. Each year, farmers level their fields to create an even grade. Farmers also build levees at regular intervals within the field to help control the flow of water. These practices help reduce on-farm water use by reducing water depth. For a relatively small additional cost, farmers can use two other practices to reduce water use. These practices are not common on the districts. In-field laterals can result in a 26 percent reduction in field inflow by concentrating the flow of water through the field and reducing evaporation losses. Spacing levees at closer vertical intervals, from regional standard of 0.20 vertical feet to 0.15 vertical feet, can reduce water depth within a field and result in a 14 percent reduction in field inflow (Stansel and Lindemann, 1987).

The cost associated with implementation of these water-saving technologies is small. In the case of infield laterals, cost is related to construction rather than maintenance. A farmer that uses infield laterals estimates that installing a half mile lateral in a 150 acre field requires a maximum of four hours to form the lateral with a levee plow and install checks and turnouts to deliver water to the cuts. If the cost of labor is $6.10 per hour, the labor cost is $24.40. He also estimates that $15.00 of material would be required to construct checks and turnouts in the lateral, and $3.00 of fuel would be required to pull the plow. For this field, the total cost of construction is $42.40, or $0.28 per-acre (Krenek, Interview, February 16, 1994). Actual cost will vary with the shape and size of the field. This practice may also improve the farmer's control over the depth of water in cuts at the upper end of the field and increase crop yield.

A second water-saving technology is to reduce the vertical distance between in-field levees. The regional standard for spacing levees is 0.2-0.3 vertical feet. Farmers that maintain a three-year field rotation survey and reconstruct levees at six to nine year intervals. Although there appears to be no specific reason for the regional spacing standard, reducing the vertical distance between levees can make the operation of machinery more difficult, especially when the slope of the field is high. Labor and machinery cost increases because farmers must repair damage caused by machinery.

The extent to which closer levees increase cost depends upon the slope of the field. For example, if the vertical distance between the top and the bottom of the field is 1.2 vertical feet, and the levees are spaced at 0.2 vertical feet, a farmer must add 0.67 additional levees to an existing six levees. This results in an 11 percent increase (0.67/6) in labor and machinery costs. However, if the vertical distance from one end of the field is 3 feet, the farmer must add five levees to his existing 15 levees. This results in a 30 percent increase in field labor and machinery costs. According to the Colorado County model farm budget, an 11 percent increase in variable field labor and machinery costs increases the cost of production $15.45 per-acre, and a 30 percent increase in these costs raises the cost of production $41.71 per-acre.

Although empirical evidence shows that these practices reduce field inflow and may even increase a farmer's yield (Stansel and Lindemann, 1987), farmers on Lakeside District and Gulf Coast District have not adopted the practice. The reason for this is probably a matter of cultural farming practice (Krenek, Interview, February 16, 1994; Crenwelge, Interview, December 1, 1993; McCauley, Interview, October 29, 1993). This suggests that the practice might be introduced in the area through some form of technology transfer, but that unless the price of water becomes very high, farmers will not adopt the practice on the basis of economic factors alone.

Laser levelling is another structural modification which has been shown to reduce field inflow. Although it is an expensive investment, its effect on water use is permanent (Krenek, Interview, February 16 1994). For the purposes of this project, laser levelling is not considered a viable technology input. For the most part, farmers on these irrigation districts do not own the land they farm. Most farmers sharecrop or cash-rent their lands. Table 3.9 shows the ratio of land under different landlord-tenant arrangements. Farmers who sharecrop or cash rent have little incentive to make long-run capital investments in the land. Landowners might have an incentive to make this investment if the price of water were so high that the water savings associated with that investment contributed to an increase in the rental rate, or an increase in their portion of net farm returns. Several landowners who farm their own land on Lakeside District, have begun laser levelling on a limited scale (Harbers, Interview, December 8, 1993).

Table 3.9
1982 Land Tenure Arrangements in Colorado, Wharton, and Matagorda Counties

	Percent of Acreage		
County	**Owned**	**Sharecrop**	**Cash Rent**
Colorado	7.7%	89.6%	2.8%
Wharton	14.9	76.6	8.4
Matagorda	17.9	79.5	2.7

Source: Griffin, Ronald C., Gregory M. Perry, and Garry N. McCauley. 1984. *Water Use and Management in the Texas Rice Belt Region.* Texas A&M University, College Station, Texas. (June.) p.60.

Although farming practices are similar between the districts, farmers on Lakeside District use less water per acre of rice than farmers on Gulf Coast District. These differences may be due at least in part to differences in water management practices. On Gulf Coast District, many farmers maintain a continuous flow of water, or a holding stream, through the field and over the levee which surrounds the field. These holding streams reduce the time and effort required to tend fields. Another difference between the districts is that farmers on Gulf Coast District reconstruct the levees which surround their fields before each crop season. If the levee is not completely settled before the farmer irrigates his field, water has a tendency to seep under the base of the levee.

Crop Alternatives and Feasible Crop Areas

Crop prices and crop alternatives influence the quantity of water demanded and the elasticity of demand. When agriculture represents the best land use, crop prices and crop alternatives define the opportunity cost of producing rice. If rice is the most remunerative alternative, or there are no crop alternatives, there is no opportunity cost and water demand will be less elastic. One means of determining the elasticity of surface water demand is to estimate what the crop mix would be on rice acreage that farmers irrigate with surface water if those farmers did not plant rice. The estimate of a potential crop mix must include constraints on the physical characteristics of the land, crop rotation practices, crop prices, and ASCS base acreage allotments for program crops. These variables limit the ability of a farmer to select a crop mix that maximizes profits.

The existing crop mix on Lakeside District consists of cattle, corn, cotton, sorghum, and soybeans. The map of the Lakeside District in Figure 3.3 shows the feasible crop areas. Information on the location and distribution of base acreage has not been collected as part of this project. However, there is no reason to assume the base acreage allotments which farmers irrigate with surface water is not distributed randomly throughout the district (Jahn, Interview, December 8, 1993). The estimated base acreage allotment in each area is equal to the projected rice base acreage in 1993 times the proportion of total land area within the feasible crop area:

$$A_{it} = \hat{A}_t * \left(\frac{L_i}{\sum_i L_i} \right) \qquad \text{(Eq. 3.3)}$$

A	number of acres irrigated (acres)
Â	acreage projection calculated in equation 3.1 (acres)
L	total land area (acres)
i	an index of feasible crop area $i = (1, 2, 3)$
t	an index of crop year $t = (1, 2, 3, ..., n)$

The acreage projection in feasible crop area 1 for 1993 is 13,010 acres. The only crop alternative in area 1 is cattle. In Area 2, the estimated rice acreage is 4,359 acres, and in Area 3, the estimated rice acreage is 8,852 acres. Farmers have several crop alternatives in these areas including cattle, sorghum, cotton, corn, and soybeans (Cosper, Interview, January 26, 1994).

Good farming practices dictate that farmers maintain a temporal and a spatial crop mix. Each year, farmers rotate their crops between fields and leave some fields fallow. Therefore, crop mix within each area will vary from year to year. Local experts defined the boundaries of feasible crop areas on the basis of their knowledge of the area, farming practices, and soil type (Jahn and Fair, Interview, December 8, 1993). Local conditions within these areas may lead to differences in the set of feasible crops on any one piece of land. However, the feasible crop set is representative for the areas as a whole.

Soils in Area 1 are dominated by soils of the Katy and Edna associations. Their heavy clay content makes them unsuitable for dryland farming; therefore cattle is the only crop alternative. In Areas 2 and 3, soils are dominated by soils of the Crowley and Edna associations and crop alternatives are also limited. Although these soils are slightly more versatile, and farmers currently use this land for a variety of crops other than rice including cattle, corn, cotton, sorghum, and soybeans, the area is not well suited for dryland farming (Cosper, Interview, January 26, 1994). What the exact crop mix would be is not known; however, the estimates in Table 3.10 represent informed estimates of the possible crop mix given the physical and economic constraints facing farmers in these areas.

Feasible crop areas on the Gulf Coast District are East Side and West Side (Figure 3.4). Local environmental conditions within these areas vary considerably. As on Lakeside District, the assumption is that base acreage is distributed randomly throughout each feasible crop area. Estimates of rice base acreage in each area are based on exponential smoothing forecasts of the proportion of total rice acreage irrigated in the feasible crop area between 1980 and 1992. Equation 3.4 states that proportion of land area on the East Side of the river in the coming season is a function of the proportion of total rice acreage on the East Side in previous years.

$$A_{i(t+1)} = \alpha \frac{Y_{it}}{\sum_i Y_{it}} + (1 - \alpha) \frac{A_{it}}{\sum_i A_{it}} \qquad \text{(Eq. 3.4)}$$

Y	actual number of acres planted on the East Side
A	forecast acreage for East Side
α	a smoothing constant

i an index of feasible crop area i = (1, 2)
t an index of crop year t = (1, 2, 3 ..., n)

Alpha (α = .99) is the smoothing constant which minimizes the mean squared error of the estimates. The high value of the smoothing constant indicates that the fraction of Gulf Coast acreage on the East Side last year is the best predictor of the fraction next year. On the East Side, the mean squared error of the estimate equals 0.01514. For the West Side, the proportion of rice acreage equals one minus the estimated fraction on the East Side. Rice acreage in each area equals the projected proportion for 1993 times the estimated rice acreage on the district. The estimated rice acreage on the East Side is 13,776 acres. On the West Side, the estimated rice acreage is 11,594 acres.

Given a scenario in which farmers were deprived of their use of surface water, the county extensionist in Matagorda County estimated the proportion of rice acreage farmers would convert to different feasible crops on each side of the river. He made this estimate on the basis of his knowledge of the physical characteristics of the land, farming practices, current crop prices, and existing ASCS farm programs. Farmers will select their crop mix to maximize profits. Even if farm programs and crop prices remain constant, farmers will select a different crop mix in successive years.

Participation in ASCS farm programs requires base acreage allotments, and farmers need to establish a history of production before they can participate. It can take several years for a farmer to build his base acreage, and the amount of land on which he receives deficiency payments will increase as he continues to raise program crops. Therefore, the crop mix which maximizes profits will change as the farmer gains partial participation in the program. For this reason, the estimates presented in Table 3.11 represent the potential crop mix in the first year that farmers convert rice acreage to alternative crops (Engbrock, Interview, December 14, 1993).

Table 3.10
Estimated Maximum Crop Acreage in Feasible Crop Areas on Lakeside District

	Area 1		Area 2		Area 3	
	Percent of Area*	Acreage	Percent of Area*	Acreage	Percent of Area*	Acreage
Crop Type						
Cattle	100.0	13,043.14	80.0	3,496.10	90.0	7,987.25
Corn	0.0	0.00	1.7	72.84	1.7	147.91
Cotton	0.0	0.00	1.7	72.84	1.7	72.84
Sorghum	0.0	0.00	15.0	655.52	5.0	443.74
Soybeans	0.0	0.00	1.7	72.84	1.7	72.84

Sources: Calculated by the author based on interviews with county extensionists: Cosper, John, 1994. County Extensionist, Texas Agricultural Extension Service, Wharton, Texas. Telephone Interview, January 26.; Fair, Connie M., 1993. District Conservationist, US Soil Conservation Service, Columbus, Texas. Interview, December 8.; Jahn, Rick. 1993. County Extensionist, Texas Agricultural Extension Service, Columbus, Texas. Interview, December 8.

Note: (*) Percent of rice acreage potentially converted to a particular crop type in the feasible crop area.

Figure 3.3
Feasible Crop Areas on Lakeside District

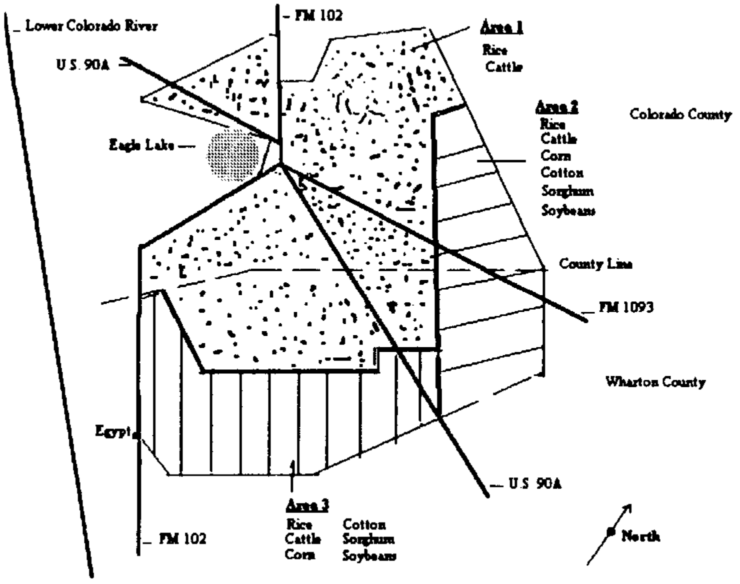


Figure 3.4
Feasible Crop Areas on Gulf Coast District

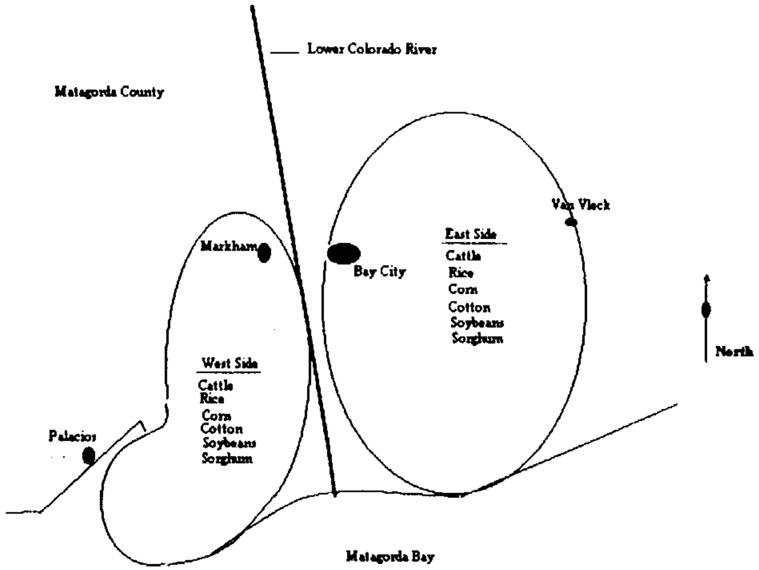


Table 3.11
Estimated Maximum Crop Acreage in Feasible Crop Areas on Gulf Coast District

	East Side		West Side	
Crop Type	Percent of Area*	Acreage	Percent of Area*	Acreage
Cattle	75 %	10,405.26	45 %	5,254.79
Corn	1	138.74	5	583.87
Cotton	5	693.68	10	1,167.73
Sorghum	4	554.94	15	1,751.58
Soybeans	15	2,081.05	25	2,919.33
Turf Grass	0	0.00	0	0.00

Source: Engbrock, James. 1993. County Extensionist, Texas Agricultural Extension Service, Bay City, Texas. Interview, December 14.

Note: (*) Percent of rice acreage converted to a particular crop type in the feasible crop area.

Farmers on Gulf Coast District also cultivate turf-grass. At this time, turf-grass is not considered a feasible crop alternative. The decision to plant turf-grass is a long-run decision and requires a significant capital investment over and above the variable costs of production. Several years ago, when turf-grass prices were higher, many farmers decided to make this investment. Since then, prices have fallen, and many farmers have converted from turf-grass to other crops. Those farmers that continue to raise turf-grass are sustained by their initial investment, but it is not considered feasible to establish new turf farms (Engbrock, Interview, December 14, 1993).

Farm Budget Residuals

Crop prices and production costs affect the demand for irrigation water. For example, the higher the crop price, the greater the farmer's willingness to pay. The farm budget residual (residual) measures farmers' willingness to pay (Gibbons, 1986). Equation 3.5 states that the residual is equal to farm revenue minus production costs, plus the variable cost of irrigation water:

$$\text{Residual} = \text{Revenue} - (\text{ Variable Cost} + \text{Water Cost }) \qquad \textbf{(Eq. 3.5)}$$

If there are no crop alternatives and no opportunity costs associated with crop production, then the residual equals the value of water in rice production. If there are crop alternatives, the relationship between the residual and the value of water becomes less clear because the productive value of water does not change, but the farmer's willingness to pay for that water does. Therefore, the value of water and the farmer's willingness to pay equal the residual minus the profit associated with the most remunerative crop alternative.

Production costs will differ between those farmers that use surface water and those that use groundwater. The availability of groundwater as an alternative source of irrigation water influences the elasticity of demand. Farmers in Colorado and Wharton Counties use both surface water and groundwater. However, there is currently no reliable information on the extent, condition, and pumping capacity of privately owned groundwater wells on the Lakeside District. Model farm budgets do not discriminate between farms that use ground water and farms that use surface water. The district owns five groundwater wells, but the volume of water pumped amounts to only about two percent of total surface water diversions. Farmers on Gulf Coast District do not have access to groundwater wells for rice irrigation.

County extensionists in Colorado, Wharton, and Matagorda Counties provided model farm budgets for rice and alternative crops. Model budgets are based on actual farm data, and represent the average production costs for farms in each county. Because many farmers on Lakeside District use groundwater, Colorado and Wharton County budgets included some costs specific to groundwater pumping. These budgets were modified by removing these costs before calculating the residual.

Tables 3.12, 3.13, and 3.14 present the model rice budgets for each county. For example, in Table 3.12, total projected returns from a first crop in Colorado County are $724.01, and the total short-run variable costs of production are $409.74. Therefore, the residual value of water is $314.07. In Wharton County, the total projected returns during the first crop are $616.55, and the total short-run variable costs of production are $361.98. Therefore, the residual value of water is $254.57. Total short-run variable costs are the sum of planting and harvest costs, and irrigation water costs have been removed from these budgets. Budgets for alternative farm products have not been modified and are not reproduced here.

Table 3.15 and 3.16 present long-run and short-run farm budget residuals for all crops in each feasible crop area. Because there are model rice budgets for both Colorado and Wharton counties, residuals for each feasible crop area on Lakeside District are the sum of the weighted residuals for each county. The residuals and farm profits are weighted by the proportion of land in the feasible crop area falling in each of the counties. For example, 75.77 percent of feasible crop area 1 is in Colorado County, and 24.23 percent of feasible crop area 1 is in Wharton County. The short-run residual for the first crop is:

$$(0.7577 * 314.07) + (0.2423 * 254.57) = 299.65 \qquad \textbf{(Eq. 3.6)}$$

No farm budgets were available for non-rice crops in Colorado County. Therefore, Wharton County budgets represent farm profits for all areas on Lakeside District. On the Gulf Coast District, the residuals and farm profits for all crops are the same on both sides of the river and come directly from the Matagorda County rice budget. The short-run residual is calculated by subtracting total variable costs from the projected returns. The long-run residual is calculated by subtracting both total variable and total fixed costs from the projected returns. Because farm budget residuals for the rice crops do not incorporate any irrigation costs, they should not be interpreted as farm profit.

Table 3.12
Colorado County Rice Budget, 1993
(Cost per Acre)

	Value per Unit		Input Use	First Crop	Second Crop	Full Crop
PROJECTED RETURNS						
Yield per-acre (cwt)				58.00 cwt	14.00 cwt	72.00 cwt
Crop sales	$ 6.5	cwt		377.00 $	91.00 $	468.00 $
Deficiency Payment	4.21	cwt		242.20	0.00	242.20
Loan Gain	1.16	cwt		67.11	16.20	83.30
Premium	0.65	cwt		37.70	9.10	46.80
TOTAL PROJECTED RETURNS:				**724.01**	**116.30**	**840.31**
VARIABLE COSTS						
PLANTING COST ITEM						
Seed	$ 21.50	cwt	1	21.50	-	21.50
Nitrogen	0.21	lb	153	31.67	-	31.67
Phosphate	0.18	lb	54	9.72	-	9.72
Potash	0.12	lb	27	3.11	-	3.11
Furadan	0.73	lb	17	12.41	-	12.41
Fungicide	29.48	acre	0.5	14.74	-	14.74
Insecticide	3.12	acre	2	6.24	-	6.24
Prop-ord	28.89	acre	1	28.89	-	28.89
Propanil	17.61	acre	1	17.61	-	17.61
Cust Air Fert	2.85	cwt	2.25	6.41	-	6.41
Cust Air Fert	3.75	appl.	2	7.50	3.75	11.25
Cust Air Insect	2.50	appl.	2	5.00	-	5.00
Cust Air Fung	9.00	appl.	0.5	4.50	-	4.50
Cust Air Herb	4.50	appl.	2	9.00	-	9.00
Irrigation Water	0.0	acre	1	0.00	0.00	0.00
Nitrogen 2nd crop	0.26	lb	45	11.74	-	11.74
Machinery - fuel	26.76	acre	1	21.56	5.20	26.76
lube	26.77	acre	1	21.56	5.21	26.77
Repair	6.10	hour	4.51	22.19	5.36	27.54
Irrigation - labor	5.25	hour	6.1	25.80	6.23	32.03
Flagging	0.50	appl.	8	4.00	-	4.00
Operating Capital	0.09	dollar	183.43	14.04	3.39	17.43
PLANTING SUBTOTAL				**287.44**	**40.87**	**328.32**
HARVEST COST ITEM						
Drying	0.85	cwt	79.2	54.23	13.09	67.32
Hauling	0.28	cwt	79.2	17.864	4.31	22.17
Sales Commission	0.05	cwt	72	2.90	0.70	3.60
Machinery - fuel	11.89	acre	1	9.58	2.31	11.89
lube	41.85	acre	1	33.71	8.14	41.85
labor	6.10	hour	0.857	4.21	1.02	5.23
HARVEST SUBTOTAL				**122.50**	**29.57**	**152.07**
TOTAL VARIABLE COSTS				**409.94**	**70.44**	**480.38**
FIXED COST ITEM						
Depreciation, Interest, Taxes & Insurance on Machinery	102.89	acre	1	102.89	-	102.89
Land, Net Share-Rent	89.08	acre	1	78.39	10.69	89.08
TOTAL FIXED COSTS				**181.28**	**10.69**	**191.97**
TOTAL COSTS				**591.22**	**81.13**	**672.35**

Source: Texas Agricultural Extension Service. 1993. "Model Farm Budget, Rice." Columbus, Texas.

Note: Numbers may not add due to rounding.

Table 3.13
Wharton County Rice Budget, 1993
(Cost per Acre)

	Value per Unit		Input Use	First Crop	Second Crop	Full Crop
PROJECTED RETURNS						
Yield (cwt)				55.00 cwt	12.00 cwt	67.00 cwt
Crop Sales (first crop)	$ 7.00	cwt		385.00 $	-	385.00 $
Crop Sales (second crop)	6.40	cwt		-	76.80 $	76.80
Deficiency Payment	4.21	cwt		231.55	-	231.55
Loan Gain (*)	-	cwt		-	-	-
Premium (*)	-	cwt		-	-	-
TOTAL PROJECTED RETURNS				**616.55**	**76.80**	**693.35**
VARIABLE COSTS						
PLANTING COST ITEM						
Seed	$ 20.00	cwt	1	20.00	-	20.00
Nitrogen	0.20	lb	220	44.00	-	44.00
Phosphate	0.28	lb	40	11.20	-	11.20
Potash	0.12	lb	40	4.80	-	4.80
Fungicide and flying	54.00	acre	0.33	17.82	-	17.82
Insecticide	3.00	acre	4.12	12.36	-	12.36
Herbicide	24.64	acre	2	49.28	-	49.28
Cust Air Fert	3.00	cwt	5	15.00	-	15.00
Cust Air Insect	3.00	acre	3	9.00	-	9.00
Cust Air Herb	4.40	acre	2.5	11.00	-	11.00
Irrigation Water	0.0	acre	1	0.00	0.00	0.00
Machinery - fuel and lube	17.25	acre	1	14.16	3.09	17.25
labor	6.10	hour	2	10.01	2.18	12.20
Irrigation labor	6.10	hour	6	30.04	6.55	36.60
Operating Capital	0.09	dollars	156.87	11.59	2.53	14.12
PLANTING SUBTOTAL				**260.27**	**14.36**	**274.63**
HARVEST COST ITEM						
Drying	0.85	cwt	75.04	52.36	11.42	63.78
Hauling	0.30	cwt	75.04	18.48	4.03	22.51
Sales Commission	0.07	cwt	67	3.85	0.84	4.69
Machinery - fuel	6.32	acre	1	5.19	1.13	6.32
lube	18.67	acre	1	15.33	3.34	18.67
labor	6.10	hour	1.3	6.51	1.42	7.93
HARVEST SUBTOTAL				**101.71**	**22.19**	**123.91**
TOTAL VARIABLE COSTS				**361.98**	**36.55**	**398.53**
FIXED COST ITEM						
Depreciation, Interest, Taxes & Insurance on Machinery	141.75	acre	1	141.75	-	141.75
Land Net Share-Rent	75.00	acre	1	66.00	9.00	75.00
TOTAL FIXED COSTS				**207.75**	**9.00**	**216.75**
TOTAL COSTS				**569.73**	**45.55**	**615.28**

Source: Texas Agricultural Extension Service. 1993. "Model Farm Budget, Rice." Wharton, Texas. (Photocopy.)

Note: (*) Loan Gain and Premium included in other Projected Returns. Numbers may not add due to rounding

Table 3.14
Matagorda County Rice Budget, 1993
(Cost per Acre)

	Value per Unit		Input Use	First Crop	Second Crop	Full Crop
PROJECTED RETURNS						
Yield (cwt)				55.00 cwt	10.00 cwt	65.00 cwt
Crop Sales	$ 6.50	cwt		357.50 $	65.00 $	422.50 $
Deficiency Payment	4.30	cwt		223.30	-	223.30
Loan Gain	1.16	cwt		63.65	11.75	75.21
Premium	0.75	cwt		41.25	7.50	48.75
TOTAL PROJECTED RETURNS				**685.68**	**84.07**	**769.75**
SHORT RUN VARIABLE COSTS						
PLANTING COST ITEM						
Seed	19.50	cwt	1.2	23.40	-	23.40
Nitrogen	0.20	lb	310	60.76	-	60.76
Phosphate	0.15	lb	40	6.04	-	6.04
Potash	0.11	lb	20	2.30	-	2.30
Methyl Para	2.76	appl.	2	5.52	-	5.52
Furadan	0.65	lb	17	11.05	-	11.05
Fungicide - tilt	23.00	acre	1	23.00	-	23.00
Fungicide - roveral	18.08	acre	1	18.08	-	18.08
Prop-ord	26.14	acre	0.33	8.62	-	8.62
Propanil	15.60	acre	2	31.2	-	31.20
Cust Air Fert	4.80	cwt	4.06	19.49	-	19.49
Cust Air Insect	3.10	acre	2	6.20	-	6.20
Cust Air Fung	3.10	appl.	2	6.20	-	6.20
Cust Air Herb	3.10	acre	2.33	7.22	-	7.22
Cust Air Seed	3.35	acre	1.2	4.02	-	4.02
Irrigation Water	0.00	acre	1	0.00	0.00	0.00
Machinery - fuel and lube	14.24	acre	1	12.05	2.19	14.24
repair and labor	6.10	hour	6.46	22.65	4.12	26.77
Irrigation - labor	6.12	hour	5.25	27.16	4.94	32.10
Operating Capital	168.88	dollar	0.09	13.57	2.47	16.04
PLANTING SUBTOTAL				**308.55**	**13.72**	**322.27**
HARVEST COST ITEM						
Drying	0.85	cwt	58.34	41.96	7.63	49.59
Hauling	0.28	cwt	58.34	13.83	2.51	16.33
Sales Commission	0.05	cwt	53.04	2.24	0.41	2.65
Machinery - fuel and lube	9.04	acre	1	7.65	1.39	9.04
labor	6.10	acre	0.95	4.91	0.89	5.81
repairs	35.09	acre	1	29.69	5.40	35.09
HARVEST SUBTOTAL				**100.28**	**18.23**	**118.52**
TOTAL VARIABLE COSTS				**408.83**	**31.95**	**440.78**
FIXED COST ITEM						
Depreciation, Interest, Taxes & Insurance on Machinery	58.75	acre	1	58.75	-	58.75
Land Net Share-Rent	57.30	acre	1	50.42	6.88	57.30
TOTAL FIXED COSTS				**109.17**	**6.88**	**116.05**
TOTAL COSTS				**518.01**	**38.83**	**556.83**

Source: Texas Agricultural Extension Service. 1993. "Model Farm Budget, Rice." Bay City, Texas. (Photocopy.)

Note: Numbers may not add due to rounding.

Table 3.15
Long-Run Farm Budget Residuals and Farm Profits in Feasible Crop Areas
(Dollars per Acre)

	Lakeside District			Gulf Coast District	
	Area 1	Area 2	Area 3	East Side	West Side
Crop Type					
Rice, first crop	$ 111.95	$ 70.62	$ 47.47	$ 167.67	$ 167.67
Rice, full crop	146.17	102.96	78.75	212.92	212.92
Cattle	-140.68	-140.68	-140.68	-188.11	-188.11
Corn	-58.98	-58.98	-58.98	-52.50	-52.50
Cotton	82.77	82.77	82.77	46.88	46.88
Sorghum	-1.40	-1.40	-1.40	-43.80	-43.80
Soybeans	33.45	33.45	33.45	-42.50	-42.50
Turf Grass	-	-	-	-780.56	-780.56

Source: Calculated by the author based on information in: Texas Agricultural Extension Service. 1993. "Model Farm Budgets for Matagorda County." Bay City, Texas. (Photocopy.); Texas Agricultural Extension Service. 1993. "Model Farm Budgets for Wharton County." Wharton, Texas. (Photocopy.); Texas Agricultural Extension Service. 1993. "Model Farm Budgets for Colorado County." Columbus, Texas. (Photocopy.)

Note: For rice, the only irrigated crop, the numbers represent the farm budget residual. For all other crops, numbers represent expected farm profits.

Table 3.16
Short-Run Farm Budget Residuals and Farm Profits in Feasible Crop Areas
(Dollars per Acre)

	Lakeside District			Gulf Coast District	
	Area 1	Area 2	Area 3	East Side	West Side
Crop Type					
Rice, first crop	299.65	271.04	255.01	276.85	276.85
Rice, full crop	344.15	312.85	295.31	328.97	328.97
Cattle	67.32	67.32	67.32	59.49	59.49
Corn	48.79	48.79	48.79	37.69	37.69
Cotton	196.67	196.67	196.67	182.56	182.56
Sorghum	91.19	91.19	91.19	47.69	47.69
Soybeans	82.05	82.05	82.05	34.54	34.54
Turf Grass	-	-	-	-180.56	-180.56

Source: Calculated by the author based on information in: Texas Agricultural Extension Service. 1993. "Model Farm Budgets for Matagorda County." Bay City, Texas. (Photocopy.); Texas Agricultural Extension Service. 1993. "Model Farm Budgets for Wharton County." Wharton, Texas. (Photocopy.); Texas Agricultural Extension Service. 1993. "Model Farm Budgets for Colorado County." Columbus, Texas. (Photocopy.)

Note: For rice, the only irrigated crop, the numbers represent the farm budget residual. For all other crops, numbers represent expected farm profits.

Farmers Reactions to Changes in the Marginal Cost of Water

Under the old fixed irrigation charge, farmers had no control over water costs. Economic theory suggests that, given an opportunity to reduce water costs and increase farm profits, farmers will use less water. LCRA's 1993 transition from a completely fixed irrigation water charge to one with a volumetric price component presents an opportunity to evaluate farmers responses to changes in the marginal cost of water.

In 1992, the LCRA measured water deliveries at each field delivery structure, but continued to charge farmers on a per-acre basis. The objective was to give farmers an opportunity to learn how their management practices affect irrigation efficiency. In 1993, LCRA implemented its new rate structure with a ten percent cap on the difference between each farmer's 1992 and 1993 per-acre cost of water. LCRA's objective was to give the farmers another opportunity to see how management practices influenced irrigation efficiency.

Changes in irrigation water use between years provide a means of estimating the absolute change in irrigation water use which results from proportional changes in the marginal cost of water. This is in one sense a demand function for irrigation water. However, estimates are based on irrigation efficiency and do not include information on other relevant factors such as crop alternatives. Estimates are based on data collected over a small range of prices and the ten percent cap on differences in water cost between years may have influenced farmers' irrigation decisions.

Another method of estimating farmers responses to changes in the marginal cost of water might be to gather information on irrigation efficiency from rice irrigation districts in other parts of the country. Environmental and economic conditions can vary substantially from one farming region to another, and volumetric pricing of water is a rare characteristic of rice irrigation districts. The empirical observations from within the river basin provide a better measure of farmers reactions than an extrapolation from other parts of the country.

Equation 3.7 presents the regression equation used to estimate farmers reactions to changes in the marginal cost of water. Parameter estimates are based on a data set that includes 1992 and 1993 water accounting database records of the volume of water delivered to fields. For Lakeside District, the analysis includes only those farmers farming in both 1992 and 1993. For Gulf Coast District, the analysis includes all farmers because many records were incomplete, and restricting the data set only to those farmers farming in both years would have resulted in an unacceptably small data set. This equation states that the volume of water used in irrigation is a function of the effective price of water, the size of the field, the number of days over which a farmer takes water, and the crop type:

$$V = \beta_0 + \beta_1 \ln(PE) + \beta_2 A + \beta_3 D + \beta_4 C \qquad \textbf{(Eq. 3.7)}$$

V	field-specific total water use (acre-feet)
PE	effective price of water (dollars per acre-foot)
A	field acreage (acres)
D	number of days between first irrigation and last irrigation (days)
C	a dummy variable equal to one for observations from second crop fields
β	coefficients are estimated by ordinary least squares regression

To test whether or not there is a significant difference between farmer's reactions on Gulf Coast District and on Lakeside District, the districts were combined in a single model using dummy variables and interactions terms:

$$V = \beta_0 + \beta_1 \ln(PE) + \beta_2 A + \beta_3 D + \beta_4 C + \beta_5 G + \beta_6 INTG \qquad \textbf{(Eq. 3.8)}$$

G	a dummy variable equal to one for observations from Gulf Coast District
INTG	an interaction term equal to G times the natural log of the effective price of water on Gulf Coast District.

All other variables are identical to those in equation 3.7. The coefficient for the INTG variable measures difference in how Gulf Coast farmers react to price changes relative to Lakeside farmers.

The effective price of water in equations 3.7 and 3.8 is the price farmers anticipate paying. Because the districts charge an additional volumetric fee for stored water and farmers do not know what fraction of a delivery is stored water, farmers do not know the exact price of water at the time irrigation occurs. The anticipated price is calculated on the basis of the probability that the farmer draws stored water. Equation 3.9 states that the effective price of water during each crop period is equal to the volumetric price of water diverted under irrigation district water rights plus the expected cost of drawing stored water during that crop period:

$$PE_i = PD + \left(\frac{\sum_j VS_j}{\sum_j VT_j} * PS \right) \qquad \textbf{(Eq. 3.9)}$$

PE	effective price of water (dollars per acre-foot)
PD	variable price of water on the irrigation district (dollars per acre-foot)
PS	price of stored water from the Highland Lakes (dollars per acre-foot)
VS	total volume of stored water diversions on the district (acre-feet)
VT	total volume of water diversions on the district (acre-feet)
i	an index of first or second crop period $i = (1, 2)$
j	an index of month $j = (1, 2, 3, \ldots, 12)$

All water diversions prior to August 1 may be attributed to the first crop, and all water diversions on or after August 1 may be attributed to the second crop (Martin, 1988). On Lakeside District, the effective price of water during the first crop period is $10.22 and during the second crop period is $12.59. On Gulf Coast District, the effective price of water during the first crop period is $6.11 and during the second crop period is $7.27.

Equation 3.8 can be modified by removing the acreage variable to relate changes in the effective marginal cost of water to on-farm irrigation efficiency. The dependent variable then represents field-specific acre-feet per acre rather than field-specific total water use. The equation states that irrigation efficiency is a function of the number of days during the growing season, the effective price of water, the crop type, and the location of the field (by district):

$$W = \beta_0 + \beta_1 \ln(PE) + \beta_3 D + \beta_4 C + \beta_5 G + \beta_6 INTG \qquad \textbf{(Eq. 3.10)}$$

W	field inflow (acre-feet per-acre)

All other variables are identical to those in equation 3.7.

Table 3.17 presents the regression results for equations 3.8 and 3.10. The parameter estimate for PE provides a measure of the absolute change in water use per acre resulting from a proportional change in the effective price of water. The R-squared value for equation 3.8 is relatively high because acreage has a strong influence on field water use. When the dependent variable is irrigation efficiency, as in equation 3.10, the regression model loses its explanatory power. This does not invalidate the parameter estimates. The fact that the t-statistics for PE, the effective marginal cost of water, and the model F-statistic are consistently significant across the two specifications supports the use of equation 3.10 as a tool for anticipating changes in water use.

The data on which these estimates are based include only two price points. Clearly, an estimate of how farmers react to changes in the price of water will improve with an increase in the number of observations at different prices. For this reason, this report does not rely on these data to estimate demand or to predict how water use will change. These equations are incorporated into the linear programming model as one factor of demand.

The functional form was selected to capture farmer's diminishing marginal propensity to conserve water. In contrast, a linear model would indicate that there is a constant change in the volume of water saved. The effect would be to overestimate the elasticity of demand for water at higher prices. Despite advantages, equation 3.10 is asymptotic at an effective water price of 0. This implies that farmers will use an infinite amount of water if it has no marginal cost (as is the case when districts charge farmers only on a per-acre basis). Because too much water can ruin a rice crop, farmers will not behave this way. This inconsistency will not affect any estimates or conclusions about the demand for water later in this paper.

An interpretation of regression results with respect to the effective price variable suggests increasing water price will produce marginally decreasing water savings on each districts. Mean on-farm water use on Lakeside District (acre-feet per acre) decreases 0.073 acre-feet per acre with a one unit increase in the natural log of the effective price. Mean on-farm water use on Gulf Coast District decreases 0.059 acre-feet per acre ($-0.073 + 0.014 = -0.059$) with a one unit increase in the natural log of the effective price. The difference in the rate of decrease in water use between districts (β_6) is not statistically significant. This suggests essentially no difference between the districts in farmers' propensity to conserve water in response to increases in marginal cost.

Figure 3.5 projects total water savings under assumptions. Projected water savings are for on-farm water use during the first crop only assuming 25,000 planted acres on each district and 100 days between first and last irrigation in all fields. Projected water savings do not reflect decreases in water use associated with acreage reductions or any change in canal losses associated with reduced pumpage requirements. Changes in the effective water price represent increases in the marginal cost of water above current first crop effective prices ($10.22 on Lakeside District and $6.55 on Gulf Coast District). Increases in the marginal cost of water will not increase district revenues, or necessarily increase a farmers' total cost of irrigation service if increases in volumetric prices are balanced by decreases in the fixed per-acre irrigation charge. The short-run nature of these estimates is discussed in Chapter 6.

In a competitive market, equation 3.8 might itself be interpreted as a demand curve for water. However, the price of water on the irrigation districts is established on a cost of service basis, and is not based on competitive demand. Therefore, it is inappropriate to interpret the curve as if it were a demand curve.

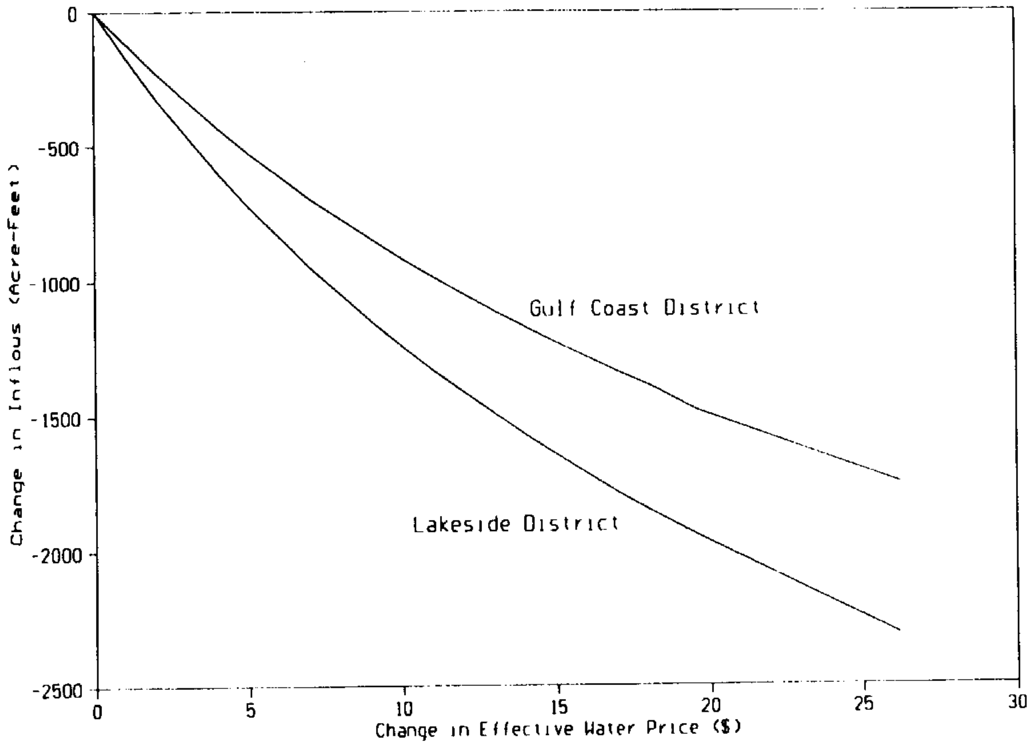
Table 3.17
Parameter Estimates and T-Statistics for the Model of Farmers Reactions

Variable	Coefficients	Eq. 3.8	Eq. 3.10
Intercept	β_0	-166.318	1.074
Effective Price (PE)	β_1	-6.349	-0.073
		(-3.597)*	(-4.400)*
Field Acreage (A)	β_2	2.629	-
		(47.181)*	-
Days Watered (D)	β_3	2.163	0.022
		(8.007)*	(8.097)*
Crop Type[†] (C)	β_4	-31.366	-0.446
		(-2.929)*	(-4.119)*
District[‡] (G)	β_5	59.808	0.739
		(4.879)*	(6.046)*
Interaction Term (INTG)	β_6	2.077	0.014
		(0.694)	(0.448)*
R-squared		0.742	0.243
Adjusted R-squared		0.740	0.239
Model F		422.400	56.807

Source: Calculations by the author based on data in: Lower Colorado River Authority. 1993. Irrigation District Water Accounting Database. Lakeside Irrigation District, Eagle Lake, Texas. (Computer File.); Lower Colorado River Authority. Irrigation District Water Accounting Database. Gulf Coast Irrigation District, Bay City, Texas. (Computer File.)

Note: T-statistics given in parenthesis. (*) Asterisks indicate significance at the 95 percent confidence level. (†) Crop type is a dummy variable indicating first or second crop. (‡) District is a dummy variable indicating observations from Gulf Coast District.

Figure 3.5
Projected Water Savings Associated with Increases in the Effective Water Price



Note: Projected water savings are for on-farm water use during the first crop only assuming 25,000 planted acres on each district and 100 days between first and last irrigation in all fields. Water savings do not reflect decreases in water use associated with acreage reductions or any change in canal losses associated with reduced pumpage requirements. Changes in the effective water price represent increases in the marginal cost of water above current first crop effective prices ($10.22 on Lakeside District and $6.55 on Gulf Coast District). The short-run nature of these estimates is discussed in the text.

Summary

The information in this chapter forms the basis for constructing a linear programming model of on-farm irrigation water demand. Table 3.18 summarizes the information presented in this chapter, and identifies the source of that information. This data represents the best information available about the irrigation districts and the factors that influence demand.

Many factors that influence the demand for water are not known. In the final section, the elasticity estimates appear extremely low. This is perhaps an artifact of the statistical methods or a reflection of the ten percent cap on the difference in the cost of irrigation between 1992 and 1993. The following chapter applies data envelopment analysis to determine whether or not farmers actually can save water and whether or not the price elasticity of demand has been underestimated.

Table 3.18
Summary of Information about the LCRA Irrigation Districts

	Information	**Source**
1	Total water diversions and percent of consumptive use in the river basin.	Texas Water Commission and Lower Colorado River Authority.
2	Stored water diversions, 1989-1992.	Lower Colorado River Authority.
3	First and second crop rice acreage, 1968-1993.	Lakeside and Gulf Coast Irrigation Districts.
4	Farmer's individual water management styles.	Irrigation district water coordinators.
5	Field acreages, field water deliveries, length of field irrigation period.	Irrigation district water accounting databases.
6	District rainfall	National Weather Service field stations at Bay City Waterworks and Columbus.
7	Feasibility of alternative crops.	Texas Agricultural Extension Service, county agricultural extension agents.
8	Rice and alternative crop budgets.	Texas Agricultural Extension Service, model farm budgets by county.
9	Farmer's reactions to a change in the marginal cost of water.	Irrigation district water accounting databases.
10	Potential water savings associated with irrigation technologies.	Texas A&M University, Less Water-More Rice research project.
11	Irrigation technology costs.	Rice farmer interviews.
12	Effect of soil type and rice varieties on field water use.	Texas Agricultural Experiment Station and US Soil Conservation Service.
13	Operational costs on each LCRA irrigation district.	Lower Colorado River Authority.

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Chapter 4
The Irrigation Efficiency Frontier in First Crop Rice Fields

For a water conservation program to work, there must be water to save through conservation. Therefore, it is necessary to determine whether or not farmers can actually improve irrigation efficiency. Can farmers maintain or improve yields while simultaneously using less water for irrigation? If so, there is a win-win solution to the problems of resource scarcity. This chapter presents empirical evidence to suggest that improved water management practices in rice farming can save a substantial amount of water. Results prescribe technically efficient field inflow for sample fields; however, more work is need to develop general standards for irrigation water use. Results can be used to establish on-farm irrigation water conservation targets for Lower Colorado River Authority (LCRA) rice irrigation districts. Conclusions rest on demonstrated performance at farms in Texas' gulf coast region.

Between 1982 and 1988, researchers at Texas A&M University's Texas Agricultural Experiment Station in Beaumont collected information on water budgets and rice yields at sample fields throughout the gulf coast region during the "Less Water-More Rice" research project. In all cases, fields contained a semidwarf variety of rice (TAES, 1982 - 86). These data provide a means of assessing on-farm water efficiency and the crop-water inflow production frontier for rice fields in South Texas. Knowledge of the production frontier is useful because it provides farmers and water management agencies with information about what might be an appropriate standard for irrigation efficiency.

There is a definite relationship between the amount of irrigation water applied to a field and crop yield. As discussed in Chapter 2, these relationships are usually expressed in the quadratic or the Cobb-Douglas forms. However, when the data on crop yield and water use collected by Texas A&M scientists is analyzed using these functional forms, there appears to be no statistically significant relationship between crop yields and field water use. One possible reason is that water in continuous flood irrigation serves more than just a means of satisfying the minimum water requirements of the rice plant. Water also serves as a substitute for labor, pesticides, and infrastructural improvements such as land levelling.

Figure 4.1 shows a scatterplot of crop yields on field water use. If one follows the highest yielding fields across the various levels of field use, there appears to be a slightly quadratic production frontier. However, economic theory suggests that farmers will not use more water than they need if this will reduce their yields. Therefore, it is not realistic to equate these estimates with a true quadratic production function. In Figure 4.1, boxes around the sample field indicate that these fields are laser-levelled. Specific information about fields is listed in Table 4.1.

Data Envelopment Analysis

Data envelopment analysis (DEA) is a linear programming technique that locates a firm's production efficiency frontier based on the performance of other firms. The DEA methodology was originally introduced by Farrell (1957), and further developed by Charnes *et al.* (1978). The following analysis presents an application of DEA methods, but the logical development and proof of these methods are beyond the scope of this paper. Rhoades (1978) provides a mathematical statement of DEA. Ganley and Cubbin (1992) provide a good reference for the reader that is interested in the logical development and application of DEA methods. Most of the analysis presented in this paper was conducted using Ideas Software, available from 1-Consulting, in Amherst, Massachusetts.

DEA estimates the technically efficient level of input use. Technical efficiency with respect to a particular input is defined in terms of two minimum conditions. The firm must produce at a level such that it may not increase its outputs without first either increasing one or more of its inputs, or reducing one or more of its other outputs. In addition, none of the firm's inputs may be reduced without also decreasing some of its outputs, or increasing some of its other inputs (Norman and Stoker, 1991, p. 15). The method may be used to establish management objectives and evaluate performance based on demonstrated achievement in private or public organizations.

DEA has been the subject of strong criticism because of limitations and ambiguities in the interpretation of results and because of operational constraints. Recent software developments have reduced some of the operational constraints. Specifically, it is no longer necessary to assume constant returns to scale. Therefore it is possible to evaluate a firm on the basis of its technical efficiency as well as its scale efficiency (Ganley and Cubbin, 1992). It is also possible to write programs that account for uncontrollable inputs (Banker and Morey, 1986) and multiple noncompeting outputs (Banker and Maindiratta, 1986).

DEA postulates that, for a given set of decision making units (DMUs), there is a convex production surface which can be located in a multidimensional world of n inputs (X_k, ($k = 1, 2, \ldots, n$)) and m outputs (Y_i, $i = (1, 2, \ldots, m)$). This surface is referred to as the hyperplane. Depending upon the management objectives and the way the program is written, the hyperplane can define how few inputs are required to produce a given output (input minimization), or how much output can be produced for a given number of inputs (output maximization).

The problem may be formulated in two ways. Although it is nonlinear, a fractional program provides a conceptually simple and logical description of the DEA methodology. It is a total factor productivity ratio (Ganley and Cubbin, 1992). The objective function for each DMU in the fractional program is maximize the ratio of the sum of weighted outputs divided by the sum of weighted inputs by adjusting the weights (prices) μ_i and v_k where the indices i and k identify specific inputs and outputs:

$$\text{MAX} \quad Z = \frac{\sum_i \mu_i Y_i}{\sum_k v_k X_k} \qquad \textbf{(Eq. 4.1)}$$

Y	a vector of m outputs	
X	a vector of n inputs	
μ	weights on outputs	
v	weights on inputs	
i	an index of outputs	$i = (1, 2, \ldots, m)$
k	an index of inputs	$k = (1, 2, \ldots, n)$

The weights μ_i and v_k are weights on outputs and inputs. DEA programs calculate weights to maximize the ratio. The ratio of the weighted sum of outputs and the weighted sum of inputs must fall between 0 and 1. This ensures that the weighted sum of outputs cannot exceed the weighted sum of inputs and that the program restricts efficiency scores to a number less than or equal to 1:

$$0 \le \frac{\sum_i \mu_i Y_i}{\sum_k v_k X_k} \le 1 \qquad \textbf{(Eq. 4.2)}$$

To differentiate between the input minimization and output maximization objectives, either the numerator or the denominator is constrained to one. In the input minimization model, the numerator is constrained to one:

$$\sum_{i} \mu_i Y_i = 1 \qquad \textbf{(Eq. 4.3)}$$

In both the input minimization and the output maximization models, all weights are constrained to non-zero values (Ganley and Cubbin, 1992). The constraint also ensures that the program first calculates the maximum proportional reduction in inputs before identifying any additional slack in the input variables (Banker and Morey, 1986):

$$\mu_i , \nu_k > \varepsilon \quad \text{for all } i , k \qquad \textbf{(Eq. 4.4)}$$

The variable ε is a constant greater than zero, usually 10E-6.

The linear form of the program flows logically from its fractional form. Since the numerator for each DMU in the input minimization model is constrained to one, the linear objective function is the reciprocal of the fractional objective function. The objective is to minimize the weighted sum of given inputs at each DMU to achieve the stated output by adjusting the weights on inputs:

$$\text{MIN} \sum_{k} \nu_k X_k \qquad \textbf{(Eq. 4.5)}$$

The variable X_k is the input level, and ν_k is the weight on input k. The first constraint limits the sum of weighted inputs to less than the sum of weighted outputs, and is tantamount to stating that outputs cannot exceed any possible combination of inputs:

$$\sum_{k} \nu_k X_k \geq \sum_{i} \mu_i Y_i \qquad \textbf{(Eq. 4.6)}$$

The variables X_k and Y_i are as before. As in the fractional program, the sum of weighted outputs is constrained to one, and weights on both input and output variables are constrained to positive values:

$$\sum_{i} \mu_i Y_i = 1 \qquad \textbf{(Eq. 4.7)}$$

$$\mu_i , \nu_k > \varepsilon \quad \text{for all } i, k \qquad \textbf{(Eq. 4.8)}$$

The primal formulation given above imposes constant returns to scale. Once all weights are established, DEA programs then determine efficiency at an individual DMU according its relative distance from the hyperplane. Banker, Charnes, and Cooper (1984) develop the dual program and add additional constraints to incorporate returns to scale by restricting the set of DMU's used in this comparison. The effect is to create a piecewise efficiency frontier composed of facets along the outer edge of the production possibility set.

Figure 4.1
The Relationship Between Field Water Use and Crop Yields, First Crop Fields

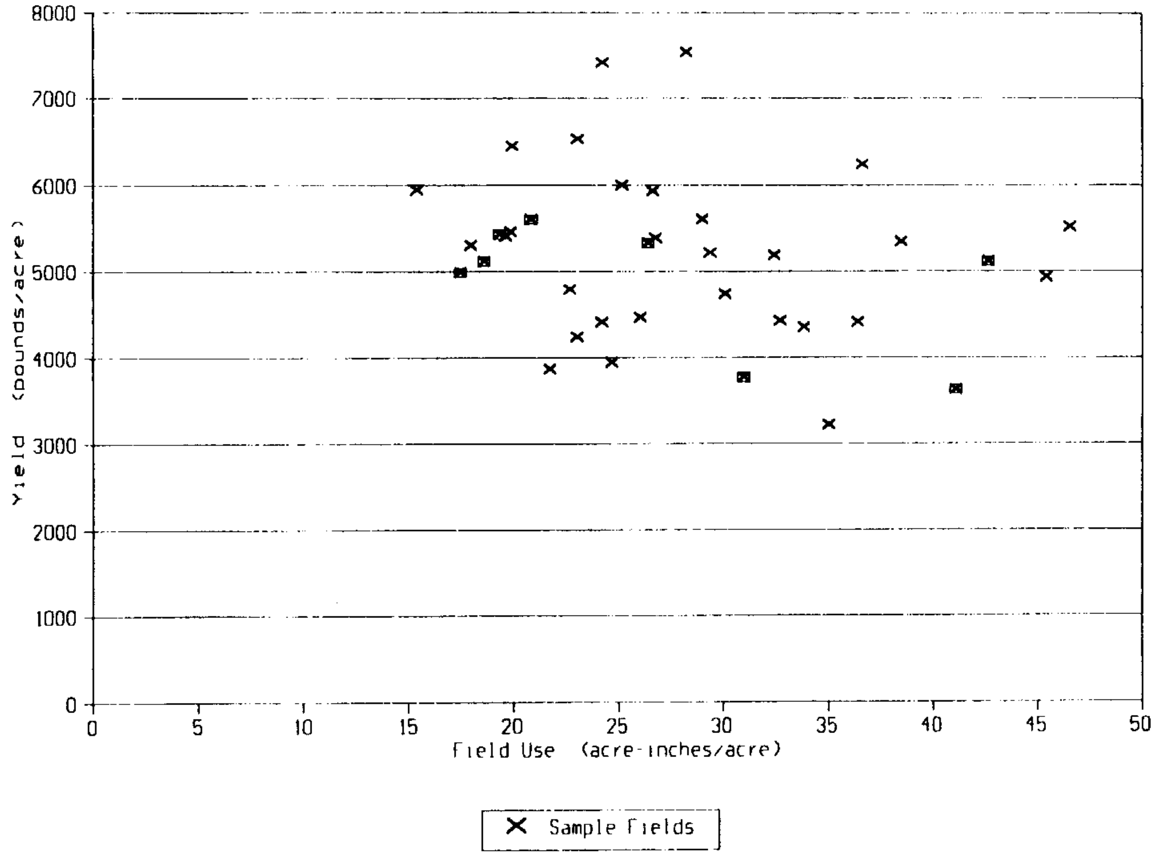

Table 4.1
Sample Field Data, First Crop Rice Fields, Texas Gulf Coast

Year	Field	Note	Rice Variety	County	Acreage	Yield lbs/ac	Inflow in/ac	Rainfall in/ac	Runoff in/ac	Field Use in/ac	N* lbs/ac	P** lbs/ac	K*** lbs/ac	Efficient in Model:
1982	821	L	Bellemont	Wharton	73.4	5,426	25.9	11.7	18.4	19.3	154.2	72.0	36.0	
1982	822		Bellemont	Jackson	27.0	4,933	55.3	10.1	19.9	45.4	121.1	45.5	45.5	
1982	823		Labelle	Colorado	28.0	5,184	30.1	9.9	7.6	32.4	109.1	28.6	28.6	5
1982	824		Labelle	Colorado	32.0	6,444	21.4	9.5	11.0	19.9	147.2	46.0	128.0	
1982	825	L	Labelle	Fort Bend	18.9	5,118	14.4	10.3	6.1	18.6	105.5	41.2	82.5	
1982	826		Labelle	Waller	83.4	5,941	16.3	11.1	12.1	15.3	92.0	50.0	80.0	2, 3, 4, 5
1983	831	L	Labelle	Fort Bend	18.9	5,113	36.8	18.0	12.3	42.6	91.4	49.4	49.4	1, 2, 3
1983	832		Labelle	Jefferson	36.0	4,399	40.3	34.7	38.6	36.4	178.0	40.0	12.5	3
1983	833		Labelle	Matagorda	43.2	5,449	16.9	18.9	16.1	19.8	121.5	40.0	20.0	
1983	834		Lemont	Chambers	23.4	4,343	40.5	35.5	42.2	33.8	173.5	40.0	10.0	
1983	835		Labelle	Colorado	25.5	3,865	46.0	13.5	37.9	21.7	129.0	30.0	30.0	
1983	836		Labelle	Liberty	67.6	4,725	28.1	26.0	24.1	30.0	128.8	0.0	0.0	3, 5
1983	837		Labelle	Jackson	41.3	5,391	12.8	15.6	8.9	19.5	120.7	40.0	20.0	3, 4, 5
1983	838	L	Labelle	Wharton	52.0	5,345	42.7	20.5	24.8	38.4	144.8	40.0	20.0	
1984	841		Lemont	Jefferson	94.0	5,330	32.4	17.5	23.5	26.4	190.4	19.3	0.0	3, 5
1984	842A		Lemont	Liberty	22.1	4,423	23.6	21.4	12.3	32.7	200.2	0.0	0.0	3
1984	842B		Labelle	Liberty	29.3	3,942	14.8	18.8	9.0	24.6	125.0	0.0	0.0	3, 5
1984	843		Labelle	Chambers	49.4	4,241	30.9	9.6	17.6	22.9	162.0	54.0	27.0	
1984	844		CB801	Brazoria	46.4	4,463	32.1	12.7	18.8	26.0	181.5	40.0	20.0	
1984	845	L	Labelle	Fort Bend	18.9	3,628	65.4	8.0	32.3	41.1	104.5	52.0	52.0	
1984	846		Lemont	Wharton	50.1	5,989	37.4	13.0	25.2	25.1	171.0	36.0	18.0	5
1984	847		Lemont	Matagorda	69.3	3,213	33.6	14.4	13.0	35.0	162.0	40.0	20.0	
1984	848		Labelle	Colorado	66.0	5,209	23.9	14.1	8.7	29.3	105.0	57.5	40.0	
1984	849	L	Lemont	Jackson	79.9	3,769	32.4	10.4	11.8	31.0	181.5	22.5	22.5	

(Continued on the following page.)

Table 4.1 (Continued)
Sample Field Data, First Crop Rice Fields, Texas Gulf Coast

Year	Field	Note	Rice Variety	County	Acreage	Yield lbs/ac	Inflow in/ac	Rainfall in/ac	Runoff in/ac	Field Use in/ac	N* lbs/ac	P** lbs/ac	K*** lbs/ac	Efficient in Model:
1985	851		Lemont	Jefferson	71.3	5,918	26.8	14.6	14.9	26.6	228.0	34.5	19.4	
1985	852	L	Lemont	Liberty	71.3	5,589	18.7	13.0	10.9	20.8	155.0	45.0	60.0	
1985	853		Skybonnet	Chambers	69.5	5,383	24.5	13.8	11.6	26.7	141.2	43.9	11.8	5
1985	854		Lemont	Brazoria	101.0	6,529	29.0	12.2	18.3	23.0	155.5	40.8	40.8	
1985	855		Lemont	Fort Bend	42.5	7,415	23.4	10.5	9.8	24.1	166.0	45.5	55.5	1, 2, 3, 4, 5
1985	856		Labelle	Wharton	30.3	4,410	19.8	14.1	9.7	24.2	153.8	59.5	16.5	
1985	857		Skybonnet	Matagorda	57.7	5,516	44.3	17.2	14.9	46.5	115.0	0.0	0.0	5
1985	858		Labelle	Colorado	18.8	4,783	21.8	15.1	14.3	22.6	127.4	52.8	26.4	
1985	859		Lemont	Jackson	37.9	5,300	22.0	9.2	13.2	17.9	198.0	45.6	24.0	5
1986	861	L	Gulfmont	Jefferson	42.6	4,982	11.6	19.1	13.2	17.4	116.7	38.9	40.0	3, 4 ,5
1986	863		Lemont	Chambers	50.0	5,597	30.1	17.4	18.6	28.9	198.0	40.9	51.8	
1986	864		Lemont	Brazoria	65.0	7,545	36.8	17.5	26.0	28.2	219.6	29.4	29.4	1, 2, 3
1986	866		Skybonnet	Wharton	43.1	6,232	31.9	14.1	9.4	36.6	163.3	44.8	56.0	

Source: Texas Agricultural Experiment Station (TAES). 1982-86. *Progress Report on Cooperative Rice Irrigation Study.* Texas A&M University: Beaumont, Texas. (Annual Report.)

Note: L denotes laser levelled fields. (*) Nitrogen. (**) Phosphorous. (***) Potassium.

In a multidimensional variable returns to scale model, the location of the target point (Y-hat, X-hat) on the hyperplane for a DMU j is:

$$\sum_{i} \mu_{ij} \phi_j Y_{ij} - \sum_{k} \nu_{kj} \theta_j X_{kj} + \omega_j = 0 \qquad \textbf{(Eq. 4.9)}$$

ϕ	proportional augmentation in outputs *possible* with no concurrent reduction in inputs	
θ	proportional input reduction *possible* with no concurrent reduction in output	
ω	constant term of the hyperplane associated variable returns to scale models	
j	an index of DMUs	$j = (1, 2, 3, ..., l)$
i	an index of inputs	$i = (1, 2, 3, ..., m)$
k	an index of outputs	$k = (1, 2, 3, ..., n)$

The variable ω_j has a unique value for each facet of the hyperplane, and indicates increasing returns to scale at the DMU for ω_j greater than 0, and decreasing returns to scale at the DMU for ω_j less than 0. Efficiency scores (θ) indicate the DMU's distance from the hyperplane relative to its distance from the origin:

$$\gamma_j = 1 - \theta_j \qquad \textbf{(Eq. 4.10)}$$

γ	proportional reduction in inputs *necessary* to achieve maximum efficiency at DMU j

For an individual input at DMU j, there may be residual excess (e) after proportional reductions in inputs. If, after a proportionate reduction in inputs, there remains some residual excess input, a DMU may only become technically efficient by altering the ratio of its inputs. DEA programs calculate the residual reduction in a particular input that is necessary to achieve technical efficiency:

$$X_{kj} - \theta_j X_{kj} - \gamma_j X_{kj} = e_{kj} \qquad \textbf{(Eq. 4.11)}$$

e	excess quantity of input X used in the production process that could be eliminated after the proportional reduction of all inputs ("the residual excess").

The term $\theta_j X_{kj}$ is the prescribed quantity of input k necessary for DMU j to achieve its target point on the hyperplane, and the variable X is the actual quantity of input k used at DMU j. The variable In a model with multiple inputs, the value of e for at least one input will equal zero.

Including variable returns to scale constraints in the DEA program enables the analyst to discriminate between scale inefficiency and technical inefficiency because firms operating at a less than optimum scale may be classified as efficient. Byrnes *et al.* (1984) note that firms may appear scale inefficient because of differences in the production technology at individual firms in the set of DMUs under analysis. It is possible to avoid this confusion by strictly limiting the analysis set to DMUs using similar technology.

For the purposes of this paper, it is sufficient to recognize two characteristics of the variable returns to scale model. First, the model provides a purer measure of technical efficiency than the constant returns to scale model because there is no confusion between technical and scale efficiency. Second, the efficiency scores tend to be higher than in the constant returns to scale model (Ganley and Cubbin, 1992).

It is worth discussing the difference between efficiency in the DEA sense, and ordinary production efficiency described in chapter 2. First, the efficiency scores (θ) in this chapter refer only to technical efficiency. To be classified as Pareto efficient in conventional economic theory, a DMU must meet three conditions. It must be simultaneously allocative, scale, and technically efficient. Such a definition is useful in terms of allocating resources among a group of users, but practical applications of the theory are rare. Secondly, the efficiency score (θ) is revealed technical efficiency and reflects the level of efficiency achieved through best practices. Given a hypothetical set of ideal (better) practices, DEA-efficient DMUs could potentially become more efficient.

Because the efficiency score (θ) is based on revealed efficiency, the location of the efficiency frontier is sensitive to the set of DMU's under analysis. In addition, the performance of individual DMUs may vary across time periods. Therefore, Ganley and Cubbin (1992) recommend using panel data sets to minimize the bias related to stochastic variation in individual DMU performance over time. These authors also recommend using parametric statistical methods to evaluate the accuracy of efficiency scores over different time periods. Banker *et al.* (1986) use the χ^2 test for non-parametric data to evaluate the differences in results between DEA and other methods. These techniques might also be applied to evaluate discrepancies between DEA models. In the analysis of irrigation efficiency that follows this discussion, four years of data collected in different fields are combined into a single DMU analysis set. Although this aggregation of data helps minimize the risk of underestimating the true frontier, there are other problems specific to the reliability of these DEA results which are discussed later in this chapter.

DEA-Defined Technical Efficiency in Rice Irrigation

Perhaps one of the most difficult problems the analyst must deal with in applying DEA is the selection of appropriate variables. Because DEA is a non-parametric approach to frontier estimation, it assumes no normality or independence between the variables, and does not require the analyst to define a functional relationship between inputs and outputs (Banker, 1978; Ganley and Cubbin, 1992). Perhaps as a result, the technique is more useful in determining what is possible than how to achieve that possible outcome. Therefore, the following discussion will focus as much on developing the problem and choosing the variables as on the presenting, interpreting, and discussing the results.

Consistent with previous chapters, the DEA model assumes that each farmer makes water management decisions in a field to maximize profits. As discussed in Chapter 2, that is distinctly different than maximizing output. Therefore, it is not reasonable to impose an output maximization objective on individual farmers. Suppose a hypothetical water management agency would like farmers to minimize their water use. DEA defines the agency's objective in terms of minimizing the distance between the amount of water a farmer uses and the amount of water his peers on the frontier (hyperplane) do use in the production of rice.

Further suppose this water management agency would like farmers to reduce their field water use according to the yields they achieve. Such an objective would be consistent with the allocation of marginal water resources to their most productive use. Model 1 consists of one output (yield) and one input (field water use). Water that enters the field via irrigation inflows or rainfall may either be used in the production process (field water use) or runoff the field. Field use is calculated by an equation that states water consumed in a field is equal to rainfall and irrigation water inflows minus water runoff:

$$F = R + I - N \qquad \textbf{(Eq. 4.12)}$$

F	water used in the production process [field water use] (inches per acre)
R	rainfall (inches per acre)
I	irrigation inflows (inches per acre)
N	water runoff (inches per acre)

Implicit in the water management agency's request is the assumption that water is a factor in the production process, and that lower yields should require less water.

Results of Model 1 are presented in Table 4.2 and indicate that fields 826, 855, and 864 are the efficient fields. These three fields are the dominant DMUs and therefore define the efficiency frontier. These results indicate the potential reduction in field water use that is possible at individual fields. For example, the farmer in field 821 could reduce field water use by 24 percent ($\gamma = 0.24$) without reducing yield.

From the water management agency's perspective, asking farmers to minimize field water use is not practical. Farmers do not measure their field use, and probably have little intuitive sense of how the relative combination of rainfall, inflow, and runoff affects their field water use. In addition, water is an intermediate factor in the production process, not a component of the final product. Therefore, water that leaves a field through runoff may or may not serve a productive purpose other than as an input to satisfy the evapotranspiration needs of the rice plant. Perhaps that purpose is as a substitute for infrastructural improvements or farm labor.

A different measure of the water input allows for the possibility that all water serves some productive purpose. From the equation 4.13, total water use can be calculated as the sum of field use and runoff, or as the sum of rainfall and irrigation inflows:

$$F + N = R + I = T \qquad \textbf{(Eq. 4.13)}$$

T field-specific total water use (inches per acre)

Other variables are as in equation 4.12. The water management agency's verbal statement of the problem might go something like this: "For the stated yield in this field, minimize the total amount of irrigation water inflows entering the field by finding as many reasonable substitutes for water as possible." In the DEA context, "reasonable substitutes" are implied by the farmer's peer group on the hyperplane. However, substitutes are not explicitly identified.

DEA Model 2 has one output (yield) and one input (total water use). Model 2 efficiency scores (θ) for individual fields are given in column 2 of Table 4.2. The average efficiency score for Model 2 is approximately 3 percent higher than for Model 1. Why might the scores for Model 2 be slightly higher than for the Model 1? One possible reason is that farmers adjust inflows according to the amount of rainfall entering the field. The input variable in Model 1 was only related to some abstract field water use variable and gave no consideration to the amount of rainfall or the volume of inflows. It is possible to test this hypothesis by looking at the correlation coefficient between the efficiency score and rainfall in Table 4.3. The coefficient is more negative for Model 2 than for Model 1. However, note that the differences are small, and that only one additional DMU is identified as efficient ($\theta = 1$). In addition, some of the other coefficients are also more negative and it is not certain that this increase in negativity is not related to random disturbances.

Also note that the runoff variable is more highly correlated with the efficiency score in Model 2 than in Model 1. A logical explanation for this is that the higher the volume of runoff, the higher the water use in relation to crop yield. There is also a high correlation between fertilizer and the efficiency score. The logical explanation is that crop yields increase in response to the amount of fertilizer applied. This idea is reinforced by the high correlation with yield. However, this is undesirable. The DEA program normalizes yields before identifying efficient DMUs and should not assign high efficiency scores to fields simply because they have high yields. Model 3 attempts to overcome this apparent bias by including the fertilizer variables along with the total water input.

Model 3 consists of one output (yield) and four inputs (total water use, nitrogen, phosphorous, and potassium). Results for Model 3 in Table 4.2 now show many more firms on the efficiency frontier and there has been no change in the original designation of efficient firms. Note, however, that efficiency scores are in general much higher than in Models 1 and 2. One possible reason is that farmers now have several different ways to be efficient. Because there are a greater number of facets on the hyperplane, the random probability that a point is close to a facet (has a high efficiency score) is greater.

The discrepancy in efficiency scores may be related to the larger number of input variables relative to the sample size. Because a larger number of inputs increases the number of facets on the hyperplane, a farmer with a unique ratio of inputs can be efficient by virtue of the fact that no other fields have a similar input ratio.

There are additional problems with Model 3. One is the persistent correlation between the efficiency measure and yields. This may indicate a bias towards fields with high yields, and result in artificially low estimates of the efficient volume of total water use. Third, in estimating the inflow requirement, there is no allowance for the periodicity or intensity of rainfall. Periodicity and intensity can affect farmers ability to make use of rainfall.

Temporarily ignoring these problems, suppose the water management agency would like to develop specific irrigation targets for inflows using this model. If each field were to somehow become efficient by reducing its inputs according to the DEA results, each field would reduce its total water use to T':

$$\theta T - e = T' \qquad \textbf{(Eq. 4.14)}$$

T	field-specific total water use (acre-inches per acre)
θ	field-specific efficiency score
e	the residual excess (acre-inches per acre)
T'	technically efficient total water use (acre-inches per acre)

Table 4.4 lists the target volume for total water use at each DMU prescribed by Models 2 and 3. The underlying objective in Models 2 and 3 was to have farmers maximize their use of rainfall. Farmers have no control over the amount of rainfall. Estimates represent the "efficient" volume of irrigation water inflows in a particular field if the farmer made maximum use of his rainfall. This is the column headed "I'." It is the difference between total water use at the target point for the field and rainfall:

$$T' - R = I' \qquad \textbf{(Eq. 4.15)}$$

I'	field-specific inflows with maximum use of rainfall (acre-inches per acre)

Table 4.2
Model Parameters and Efficiency Scores (θ) for DEA Models 1, 2, and 3

		Model 1	Model 2	Model 3
Model Parameters				
Outputs				
	Yield (Y)	x	x	x
Inputs				
	Field Water Use (F)	x	-	-
	Total Water Use (T)	-	x	x
	Nitrogen	-	-	x
	Potassium	-	-	x
	Phosphorous	-	-	x
Fields			**Efficiency Scores (θ)**	
	821	0.79596	0.68276	0.75540
	822	0.33803	0.37796	0.81347
	823	0.47394	0.62260	0.98924
	824	0.92280	0.95947	0.96856
	825	0.82590	1.00000*	1.00000*
	826	1.00000*	1.00000*	1.00000*
	831	0.36038	0.44996	1.00000*
	832	0.42225	0.32943	0.62910
	833	0.77314	0.71851	0.95672
	834	0.45393	0.32484	0.64859
	835	0.70829	0.41493	0.82468
	836	0.51080	0.45627	1.00000*
	837	0.78458	0.89893	1.00000*
	838	0.39964	0.40258	0.75807
	841	0.58176	0.50979	1.00000*
	842A	0.46974	0.54882	1.00000*
	842B	0.62328	0.73361	1.00000*
	843	0.66855	0.60896	0.71823
	844	0.59002	0.55090	0.67379
	845	0.37378	0.33665	0.88912
	846	0.62253	0.54977	0.82289
	847	0.43864	0.51414	0.70541
	848	0.52368	0.65375	0.96926
	849	0.49565	0.57699	0.72606
	851	0.57739	0.66046	0.89446
	852	0.73788	0.82814	0.88342
	853	0.57415	0.66688	0.86080
	854	0.82089	0.72821	0.89990
	855	1.00000*	1.00000*	1.00000*
	856	0.63512	0.72928	0.86021
	857	0.33004	0.42364	1.00000*
	858	0.67919	0.66946	0.85594
	859	0.85627	0.81136	0.90999
	861	0.87929	0.80449	1.00000*
	863	0.53018	0.55365	0.67439
	864	1.00000*	1.00000*	1.00000*
	866	0.46690	0.62503	0.78565

Note: (*) Asterisks indicate efficient fields.

Table 4.4 includes Model 2 results to illustrate the sensitivity of the analysis to changes in the definition of variables. The results for Model 2 show that efficient total water use (T') is fairly consistent across fields. This contrasts with highly variable values for efficient water use prescribed by Model 3. Note, however, that for efficient fields, the value of efficient total water use is identical in both models. Extrapolation of the results to estimate a value for efficient irrigation water inflows (I') in particular fields also produces divergent results. The negative I' values for Model 2 make these results highly suspect. The I' values for Model 3 are much more reasonable, however, variation between fields makes it doubtful that there would be enough information to apply an irrigation efficiency standard to individual fields on the LCRA rice irrigation districts.

Table 4.3
Correlation of Factors of Production with Efficiency Measures

	Correlation with Efficiency Measure		
	Model 1	**Model 2**	**Model 3**
Output Variable			
Yield	0.5601	0.5992	0.3947
Input Variable			
Field Acreage	0.1961	0.1595	-0.0082
Field Water Use	-0.8818	-0.7518	-0.2219
Irrigation Water Inflow	-0.6328	-0.7709	-0.4041
Rainfall	-0.3262	-0.4415	-0.2252
Runoff	-0.2525	-0.6302	-0.4820
Nitrogen	0.0719	-0.0095	-0.3905
Phosphorous	0.2609	0.2114	-0.3299
Potassium	0.3672	0.4547	0.0945

Table 4.4
DEA-Efficient Values for Total Water Use (T') and Inflows (I') in Sample Fields DEA Models 2 and 3 (Acre-Inches per Acre)

	Model 2		Model 3	
Field Number	Total Water Use θT - e	Technically Efficient Inflow (θT - e) - R	Total Water Use θT - e	Technically Efficient Inflow (θT - e) - R
821	25.77	14.00	28.52	16.75
822	24.73	14.61	53.23	43.11
823	24.95	14.97	39.65	29.67
824	29.72	20.22	30.01	20.51
825	24.73	14.43	24.73	14.43
826	27.52	16.38	27.52	16.38
831	24.73	6.65	54.96	36.88
832	24.73	-10.03	47.23	12.47
833	25.85	6.86	34.42	15.43
834	24.73	-10.85	49.38	13.80
835	24.73	11.15	49.15	35.57
836	24.73	-1.28	54.20	28.19
837	25.66	9.99	28.54	12.87
838	25.50	4.93	48.02	27.45
842A	24.73	3.29	45.06	23.62
842B	24.73	5.91	33.71	14.89
841	25.45	7.94	49.92	32.41
843	24.73	15.09	29.17	19.53
844	24.73	11.99	30.25	17.51
845	24.73	16.72	55.38	47.37
846	27.73	14.72	41.51	28.50
847	24.73	10.25	33.93	19.45
848	24.90	10.72	36.92	22.74
849	24.73	14.30	31.12	20.69
851	27.44	12.75	37.16	22.47
852	26.33	13.25	28.08	15.00
853	25.63	11.79	33.08	19.24
854	30.08	17.81	37.17	24.90
855	33.98	23.43	33.98	23.43
856	24.73	10.63	29.17	15.07
857	26.08	8.87	61.56	44.35
858	24.73	9.63	31.62	16.52
859	25.35	16.13	28.43	19.21
861	24.73	5.62	30.74	11.63
863	26.35	8.89	32.10	14.64
864	54.35	36.83	54.35	36.83
866	28.80	14.68	36.19	22.07
Average	26.70	11.17	38.65	23.12
Standard Deviation	5.00	8.11	10.06	9.37

Uncontrollable Input Analysis for First Crop Rice Fields

Models 2 and 3 consider only total water use. Because farmers cannot control rainfall, and the Ideas software (version 5.02) cannot model uncontrollable inputs, these analyses do not treat inflows and rainfall as unique inputs. Banker, Charnes, and Cooper (1984) have addressed this problem by developing a linear program that accounts for the uncontrollable nature of inputs, thus allowing a distinction between inflows and rainfall. These programs treat an uncontrollable input such as rainfall as a potential substitute for controllable inputs. Each DMU receives an efficiency score based only on the demonstrated achievement of DMUs with smaller amounts of uncontrollable inputs. Residual excess (e) in the uncontrollable input represents that portion that cannot be substituted (Banker and Morey, 1986). This section presents DEA models 4 and 5. These variable returns to scale models were run in a DEA program developed by Bardhan (1994).

Suppose the hypothetical water management agency discussed in the previous section is interested in determining the minimum volume of irrigation inflows (I) rather than total water use. This agency could not compare water use across fields directly because rainfall varies between fields. Model 4 characterizes the problem with one output (yield) and two inputs (irrigation inflows, rainfall). The rainfall variable is considered to be an uncontrollable input. Efficiency scores are presented in Table 4.5. As in the previous models, the efficient level of input use is calculated by multiplying the efficiency score (θ) by irrigation inflows, and subtracting residual excess (e):

$$\theta I - e = I' \qquad \textbf{(Eq. 4.16)}$$

θ	the efficiency score
I	field-specific irrigation inflow (acre-inches per acre)
e	the residual excess irrigation inflow (acre-inches per acre)
I'	field-specific efficient irrigation inflow (acre-inches per acre)

As in Model 2, the efficiency scores and inflow prescriptions appear low. Efficient DMUs are 826, 837, 855, and 861. Model 4 results show an average efficiency score of 0.523 and an average efficient inflow of 13.14 acre-inches per-acre (the standard deviation is 3.33). Correlations with input and output variables are provided in Table 4.7. The efficiency score is much less correlated with rainfall than in previous models. However, correlations with the runoff variable appear similar to those in previous models. There is also a slight increase in the correlation with inflow. Finally, the estimates appear correlated with yield, suggesting a bias towards fields with high yields. Increasing the number of inputs in the DEA model could resolve correlations with yield.

As in the transition from Model 2 to Model 3, Model 5 addresses the correlation with yield by including fertilizers as input variables. Model 5 has one output (yield) and five inputs (irrigation inflows, rainfall, nitrogen, phosphorous, and potassium). The rainfall variable is considered an uncontrollable input. Efficiency scores and efficient levels of irrigation inflows are presented in Table 4.5. Correlations with efficiency measures are presented in Table 4.6.

Efficiency scores for Model 5 are higher than for Model 4. This is probably the result of an increase in the number of facets surrounding the production possibility set. The average efficiency score for DMUs in Model 5 is 0.831. The average efficient irrigation inflows is 22.11 acre-inches per acre (standard deviation is 7.27). The average efficient irrigation inflow in Model 5 is 1.01 acre-inches per acre lower than the average efficient irrigation inflows estimated in Model 3.

Table 4.5
Model Parameters and Efficiency Scores (θ) for Uncontrollable Input Models 4 and 5

	Model 4	Model 5
Model Parameters		
Outputs: Yield (Y)	x	x
Uncontrollable Inputs: Rainfall (R)	x	x
Controllable Inputs:		
Irrigation Inflows (I)	x	x
Nitrogen	-	x
Potassium	-	x
Phosphorous	-	x

	Model 4		Model 5	
	Efficiency Score	Technically Efficient Inflow (acre-inches per acre)	Efficiency Score	Technically Efficient Inflow (acre-inches per acre)
Field Number	θ	θ I - e	θ	θ I - e
821	0.554	14.388	0.758	19.692
822	0.240	13.289	0.788	25.403
823	0.472	14.200	1.000*	30.100
824	0.934	20.067	0.945	20.058
825	0.960	13.859	0.974	14.054
826	1.000*	16.380	1.000*	16.380
831	0.326	12.023	0.960	22.511
832	0.255	10.269	0.529	21.324
833	0.755	12.829	0.959	16.293
834	0.250	10.138	0.538	21.815
835	0.198	9.093	0.572	24.359
836	0.361	11.030	1.000*	28.190
837	1.000*	12.870	1.000*	12.870
838	0.292	12.488	0.745	31.863
841	0.389	12.607	1.000*	32.410
842A	0.437	10.321	0.997	23.549
842B	0.618	9.202	1.000*	14.890
843	0.358	11.087	0.578	17.900
844	0.334	10.738	0.558	17.939
845	0.146	9.555	0.614	16.594
846	0.424	15.870	1.000*	37.430
847	0.223	7.497	0.418	14.053
848	0.535	12.791	0.919	21.973
849	0.283	9.177	0.513	16.636
851	0.560	15.041	0.905	24.308
852	0.774	14.481	0.824	15.417
853	0.549	13.499	1.000*	24.590
854	0.620	18.004	0.897	26.048
855	1.000*	23.430	1.000*	23.430
856	0.528	10.459	0.638	12.638
857	0.295	13.083	1.000*	44.350
858	0.520	11.356	0.768	16.773
859	0.693	15.259	1.000*	22.020
861	1.000*	11.630	1.000*	11.630
863	0.441	13.291	0.644	19.410
864	0.532	19.593	0.939	34.583
866	0.510	16.294	0.769	24.569

Table 4.6
Correlation of Factors of Production with Efficiency Measures

	Correlation with Efficiency Measure	
	Model 4	**Model 5**
Output Variable		
Yield	0.5592	0.5994
Input Variable		
Field Acreage	0.0722	0.0900
Field Water Use	-0.7465	-0.2620
Irrigation Water Inflow	-0.8325	-0.4686
Rainfall	-0.2759	-0.1404
Runoff	-0.6015	-0.4717
Nitrogen	-0.1789	-0.2368
Phosphorous	0.1980	-0.2974
Potassium	0.4078	0.0364

The addition of input variables in Model 5 has not resolved the high correlation with yield in Model 4. The correlation between the efficiency measure and yield in Model 5 is 0.599, slightly higher than in Model 4. As discussed earlier, this might suggest that the efficiency scores are biased towards those fields with higher yields. However, correlation between the efficiency score and rainfall is, as in Model 4, lower than in Models 2 and 3. This would suggest that Model 5 is closest of all the models to eliminating bias towards assigning high scores to fields with high rainfall. Overall, the correlations between Model 5 efficiency scores and each of the input variables appear lower than in previous models.

Estimates of efficient irrigation inflows in Model 5 appear to be slightly more consistent than those in Model 3. This is evidenced by the lower standard deviation for the estimates in Model 5. However, these estimates still do not seem consistent enough to develop targets for irrigation water use in individual fields.

The most practical use of the information presented here appears to be an estimate of the total water savings potential associated with on-farm water conservation programs. In other words, "how much water could farmers potentially save on the irrigation districts by collectively adopting best practices?" Given a value for water, it would also be possible to estimate how much LCRA should invest in an on-farm water conservation program that encourages farmers to adopt best practices. The potential water savings is the difference in average technically efficient irrigation inflows in sample fields and average irrigation inflows. Tables 3.6 and 3.7 give the average irrigation inflows in 1993 for fields on LCRA irrigation districts.

On Lakeside District for example, average irrigation inflows during the first crop period in 1993 were 29.27 acre inches. The difference between 29.27 acre-inches per-acre and average technically efficient inflows prescribed by Model 5, 22.11 acre-inches per-acre, is 7.16 acre-inches per-acre. The potential water savings associated with on-farm water conservation on Lakeside District during the first crop period in 1993 is therefore 24.46 percent of irrigation inflows. Based on 1993 acreage estimates from equation 3.1, and average first crop irrigation inflows during the 1993 crop year, an on-farm water conservation program could produce a maximum of 10,916 acre-feet of water during the first crop period on Lakeside District.

On Gulf Coast District, average irrigation inflows during the first crop period in 1993 were 45.51 acre inches per-acre. The difference between 45.51 acre-inches per-acre and 22.11 acre-inches per-acre is 23.4 acre-inches per-acre. The potential water savings associated with on-farm water conservation on Gulf Coast District during the first crop in 1993 was 51.42 percent of irrigation inflows. Based on 1993 acreage estimates from equation 3.1 and average first crop irrigation inflows during the 1993 crop year, an on-farm water conservation program could produce a maximum of 47,338 acre-feet of water during the first crop period on Gulf Coast District.

These results are useful for planning. However, estimates of potential water savings may be overstated. The variable I' represents a frontier efficiency, not necessarily an "acceptable efficiency." It would be unreasonable to expect all farmers to operate at 100 percent efficiency all of the time. Errors in judgement, stochastic environmental influences, and unique properties of individual fields may all influence an individual farmer's ability to achieve DEA-efficient water use. For these reasons, some sources consider that efficiency scores of 0.80 or larger represent a satisfactory level of efficiency in private enterprise (Ganley and Cubbin, 1992). Estimates of the potential water savings should probably be adjusted downward to reflect these considerations.

Summary

This chapter has presented a methodology for analysis of on-farm water efficiency. The method could be applied to any area of the state and to any crop type. More analysis is needed to develop an enforceable standard for irrigation inflows in rice fields on the LCRA Districts. However, results are useful for developing on-farm irrigation water conservation targets. This summary presents a discussion of two interesting results and makes several points that would be useful in future DEA analyses.

Two interesting results of this analysis deserve discussion. First is the apparent non-performance of laser-levelled fields. Second is that rice farmers in Texas' gulf coast region appear to operating in the region of increasing returns to scale. Laser levelling is an expensive investment designed to improve yields by creating a more constant depth of water throughout the field. Because there is less variation in the elevation of the field, farmers can maintain a more consistently shallow water depth. This should reduce the amount of water inflows required to maintain a flood and reduce runoff and seepage (Stansel and Lindemann, 1987). The results presented here suggest that laser-levelling is not necessarily a key to achieving high levels of irrigation efficiency.

Farmers appear to operate in the region of increasing returns to scale. This conclusion is based on the value of the constant term of the hyperplane, ω, described in equation 4.9. It implies that farmers could achieve proportionally higher yields relative to increases in the input variables. However, more analysis is needed to firmly establish this result. Banker *et al.* (1986), and Byrnes *et al.* (1984) show that estimates of scale efficiency are often sensitive to the specific input variables used in DEA models.

The most efficient fields according to this model are distributed in time and space throughout Texas' gulf coast region. This supports the conclusion that high levels of irrigation efficiency are achievable in different fields throughout the region and in different years despite environmental factors. However, the exclusion of factors that influence yield or irrigation efficiency could bias results and lead to unreliable estimates of the maximum achievable efficiency level in certain fields. For example, evaporation rates from fields will vary across locations according to differences in temperature, relative humidity, and wind. Similarly, the frequency and timing of rainfall is an important factor that influences a farmer's ability to use that water input. Although soils do not appear to influence water use between fields on these irrigation districts, there may be significant differences in water holding capacity across soils in the region.

Results of this analysis are applicable to semidwarf varieties of rice only. Other varieties of rice may exhibit significantly different irrigation efficiency frontiers. A future DEA study should compare results across rice varieties. Similarly, a future study should consider a greater number of variables. This will require a larger set of DMUs in the analysis set. As a general rule, there should be at least seven DMU's for each analysis variable. Alternatively, a future study might substitute more appropriate variables in the analysis. In particular, this study has been constrained by the range of data collected during the Texas A&M study and the small number of sample fields.

DEA results show large differences in field-specific inflow prescriptions. Differences between fields may be the result of differences in the ratio of those inputs specified in the model as well as field characteristics and unspecified input variables. These variables could be identified through further analysis.

Additional analysis could also draw conclusions about best irrigation practices. This might be accomplished by examining all of the relevant data regarding sample fields to identify those practices that are correlated with the lowest frontier estimates (lowest potential water use). This differs from the traditional method that focuses on correlations between specific practices and those fields with the lowest actual water use. Aligning all farmers practices with best practices identified in this manner will mean that all farmers have a similar target efficiency level on the production frontier.

Implementing best irrigation practices among farmers could increase the potential water savings associated with on-farm water conservation programs relative to estimates of water savings presented in this report. Implementation of best irrigation practices might be accomplished through monetary incentives such as subsidies or water prices that encourage farmers to voluntarily adopt different technologies or alter their input ratios.

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Chapter 5
A Linear Programming Model for Estimating Derived Demand

The purpose of this chapter is to present the linear programming model and the assumptions used to analyze the demand for water on LCRA's rice irrigation districts. The approach and assumptions employed in this study are a product of several factors. These factors include the nature of the method itself, the availability of data, and the objectives of the study. Many of the assumptions presented in Table 5.1 are common assumptions of farm budget and linear programming techniques.

Assumptions of the Linear Programming Model

One assumption common to all models of this type is that demand for farm products is perfectly elastic. As farm output decreases in response to a changing water cost, crop prices do not increase. For these irrigation districts, this is probably not an unreasonable assumption. Farmers serve a world market that is so large in relation to the district rice output that reduced output would not affect supply. Two other factors also support this assumption. First, US rice stores provide a buffer between the farmer and the market so that there is a lag time between market response to a reduction in farm output and farmers' decisions to stop producing. Secondly, farmers typically operate within Agricultural Stabilization and Conservation Service (ASCS) programs that usually provide the farmer with a higher-than-market price for his rice.

The second set of assumptions deals with farmer behavior. A standard assumption throughout economic theory is that the individual acts to maximize profits. Therefore, each farmer will plant the crop that provides the highest return. However, because of a lack of information about individual farms, this model treats the irrigation district as one farm unit. Different farms face different constraints, and the crop mix that maximizes profits on the irrigation districts may not be the same as the one that maximizes profits on individual farms. A detailed survey of individual farm firms was beyond the scope of this report.

Because farming costs and water demand are determined on a per-acre basis, this linear programming model is valid as long as farms exhibit constant returns to scale and farmers use a fixed proportion of inputs. A recent study by the US Department of Agriculture supports the assumption that rice farms exhibit constant returns to scale (USDA-ERS, 1992). However, a study by Texas A&M University contradicts this conclusion (AFPC, 1989). That study found that variable cash expenses on a 1300 acre rice farm were 5.17 percent higher than on a 500 acre farm. The methods used here assume that model farm budgets average out any differences in variable cash expenses among different size farms.

Another assumption this model makes about farmer behavior is that farmers make their planting decisions in the short run. The study by the Agriculture and Food Policy Center (AFPC) at Texas A&M University (1989, p.43) supports this assumption and concludes that farmers may continue to farm rice despite negative economic returns in the hope that conditions will improve in the long run. If a farmer can meet variable and cash costs in the short-run, and expects conditions to improve in the future, the decision to farm rice is still a rational one. However, a farmer with an optimistic outlook may actually withstand negative returns on variable costs in one year in order to preserve an ability to take advantage of rice markets in the future. The reason for this is that a farmer must maintain ASCS base acreage allotments by farming rice in every year in order to participate in ASCS programs in the future. In the context of this model, farmers have no perception of the future, and therefore only maximize profits in the current year. Therefore, the model may not accurately describe how farmers make their planting decisions.

Table 5.1
Assumptions of the Linear Programming Model

	Subject	Assumption	Implications
1	Output price	Farmers are price takers.	Crop price does not vary with farm output, and the marginal cost of the last unit produced is equal to the output price.
2	Farmer behavior	Farmers make their planting decisions individually and collectively to maximize profits.	Farmers will select the most remunerative crop alternative.
		Farmers make their planting decisions in the short run.	The budgets include only short-run costs, and exclude fixed costs.
3	Farm budgets	Model farm budgets are valid for all areas of the irrigation district.	Farm production and farm inputs do not vary across farms.
		There are no opportunity costs associated with land use or farm management.	Budgets do not include opportunity costs for land or farm management.
		Soils, farm management, and technology inputs have no effect on crop yield.	Crop yields do not differ across farms, or in response to management and technology inputs.
		There are constant returns to scale with respect to field acreage.	There is no minimum field size, and farm budgets are applicable on one acre of land.
4	Farm inputs	The cost of farm inputs other than water is equal to the marginal value product.	The farm budget residual equals the value of water in crop production.
5	Farm water requirements	Water requirements do not differ across soil types or rice varieties.	The water requirement is fixed in the model farm budget.
6	ASCS base acreage	Farmers participate in ASCS programs on all rice land.	Farmers plant rice in an area equal to the what the acreage model (equation 3.1) projects given ASCS program parameters.
		ASCS base acreage is randomly distributed throughout the districts.	The area of base acreage in each feasible crop area is equal to the proportion of district base acreage within the feasible crop area.
7	Farm management	There are no costs associated with higher levels of water management style.	Farm budget residuals are equal across all management categories.
		Farmers do not alter their water management style in response to higher water prices.	The acreage managed under a particular water management style is fixed in proportion to the number of farmers using that style.
8	Irrigation technology	Farmers do not currently use closer levees or infield laterals as a means of reducing farm water requirements.	Farmers can reduce irrigation water costs by adopting irrigation technology.
		The reason farmers do not use closer levees or infield laterals is a matter of cultural farming practice, and not economic.	The number of farmers using a particular technology is limited through acreage constraints in the linear program rather than additional costs in the farm budget.
9	Canal water losses	Canal losses are 17 percent of on-farm water demand.	May underestimate actual canal losses at low levels of on-farm water use.

Model farm budgets fix crop yields and farm inputs. A fixed input assumption imposes constant returns to scale. However, the use of model farm budgets based on county averages accounts for differences in the proportion of farm inputs across different size farms. Of greater concern is the fact that farmers may alter the proportion of farm inputs as the price of water increases. Therefore, the model may not accurately portray production costs under varying levels of irrigation intensity.

Farm budgets do not include opportunity costs. The assumption is that no opportunity costs associated with land use and farm management. This assumption implies no better alternatives to current land use, and no non-farm employment opportunities available to the farmer. This is an appropriate assumption in the short-run context of a linear programming demand model (Gisser, 1970).

Crop yield does not vary across management and technology categories. While soils and management may obviously affect crop production there is little reliable information on the effect of technology and management on production. Therefore, this latter assumption is a necessary over-simplification of a complex relationship.

Similarly, there is little information on differences in the water requirement of soils and rice varieties. Although these differences appear to be small, they could result in as much as a 7-8 acre-inch per acre difference in water requirements between farms. However, because the model uses an average on-farm water requirement for farms on the irrigation districts, differences in individual farm water requirements that are a direct result of differences in the variety of rice and field soil types should not vary more than about 4 acre-inches from those specified in this model.

Under the assumption that all farmers participate in ASCS programs, the extent of ASCS base acreage on the districts defines the area which may be used in rice production. The extent of base acreage will not affect estimates of farmers willingness to pay for water or water price prescriptions. Estimates of benefits and costs associated with water rights will be sensitive to acreage variables. Acreage projections may be less appropriate for retrospective studies when acreage is known, but are necessary when the model is used as a planning tool.

Another assumption is that ASCS base acreage is distributed randomly throughout the districts, and is therefore proportionally distributed among feasible crop areas. Interviews with county extensionists and others indicate that this is an appropriate assumption. If the location of ASCS base acreage is not random, the model will not accurately reflect the elasticity of demand for irrigation water because the feasible crop set differs between feasible crop areas.

There are no costs associated with higher levels of water management style. Water coordinators rated farmers on characteristics that indicate more intensive management strategies require more labor inputs. However, there is little information on the cost of these inputs or their effect on crop yield. Therefore, the proportion of land managed under various management strategies is fixed and farmers will not improve their management styles in response to an increase in water price. In reality, a profit maximizing farmer would increase his management intensity as long as the cost of additional labor was less than the cost of additional water. As a result, the linear programming model will tend to underestimate the elasticity of demand for irrigation water.

Many of the assumptions used in this model are valid. While the analysis also highlights potential flaws in assumptions, these flaws do not invalidate model results. The analysis of model assumptions is a weigh station on the road to perfection. Knowledge of the potential flaws in a model assists in the interpretation of results. Understanding how possible flaws affect the results permits the analyst to develop methods of overcoming those flaws. It opens up new avenues for research into what factors affect the value of water on the irrigation districts. It also gives insights into how the model may be manipulated to provide additional information about the allocation of water and the potential benefits associated with water conservation.

The Linear Programming Formulation

The objective function for this linear program is to maximize profit subject to constraints on the availability of land, water, and crop alternatives:

$$\text{MAX} \quad \sum_{i} \sum_{j} \sum_{k} \sum_{l} PR_{ijkl} * A_{ijkl} \qquad \textbf{(Eq. 5.1)}$$

PR	profit on one acre of land (dollars per acre)
A	the number of acres planted (acres)
i	an index of crop type
j	an index of the farmer's water management style
k	an index of irrigation technology
l	an index of feasible crop area

Profit per acre is calculated by subtracting the cost of water from the farm budget residual. The calculation of other parameters is discussed in Chapter 3 and is not repeated here. Differences between the irrigation districts resulted in a slightly different assignment of indices. Table 5.2 shows how each index was assigned on each district.

The index i represents crop type. With the exception of turf grass, alternative crops are identical on both districts. Turf grass is not a crop alternative on Lakeside District because there are no farmers that raise this crop. Although turf grass is a crop alternative on Gulf Coast District, it is not considered a feasible alternative. The reason is that the economics of turf grass farming do not seem to fit the theoretical basis on which the model rests. The model assumes that farmers will switch from irrigated crops to dryland crops when they can no longer meet their variable production costs. In 1993, the variable production cost on turf grass farms was approximately $0.67 per square yard, and the sale price was approximately $0.475 per square yard (Engbrock, Interview, 1993). Although theory suggests that these farmers should switch crops, this has not been the case. This is apparently related to farmer's large capital investments in turf farms and an optimistic perception of the market for turf in the future.

Although turf grass is not a feasible alternative to rice on either district, irrigation of turf grass contributes to the total on-farm demand for water. Therefore, excluding turf grass farms from the model will bias the estimate of total irrigation water demand downward, but will not affect the estimate of water demand on rice farms. In 1993, 1,113.5 acres of turf grass farms accounted for only 1,424.54 acre-feet of water demand on Gulf Coast District (LCRA, 1993b). In 1993, this represented less than 2 percent of the total demand for water among a marginal user group. For the district as a whole, the specification bias that results from excluding these users will be small and restricted to estimates at low water prices.

The index j represents water management style. Statistical analysis of water coordinator's assessment of farmer's water management style showed that, with the exception of farmers who use a "low" water management style on Gulf Coast District, there were no significant differences in water consumption between groups. On Lakeside District, the actual difference in average water use between categories showed no logical pattern; therefore, management categories are excluded from the model on Lakeside District. On Gulf Coast District, these differences appeared to follow a logical pattern and are included in the model despite the weak statistical evidence. However, this is consistent with casual reports from the water coordinators who suggest that there is an identifiable block of farmers who are inefficient water managers.

The index k represents farming technologies. Farmers can implement two simple irrigation technologies that conserve water. The index k = 1 is a base case for which the operative assumption is that farmers do not currently implement the two alternative water-saving technologies. Because these farming practices are apparently cultural, and the actual cost of implementing improved technologies is low, the barrier to adoption of these practices is greater than the cost of implementation alone. This barrier must be imposed on the model in the form of acreage constraints. For the index k = 2 or 3, the assumption is that if the marginal cost of water increases, farmers will have an incentive to implement these technologies, but will not necessarily do so.

The index l represents the set of feasible crop alternatives. In contrast to the technology index, each farmer has a unique set of alternative crops to which he may switch his land use. The index l represents feasible crop areas in which farmers have a common set of crop alternatives. As the marginal cost of water increases, farmers in each of these areas will alter their land use according to these alternatives.

Table 5.2
Assignment of Model Indices

Index		**Value**	**Lakeside District**	**Gulf Coast District**
i	Crop Type	1	Rice, first crop only	Rice, first crop only
		2	Rice, full crop	Rice, full crop
		3	-	Turf grass
		4	Cattle	Cattle
		5	Sorghum	Sorghum
		6	Corn	Corn
		7	Cotton	Cotton
		8	Soybeans	Soybeans
j	Management Style	1	Average management	Low management
		2	-	Medium management
		3	-	High management
k	Irrigation Technology	1	No specific technology	No specific technology
		2	Closer levees	Closer levees
		3	Infield laterals	Infield laterals
l	Feasible Crop Area	1	Area 1	East side
		2	Area 2	West side
		3	Area 3	-

Constraints on the availability of land, water, and crop alternatives describe the agricultural and economic conditions that farmers face. Equation 5.2 is a constraint on the availability of land. It states that acreage for rice and all crop alternatives, regardless of the farmer's water management style and technology inputs, may not exceed the maximum amount of acreage available for each crop in each feasible crop area:

$$\sum_{j} \sum_{k} A_{ijkl} \leq L_{il} \qquad \text{for all } i, l \qquad \textbf{(Eq. 5.2)}$$

A number of acres planted (acres)
L maximum land area that could be planted in an alternative crop (acres)

Two constraints limit the acreage for all crops combined. The constraint in equation 5.3 states that the total acreage for all crops combined in each feasible crop area may not exceed the total acreage on which farmers could choose to plant rice in that feasible crop area:

$$\sum_{i}\sum_{j}\sum_{k} A_{ijk} \leq L_{l} \qquad \text{for all } l \qquad \textbf{(Eq. 5.3)}$$

The constraint in equation 5.4 states that the acreage for all crops in all feasible crop areas may not exceed the total acreage on which farmers could choose to plant rice on the irrigation district:

$$\sum_{i}\sum_{j}\sum_{k}\sum_{l} A_{ijkl} \leq LA \qquad \textbf{(Eq. 5.4)}$$

LA	maximum land area on which farmers could choose to plant rice on all feasible crop areas on the irrigation district (acres)

The fourth constraint is a limit on the availability of water. The constraint states that total diversions may not exceed the water right:

$$\sum_{i}\sum_{j}\sum_{k}\sum_{l} A_{ijkl} * W_{ijkl} \leq WQ \qquad \textbf{(Eq. 5.5)}$$

W	water requirement on each acre of land (acre-feet)
WQ	district water quota (acre-feet)

The water quota is the maximum volume of water each district can deliver to farmers under its water right. Because the volume of water rights must satisfy the demands associated with canal losses as well as farm water requirements, the water quota must be less than the maximum allowable diversion to accurately reflect the volume of water available to farmers. LCRA estimates that canal efficiency on both districts is approximately 17 percent (Taylor, Interview, January 25, 1993). Therefore, the variable WQ is equal to maximum allowable diversions multiplied by a factor of 0.83.

There is probably a non-linear relationship between canal efficiency and farm water requirements. If farm water requirements are low, the actual volume of water lost as a result of inefficiencies in the canal system will be relatively large. However, because the linear programming model estimates on-farm water use only it will not be sensitive to an increasing proportion of canal losses as rice acreage decreases.

For the purposes of estimating total diversions, this report assumes canal losses vary in direct proportion to the district-wide farm water requirement. Once farm water requirements are established through the linear program, the quantity of water can be adjusted outward by the appropriate volume to account for canal losses. This is an important consideration because part of on-farm demand includes water losses in the canal system as water is transported from the river to the farm gate.

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Chapter 6
Linear Programming Model Results

This chapter presents linear programming results to estimate derived demand for water, the value of water, and farmer;s willngness to pay for water. Analysis of irrigation district costs and willingness to pay suggests an appropriate price for irrigation water in the absence of a competitive market. Another direct application is evaluation of the costs and benefits of irrigation water rights. The model can be manipulated through sensitivity analysis to provide more information about different management alternatives on the districts. For example, the Lower Colorado River Authority (LCRA) might evaluate the benefits of investing in irrigation technologies. The LCRA might also evaluate the impacts associated with implementation of its drought management plan. That plan restricts the sale of interruptible stored water to farmers during drought periods.

The first section of this chapter presents the model results in terms of rice acreage and water use at increasing water prices. This model does not incorporate the farmer reaction curve and therefore assumes a fixed irrigation rate. This is the standard method in the absence of information on how water use and crop production vary with water price. A second set of linear programming solutions follow the first set of results. These models include the farmer reaction curve so that the model adjusts on-farm water use as water price increases. This is a unique addition and a more adequate assumption than a fixed irrigation rate. The fact that the kind of empirical data on which this reaction curve is based is almost never available probably explains why such an estimate has not previously been used as a surrogate for the crop-water production relationship. Estimates of the value of water, the subsidy to irrigators, and the appropriate price for water under an average cost pricing system follow linear programming results.

The Linear Programming Solution

Tables 6.1 through 6.5 summarize model results. Figures 6.1 and 6.2 display the linear programming solutions to changes in the marginal cost of water under a fixed irrigation rate. Tables 6.2 and 6.3 list acreage solutions and water demand at different price points. For example, Table 6.2 shows how the acreage would be allocated at select water prices. If the price of water were $54.25 per acre-foot, farmers would cultivate 26,000 acres of rice during the first crop, but would not cultivate a second crop. On Lakeside District, 220 acres of rice would be diverted to the production of cotton. The total volume of water demanded at a price of $54.25 would be 63,235 acre-feet. This figure does not include canal losses.

Figures 6.1 and 6.2 graph the stepped demand curves for water. For example, in Figure 6.1, farmers would demand approximately 86,000 acre-feet of water at a price of $40.00 per acre-foot. The steep rise in the curves at $24.25 per acre-foot on Lakeside District and $34.25 per acre-foot on Gulf Coast District indicate a region of inelastic demand. As the price increases, farmers continue growing rice, but achieve lower profits as the price rises. Corners in Figures 6.1 and 6.2 represent "no-profit" points. These are points at which rice acreage on the irrigation districts is converted to alternative crops because the farmers have more remunerative crop alternatives available. The term "no-profit" point is a misnomer. At these points, farmer's can still earn a profit growing rice, but in order to maximize profits in the short run, farmers switch to non-irrigated crops for which the profit is higher.

The stepped demand curve is generated by raising the price of water at intervals of $5.00 per acre-foot. In theory, demand curves are smooth to reflect the gradual change in the quantity demanded as the price changes. These stepped curves are not smooth for two reasons. The steps are first a product of raising the price at relatively large intervals and secondly, a reflection of the detail of the data on which the model rests.

Tables 6.4 and 6.5 list acreage solutions and water demand for different price points. These estimates are based on the linear programming model that incorporates the farmer reaction curve. Figures 6.3 and 6.4 display the derived demand curves on Lakeside District and Gulf Coast District with the farmer reaction curves (Eq. 3.9) included in the linear program. The solutions are similar to the more basic solution, but are less steeply sloped in regions of inelastic demand. The interpretation of these figures is the same as in Figures 6.1 and 6.2. The demand curve reflects on-farm demand for water and does not include canal losses. Therefore, it may not be equated with the total diversion of water on the LCRA districts. All subsequent analysis is based on estimates of derived demand that incorporate the faremr reaction curve.

The derived demand equations in Table 6.1 are based on a line between critical values on the X-axis. Critical values are those points on the X-axis at which the slope of the demand curve changes dramatically. Table 6.1 shows the piecewise equations for the derived demand functions in Figures 6.3 and 6.4. For example, if the maximum quantity of water available on Lakeside District is 70 thousand acre-feet, farmer's maximum willingness to pay can be calculated from the equation in the third row. Therefore, farmers maximum willingness to pay is:

$$P = 43.746 - (0.00032 * 70000) = 21.35 \qquad \textbf{(Eq. 6.1)}$$

P water price at which farmers use exactly 70,000 acre-feet (dollars per acre-foot)

The quantity of water available on the irrigation district, 70,000 acre-feet, has been substituted for Q.

Table 6.1
Piecewise Estimates for Derived Demand with Farmer Reaction Curves

Lakeside District

Q-Range			Equation
0	$\le Q \le$	56,217.3	$P = 104.250 - 0.00036Q$
56,217.3	$\le Q \le$	61,568.9	$P = 657.109 - 0.01028Q$
61,568.9	$\le Q \le$	108,937.0	$P = 43.746 - 0.00032Q$

Gulf Coast District

Q-Range			Equation
0	$\le Q \le$	86,216.9	$P = 75.400 - 0.00029Q$
86,216.9	$\le Q \le$	88,797.8	$P = 885.559 - 0.00969Q$
88,797.8	$\le Q \le$	126,109.7	$P = 49.203 - 0.00027Q$
126,109.7	$\le Q \le$	127,985.0	$P = 685.498 - 0.00531Q$

Note: Q-Range is the range of volumes over which the linear equation describes the demand curve. P is farmers maximum willingness to pay in dollars per acre-foot. Q equals the volume of water delivered to farmers on the irrigation district.

Figure 6.1
Derived On-Farm Demand for Surface Water on the Lakeside Irrigation District without the Farmer Reaction Curve

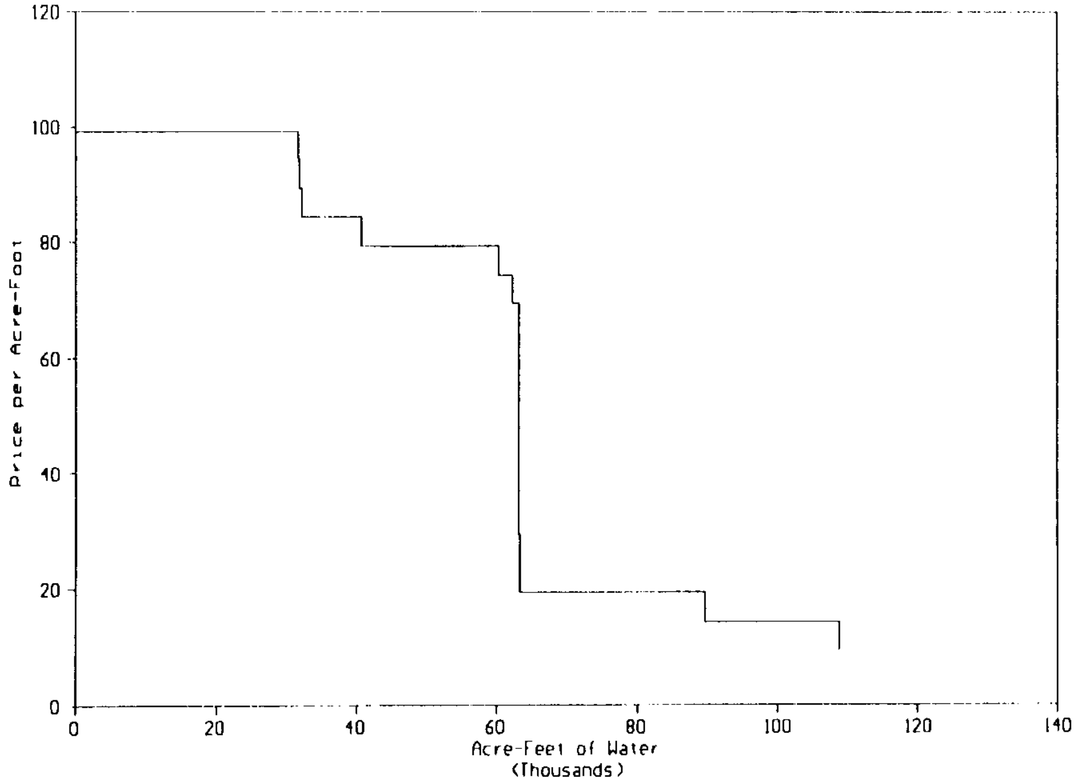


Figure 6.2
Derived On-Farm Demand for Water on Gulf Coast District without the Farmer Reaction Curve

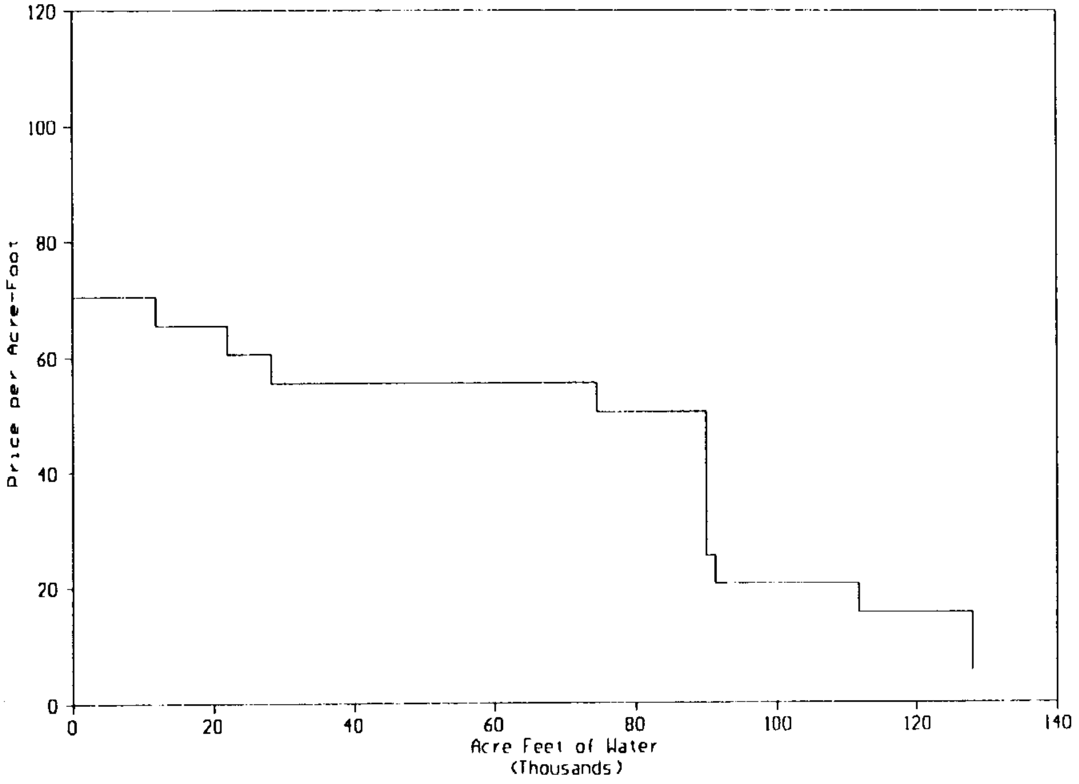


Table 6.2
Acreage Solutions and Volume of On-Farm Water Demand without the Farmer Reaction Curve, Lakeside District

	Acreage for Crop Type							
Rice - First Price (S/Acre-Foot)	Rice Crop Only (Acres)	Full Crop (Acres)	Cattle (Acres)	Corn (Acres)	Cotton (Acres)	Sorghum (Acres)	Soybeans (Acres)	Volume of Water (Acre-Feet)
9.25	3,566	22,655	0	0	0	0	0	108,937
14.25	3,566	22,655	0	0	0	0	0	108,937
19.25	13,211	13,010	0	0	0	0	0	89,708
24.25	26,073	0	0	0	147	0	0	63,412
29.25	26,073	0	0	0	147	0	0	63,412
34.25	26,000	0	0	0	220	0	0	63,235
39.25	26,000	0	0	0	220	0	0	63,235
44.25	26,000	0	0	0	220	0	0	63,235
49.25	26,000	0	0	0	220	0	0	63,235
54.25	26,000	0	0	0	220	0	0	63,235
59.25	26,000	0	0	0	220	0	0	63,235
64.25	26,000	0	0	0	220	0	0	63,235
69.25	26,000	0	0	0	220	0	0	63,235
74.25	25,558	0	0	0	220	442	0	62,158
79.25	24,756	0	0	0	220	1,096	147	60,209
84.25	16,717	0	7,966	0	220	1,096	220	40,657
89.25	13,230	0	11,454	0	220	1,096	220	32,176
94.25	13,082	0	11,454	147	220	1,096	220	31,817
99.25	13,009	0	11,454	220	220	1,096	220	31,640
104.25	0	0	24,463	220	220	1,096	220	0

Note: Prices reflect the stated variable price for one acre-foot of water, not the effective price that results from the probability of drawing stored water. The volume of water demanded reflects on-farm demand only and does not represent total diversions of water on the irrigation district. Numbers rounded down for tabulation.

Figure 6.4
Derived On-Farm Demand for Surface Water on the Gulf Coast District with the Farmer Reaction Curve

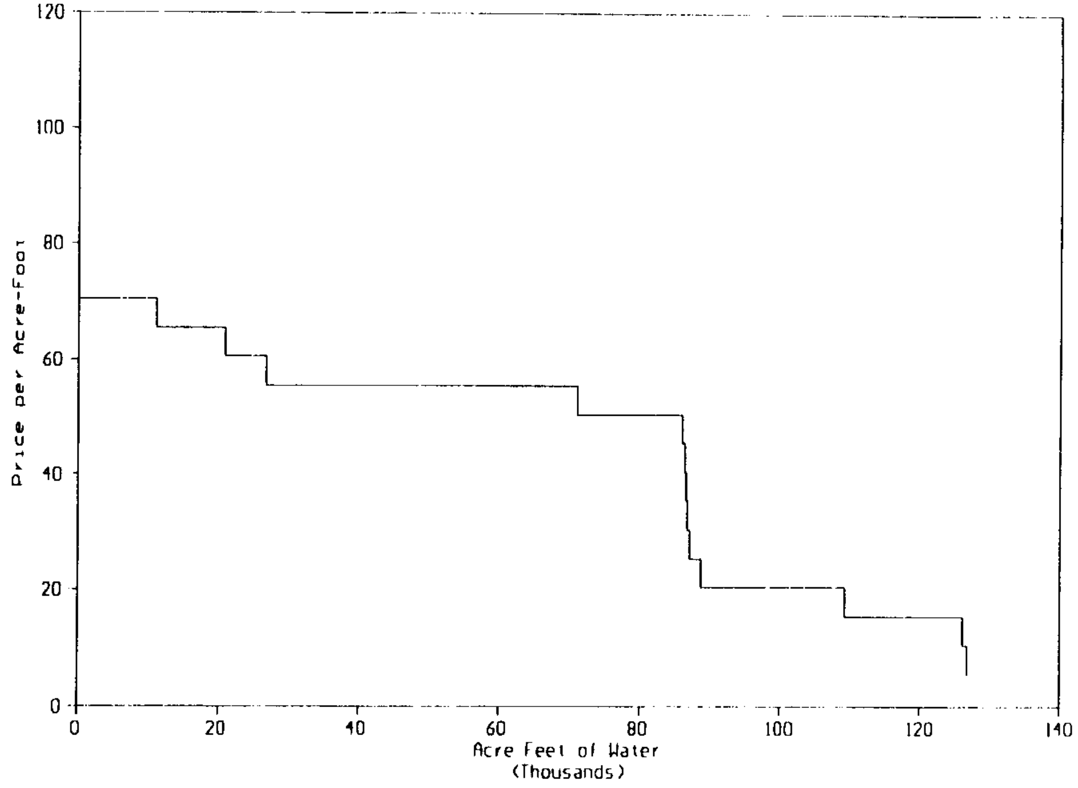


Table 6.4
Acreage Solutions and Volume of On-Farm Water Demand with the Farmer Reaction Curve, Lakeside District

	Acreage for Crop Type							
Price (S/Acre-Foot)	Rice - First Crop Only (Acres)	Rice Full Crop (Acres)	Cattle (Acres)	Corn (Acres)	Cotton (Acres)	Sorghum (Acres)	Soybeans (Acres)	Volume of Water (Acre-Feet)
9.25	3,566	22,655	0	0	0	0	0	108,937
14.25	2,815	23,406	0	0	0	0	0	108,937
19.25	13,211	13,010	0	0	0	0	0	87,654
24.25	26,073	0	0	0	147	0	0	61,568
29.25	26,073	0	0	0	147	0	0	61,119
34.25	26,000	0	0	0	220	0	0	60,717
39.25	26,000	0	0	0	220	0	0	60,447
44.25	26,000	0	0	0	220	0	0	60,208
49.25	26,000	0	0	0	220	0	0	59,995
54.25	26,000	0	0	0	220	0	0	59,802
59.25	26,000	0	0	0	220	0	0	59,625
64.25	26,000	0	0	0	220	0	0	59,463
69.25	26,000	0	0	0	220	0	0	59,313
74.25	25,558	0	0	0	220	442	0	58,165
79.25	24,756	0	0	0	220	1,096	147	56,217
84.25	16,717	0	7,966	0	220	1,096	220	37,882
89.25	13,230	0	11,454	0	220	1,096	220	29,920
94.25	13,082	0	11,454	147	220	1,096	220	29,532
99.25	13,009	0	11,454	220	220	1,096	220	29,315
104.25	0	0	24,463	220	220	1,096	220	0

Note: Prices reflect the stated variable price for one acre-foot of water, not the effective price that results from the probability of drawing stored water. The volume of water demanded reflects on-farm demand only and does not represent total diversions of water on the irrigation district. Numbers rounded down for tabulation.

Table 6.5
Acreage Solutions and Volume of On-Farm Water Demand with the Farmer Reaction Curve, Gulf Coast District

	Acreage for Crop Type							
Rice - First Price ($/Acre-Foot)	Rice Crop Only (Acres)	Full Crop (Acres)	Cattle (Acres)	Corn (Acres)	Cotton (Acres)	Sorghum (Acres)	Soybeans (Acres)	Volume of Water (Acre-Feet)
5.4	12,104	13,266	0	0	0	0	0	127,985
10.4	12,104	13,266	0	0	0	0	0	126,829
15.4	12,104	13,266	0	0	0	0	0	126,103
20.4	18,587	6,783	0	0	0	0	0	109,304
25.4	22,802	720	0	0	1,848	0	0	88,797
30.4	23,522	0	0	0	1,848	0	0	87,131
35.4	23,522	0	0	0	1,848	0	0	86,856
40.4	23,522	0	0	0	1,848	0	0	86,617
45.4	23,522	0	0	0	1,848	0	0	86,406
50.4	23,522	0	0	0	1,848	0	0	86,216
55.4	19,940	0	3,581	0	1,848	0	0	71,026
60.4	7,972	0	15,549	0	1,848	0	0	26,859
65.4	6,363	0	15,549	137	1,848	782	6,88	20,922
70.4	3,478	0	15,549	137	1,848	2,290	20,66	11,226
75.4	0	0	15,549	717	1,848	2,290	49,65	0

Note: Second cropping rate restricted to a maximum of 60 percent of first crop acreage. Prices reflect the stated variable price for one acre-foot of water on the district, not the effective price that results from the probability of drawing stored water. The volume of water demanded reflects on-farm demand only and does not represent total diversions of water on the irrigation district. Numbers rounded down for tabulation.

The Value of Water on LCRA Irrigation Districts

The total value of water on the irrigation districts at a particular price is equal to the area beneath the derived demand curve and above the price line. Because this model is defined in the short run, values reflect the value of water in a single crop year. This value is equal to the consumer surplus that farmers making a positive profit receive by having access to water during the crop year. The value of water is not equal to farm profit on the irrigaiton districts, but is specifically the increase in farm profit that results from having access to water. The value of water is net of all delivery and purchase costs. Figure 2.2 displays the value of water graphically. It is calculated by the area of the shaded triangle in Figure 2.2 minus fixed irrigation charges. In this case, per-acre charges are subtracted from the estimate because fixed irrigation charges were removed from the budgets.

If effective water prices are averaged over the full crop period, the effective price is $11.11 per acre-foot on Lakeside District and $6.55 per acre-foot on Gulf Coast District. More exact estimates would distinguish between the cost of water used during the first and second crop periods. But the difference is small, and that level of detail is beyond the useful scope of the data presented here. The value of 108,937 acre-feet of water delivered to fields on Lakeside District is $4,133,852 and the value of 127,985.6 acre-feet of water delivered to fields on Gulf Coast District is about $4,198,270. The short -run average value of one acre-foot on Lakeside District is about $37.94, and on Gulf Coast District is about $32.80. By themselves, these values indicate that farmers on Lakeside District make more profitable use of water than farmers on Gulf Coast District. They also show that the net returns from water during both crop periods combined are less than the minimum average value of stored water purchased from the Highland Lakes.

Table 6.6 presents average values of water during each crop period. For example, the average value of one acre-foot of water delivered to fields during the first crop period on Lakeside District is $61.44, and the average value of one acre-foot of water delivered to fields during the second crop is $7.41. The difference in the average values can be attributed to the difference in yields relative to the volume of water used in the production process.

Table 6.6 also presents average values for land during each crop period. For example, the average value of one acre of land on Lakeside District during the first crop period is $144.27, and the average value of one acre of land during the second crop period is $13.38. The average value of land may be interpreted as the difference between the value of one acre with access to irrigation water and the value of one acre without access to irrigation water. The values of land and water are not additive. Implicit in the value of water is the assumption that land is available to use that water. Similarly, the value of land implies that there is water on that land with which to irrigate a rice crop.

There are large differences in the average value of water between the two districts. This is the result of the difference in the cost of water, production, and water use. Farmers on Lakeside District use less water per-acre, pay a higher price for water diverted under the district's water right, and use a higher proportion of stored water.

Table 6.6
Short-Run Average Value of Water on LCRA Irrigation Districts in 1993

Description		Lakeside District	Gulf Coast District
Average Value of Water:			
(Value per acre-foot)	Full Crop*	$37.95	$32.80
	First Crop	61.44	41.47
	Second Crop	7.41	13.15
Average Value of Irrigated Land:			
(Value per-acre)	First Crop	$144.26	$145.16
	Second Crop	13.38	33.85

Source: Calculated by the author based on data generated by the linear program using XA Software.

Note: Values based on 1993 agricultural markets, farming costs, and farm water use. (*) The average value during the full crop period is the average value of water in the first and second crop period combined.

Allocational decisions within a region must be made on the basis of marginal values of water, not average values. In most cases, it is possible to derive the marginal value directly from the slope of the demand curve. However, in this case, the limiting factor on the irrigation districts is rice acreage, not irrigation water. Therefore, the marginal values must be derived from the change in total profits on the districts as the supply of water is restricted. This is accomplished by holding the price of water constant at the effective price ($11.11 on Lakeside District and $6.55 on Gulf Coast District) and reducing the quantity of water available to farmers in 10 percent increments. Because the objective function maximizes profits on the irrigation district, water supplies are allocated to acreage where farmers make the most profitable use of that water. This is consistent with economic theory that suggests scarce resources will be allocated to those willing to pay the highest price.

The marginal value is the increased profit associated with access to additional water supplies minus the cost of supplying that water divided by the increased volume:

$$V_t = \frac{(\Pi_t - (A_t * F)) - (\Pi_{t-1} - (A_{t-1} * F))}{W_t - W_{t-1}} \tag{Eq. 6.2}$$

V	marginal value of water (dollars per acre-foot)
Π	farm profits on rice and non-rice acreage as calculated in the linear program (dollars)
A	first crop acreage (acres)
F	fixed per-acre charge for all first crop rice acreage (dollars per acre)
W	the volume of the water increment (acre-feet)
t	an index of an increasing water increment

Table 6.7 lists the marginal values and the corresponding water volume. For example, if the quantity available to farmers on Lakeside District were restricted to 64,231 acre-feet, the potential increase in aggregate farm profits associated with access to one additional acre-foot of water on this district would be $42.52. Notice that on Gulf Coast District, there is a rise and a drop in the marginal value of water. This is the result of acreage dropping out of production in the feasible crop area on the East Side, therefore a reduction in the total cost of the fixed per- acre charge.

It is not possible to go from these estimates to a determination of exactly how much water has been inefficiently allocated. The reason for this is that no information on the marginal value of water in other economic sectors of the river basin is available. The price for stored water from the Highland Lakes does not provide this value because, like the prices for irrigation service on LCRA's Districts, that price is determined on a cost of service basis rather than by market forces. A simple illustration demonstrates how an allocation by marginal values might occur.

Suppose these two districts were forced to bid for the right to divert each acre-foot of water. It can be seen from Table 6.7 that the first 42,205 acre-feet of water have a higher value on Lakeside District than Gulf Coast District. This would suggest that, under conditions of water scarcity, Lakeside District would win the first 42,205 bids against Gulf Coast District to divert the first 42,205 acre-feet. Once Farmers on Lakeside District have diverted that water, farmers on Gulf Coast District would win subsequent bids to divert the next 23,715 acre-feet. At this point, farmers on Lakeside would be able to divert water again because the marginal value is again higher on that district.

However, these results may be misleading. Farmers cannot make use of the water if that water is diverted in large chunks. Water must be drawn over the length of a crop season. Therefore, it is necessary to determine what the marginal value of water is during that point in the crop season when the run-of-river flows are available for diversion. That is a complex stochastic problem that can only be addressed by linear programming methods through the use a multiperiod model. This problem is very similar to the rationale for substituting a Jensen growth stage equation for quadratic or Cobb-Douglas production functions.

The Value of the Indirect Subsidy to Farmers

The value of the indirect subsidy to farmers is shown graphically in Figure 2.3. With reference to Figure 2.3, the value of the subsidy is estimated by the sum of areas A and B. Area A is bounded on the X-axis by the quantity of water farmers would use at its current price on the irrigation district, and the quantity of water farmers would use at a competitive price P*. The area is equal to the value of that water to farmers. The difference between the competitive price and the value of water is equivalent to the subsidy farmers receive.

There is little information on the demand for water among those that own water rights, or among those who would use water if they owned water rights. Therefore, it is not possible to make an exact estimate of what the competitive price, P*, might be. However, it seems likely that a competitive price would be less than the price of stored water. The price of stored water from the Highland Lakes is $50.50 per acre-foot. The rationale for selecting this value rather than the total cost of maintaining stored water contracts is the assumption that less-senior owners of water rights would continue to maintain their firm water contracts for security in the event of a drought despite any increase in run-of-river water supplies.

Assuming that the competitive price for run-of-river water is less than the price of stored water, the maximum value of the subsidy to Lakeside District can be estimated as shown graphically in Figure 6.5. The benefit to farmers that results from the allocation of water rights is equal to the value of water farmers would not have access to in a competitive market. Farmers would use 59,009 acre-feet of water if the variable cost of water were $50.50 per acre-foot. The volume of water diverted at the current price is 108,937 acre-feet. Therefore, the additional volume of water farmers have access to is 49,929 acre-feet. The value of that water to farmers on Lakeside District is $395,249. Following a similar analysis on Gulf Coast District, farmers have access to 42,122 acre-feet for which they would be unwilling to pay a price of $50.50 per acre-foot. The value of this water to farmers on Gulf Coast District is $561,895.

Table 6.7
Marginal Value of the Water Delivered to Farmers on LCRA Irrigation Districts

Lakeside District		Gulf Coast District	
Total Water (Acre-Feet)	Marginal* Value (Dollars per Acre-Foot)	Total Water (Acre-Feet)	Marginal* Value (Dollars per Acre-Foot)
-	-	127,985	13.42
-	-	115,187	12.67
108,987	8.04	103,668	12.33
98,043	8.97	93,301	27.98
88,239	10.12	83,971	32.33
79,415	10.12	75,574	36.14
71,474	10.12	68,016	36.84
64,327	39.05	61,215	37.44
57,894	49.47	55,093	37.44
52,104	49.47	49,584	37.44
46,894	49.47	44,625	37.44
42,205	53.67	40,163	37.44
37,984	56.06	36,146	38.12
34,186	59.57	32,532	38.20
30,767	67.82	29,279	48.26
27,690	67.82	26,351	48.62
24,921	67.82	23,715	57.76
22,429	67.82	21,344	59.87
20,186	67.82	19,209	59.87
18,168	67.82	17,288	48.29
16,351	67.82	15,560	46.43
14,716	67.82	14,004	46.43
13,244	67.82	12,603	47.71
11,920	67.82	11,343	49.35
10,728	67.82	10,208	50.01

Source: Calculated by the author based on data generated by the linear program using XA Software.

Note: (*) Marginal value is the increase in total farm profits that results from the delivery of one additional acre-foot of water to a rice field on the irrigation district.

If water were allocated efficiently among those who own water rights, farmers would not have access to water for which their maximum willingness to pay is below the competitive price. In the absence of senior water rights, farmers would have to replace the lost water with stored water (firm yield) from the Highland Lakes. Farmers could not afford to do this, but if they did, the cost on Lakeside District would be $50.50 times the 49,929 acre-feet, or $2,521,380. Similarly, on Gulf Coast District, the cost would be $50.50 times 42,122 acre-feet, or $2,127,208. Because there is no cost for run-of-river water to those that own water rights, farmer's replacement cost may be equated with the current cost to those less-senior owners of water rights who would have had access to that water.

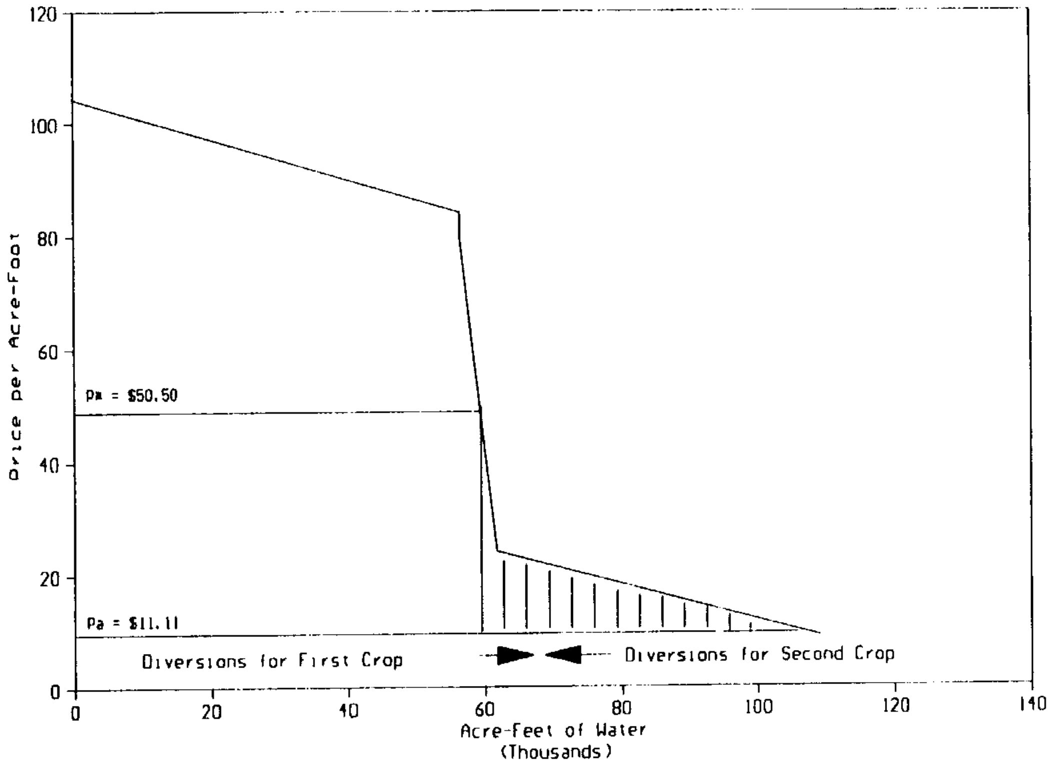
The sum of areas A and B in Figure 2.3 equals the total subsidy that farmers receive as a result of owning senior water rights and diverting water at a cost less than a competitive market price. The area B is not included in calculations of the indirect subsidy because that subsidy is potentially no different than the subsidy any owner of water rights receives. The values presented here are not exact estimates. However, they are useful because they represent the magnitude of the market inefficiency related to each district's ownership of water rights.

Linear programming results show that demand decreases significantly at higher prices but there is little reduction in first crop rice acreage at price of water was $50.50 per acre-foot (Tables 6.3 and 6.4). As marginal cost increases, farmers eliminate the second crop because higher water prices result in negative profits. There are no alternative crops at that point in the growing season; therefore, the change in acreage for which farmers pay a fixed rate is very small. On Lakeside District, 220 first crop acres go out of production and on Gulf Coast District, 1,848 acres go out of production.

Estimates of the value of water and the value of the indirect subsidy are sensitive to changes in the price of rice, the price of alternative crops, and the demand for irrigated acreage. When banks impose restrictions on farmer's rice acreage as a condition of lending, or when the Agricultural Stabilization and Conservation Service increases the minimum setaside requirement, the total value of the subsidy to farmers will decrease in proportion to the reduced water requirement. Therefore, precise estimates must be made for a given year with known acreage and crop price. In general, reductions in the second crop acreage will have a larger effect on the market inefficiency than reductions in first crop acreage. The reasoning behind this is that the water farmers would be unwilling to purchase at a price of $50.50 is the water they use during the second crop period. Similarly, increases in acreage during the first crop period will have a smaller effect on the value of this indirect subsidy than increases in the second cropping rate. Therefore, it seems that an effective water conservation program should focus first on reducing the demand for second crop acreage. This interpretation is important in determining the volume of water savings that LCRA should seek to achieve through its water conservation program, and the objectives that LCRA should establish for that program.

The estimates presented here reflect the maximum subsidy to farmers. The estimates imply that all water that is not diverted on the irrigation districts would be diverted elsewhere in the river basin. The estimates are valid as long as this is true. However, it is not clear how the hydrology of the river or the availability of water would change if the irrigation districts stopped diverting water. In addition, some of the run-of-river water diverted by the irrigation districts originates from run-off below other major diversion points. Reductions in the diversion of this water might not increase run-of-river flows at other diversion points. Unless there are owners of water rights that could make use of the increase in run-of-river flows, and offset their purchase of water from the Highland Lakes, there is no alternative use for that portion of district water diversions. In this case, there is no opportunity cost associated with its use in rice irrigation. One next logical step in refining this model is to determine what portion of stored water diversions would be offset by reductions in water diversions on the irrigation districts.

Figure 6.5
Value of the Indirect Subsidy to Farmers on Lakeside District



The Potential for Average Cost Pricing

The LCRA irrigation districts, like most public utilities, operate on a cost of service basis. When the cost structure of a public utility organization exhibits a high fixed cost and a small variable cost, public utilities frequently use average cost pricing to establish rates. The price is equal to the average cost of providing service divided by the total amount of goods or services provided. Historically, this has been the method of establishing irrigation water rates on the districts. However, those rates have been based on the number of acres a farmer irrigates, not the volume of water he uses. Because farmers have paid for the irrigation service, not the water itself, farmers have had very little incentive to control their use of water. By assigning a marginal cost to the water itself, and calculating the average cost of service on the basis of the total volume of water delivered, rather than the total number of acres irrigated, LCRA can maximize the farmers incentives to conserve water.

Knowledge of the demand for water should help LCRA evaluate its options for establishing a volumetric water rate under an average cost pricing strategy. LCRA has been reluctant to use this approach because it fears the cost of water will be too high, and the acreage and total volume of water delivered on the districts will decline as a result of some farmers unwillingness to pay the higher price. A high volumetric water rate would make it difficult for inefficient farmers to continue their farming operations. If the acreage on the districts declines, the average cost of providing service could increase. If the average cost of providing water to remaining farmers is too high, these farmers could not afford to operate and the districts would close.

LCRA completed a rate study in 1992 in preparation for the water measurement and volumetric pricing program. That study evaluated fixed and variable costs on the irrigation districts to plan the distribution of each district's fixed costs to a per-acre irrigation charge and its variable cost of pumping and delivering water to a volumetric water charge. Each district's 1993 rates are based on this study and are presented in Table 3.3.

Figure 3.3 gives the general form of the average cost function. The equation states that total average cost is a function of fixed and variable costs:

$$C = \frac{(F + (V * Q))}{Q} \qquad \textbf{(Eq. 6.3)}$$

C	average cost of pumping and delivering water (dollars per acre-foot)
Q	volume of water delivered to farmers on the district (acre-feet)
V	variable cost of operating and maintaining the districts (dollars)
F	fixed cost of operating and maintaining the districts including administrative overhead and debt service (acre-feet)

An exponential function can substitute for variable cost to account for increasing returns to scale as the district pumpage requirements increase:

$$C = \frac{F + (Q(\beta_1 Q^{\beta_2}))}{Q} \qquad \textbf{(Eq. 6.4)}$$

β	parameters estimated by ordinary least squares regression from data on the cost of meeting three specific pumpage requirements

Table 6.8 lists LCRA's estimates of the average cost of delivering enough water to meet specific pumpage requirements. For example, if the pumpage requirement on Lakeside District is 124,960 acre-feet, the average variable cost of delivering that water would be $7.13.

Equations 6.5 and 6.6 give the specific total cost functions with parameter estimates for the Lakeside and Gulf Coast Districts respectively:

$$C = \frac{1678522 + Q \exp(5.027 - 0.26098 \ln Q)}{Q} \qquad \textbf{(Eq. 6.5)}$$

$$C = \frac{1887194 + Q \exp(4.867 - 0.29001 \ln Q)}{Q} \qquad \textbf{(Eq. 6.6)}$$

For example, if the Lakeside District delivered 124,960 acre-feet of water to the farmgate, the average total cost would $20.56. These equations are estimated on a narrow range of water volume and they may not adequately represent the true average cost of pumping water below the lowest pumpage estimates provided in Table 6.8.

Setting each equation equal to the derived demand curve solves for the quantity of water farmers would demand and indicates the appropriate price that farmers should pay for one acre-foot of water under an average cost pricing strategy. Therefore, LCRA can allocate all of its costs to the volumetric rate, eliminate the per-acre charge, and maximize farmer's incentive to conserve water while providing irrigation water on a cost of service basis. According to the model of derived demand, the appropriate variable cost per acre-foot on Lakeside District is approximately $36.42, and the appropriate price per acre-foot on Gulf Coast District is approximately $26.05. At these prices, all second crop acreage goes out of production on both districts. Average cost pricing estimates assume that the price elasticities reflected in the derived demand curves do not change in the long-run. If the price elasticities have been underestimated, the average cost of delivering water will stabilize at a higher rate.

Table 6.8
Variable Cost Estimates at Different Pumpage Requirements

	On-Farm Demand (Acre-Feet)	Pumpage Requirement (Acre-Feet)	Average Variable Cost* (Dollars)
Lakeside District			
Low	106,803	124,960	$7.13
Medium	121,367	142,000	6.89
High	131,077	153,360	6.17
Gulf Coast District			
Low	142,135	166,298	$3.97
Medium	162,903	190,596	3.84
High	203,680	238,306	3.58

Source: Lower Colorado River Authority. 1992. "Lakeside and Gulf Coast Rate Options." Austin. Texas.

Note: Estimated pumpage requirements represent on-farm demand adjusted 17 percent to account for canal losses.
(*) Average variable cost per acre-foot of water delivered to the farmgate.

The Price Elasticity of Demand for Irrigation Water

Price elasticities reflect the percentage decrease in on-farm water demand that may be expected in response to a one percent increase in the price of water. Elasticities may be used to estimate the potential reduction in water use associated with increases in the variable price of water. The elasticity of demand for water will vary depending upon the price of water at which the elasticity is calculated, and whether it represents an arc price elasticity or a point price elasticity. Point price elasticities are specific to a single price value. To calculate the point elasticity, the derived demand equations given in Table 6.5 may first be rearranged to express quantity as a function of price. The equation for derived demand is:

$$P = \beta_0 + \beta_1 Q \qquad \textbf{(Eq. 6.7)}$$

P	water price at which farmers use exactly Q acre-feet (dollars per acre-foot)
Q	quantity of water (acre-feet)
β_0	the intercept term of the derived demand equation
β_1	the slope term of the derived demand equation

The values of these variables are described in equation 6.1 and listed in Table 6.5. The equation may be rewritten to express quantity as a function of price:

$$Q = -\frac{\beta_0}{\beta_1} + \frac{1}{\beta_1} P \qquad \textbf{(Eq. 6.8)}$$

Since β_0 and β_1 are known, the price elasticity is easily calculated by equation 6.9. The equation states that the percent change in water consumption that results from a one percent change in the price is a function of the ratio of the price and quantity at the price point of interest:

$$\varepsilon = \frac{1}{\beta_1} * \frac{P}{Q} \qquad \textbf{(Eq. 6.9)}$$

If the concern over price elasticity centers around a range of prices, for example a particular leg of the derived demand equations, the price elasticity can be calculated at a price and quantity associated with the midpoint of the price range.

The price elasticity may be calculated at various price points along the derived demand curve. The decision about which estimate of the elasticity to use will be a matter of the analysts particular interest. From the LCRA's perspective, the elasticity is appropriately calculated within the narrow range of prices that LCRA might set its volumetric water rate. In the lower leg of the demand curve, the price elasticity at $16.46 per acre-foot on Lakeside District is -0.6035, and the price elasticity at $10.87 per acre-foot on Gulf Coast District is -0.0161. For example, a one percent increase in the price of water on Lakeside District would result in a 0.60 percent reduction in the total on-farm water demand.

Demand for water in agriculture is known to be inelastic. However, linear programming assumptions may have underestimated the price elasticity. If so, the value of water and water demand may be overestimated at higher water prices. It is therefore desirable to determine how large an error may have occurred. The following analysis develops elasticity estimates from the farmer reaction curves and compares these results with those obtained from the derived demand equations.

No acreage goes out of production on Gulf Coast District in the lower leg of the derived demand curve where the price elasticity is estimated. Therefore, this elasticity may be equated with reductions in on-farm water use rather than acreage. The Lakeside elasticity estimate is higher than the Gulf Coast elasticity estimate, suggesting that water use will decrease in response to water price increases more quickly on Lakeside District. This is due to second crop acreage reductions below the price point at which the Lakeside District estimates are calculated.

This analysis first tests whether derived demand elasticity estimates can be equated with elasticity estimates based on the farmer reaction curve. Because the functional form of the farmer reaction curve may underestimate farmers' responses to increases in the marginal cost of water, the analysis then estimates a maximum price elasticity from the farmer reaction curve assuming a constant propensity to conserve water over all water prices.

The farmer reaction curve is discussed in Chapter 3 and given in equation 3.10. The equation is repeated in equation 6.10. It states that water use is a function of the amount of rainfall during the crop period, the number of days during the growing season, the price of water and the crop type:

$$W = \beta_0 + \beta_1 D + \beta_2 \ln(PE) + \beta_3 C + \beta_4 G + \beta_5 INTG \qquad \textbf{(Eq. 6.10)}$$

W	field-specific water use (acre-feet per-acre)
D	number of days between first and last water delivery (days)
PE	the effective price of water (dollars)
C	a dummy variable equal to 1 for observations from second crop rice fields
G	a dummy variable equal to 1 for observations from Gulf Coast Irrigation District
INTG	an interaction term equal to 1 times the ln (PE) for fields on Gulf Coast District
β	coefficients estimated by ordinary least squares regression.

Price elasticity based on the farmer reaction curve is calculated by first substituting the known price point of interest in place of the variable PE (equation 6.10) and subsequently calculating per-acre water use. Values of W will represent per-acre water use rather than total water use on the irrigation district. Therefore, these elasticity values do not reflect the loss of acreage as the marginal cost of water increases, only the reduction in on-farm water use. To obtain price elasticity by the farmer reaction curve the parameter estimate β_2 is multiplied by the inverse of the estimated on-farm water use at the price point of interest:

$$\varepsilon' = \beta_2 \left(\frac{1}{\hat{W}} \right) \qquad \textbf{(Eq. 6.11)}$$

ε'	price elasticity
β_2	parameter estimate from equation 6.10
$\hat{W}$	estimated W, field-specific water use (acre-feet per-acre), from equation 6.10

On Lakeside District, price elasticity at $16.46 per acre-foot is -0.03025. On Gulf Coast District, price elasticity at $10.87 is -0.02293.

If, as discussed above, price elasticity in the derived demand model for Gulf Coast District is strictly a function of the farmer reaction curve, the two estimates of price elasticity should be equivalent. There is a small difference in the two estimates for Gulf Coast District. This difference may have resulted from categorizing farmers' water use in the linear program according to individual water management styles. Elasticity estimates based on the farmer reaction curve will only be comparable to those of the derived demand equations if no acreage has dropped out of production.

Price elasticities based on the farmer reaction curve for Lakeside District differ significantly from those calculated from the derived demand equations. Because price increases result in second crop acreage reductions, the elasticity estimate provided by the farmer reaction curve represents that portion of the elasticity that may be attributed purely to farmers' adjustment in water use. The remaining portion of the original elasticity estimate, -0.57325, is the result of acreage reductions (-0.6035 - -0.03025 = -0.57325).

The following analysis is concerned with whether or not the elasticity estimates have been underestimated in the farmer reaction curve specifically. Elasticity estimates for the Lakeside and Gulf Coast Irrigation Districts reflect underlying assumptions about the functional form of the farmer reaction curve. The reaction curve imposes a nonlinear relationship to reflect farmers' diminishing propensity to conserve water. However, because this is a short-run estimate based on two years of data, the existence of a diminishing propensity to conserve water is difficult to test. Elasticity may actually be much higher at low water prices. Under the assumption that there is a at least some diminishing marginal propensity to save water, but the elasticity has been underestimated because of the lack of data, it is possible to estimate how big that error might be by fitting the farmer reaction curve using a linear form rather than a lin-log form.

To determine price elasticities based on a reaction curve with a linear form, equation 6.10 must be re-estimated. Equation 6.10 becomes linear when the effective price of water (PE) is transformed from a logarithm to its original value:

$$W = \beta_0 + \beta_1 D + \beta_2 PE + \beta_3 C + \beta_4 G + \beta_5 INTG \qquad \textbf{(Eq. 6.12)}$$

All of the variables are the same as discussed above in equation 6.10. Regression results for equation 6.12 are given in Table 6.9. A maximum elasticity is calculated by substituting the price point of interest into equation 6.12, estimating per-acre water use, $\hat{W}$, and solving for ε'' using equation 6.13. The calculation is:

$$\varepsilon'' = \beta_2 \frac{P}{\hat{W}} \qquad \textbf{(Eq. 6.13)}$$

ε''	maximum price elasticity
P	price point at which elasticity is to be estimated
$\hat{W}$	estimated W, field-specific water use (acre-feet per-acre), from equation 6.10
β_2	parameter estimate from equation 6.12

At the price $16.47 on Lakeside District, the price elasticity is -0.3528. At the price $10.87 on Gulf Coast District, the price elasticity is -0.1753.

Estimates of maximum price elasticity are substantially higher than those obtained from the lin-log reaction curves. They measure the percent change in on-farm water use that will result from an increase in water price with no concurrent reduction in irrigated acreage. At these prices, they may be interpreted as maximum elasticities related to non-acreage variables under the following assumptions. The first assumption is that the farmer reaction curve would not change if it were based on more than a two year span of data. The second assumption is that farmers do have at least some diminishing marginal propensity to conserve water in response to increases in water price.

Table 6.9
Parameter Estimates and T-Statistics for the Linear Farmer Reaction Curve

Variable	Coefficient	Eq. 6.12
Intercept	β_0	1.4183
Days Watered (D)	β_1	0.2018
		(8.017)*
Effective Price (PE)	β_2	-0.0466
		(-4.205)*
Crop Type[†] (C)	β_3	-0.4098
		(-3.796)*
District[‡] (D)	β_4	0.7139
		(4.758)*
Interaction Term (D * ln PE)	β_5	-0.0236
		(-0.858)
R-squared		0.2427
Adj. R-squared		0.2384
Model F		56.6080

Source: Calculated by the author based on data in: Lower Colorado River Authority, 1993a. Water Accounting Database for 1992 and 1993. Lakeside Irrigation District, Eagle Lake, Texas. (Computer File.); and Lower Colorado River Authority, 1993b. Water Accounting Database for 1992 and 1993. Gulf Coast Irrigation District, Bay City, Texas. (Computer File.)

Note: T-statistics given in parenthesis. (*) Asterisks indicate significance at the 95 percent confidence level. (†) Crop Type is a dummy variable indicating equal to one for the second crop. (‡) District is a dummy variable equal to one for Gulf Coast District.

Summary

The results provided in this analysis of on-farm water demand will be useful in determining an appropriate direction for volumetric pricing and water measurement components of LCRA's water conservation program. The results provide answers to many questions about the effect of the districts on the supply of water, and the economic benefits associated with water conservation. The method has its weaknesses as well as its strengths. Among its principle weaknesses is the need to explicitly describe the conditions in the farming area. Errors in measurement or judgments about conditions on the districts could lead to inaccurate results. On the other hand, it is possible to test how big these errors might be by making slight changes to the data on which the model is based.

Perhaps one of its biggest strengths is the ability to manipulate conditions on the districts by changing assumptions about water use and farmer behavior. Results of sensitivity analysis enables water managers to test different management options and evaluate their impact on water use. For example, it is possible to examine changes in the demand for water in response to changes in crop prices, and it is possible to examine the impact of LCRA's drought management plan. Given the necessary information, it is also possible to examine the potential impact of infrastructural investments that might reduce field water use. Results provide a basis for evaluating policy options and drawing conclusions about management alternatives. These are discussed in the following chapter.

Chapter 7
Conclusions

The impetus for this linear programming model was a series of questions about how water rights influence the availability of water in the river basin. Of particular interest is the question of whether or not the existing allocation of water in the river basin is inefficient, and whether or not the allocation of water presents an impediment to water conservation efforts. Results provide insights into how a water conservation effort might work within the constraints of an existing legal framework that establishes water rights. Applications of model results for water resources planning and management include the evaluation of policy options, and estimation of economic benefits associated with water conservation programs. The model could be restructured to estimate the impact of drought management policies.

Economic theory provided a normative framework for structuring the analysis and estimating derived demand and the value of water. Because competitive markets for water do not exist on the irrigation districts or in the river basin, demand for water is based on the demand for farm products. This is not an entirely satisfying approach because the demand for farm products and irrigated acreage are not themselves rooted in competitive markets. All else equal, the value of water used to irrigate subsidized crops will be higher than water used to irrigate unsubsidized crops.

Linear programming methods and farm budget analysis require a rigid specification of conditions on the irrigation districts. Results in this report are based on the best information available at the time, but a detailed survey of farm characteristics was beyond the scope of the study. One advantage of the linear programming model is that it is easily updated to reflect changing conditions. New information can be added to the model as it becomes available.

The first section of this chapter discusses the effect of water rights on farm water use. These considerations could prove useful in providing some more direction to water conservation programs. The second section discusses goals of water conservation programs and assesses alternative water conservation tactics. The linear programming model can be manipulated to provide some answers to these questions. Finally, this paper concludes with a brief discussion of what institutional changes might increase the economic benefits associated with the distribution of run-of-river water.

The Impact of Water Rights on Farm Water Use

The conventional view of water conservation may be limited. Many see it as a necessary evil to increase water supplies when they are scarce, and some see the institutional changes associated with the redistribution of access to water resources as a deliberately rent-seeking activity. Somehow, those who live in the river basin must find ways of doing more with less so that they can continue to support their standard of living as the population and the volume of goods and services produced expands in the future. Water conservation is a long-term process. Preparation and planning for most water development projects begins many years before they become a reality. If water conservation is an alternative source of water supply, then it is also appropriate to begin that process many years before the water is actually needed. Water conservation requires substantial technical change and innovation in existing industries to ensure that water is available.

When Texas was a young state, perhaps it made sense to allocate water rights to agricultural interests in order to advance the economic development of particular regions. Water rights were necessary to guarantee the availability of water when river flows were low during drought years, thereby improving the prospects for long-term investment in those regions. In particular, the location of the LCRA irrigation districts at the lower end of the river basin required some sort of protection to ensure an equitable distribution of water. There was a danger that upstream interests might divert all of the water and prevent any water from reaching these irrigation districts during critical periods of low flow.

Despite any good reasons for having institutionalized farmers' rights to water in the first place, the primitive irrigation practices and the inefficient use of water in Texas' gulf coast region reflect this elimination of risk to rice farmers. The consequence of eliminating this risk is analogous to what happens in other subsidized industries. Performance in subsidized or protected industries is characteristically low because they are protected from market competition. Similarly, senior water rights protect and subsidize farmers' access to water. Agricultural water use becomes inefficient because there is no incentive to manage the risk of suspended access to water or compete economically for water supplies. This can be accomplished by increasing the value of water and farmer's willingness to pay relatve to other uses.

Water rights have come back to haunt us because they now make implementing water conservation in agricultural areas more difficult. Irrigation technologies and cultural farming practices have not developed to use water efficiently. Water rights are only one of the many subsidies available to agricultural interests, and these have also stifled technological change. Agricultural Stabilization and Conservation Service programs subsidize farm output at guaranteed price levels and U.S. trade policies have protected farmers from foreign competition. When LCRA tries to implement a water conservation program on its irrigation districts, the problems it faces are the result of a long history of poor technological development.

While making water available when and where it is needed in the future is an appropriate goal of water conservation, it may be a limited objective. Water conservation not only makes water available for the production of more goods and services, it also increases the value of water in its existing use. If the value of water may be defined by the farm budget residual in agriculture, it may also be defined by the budget residual in other industries. If the producer uses less water to produce the same output, the marginal product of water increases as less water is used. Because this producer has reduced his demand for water, he has increased the amount of run-of-river flows that may be diverted by others. If this reduces the volume of stored water purchases, there is an increase in the net returns to water in the river basin as a whole. The inefficient use of water by any one sector in the river basin is an externality that affects all others who might make use of that water otherwise, even if stored water remains available in the Highland Lakes under current conditions.

The economic benefits of water conservation can be seen today. In the absence of a competitive market in which water is distributed on the basis of its marginal value, a surrogate water conservation goal might be to raise the average value of run-of-river water above the price of stored water. This is accomplished by reducing water use and altering the input ratio, or increasing yields without increasing water use. The simple re-allocation of water from the districts to other sectors of the economy is not necessarily a satisfactory goal because it does not ensure that other sectors are necessarily efficient in their use of water. For example, re-allocation of water to uses for which the marginal product of water is less than rice irrigation produces a net loss to the economy in the river basin.

Water Conservation Alternatives

In practice, agricultural water conservation programs can seek to achieve several goals. One goal is to increase the volume of run-of-river flows during periods of low flow. This may be accomplished through acreage reductions. Another goal is to evenly distribute the economic benefits of water use to all water users in the river basin. This may be accomplished by increasing irrigation efficiency and eliminating marginal water uses. Yet another goal is to maximize the net returns to water use within the river basin as a whole. This requires the elimination of all existing water rights and the distribution of water among users according to its marginal product. The marginal product of water on the LCRA districts is known, but not the marginal product of water in alternative uses; thus, it is not possible to evaluate the impact of this alternative.

Conclusions about water conservation alternatives can be drawn from derived demand model results. Proposals for reducing water use and increasing the volume of run-of-river flows include transfer payments to farmers and volumetric water rates. Two forms of transfer payments have been proposed. The first is to pay farmers not to raise a second rice crop, and the second is to make technological investments in laser levelling or other infrastructural improvements that reduce water use. Although there are several means of increasing the supply of water in the river basin, which alternative LCRA might choose to pursue will be a matter of its program objectives.

Transfer Payments to Reduce Second Crop Acreage

If the objective of water conservation is to increase the volume of run-of-river flows, transfer payments that create incentives not to divert water make sense. The model shows that Lakeside District needs about 47,369 acre-feet of water for 22,655 acres of second crop rice. The total on-farm value of water diverted during the second crop is approximately $351,002, and the short-run average on-farm value of this water is $7.41 per acre-foot. Under the assumption that 60 percent of 25,371 first crop acres are second cropped in Gulf Coast District, and this acreage has a water requirement of 39,187 acre-feet, the on-farm value of water delivered to Gulf Coast District fields during the second crop is approximately $515,405. The short-run average value of this water is approximately $13.15 per acre-foot.

The cost per acre-foot of incentives to reduce second crop water use would differ from the average value of water. LCRA would probably have to pay farmers for each first crop acre of land on which they did not grow a second crop. The average value of one acre of land during the second crop period is equal to the value of water divided by the number of acres farmed. The short-run average value of one second crop acre is $13.38 on Lakeside, and $33.85 on Gulf Coast. These estimates are made on the basis of model acreage parameters and 1993 crop and water prices. Changes in acreage would not affect estimates of average value, but changes in crop and water prices would.

Because farmers do not pay a per-acre charge during the second crop, and there are no crop alternatives available that late in the season, the value of water is equal to the entire profit farmers make from growing rice during the second crop period. In addition, water values are the value of water delivered to the fields, and do not represent instream values because estimates do not account for canal losses. Accounting for canal losses would lower estimates of the average value but would not affect acreage values. Potential on-farm water savings equal 86,556 acre-feet. The increase in run-of-river flows would be higher due to corresponding decreases in canal losses.

One problem with incentives to reduce second crop acreage is that LCRA has no mechanism to determine on which acreage farmers would raise a second crop. To pursue this alternative, it is conceivable that LCRA would have to pay farmers for each acre on which they raised a first crop. In addition, this would only increase the volume of run-of-river flows during August, September, and October, after farmers raise their first crop. If LCRA emphasized the reduction in water diversions exclusively during the second crop period, part of their objective must include increasing run-of-river flows during this period.

If the water conservation objective is to maximize the economic benefits associated with water in the river basin rather than increase run-of-river water flows, this is no solution at all. The cost of buying farmers acreage, approximately $1.22 million a year, is calculated by multiplying first crop acreage by the average value of second crop acreage. This cost would fall directly on those who purchase stored water from the Highland Lakes. The program would redistribute the cost of any market inefficiencies related to senior water rights to those who continue to rely on stored water supplies.

Transfer Payments to Implement Water-Saving Technology

Rather than paying farmers not to raise a second crop of rice, LCRA could make investments in irrigation technology. However, LCRA should be cautious about making large investments in such things as laser-levelling. Results from Chapter 4 indicate that investment in irrigation technology is not a substitute for good water management. The most appropriate technologies and the largest water savings are likely to be those that farmers decide to implement on their own behalf, particularly if they have adopted these technologies as a result of increases in the price of water. The reason is that each farmer is the best judge of what technologies and input mixes maximize profits. LCRA could conceivably adjust the price of water to encourage farmers to adopt specific technologies if the cost and water savings are known.

Raising the marginal cost of water to farmers would induce adjustments in technology and input ratios. The linear program can be manipulated to determine what price of water would induce farmers to adopt these technologies. This is accomplished by adding the operational cost of implementing the technology to the farm budget residual. Capital costs are excluded because this model reflects demand for water in the short-run. However, the operational costs of implementing some technologies appears to be low and the resistance to new water-saving technologies may be related to cultural farming practices. Cultural biases may be a barrier to farmers' rational adjustment of input ratios to maximize profit.

Average Cost per Acre-Foot Pricing Strategies

Laws governing water use require that state water sold for irrigation be sold on a volumetric basis (Texas Administrative Codes, 31 TAC 297.46). The law states that:

> "Persons supplying state water for irrigation purposes shall charge the purchaser on a volumetric basis. The [Texas Water] Commission may direct suppliers of state water to implement appropriate procedures for determining the volume of water delivered."

Volumetric pricing has not been adopted on irrigation districts, perhaps because it is difficult to reliably measure water deliveries in open canal systems and the state has never enforced the law (Boyd, 1992). LCRA adopted volumetric water rates during the 1993 crop season as a water conservation tactic. The agency established the rates to encourage water conservation by raising the marginal cost of water to farmers. Water prices are set to recover the variable costs of operating the districts. A fixed per-acre irrigation charge supplements the volumetric water rate and is designed to cover each irrigation districts' fixed costs.

The higher the volumetric water rate, the less water farmers will use. How much LCRA might raise the price of water as an incentive to adjust technology and input ratios is limited. Because LCRA is a public utility, district revenues must reflect the cost of supplying irrigation water. Average cost per acre-foot prices described in Chapter 6 replace the fixed per-acre irrigation charge and do not lead to an increase in district revenues; thus they allow LCRA to raise the marginal cost of water within its revenue constraint. Estimates of derived demand and district costs show that prices would stabilize at $36.42 per acre-foot on Lakeside District, and $26.05 per acre-foot on Gulf Coast District. Only 1,848 first crop acres would go out of production on Lakeside District, and only 220 first crop acres would go out of production on Gulf Coast District.

Model results show that average cost per acre-foot pricing eliminates second crop acreage and reduces per-acre water use. Farmers could only continue raising a second crop by increasing the value of water. This may be accomplished by increasing rice yields or by reducing the quantity of water used in the production process. On Lakeside District, farmers would have to raise the average value of water above $22.79 per acre-foot, which would be LCRA's cost of delivering 108,937 acre-feet of water.

Farmers on Gulf Coast District would have to raise the average value of water above $19.36 per acre-foot, which would be LCRA's cost of delivering 127,985 acre-feet of water.

LCRA's concern over average cost per acre-foot pricing has been that farmers would respond by greatly reducing *first and second* crop rice acreage rather than by adopting water-saving technologies during the first crop period. First crop acreage reductions would reduce water use much more than moderate reductions in per-acre water use. If the demand for irrigation water decreases too much, LCRA districts could not meet their fixed costs. This analysis shows that not much acreage drops out of production and that LCRA can meet its fixed costs.

Although LCRA can meet its fixed costs, there remains a risk that average cost per acre-foot prices prescribed by the linear programming model would not produce enough revenue to cover total cost on the districts. Water price prescriptions are sensitive to model parameters LCRA cannot control such as crop acreage, crop price, ASCS program parameters, and elasticity estimates.

Water price prescriptions are sensitive to rice acreage variables. Factors other than water price influence rice acreage, and these factors are not included in the linear programming model. In particular, rice acreage shifts from year to year in response to ASCS program parameters and crop prices. Estimating derived demand using acreage projections based on these variables (equation 3.1) alleviates this problem, but does not resolve the issue.

Water price prescriptions are sensitive to elasticity estimates which project decreases in per-acre water use. Model results show that the elasticity of demand for water, the percent change in water use relative to a percent change in price, is very low after controlling for acreage reductions. Only small decreases in per-acre water use can be expected. Analysis of model assumptions indicate that some assumptions may have contributed to this low estimate.

Reductions in per-acre water use are based on the farmer reaction curve (equation 3.9). Data used to estimate the farmer reaction curves were collected over a two-year period and a narrow range of prices. The functional form of the farmer reaction curve reflects a diminishing marginal propensity to conserve water. This is consistent with economic theory, but because the amount of data is limited, data do not confirm this assumption. Moreover, maximum elasticity estimates based on a model that assumes constant propensity to conserve water are much higher.

Because elasticity estimates are based on two years of data, they are short-run elasticities. Short-run elasticities tend to be lower than long-run elasticities because there is a lag time between price increases and consumer responses. Farmers need time to adjust to increasing water prices by developing technology and input substitutes. On-farm water demand will probably become more elastic in the long-run.

Although risks exist, it is not clear that the expected cost of these risks is any greater than the risk of not meeting district costs when average costs are distributed among farmers on a per-acre basis. LCRA charged farmers on strictly average cost per-acre basis for many years. Acceptance of the revenue risk is an investment in water conservation. Because LCRA has expressed a willingness to invest in other water conservation efforts, it should be willing to absorb or carry any operational losses on the districts if volumetric rates increase irrigation efficiency. However, carrying the operational costs of water savings may simply be another method of subsidizing farmers' water use. A more cost effective method of managing this risk would be to make capital investments on the districts that reduce fixed costs, thereby reducing the risk of acreage reductions.

Irrigation Technology Requirements as a Condition for Irrigation Service

Empirical studies of technology transitions have applied multinomial logit models to describe irrigation technology transitions. Farmers adopt new irrigation technologies in response to several market signals. Among the principal signals to which farmers respond are crop and water prices. These studies show that production costs rather than potential increases in farm revenue appear to be the more significant factor that induces technological change (Cason and Uhlaner, 1991). In addition, farmers appear to adopt technologies for crops that are not subsidized by Agricultural Stabilization and Conservation Service (ASCS) farm programs much more readily than ASCS program crops (Schaible *et al.*, 1991). Probably as a result of their water rights, farmers do not appear to adopt technologies in response to regional water shortages. These authors conclude that water savings through technology transitions in agriculture will be slow to develop in the absence of more sweeping policy changes.

Policy changes are an alternative to adjustments in water price. LCRA or the state could require that farmers adopt specific irrigation technologies as a condition of irrigation service. For example, infield laterals require only a low capital investment and appear to have almost no operational cost. One advantage to this alternative is that the districts could effectively implement and enforce this measure. This alternative assumes that farmers will make effective use of those improvements. As in the case of laser-levelling, infrastructural improvements are not a substitute for water management. However, one concern that needs to be addressed here is why, for example, the Gulf Coast District has not successfully implemented a program that prohibits the use of holding streams. It may be that management practices are simply more difficult to enforce than infrastructural improvements.

Institutional Change in Water Rights

What is apparent in this analysis is that the initial allocation of water rights was created to satisfy policy objectives that are now inconsistent with public policy goals. The existence of agriculture's property right in water makes agricultural interests immune or insensitive to changing public needs. Yet this insensitivity produces costs that lead to a suboptimal economy in the river basin. It generates conflict between farmers and others over the allocation of resources. Solutions to creating technical and institutional change in these property rights can be resolved through two methods. Pareto efficient conflict resolution, in which the public compensates farmers for giving up their property rights is accomplished through bargaining. Institutional changes in the property rights themselves are considered a Pareto non-comparable conflict resolution tactic that the public resorts to when Pareto-efficient bargaining fails to produce results (Larson and Knudson, 1991). If the cost of a Pareto-efficient outcome is large, or the ability to enforce the agreement is too difficult, the public is forced to resort to institutional changes in order to rectify the inefficiencies.

Several options for institutional change exist. The simple reallocation of a portion of the agricultural water right has already been discussed. A better solution may be the introduction of temporal restrictions on when the irrigation districts may divert water. However, these options do not promote technological adjustments and increases in the economic value of water. Another alternative is to redefine the property right. For example, water diversions under existing water rights are restricted to beneficial use. Beneficial use is defined in engineering terms as the average quantity of water used to irrigate one acre (TWC, 1988a; TWC, 1988b). It would be possible to define beneficial use in economic terms. Although such a definition would be hard to identify, and even harder to enforce, the potential improvement associated with the equitable distribution of water and the economic returns when run-of-river flows are scarce is worth considering.

It is probably true that the larger the scope of a policy change, the more difficult it is to implement. Management decisions on a local level may be more effective than state-wide policy changes. LCRA can manage the districts to achieve on-farm water savings in addition to savings from canal rehabilitation and operational improvements by increasing the marginal cost of water through average cost pricing and other technology forcing measures.

What this study has shown is that farmers can reduce their demand for water through input substitutes and technology investment. Farmers will withstand increases in the marginal cost of water, if not the total cost. Studies of technical change in agriculture show that conflict over shortages of water in a river basin will not reduce on-farm water use locally as long as farmers are protected by a water right. Increasing the marginal cost of water to farmers relays the cost associated with their use of water to others. Transfer payments to farmers in the form of technology investment or compensation for the second crop do not appear to solve the problem of an uneconomic distribution of water in the river basin.

Recommendations for Further Research

Additional work could provide answers to some questions raised during the course of this study. Resolving questions about the role of water in the production process, the potential reduction in on-farm water demand, and the hydrology of water in the river basin could lead to improved estimates of the economic impact associated with the allocation of water and the potential water savings associated with water conservation. The following section describes some possible approaches to these questions.

Data envelopment analysis provides information on the location of the efficiency frontier for water as an input in the rice production process. The results presented in this paper are sensitive to the variables and methods selected for analysis. These data need more scrutiny to determine whether or not selected non-water input variables are the most appropriate. Additionally, the analysis might be conducted against a series of categorical variables relating to irrigation technology or soil type. Any expansion of the number of variables under analysis, however, will require a larger sample size for analysis. There is also an opportunity to explore the use of DEA as a tool for identifying best irrigation practices.

It is not clear how the mechanics of river flow would change if the irrigation districts reduced run-of-river water diversions. Some run-of-river water not diverted by the districts might not be available for diversion by less-senior owners of water rights. If this is the case, the cost associated with allocating water to the districts could be considerably less than the estimates presented in this paper. Estimates might be obtained through the use of time series models that analyze changes in stored water sales since 1988 in relation to the LCRA's water conservation program. Existing hydrologic models of the river might also provide some clues as to the potential re-distribution of water savings among users in the basin. This knowledge could suggest at what point in the growing season on-farm water conservation efforts might produce the greatest benefit.

Run-of-river water saved through conservation must be available when and where it is needed to produce a benefit. There is only a benefit if the individual that diverts water would be willing to pay more than the potential value of that water in rice irrigation. Therefore, it is important to determine the relative impact of reductions in the supply of water at different times during the growing season. A multiperiod linear program might be a useful means of accomplishing this task.

Economic theory suggests that the water produces the greatest benefit within a region when it is allocated according to its marginal product. The linear programming model presented in this paper suggests possible values for the marginal product of water in rice irrigation. However, it is not possible to deduce what a more productive distribution of water might be if there is no information on the marginal value of water in alternative uses. Therefore, it would be useful to know what the marginal benefit of water is in its existing uses and in its potential uses. For example, it may be that other uses of water within the river basin are actually less efficient than rice irrigation.

Finally, estimates of the elasticity of demand presented in this paper were developed before much data on water use and water prices were available on the irrigation districts. Information regarding on-farm water deliveries in the future will provide better estimates of how farmers react to changes in the marginal cost of water, particularly if LCRA adjusts the variable price of water from year to year. A similar analysis done two or three years from now could significantly improve derived demand estimates.

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A Survey of Rice Farmers Along the Colorado River

William Eugene Roberts, Jr.

THE UNIVERSITY OF TEXAS AT AUSTIN

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ABSTRACT

A SURVEY OF RICE FARMERS ALONG THE COLORADO RIVER

by
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The University of Texas at Austin, 1994
SUPERVISOR: Kent Butler

The report is based upon a mail survey of rice farmers who contract with the Lower Colorado River Authority (LCRA) for their irrigation water. The survey gathered information in four main areas: farmer personal characteristics, farming practices, farmer opinion on the performance of the LCRA, and attitudes toward the LCRA's decision to charge for water on a volumetric basis.

The report begins with a background discussion of the two irrigation districts operated by the LCRA. All farmers within these two districts who contract with the LCRA were included in the survey. The following sections include an extensive discussion of published research on the adoption of conservation practices by farmers and in survey methodology. The results of the survey are then presented and analyzed. Some statistical analysis was done on the results using cross-tabulation and Pearson chi-square calculations.

The survey's main findings were that farmers were generally satisfied with the performance of the LCRA but were apprehensive about being charged for water on a volumetric basis. The apprehension derived mainly from a belief that water delivery measurement was inaccurate.

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Chapter 1. Introduction

LCRA Irrigation Districts

The Lower Colorado River Authority (LCRA) was established in 1934 as a conservation and reclamation district. The LCRA manages water storage and withdrawal along the lower Colorado River, operates the Highland Lakes system, produces electricity, and owns two irrigation districts--the Gulf Coast and Lakeside Irrigation Districts.

The Gulf Coast Irrigation District is located around Bay City, Texas. The Lakeside irrigation district is located around Eagle Lake, Texas. The two districts were first granted water rights in 1900 and 1901. In 1953 the LCRA purchased the Gulf Coast district and in 1983 it purchased the Lakeside district.

The LCRA operates a system of canals in the districts through which it provides water from the Colorado River to farmers operating within the districts' boundaries. The majority of this water is used for rice farming but other crops are also represented. A total of slightly over 50,000 acres was irrigated by this system in 1992 (LCRA, 1993).

The LCRA has recently implemented a three-part program to reduce the amount of water used for agriculture by the two irrigation districts in order to stabilize and increase water supplies for other users in the Lower Colorado River Basin (i.e. industrial and municipal).

The first component of the water conservation program consists of rehabilitation of the approximately 650 miles of canals in the irrigation districts. Large amounts of water were being lost to evaporation because of the wide, shallow canals and transpiration due to abundant plant life along the edges of the canals.

The second component of the LCRA's water conservation program is the transfer of conservation technology to the farmers. The third component of the program is the transition to a volumetric pricing system for irrigation water. Previously, farmers paid the LCRA a flat rate, based on the amount of acreage farmed, to cover the operation of the canal system.

Water has become a scarce resource in the region and the LCRA will begin basing the farmers' water bills on the amount of water used. This strategy is designed to discourage wasteful practices and promote those that conserve water.

Farmers will continue to pay a flat rate to cover fixed costs the LCRA incurs in operating the irrigation system. Another portion of the farmers' bills will cover the costs that the LCRA incurs from storing water in the Highland Lakes system. Stored water is that which has been retained in the Highland Lakes system at an operational cost to the LCRA. This second, variable part of the bill will reflect the amount of stored water the farmers are using.

In 1992, the LCRA began measuring the amount of water delivered by the irrigation system. However, farmers were still billed according to the old rate structure. The 1993 season was the first season that farmers were billed using the new rate structure including the portion calculated on a volumetric basis.

Policy Research Project Survey

The Policy Research Program in the LBJ School of Public Affairs at The University of Texas at Austin is a seminar in which graduate students at The University work on real projects as opposed to pursuing purely academic studies. A Policy Research Project (PRP) was set up and coordinated by Professor David Eaton with the LCRA as a client. The students in the seminar were to provide the LCRA with an independent evaluation of its water conservation programs.

One aspect of the PRP's investigation of the LCRA's project was a survey of the farmers who purchase irrigation water from the LCRA. The LCRA and the farmer community were interested to learn the results of the survey.

An initial analysis of certain aspects of the survey constitute a chapter in the full report of the program evaluation by the PRP members. The chapter addressed the farmers' evaluation of the LCRA's performance in numerous areas as well as opinions on the new billing system.

Extent of the Professional Report

This professional report is a significant extension of the work produced for the PRP. This report uses the database gained from the survey of the farmers but performs much additional analysis on the survey data, adds information on the existing literature about the adoption of conservation techniques, and contains an extended discussion of the theory of mail survey methodology.

The report extends the discussion to the results of all questions on the survey. It also examines numerous cross tabulations and compares and contrasts the characteristics of farmers who answered differently to significant questions. This report also compares the findings from this survey to the existing literature on farmer attitudes and demographics. Finally, the report makes recommendations to the LCRA with the aim of promoting water conservation and improving relations with the farmers.

Chapter 2. State of the Field: Previous Studies

Adoption of Conservation Techniques

Many previous studies on farmer attitudes and factors associated with the adoption of conservation techniques have focused on soil conservation and specifically the use of minimum tillage techniques, not on water conservation.[1] Therefore, what follows is mostly a discussion of the adoptions of conservation tillage.

Investigations of the factors affecting adoption and use of soil conservation practices began in the 1950s. The North Central Farm Management and Land Tenure Research Committee (1952) discussed six factors which may act as obstacles to adoption of conservation techniques. Most of the factors are economic. The first was a lack of information on the costs and benefits of new practices. Another factor was the organization and income constraints on small farms. The reluctance to forego short-term benefits for uncertain long-term gain was cited as a factor as well as debt constraints.

Two non-economic factors were cited as possible obstacles to conservation practice. First, farm operators would be reluctant to change familiar methods of farming. Second, rental arrangements, or ownership of the land by someone other than the tiller, might inhibit the adoption of conservation practices by the farmer.

Blase (1960) found three factors were statistically significant in explaining reductions in soil loss. As in the North Central study, a majority of the factors are economic. One is off-farm income. This outside income allowed farmers to overcome the financial constraints that may be felt by those deriving all their income from the farming enterprise. Related to the first factor was a second which was the ability to borrow funds. The third factor was the perception of soil erosion as a problem. Two out of the three factors were economic in nature while the third was attitudinal.

More recent investigations have been stimulated by Section 208 of the 1972 Amendments to the Federal Water Pollution Control Act. These investigations have expanded the range of variables to include the personal characteristics of farmers. Current research favors the investigation of these personal factors while studies stressing economic variables appear with less frequency.

Research has become somewhat divided into two camps. Some authors examine the economic constraints that operate in the adoption of conservation techniques while others concentrate more on the socio-psychological situation of the farmers. Fortunately, some authors (Lee and Stewart, 1983; Gould et al, 1989) note the importance of a range of factors including economic, geographic, land use, and operator related variables. They call on other researchers to be open enough in their studies to recognize the influence of all these variables on adoption decisions.

The proponents of the economic constraint model (Heffernan, 1972; Aikens et al, 1975; Flora and Rodefeld, 1978; Goss, 1979; Buttrel and Newby, 1980; Flinn and Buttrel, 1980; Lancelle and Rodefeld, 1980; Hooks et al, 1983) argue that economic constraints frequently prevent individuals from acting and deserve more research attention. Using an econometric model, Rahm and Huffman (1984) found that determinants of conservation tillage adoption efficiency could be predicted and varied widely across sample farms. Factors such as soil characteristics, the cropping system, and the scale of operation significantly affected the probability of adopting reduced tillage in Iowa corn enterprises.

Lichtenberg and Lessley (1992) attempted to determine whether the required capital investment for conservation techniques acted to discourage adoption. They found that the adoption of best management practices (BMPs), defined as farming practices that reduce soil and nutrient losses at reasonable cost, was not affected significantly by the offer of cost-sharing on the part of government agencies.

Reasons why farmers may not participate in cost-sharing programs are difficult to identify. One possible explanation is that farmers are already using the runoff control measures that are profitable for them. While cost-sharing may reduce the loss they would incur if they adopted additional BMPs, the fact that adoption is voluntary means they would still save money by not adopting the techniques.

Transaction costs could be another discouraging factor for farmers. Small, part-time farmers especially may see governmental paper work and procedure as a major impediment since they may have little spare time, be unfamiliar with the workings of government agencies, and have less to gain from the program.

Lichtenberg and Lessley felt that the major reason farmers did not adopt BMPs or take advantage of cost-sharing was because of a lack of understanding as to the extent or seriousness of water quality problems. While the farmers recognized that water quality is a problem, they tended to perceive it as someone else's problem.

Behavioral research concentrates on the personal characteristics of the farmers and the institutional setting within which they make their decisions. One theoretical model from this line of reasoning is termed the diffusion-farm structure perspective (Napier et al, 1983; Napier and Camboni, 1988; Napier and Napier, 1988).

The diffusion component of the theoretical model asserts that psychosocial perceptions and past learning experiences affect adoption of innovations. It assumes that before a farmer will make a change in technique, they must become aware that a problem exits. Therefore, the greater access the farmer has to information, the more likely they are to adopt new techniques. Information access has been shown to be a very important predictor according to several studies (Lionberger, 1960; Rogers and Shoemaker, 1971; Taylor and Miller, 1978; Nowak and Korsching, 1980; Rogers, 1983).

The diffusion component also contends that farmers must have internalized favorable attitudes toward the techniques in question (Napier and Camboni, 1993).

The farm structure component stresses that the current state of the farm enterprise and farm policy enter the decision making process and affect the outcome. Farm structure can influence the ability of farmers to adopt innovations. Potential adopters must possess not only the economic means to install new practices but also the skill to use them.

The structure and organization of the farm can be related to the adoption of conservation techniques (Carlson et al, 1977; Pampel and van Es, 1977; Choi and Coughenour, 1979; Earle et al, 1979; Ervin and Ervin, 1982; Miranowski, 1982; Nowak and Korsching, 1982; Rogers, 1983). These studies show that acreage and income, two important indicators of farm structure, can be especially important to adoption when the new practice requires a financial investment. In a study of 7,649 cropland observations, Lee and Stewart (1983) found that the corporate structure of the farm operation did not significantly influence the adoption decision.

Other studies have also found farm size and conservation not to be correlated. Napier and Forster (1982) found that farm size was not significantly related to the adoption of soil erosion control practices but did find that indicators of the complexity of a farm operation were inversely related to adoption of minimum tillage techniques. Butrell et al (1981) found farmers with larger farms tended to be concerned less about the environment than persons who farmed smaller acreage though adoption of conservation techniques could still be due to economic gain factors and not the farmer attitude toward the environment.

While farm size appears to be correlated with adoption of conservation tillage, it may not be as determining a factor as the managerial skill of the farmer. Large farms may have a higher adoption rate because the farmers have the skill to coordinate the more complex operations required for conservation tillage (Korsching et al, 1983).

Numerous studies have found age and education to be associated with the adoption of new farming techniques. Younger and better educated farmers are more efficient in the decision to adopt conservation techniques (Carlson and McLeod, 1977; Choi and Coughenour, 1979; Earle et al, 1979; Rogers, 1983). Younger and better educated farmers are thought to be more knowledgeable about new farming practices as well as more prone to risk taking. In addition, the younger farmers will have a longer payoff time.

Bultena and Hoiber (1983) tested for the factors of youth, education, and risk taking and found support for the traditional view of these farmers adopting conservation practices more efficiently. Korsching et al (1983) found that the younger farmers were not necessarily more likely to change to conservation techniques but noted that the particular innovation or technique in question may be a factor. The study did find a relationship between education and adoption of conservation techniques with higher education associated with greater innovativeness.

Napier and Napier (1991) surveyed 371 Ohio farmers and found that levels of knowledge were correlated with conservation practices. The study asked farmers about the Conservation Title of the Food Security Act of 1985. Farmers who indicated that they were more knowledgeable of compliance details were more favorable toward the legislation. The authors surmised that more knowledgeable individuals were better able to asses the potential impacts of the program on their farming operations. On the other hand, persons not adequately informed of the program may have over-estimated the costs and under-estimated the benefits. Napier and Napier concluded that unrealistic fears of adverse impacts of such programs can be reduced by information provided by contact with farm program agency personnel.

Farmer attitudes were found to be the best predictors of whether farmers were favorable toward a particular soil conservation program in a study by Napier and Camboni (1988). The authors of this study found that nearly all variance in the farmers' attitudes toward the conservation program was attributable to farmers' attitudes toward: land operators' rights, extent of soil erosion in the county of residence, the party responsible for paying the costs of erosion control, and risk.

In conclusion, economic and structural factors are going to play a part in the decision making of the farmer when it comes to employing conservation techniques. Attitudes, personal characteristics, and knowledge have also been shown to play an important role in the adoption of conservation techniques. Conservation advocates are not able to change the personal characteristics of farmers but education and instruction can alter levels of knowledge and attitudes.

Some reservations toward conservation can be addressed with cost-sharing programs, but as Lynne, Shonkwiler, and Rola (1988) found, stronger attitudes favoring conservation raise the levels of effort. If attitudes can be strengthened enough, there will be a reduced dependence on technical assistance and other net income-enhancing programs such as cost-sharing and tax incentives. While education may never totally replace economic incentives, any method to increase the ecological soundness of farming should be pursued to help insure future resources.

Notes

1. The author searched several electronic databases: GeoRef, Economic Literature Index, AGRICOLA, Academic Periodicals Index; as well as a certain amount of manual searching through professional journals for resources. It is especially noteworthy that the Journal of Soil and Water Conservation contains so little work on the adoption of water conservation techniques by farmers. It does, however, contain work on the types of techniques available. Also, water conservation specialists at both the Texas Water Resources Institute and the Texas Department of Agriculture's Rice Experiment Station were consulted in the search for reports on water conservation studies.

Chapter 3. The Survey Instrument

Water conservation in irrigated rice agriculture cannot succeed without the enthusiastic and active involvement of the farmers, reflecting a belief that more rice can be produced with less water. Canal rehabilitation, water measurement, volumetric pricing, and training will not be successful in promoting irrigation water conservation unless the farmers believe in the program's motives and methods.

One way to access the attitudes and knowledge of farmers who work the land in the Gulf Coast and Lakeside Irrigation Districts is to survey them directly. This chapter describes the development, implementation, and results of a survey of all 230 persons farming at the irrigation districts with active accounts for irrigation water.

Survey results can be used to evaluate farmer knowledge and attitudes toward irrigation water conservation. Farmers are the LCRA's irrigation customer base; because the LCRA is a public entity, farmers are its constituents. A survey allows the LCRA to gauge farmers' opinions about how well the LCRA does its job. Survey results can help the LCRA focus its resources and improve its performance. The survey also may indicate topics for which communication between the LCRA and the farmer can be improved. Finally, this survey can be a means for farmers to affect the LCRA's policies, as it can mirror their thoughts and concerns.

Project members selected a survey as a means for determining the farmers' attitudes and beliefs because a survey is a more representative means for obtaining information about farmer concerns than methods which rely upon farmer initiative. For example, farmer phone calls, letters, or visits to the LCRA offices are not necessarily representative of all farmers' concerns. A survey initiated by a third, independent party can obtain information that is representative of the entire farmer population.

Survey Theory and Methodology

The researcher has the choice between personal interview or mail surveys. Mailed surveys have traditionally been unfavorably compared with scheduled interviews because of poor response rates (Helmstadter, 1970; Leik, 1972). Numerous textbooks assumed response rates would be below 50 percent for mail surveys (Boyd and Westfall, 1964; Labovitz and Hagedorn, 1971; Babbie, 1973; Kerlinger, 1973; Meyers and Grossen, 1974; Black and Champion, 1976; Orenstein and Phillips, 1978; and Kidder, 1981). However, since 1960 much progress has been made in mail interview methodology (Harvey, 1987). Response rates to mail surveys now often rival, or surpass, response rates for personal interviews (Neuhauser, 1976; Brook, 1978; Goyder, 1985).

More recently authors have stated that returns of 70 percent have been achieved (True, 1983; Cole, 1980) with 60 percent (Sanders and Pinhey, 1983) being noted as an average. Weisberg and Bowen (1977) and Miller (1977) have achieved a consistent rate of 70 percent from the general public, not members of clubs or special groups. One researcher reported that while response rates for personal interviews have fallen, mail interviews appear to be free from this drop (Goyder, 1985).

The rest of this chapter describes the process through which the survey was developed. A mail survey was selected as the most appropriate for this project. The reasoning in this decision is discussed first. Mail surveys have several advantages but they also have some disadvantages. The relative importance of these advantages and disadvantages is discussed. The steps in developing the survey instrument itself is next. Finally, the types of questions present on the survey are outlined.

Advantages of Mail Surveys

Mail surveys have several advantages over personal interviews. They also have several disadvantages. These are summarized in Table 3.1.

Table 3.1
Advantages And Disadvantages Of Mail Surveys to Personal Interviews

Advantages	Disadvantages
Can cost much less than interviews.	Mailing list is necessary.
Can provide a time savings.	Respondent cannot ask clarifying questions.
Respondent may complete at his/her convenience.	Prevent researcher from asking clarifying questions.
May achieve more truthful replies.	No obvious check on veracity of information provided.
Allows centralized control of survey process.	
Respondent may be guaranteed anonymity.	

Mail surveys can cost much less than interviews. Although the questionnaire in a mailed study may be more expensive than the survey form used in an interview study, with higher quality printing, envelopes, and postage, a mailed study may cost far less than an interview study with the same sample size. This is true even if first class postage is used for the survey instrument and several follow-up mailings are used as reminders.

The lower cost of the mail survey leads to another advantage: wider distribution. Because of relatively lower cost of mail surveys, the often wide geographic distribution of the sampled population is not a factor. In fact, the wider the geographic distribution of a sample, the greater the savings by employing a mail survey.

Mail surveys can provide a time savings. Most surveys will be returned within one to two weeks with very little effort put in by the researcher. Obviously, as the sample size and geographic distribution increase, so does the time benefit of a mail survey.

The respondent is free to complete a mail survey at his/her convenience. This may be late at night or at other times and locations that would be difficult or impossible for a interviewer to replicate. As a result, the respondent may spend more time on the survey. This convenience allows them to consider more difficult questions over a longer period.

Mail surveys may achieve more truthful replies (Erdos, 1970; Bailey, 1982). There are two main reasons for this generalization. The first is the reduction of interviewer bias. Even the best interviewer can bias responses due to voice inflection, accent, ethnic background, dress, and mannerisms, or other factors. The questions on a mail survey can be carefully scrutinized to avoid leading questions or offensive terms. The second reason is that a mail survey is more controlled than an interview as the same form can be sent to all respondents. This eliminates any interference due to mood, time of day, or similar factors.

A mail survey allows centralized control of the process. One researcher, or at most a few, can construct the survey, mail it out, collect the returns, and enter the data in the database. Fewer people involved typically lowers the chance of error and makes it easier to maintain a high level of quality control.

The respondent may be guaranteed anonymity. It has generally been assumed that ensuring someone's anonymity may induce them to give a more truthful answer to certain sensitive questions.[1]

Disadvantages of Mail Surveys

Though mail surveys certainly have many advantages over personal interviews, they have some disadvantages as well.

A mailing list is necessary before a mail survey can be carried out. In some instances a list may not be available. The cost of constructing a mailing list could exceed the cost of conducting personal interviews. In such a case, the mail survey no longer benefits from one its strongest advantages. In other occasions, only an incomplete, unreliable, or biased mailing list may exist. This situation will result in sample bias and/or a high non-response rate due to such things as undeliverable survey forms.

An example of a biased mailing list would be the subscribers to a particular magazine. Any survey done using this list would not necessarily be representative of the entire or desired population. The survey would only cover those individuals who have one common characteristic--subscribing to a certain magazine. While this is not a problem of mail surveys per se but of sampling method, it should be kept in mind when obtaining addresses.

The respondent cannot ask clarifying questions. To some extent this problem can be controlled by ensuring that survey questions are as clear and concise as possible. However, some subject matter is complex to the extent that it is difficult or impossible to present the questions in a manner which is sure to be understood by all respondents. Whereas an interviewer can adjust his/her presentation to each respondent, a mail survey will generally send the exact same wording to all respondents. If a respondent does not fully understand a mail survey question usually the only choice is to take a best guess. This inability to clarify a question can lead to error if a respondent misses the meaning and provides incorrect information. The researcher may not be aware of this error and therefore the results would mislead.

The mail survey prevents the researcher from asking clarifying questions as well. If a respondent's answer to a particular question is unclear or obviously in error the data will have to be discarded. In an interview situation a researcher can recognize this difficulty and rephrase a question or ask the respondent to be more precise with an answer.

This survey attempted to achieve clarity of questioning. However, as indicated below, some of its questions were interpreted in different ways by different respondents.

The mail researcher is at the mercy, so to speak, of the respondent more than the interviewer. While it is possible to ask so-called filter questions on a mail survey, questions that elicit information without the respondent necessarily being aware of it, there is no reason a wealthy person could not claim low income, an uneducated person claim advanced education, or any combination of these or similar characteristics. With the researcher present in a personal interview, a respondent may feel compelled to provide correct information on subjects which would be obvious to the interviewer but not obvious to a mail researcher. In cases where the researcher has good reason to believe inaccurate information has been provided, there is often no choice but to discard the data altogether. Fortunately, respondents rarely provide false information intentionally.[2]

Goode and Hatt (1952) contend that mail surveys are not an effective research tool because they will usually be biased in some way. However, McDonagh and Rosenblum (1965) compared the results of a mailed questionnaire and interviews by studying persons who responded to the questionnaire and persons who failed to respond. They found no statistically significant difference between the two groups.

Other researchers have suggested additional drawbacks to mail surveys. For example, a mail survey allows no control over the order in which questions are answered (Bailey, 1981). It may also be difficult to separate an incorrect address from non-response (Lansing and Morgan, 1971).

Creating the Questionnaire

After considering all of these factors, the PRP team members in charge of gathering this information decided to employ a mail survey rather than a personal interview survey. Before questions could be designed, it was necessary to determine exactly what information was desired. The first step was to become familiar with the operations of the irrigation districts.

Several meetings were held with LCRA personnel from both the Austin and Bay City offices. Documents of the LCRA and other entities such as the Texas A&M Rice Experiment Station were reviewed for an understanding of the issues involved and the management structure employed. Finally, a site visit to the irrigation districts was performed to attend a farmer meeting and observe the operations of the district.

After an understanding of the issues was achieved and the information to be gathered from the survey was determined, the actual survey questions were developed. As the development of the questionnaire began, the following objectives were kept in mind (paraphrase of Erdos, 1970):

(1) The questionnaire should include questions on all subjects which are essential to the project.
(2) The questionnaire must be clear, professionally done, and easy to complete.
(3) The respondent must be made to feel that the time and energy put into the questionnaire is worthwhile (in other words, that their participation is important and they have something to gain by completing the form).
(4) The questionnaire should not contain any questions which could bias the answers.
(5) It must be designed to elicit clear and concise answers to all questions.
(6) The structure of the form must be designed with the easy tabulation of results in mind.

Design of Questions

The construction of the questions to be included on the survey form may seem fairly easy to those who have not attempted it. The development of 50 or more quality questions is no small matter. Many pitfalls need to be avoided if all the criteria mentioned above are to be satisfied.

The survey writer must be careful to avoid two questions posed as one. For example, the question, *Do you meet with the LCRA and other farmers to discuss possible water conservation practices?* may not be possible to answer. What if the farmer does discuss the matter with other farmers but not the LCRA? If the farmer answered positively we would be led to believe the farmer also discussed the matter with the LCRA which is inaccurate. On the other hand, a negative answer would indicate that the farmer spoke to neither group about the matter, also untrue. Questions with the words *and* or *or* were checked to avoid this problem.

Questions may also be ambiguous. The use of slang terms should be avoided as non-standard English may have an undefined meaning or may mean different things to different respondents. Even non-slang words can be open to different interpretations. One question on the survey asked, *Did you receive any technical information from the LCRA last year?* It is possible that what qualifies as technical information to one farmer may not qualify as technical to another. For example, did the farmer inquire about a new farming technique or did the LCRA send the farmer information about the state of the Highland Lake levels? Both types of data may be considered technical information. Another example of variability in word definition would be the use of the word *progressive* in regards to farming technology. While some farmers may consider himself/herself progressive because they have the latest equipment and use the newest fertilizers and pesticides, another farmer may consider themselves progressive because the use of artificial fertilizers and specialized equipment is avoided. Therefore, the question, *Do you practice progressive farming techniques?,* may elicit positive responses from diametrically opposed philosophies.

The desire to keep the questionnaire length to a minimum also leads to the exclusion of long or even moderate-length explanations. The shorter the explanation for certain issues, the more likely it is to be interpreted in more than one way. For example, the question, *Do you rotate crops?* may seem very clear, requiring a yes or no response. On closer examination, other factors complicate the question. Some farmers may rotate their crops on an annual basis while others may rotate their crops only every few years. In addition, most farmers in the survey area plant more than one crop per year. How will we know if they rotate after every planting or only on an annual basis?

Another concern is the level of wording of the questions. This includes not only the difficulty of the vocabulary but also the degree of formality and the use of colloquialisms. Even while the terms used may have the same basic meaning, specific terms can elicit different feelings in the respondents (Schuman and Duncan, 1974; Fee, 1981; Smith, 1987; Rasinski, 1989). For example, a common practice in one of the districts is to use a stream to keep the water level in the field at a constant level. This stream is typically called a "cheater" stream but the use of this term may make the respondent less likely to admit to its use than the less judgmental feeder stream.

A common pitfall in question wording is the leading question. The question should be carefully worded to avoid leading the respondent and thus artificially increasing the probability of a particular response. Leading questions may result not only from obvious bias on the side of the writer but by the citation of authorities. For example, the question, *Do you agree with most experts that . . . ?* may put the respondent in the position of appearing uninformed or stupid.

The decision was made to employ closed-ended questions on the majority of the survey form. This was done mostly to ensure ease of tabulation and a more accurate quantifying of the results allowing for statistical analysis. The one exception was the final question which was an essay style question allowing the respondents to write about whatever they wanted.

Some criticism has been brought against essay or open-ended type questions (Craig, 1985; Stanga and Sheffield, 1987) based on the belief that people may not respond to these questions because they are not articulate enough to put forth an answer. If this were the case, open-ended questions would be measuring, in part, people's education level, not their attitudes. Others (RePass, 1971; Kelley, 1983; Wattenberg, 1984; Geer, 1988) support the use of open-ended questions as a way to allow the expression of heterogeneous attitudes and prevent the respondent from being forced to conform their answer to a stock reply. Because of this latter point it was considered important to include a section on the survey which allowed the respondents to have complete freedom to express feelings, beliefs, and attitudes.

Many of the questions on the survey form asked for quantitative information. The development of the response choices for these questions was relatively straightforward. For example, the answer choices to the question, *How many assistants do you employ?* would be something like: zero, one, two, three or more. This scale would be considered a ratio measurement since there is a meaningful distance between variables and a zero point can be meaningfully designated.

Questions about more personal issues such as the age, income, and education of the farmer could be quantitative. However, a respondent may be sensitive about giving out exact information. In cases of sensitive subjects, ranges are frequently used. The hope is that while the precision of the information may be reduced, non-response will be reduced, and accuracy will remain the same.

Other questions on the survey sought attitudinal information, such as perceptions of the performance of the LCRA. To obtain this type of data an ordinal scale was usually employed. Ordinal scales are used when it is possible to rank or order all categories according to some criterion. For example, the question, *How would you rate the LCRA's attempts to inform you of its proposed volumetric rate structure?* offered the choices of *very adequate*, *adequate*, *inadequate*. Clearly, there is a relative distinction that very adequate is "better" but we do not know how much better. There is not an absolute scale by which we can measure the relative differences.

Length

Researchers have long assumed that all other things being equal, shorter surveys will have a higher response rate than longer ones (Berdie, 1973). However, this assumption is not supported by any empirical studies.

One early study done by Sletto (1940), sent out questionnaires of 10, 25, and 35 pages. The 10 page form had a 68 percent response rate, the 25 page form had a 60 percent response rate, and the 35 page form had a 63 percent response rate. This would indicate that length and response rate may not be related.

In a more recent study by Champion and Sear (1969) questionnaires of three, six, and nine pages were sent out. Significantly, the nine page forms had a higher response rate than the three page ones. Champion and Sear concluded that the relationship between length and response rate is more complex than had been originally anticipated.

Berdie (1973) tested for a relationship between length and response rate by sending out questionnaires of two, three, and four pages. He did not find a statistically significant difference in the response rates of the various lengths.

Research on this subject conducted by Clausen and Ford (1947), Mason et al (1961), Scott (1961), Brown (1965), Dillman et al (1974), Sheth and Roscoe (1975), Paliwoda (1981), Goyder (1982), and Cartwright (1986) suggests that the number of questions may not affect the response rate.

The empirical evidence thus suggests that there is not a certain relationship between response rate and length. Perhaps some respondents perceive an importance factor for a long survey versus a short one and this offsets the extra time required to fill out a longer survey. While someone receiving a short survey may not feel that the form is worth bothering with, someone receiving a long form may be impressed by the obvious amount of work the survey writer did and the expense involved. This potential respondent could conclude that the survey must be one of importance and therefore worth filling out and returning. Some potential respondents may be pleased to be chosen for a study and appreciate the chance to state their views.

One relationship which definitely exists and that is between length and cost. The longer the questionnaire, the higher the cost of printing and postage. This project settled on a length of 50 questions as appropriate. This required six page faces which were then copied two-sided, to reduce the total questionnaire to three pages, excluding a cover letter.

Anonymity

Whether the survey was to promise anonymity or not needed to be determined. As mentioned above, a respondent's identity is sometimes left unknown to prevent the action of providing the answer the interviewer wants to hear, a tendency known as *social desirability bias*. This bias is not the result of a respondent engaging in a conscious, deliberate attempt to mislead the interviewer but rather a non-deliberate tendency of which the respondent may not be aware (Anastasi, 1968; Edwards, 1957).

However, the problem of social desirability bias is not necessarily one which would be prevented by anonymity. A respondent may answer a question in a desirable way to a person sitting in front of them but there is no reason to believe they would also answer in a socially desirable manner just because their identity is indicated on a questionnaire. The bias occurs mostly because of a personal interaction between two people. Numerous researchers (Olson, 1936; Corey, 1937; Fischer, 1946; Gerberich and Mason, 1948; Evans, 1949; Elison and Haines, 1950; Ash and Abramson, 1952; Hamel and Reif, 1952; and Rosen, 1960; Pearlin, 1961; Rosen, 1963; Butler, 1973; Fuller, 1974; Futrell and Swan, 1977; Matteson and Smith, 1977; Futrell et al, 1978) have examined the effect of anonymity and its effect on the type of answers given on questionnaires. No consistent relationship has been shown to exist. Futrell and Swan (1977) attribute this lack of consistency to several factors: relative sensitivity of the items on the questionnaire, whether confidentiality was promised, relationship between the sponsor and the respondent, and the characteristics of the respondents. Without the control of these factors the benefits of anonymity appear to be minimal.

For this survey it was decided to attempt the use of anonymity in the hope of obtaining a more accurate response in regards to the LCRA and its performance in certain areas.

Drafts and Pre-testing

The survey went through several drafts, each of which was examined by the members of the larger PRP group. Any questions that were not clear to group members were re-worded to achieve greater clarity. Ideas for entirely new questions were also discussed. Several group members had specific information that they wanted the survey to address and several new questions resulted from this process. For example, one of the group members was studying the possibility of conjunctive use of groundwater and surface water for irrigation. The group member requested a question relating to the percentage of irrigation water the farmer currently obtained from surface sources and the amount from ground sources.

After these initial reviews, the input of various LCRA officials was sought. Officials from both the Austin and Bay City offices made suggestions in regards to the wording of questions and the types of questions asked. The Austin officials were particularly helpful with questions which discussed the new water rate structure. Such discussion with LCRA staff was helpful because a survey would lose credibility instantly if it asked questions which exhibited a lack of understanding of the situation. For example, a question which asked whether the farmer had been invited to any meetings with the LCRA staff in the past year would be ridiculous if the LCRA had in fact never had any such meetings. Or, if a survey should ask whether a farmer is apprehensive about the implementation of the new rate structure in the coming year if, either (a) the new rate structure had already been implemented or (b) it would not be implemented for several more years. It was important to avoid such errors for the success of the survey.

After it was certain that the survey did not make any theoretical or factual errors in regards to LCRA policy or the water conservation program, the survey was sent to the local officials for further testing. The local officials also checked for theoretical errors about the LCRA's operations but their main job was to ensure that language of the survey accurately reflected the meaning and intent of the PRP class. The local LCRA officials, specifically the so-called "water bosses", played a role in this area. The water bosses are the LCRA employees who are responsible for the opening and closing of the gates on the LCRA's canals. These gates regulate water flow to the farmers' fields. As a result, the water bosses are intimately familiar with the farmers and their attitudes. The water bosses could thus tell if a particular term could offend some farmers or if they may not be familiar with a certain phrase.

As the PRP class wanted the farmers to feel comfortable with the survey, testing was a necessary step to avoid words or terms unfamiliar to farmers or that sounded overly formal and strained.

The finalized survey was composed of three basic sections.[3] The first section contained questions generally about farming, such as number of acres farmed and the employment of various farming techniques and practices. The second section asked about the personal characteristics of the respondent such as age and education. The final section sought to acquire attitudinal information about two related subjects. The first of these subjects concerned the farmers relations with, and opinions of, the LCRA. The second subject was the proposed volumetric price structure for water.

Finally, space was provided for the respondent to express in free form any concerns not addressed in the survey properly. Forty-two of the seventy-nine respondents, or 54 percent, took advantage of the opportunity to express their thoughts in this section.

Accompanying Documents

The questionnaire itself was not the only item needed to complete a successful survey. While it is possible to send only a questionnaire to those being surveyed, several additional tools were developed to increase response rate for mail surveys.

Advance Notice

Advance notice is a technique employed to reduce non-response in mail surveys while retaining the economics of the mailed questionnaire survey design. Pre-contact can be either by phone or by an advance postcard informing the addressee that the survey will be arriving soon.

Numerous studies have been done examining the response rate impact of pre-contact by letter or postcard. Pre-contact letters resulted in a much higher response rate for Heaton (1965), Ford (1967), Myers and Haug (1969), Pucel et al (1971), Smith and Hewett (1972), Marks (1981), and Martin et al (1989). Other studies using letters for pre-notification have achieved higher response rates but the increases were not as significant (Kephart and Bressler, 1958; Scott, 1961; Fuller and Hare, 1974; Chebat and Picard, 1984). For example, Parsons and Medford (1972) conducted a study with two groups; while pre-notification increased the response rate by 6 percent in one group, in the other group the pre-notification was associated with lower response.

Studies using postcard pre-notification by Eisinger et al (1974) and Dommermuth et al (1981) reported significantly higher response rates from the pre-contact groups.

Other research has been performed on the value of pre-notification by telephone as opposed to postcards or letters. Stafford (1966) showed large increases in response rate as a result of telephone pre-contacts. Waisanen (1954) had shown a doubling of response rate in a small scale study. Allen et al (1980) also showed that telephone pre-contact enhanced response rate. However, Hornik (1982) indicated that telephone pre-contact had a variable effect on response rates in his study in Chicago.

Several researchers have compared the effect of telephone versus mailed pre-notification. Kerin (1974) reported significantly higher response rates using telephone pre-contact over pre-contact by letter. Stafford (1966) achieved significantly higher response rates from a telephone pre-contact group over a letter pre-contact group, although both the pre-notified groups responded at much higher rates than the control group which was not pre-notified in any way.

Schlegelmilch and Diamantopoulos (1991) found that pre-notification does significantly increase the response rate and that for all forms the average improvement is approximately 13 percent. They also note that telephone pre-notification achieved an improvement of nearly twice this average. The results of their study also showed that pre-notification does not always work. The researcher is faced with a cost-benefit dilemma between spending on response-inducement techniques or increasing the size of the initial mailout. Therefore, in cases where it is imperative to reach a substantial proportion of a limited population, pre-notification of some type should be pursued. On the other hand, if the population is not limited the researcher may want to consider simply increasing the mailout size instead.

If it is thought that non-response bias will be small or that a response stimulating technique will not reduce the bias by any substantial amount, the researcher may want to use the technique with the lowest cost per usable return. Walker and Burdick (1977) found that using no advance correspondence would produce the largest number of returns within a fixed budget. They also note that this does not mean the number of returns will always be maximized by not using a response stimulating technique. The PRP decided to employ pre-notification using a postcard.[4]

Cover Letter

In a typical mail survey, the researcher wants something from the respondent--specifically the completion of the survey form. The researcher is prompted to make several types of appeals to the respondent to encourage completion and return of the questionnaire. Appeals may be needed in the cover letter which accompanies the questionnaire.

Normal practice is to include in the cover letter an appeal for assistance along with an indication of the importance of the research. Linsky (1965) found that there were substantial differences in response rates between respondents who received a cover letter with an explanation of the importance of the respondent in comparison with those who did not. Likewise, Hornik (1981) showed that response rate is influenced by cover letter cues.

Of the types of appeals which might work most effectively, Champion and Sear (1969) found that egoistic types seem to more readily received by respondents than altruistic ones. However, Houston and Nevin (1977) found that the type of appeal and the response it gets depends to some degree on the sponsor of the survey. For example, an appeal based on the social utility of the research is most effective for a university, whereas an appeal emphasizing the opportunity for the respondent to express opinions is most effective for a commercial sponsor.

The PRP cover letter stressed the fact that the LBJ School of Public Affairs was conducting the survey and not the LCRA.[5] It was hoped that this fact would elicit a higher response rate since a third party would presumably be more objective in its analysis of the results. The cover letter also stressed the importance of the research and the fact that this was the respondents' chance to have his/her opinions heard.

Reminder

An important technique to stimulate response is the reminder notice. Abundant research has been done on reminding survey participants to complete the survey (Sletto, 1940; Eckland, 1965: Robin, 1965; Watson, 1965; Francel, 1966; Nichols and Meyer, 1966; Myers and Haug, 1969; Hochstim and Athenosopoulos, 1970; Dillman et al, 1974; Etzel, 1974; Hinrichs, 1975; Goulet, 1977; Herberlein and Baumgartner, 1978; Goyder, 1982). Numerous strategies have been tested by these authors; the result is, the more one reminds the respondent, the higher the response rate.

Eckland (1965) found that the more intensive the reminding, the better the response rate. Goulet (1977) used up to three reminders and found a significant increase in response rate as judged by an independent test of proportions. Telephone reminders were reported to be the most effective (Roscoe et al, 1975).

Hinrichs (1975) believes the fact that a researcher keeps track of a respondent through reminders communicates to a respondent that their role in the study is important enough to be singled out. Reminders may instill a sense of obligation and prior commitment.

The PRP Group sent a reminder postcard to the farmers approximately two weeks after the survey itself was sent out.[6] The postcard was sent to all persons on the mailing list not just those who had not returned the questionnaire. The postcard was mailed to all farmers to avoid the task of determining which farmers had or had not returned the survey yet. The postcard simply reminded the farmer of the survey and asked them to return it. The postcard also provided a toll free number which could be called if a copy of the survey was lost or never received. It was hoped that this willingness on the part of the researcher to pay for the phone call and send more copies would communicate to farmers the commitment of the researcher and the importance of the information thus increasing the response rate.

Non-Response Bias

All surveys, not just mail surveys, are subject to the problem of bias. Non-response bias occurs when the persons who respond differ significantly in their answers from those who do not respond. If non-response bias is present, the results would not directly allow one to say how the entire sample would have responded. This problem could prevent the generalization of the sample data to the entire population. In fact, unless the response rate is 100 percent, a surveyor can never be sure that some non-response distortion has not occurred. In other words, only when non-response is 0 percent is the sample data certainly representative of the population.

The best defense against non-response bias is, of course, the reduction of non-response itself through the use of response stimulating techniques. Another strategy is to resample the non-respondents. Reid (1942) chose a 9 percent subsample from his non-respondents, surveyed again, and obtained responses from 9 percent of them.

A cheaper, but potentially more difficult, strategy is to estimate the effects of non-response (Daniel, 1975; Hendricks, 1949). Some researchers maintain that estimation is difficult to the point of impossibility (Hochstim and Athanasopoulos, 1970; Ellis, 1970; Lansing and Morgan, 1971; Ognibene 1971). Filion (1976), on the other hand, reanalyzed data from Ellis (1970) and found that estimation did help. Clausen and Ford (1947), Pearl and Fairley (1985), and Erdos (1970) also feel that estimation using statistical techniques can be a valid strategy.

Four methods of estimation are described in the literature. These are: comparisons with known values for the population, subjective estimates, differential weighing of data, and extrapolation. (Pace, 1939; Politz and Simmons, 1949; Stephan, 1958; Kish, 1965; Pearl and Fairley, 1985)

Comparisons with values which are known for the population, such as age or income, can be compared to determine with the sample results to determine whether there is a significant difference. If no difference is present in these known areas it may be assumed that there are no differences in other areas as well.

Subjective estimates are judgments made by knowledgeable persons as to the direction and extent of bias. Armstrong and Overton (1977) found that such judgements were valid in most cases for the prediction of the direction of non-response bias especially for items which were significantly biased. The use of a consensus among the judges furthered the accuracy of this technique.

Pace (1939) and Politz and Simmons (1949) used a technique which gave a greater weight to respondents who took longer or were more difficult to bring into the sample on the assumption that they more closely resembled the non-respondents.

Pearl and Fairley (1985) proposed a more rigorous statistical method by linking response rate to the strength of feeling about an issue. It has been shown that persons who feel more strongly about an issue are more likely to respond to a questionnaire (Baur, 1947; Donald, 1960; Scott, 1961; Armstrong and Overton, 1977). They used this fact to attempt to predict what the answers would be from non-respondents. In some cases they were successful, but not in all of them. It appeared that factors other than just strength of feelings were at work.

Armstrong and Overton (1977) also tested an extrapolation technique. They attempted to predict bias in a third wave of surveys based on information from the first two. They were correct 89 percent of the time using this technique.

The PRP Group decided not to attempt the use of any of these prediction techniques for two reasons. First, the highly theoretical and often subjective nature of these techniques makes them difficult to use successfully. Second, the mixed results which have been obtained by previous researchers makes the justification of these techniques rather difficult.

Logistics of Getting out the Survey

Normally, when performing a survey, a sample is taken from the population with the assumption that the sample results would match those for the population as a whole. The number of farmers in the Gulf Coast and Lakeside districts was small enough to dispense with the need for taking a sample in this study. Survey forms were sent to the entire population.

The LCRA provided the PRP with the names and addresses of all of its customers in both the Gulf Coast and Lakeside Irrigation Districts. This list was entered in a microcomputer to generate address labels.

In January, 1993, a postcard was sent to the entire population informing them of the survey and attempting to elicit their support. One week later, the survey was mailed to the farmers. A pre-addressed, postage paid envelope was included to encourage the farmers to return the survey. A postage paid postcard was also included which the farmer could return separately from the survey if the farmer wished to receive copies of the survey results.

A cover letter was included explaining the purpose of the survey, indicating the anonymity of the respondent, and pointing out that the study was being conducted by the LBJ School of Public Affairs at The University of Texas at Austin, and not the LCRA. As the survey was being conducted by an independent third party, the PRP group thought the response rate would be higher because farmers would have more confidence that their opinions would be taken seriously.

Two weeks after the day the surveys were mailed, the number being returned began to decline greatly. At this time a reminder postcard was mailed to all survey participants. After this reminder, 23 more surveys were received for a total of 79.

Strengths and Weaknesses

Two aspects of the survey situation not related to the questionnaire or accompanying documents worked to strengthen it. The first was the ability to send surveys to the entire population instead of only a sample of the population. This was made possible by the relatively small size of the population, 230 persons.

The second factor working in the survey's favor was that it was sponsored by an independent third party. Sponsorship can affect a respondent's willingness to return a mailed questionnaire by convincing him or her of the study's legitimacy and value (Hammond, 1959; Scott, 1961; Roeher, 1963; Vocino, 1977; Labreque, 1978; Harvey, 1987). Sponsorship by scientific, governmental, university, or well-known nonprofit agencies indicates some legitimacy. On the other hand, sponsors who might seem to have an ulterior motive such as commercial organizations or regulators, like the LCRA, often have difficulty in achieving satisfactory response rates. In this case, farmer confidence was apparent from the excellent response rate of 35 percent.

The PRP's procedure was not perfect. For example, possible bias existed in the mail survey. Even though surveys were mailed to all farmers, some surveys were not returned. The chance exists that the responses on the unreturned surveys would have been different, as a group, from those which were returned. For example, an argument could be made that the persons who did not return the surveys may be less active in their relations with the LCRA. These same farmers may have also be less likely to attend an LCRA-sponsored farmer meeting. If this were to be true, the number of persons indicating that they had been invited and attended the meeting would not accurately reflect the entire farmer population. However, as mentioned earlier, research by McDonagh and Rosenblum (1965) found no statistical difference between the answers of those who did respond to a mail survey and those who did not. Various techniques designed to combat this were discussed above along with the reasons for not employing them.

A second problem is item non-response. Item non-response occurs when a particular question on a survey is not answered. A respondent may not answer a particular question for several reasons. The respondent may consider the question a private matter. Another reason for item non-response is that the question does not apply to the respondent. An example of the later reason were the questions about the value of the water conservation demonstration projects and the value of farmer meetings. If the farmer did not attend either of these functions, they may not feel qualified to answer on its value, and thus would skip the question.

The several questions on the survey that had significant non-response were of the second type.[7] The question on the value of farmer meetings had a 16.5 percent non-response rate. The question on the value of the water conservation demonstration projects had a 33 percent non-response rate. The question which asked for the helpfulness of the LCRA staff when they are asked questions about water deliveries had a 15.2 percent non-response rate. The remaining questions averaged a non-response rate of less than or equal to 10 percent.[8]

Another weakness of the survey was a mistake in the phrasing of some response choices. In questions where the choices were: *very helpful, helpful,* and *not helpful,* the choice of *helpful* should have been ***somewhat helpful.*** Several related questions suffered the same problem, only in these other questions the choices were *fair, adequate,* and *accurate*. The choices should have been ***somewhat fair, somewhat adequate,*** and ***somewhat accurate***. The results are still valid but the existing questions become close to binary choices. However, the questions do provide more information than a pure binary response choice since we are able to resolve which respondents are very satisfied with a particular situation by examining the number of respondents that indicated the extreme positive response.

A final potential weakness to the survey data is the possible effect of political motives when answering the questionnaire. The LCRA and the farmers have many years of historical interaction. On some occasions, relations between the two groups has been rather strained. At other times, the relations have been better. The possibility exists that when answering the questions about the performance of the LCRA, a farmer's responses would reflect past farmer/LCRA interactions. Specifically, there may be a concern that the farmers would intentionally, or unintentionally downgrade the LCRA's performance.

The fear appears not to have materialized however, as the results to the questions on the LCRA's performance show a strong majority of the farmers are satisfied with the LCRA's performance. Currently, the relationship between the farmers and the LCRA appears to be positive on balance. One farmer remarked that relations were the best they had been in many years.[9] This situation could change in the future as the past has been marked by alternating times of improved relations and deteriorating ones.

Summary

The PRP decided to survey the farmers to obtain information about the LCRA's performance and attitudes about the new rate structure. Three types of survey are available: personal interviews, telephone interviews, and mail surveys. A mail survey was chosen for its multiple advantages including its low cost. The strategy of ensuring anonymity was examined and was determined appropriate for this survey. This chapter also describes the specific steps taken to administer the survey.

The following section recounts the development of the survey form and examines the various aspects of a mail survey, as discussed in the published literature. Open-ended and closed-ended questions were considered and both types were finally included. Closed-ended questions allowed for consistency and ease of tabulation. Open-ended questions were included to allow the farmers to address issues the questionnaire had missed.

Various response stimulating techniques were analyzed including advance notification, cover letters, and follow-up notification. All of these techniques were used as they have been shown to increase response rates.

Non-response bias was addressed as were several techniques to cope with it. Because of the theoretical difficulties of successful bias adjustment and the difficulty of defending the practice, it was not used in this survey.

Notes:

1. This issue of respondent anonymity is discussed at greater length below.
2. See the section about anonymity below.
3. Appendix A contains a copy of the final survey.
4. Appendix A contains a copy of the pre-notification postcard.
5. Appendix A contains a copy of the cover letter.
6. Appendix A contains a copy of the reminder postcard.
7. The following percentages are based on the surveys that were returned.
8. The number and percentage of farmers who did not respond to any question, along with all raw survey data, can be found in the raw data presented in Appendix B.
9. Much of this improvement may be attributable to the efforts of Bruce Hicks, the LCRA's Manager of Irrigation Operations for the two districts.

Chapter 4. Data Management and Analysis Performed

Initial Tabulation of Results

The first step in the analysis of the survey was to enter them into a computer database. For this project, the results for each survey were entered into the spreadsheet program *Lotus 1-2-3*. This program was used as a database and translation program. The program was used as a translator program because its great popularity means many other specialty programs are capable of exchanging files with it. With the results in the *Lotus* program, it was possible to transfer the data into any other specialty program as needed.

To tabulate the results, a spreadsheet was set up in the *Lotus* program. Spreadsheets use computer files which form a large matrix with *rows* running horizontally and *columns* running vertically to make a table.

The first row was designated for *field* names. Therefore each column represented a different field. Subsequent rows were each reserved for one respondent. Each row after the first contained information on one respondent only. Field names were a code name given for a response on the questionnaire.

In most instances, each question was represented in one column. However, certain questions, specifically ones which allowed multiple responses, required multiple columns. For example, the response to the question on the number of fields farmed could be contained within one column, the answer being a single number from 0 to 5. The question for the types of crops raised required one column for each potential crop. This question needed one column for rice, one for corn, one for soybeans, etc. Since one farmer could grow more than one crop at a time, it was necessary to be able to indicate this on the spreadsheet. Multiple columns, one for each crop, allowed the coding of a positive or negative response for each crop independent of the others.

Questions that elicited a simple *yes* or *no* were coded numerically with a yes represented by a *1* and a no response being indicated by a *0*. Assigning alpha responses a numeric value made data entry, the statistical analysis, and simple frequency calculations possible.

Many of the questions on the survey did not contain simple binary answers but instead the choice of responses was given in a range. In this case, each response was assigned a number and this number was entered in the database as the answer. For example, for the question on age, five possible choices were presented to the respondent. The response *less than 30* was assigned the number *1*. The response *30-40* was assigned the numeral 2, and so on. If a farmer indicated he/she was *30-40*, numeral 2 would be entered into the database.

Some questions presented a range of subjective responses, such as *very adequate*, *adequate*, and *inadequate*. These responses were quantified by using numbers. For example, the response, *very adequate,* was coded with the numeral *1*, the response, *adequate*, was coded with the numeral 2, and the response, *inadequate,* was coded with the number *3*.

Statistical Analysis

The data was transferred to the application *SPSS* for statistical analysis. This was done by loading the *Lotus* file onto the hard drive of a computer. *SPSS* was opened and *SPSS* retrieved the data file in the *Lotus* format.

It would have been possible to perform the initial data tabulation in *SPSS*. This was not done for two reasons.

One, when the initial tabulation was being performed, it was not clear which statistical or other programs would be appropriate for the data. The *Lotus* program was used to enter the data, because it could be used to transfer the data to other formats.

SPSS was used to compute frequencies, percentages, cross tabulations, and chi-square analysis. Frequencies were calculated by selecting the field or column which represented the question for which a frequency was desired. The program was instructed to calculate the respective number of times which a particular response occurred in the column. The results would be the frequency of each answer for a question.

Percentages were gained in the same manner as frequencies. The program was instructed to present the results in percent of total rather than simple frequency of occurrence.

Cross tabulations were run on a large number of questions. A cross tabulation compares the responses from two questions by setting up a contingency table. The rows of the table represent the possible responses to one question and the table's columns represent the possible answers to the other question. The program then calculates the number of responses which belong in each cell of the table. Each cell represents the combination of answers to both questions. From this data the researcher can tell how many individuals (numbers or percentage) gave one response to the first question and another response to the second question. For example, on a cross tabulation of place of birth and education, one could tell how many respondents are native to the area *and* have only a high school education (see Table 4.1).

Table 4.1 Contingency Table:
Farmers Native to Area by Level of Education
(Number and Percentage of Respondents)

	High School	**College**	**Graduate School**	**Total**
Non-Native	3 (4%)	3 (4%)	3 (4%)	**9 (12%)**
Native	26 (33%)	38 (49%)	5 (6%)	**69 (88%)**
Total	**29 (37%)**	**41 (53%)**	**8 (10%)**	**78 (100%)**

Source: Policy Research Project Survey.

Cross tabulations can be linked to the chi-square test of independence. The chi-square distribution is used for testing hypotheses of the independence of two variables. Two variables may be inferred to be independent if the probability that a case falls into a given cell of the table is simply the product of the marginal probabilities of the two categories defining the cell (Norusis, 1992). A chi-square test computes probabilities and compares the expected number of cases in a particular cell to the observed number of cases in the cell. If the observed number of cases in the cell is sufficiently different from the expected number, the two variables are considered to be related in some way, or *not independent*.

The chi-square test of independence was applied to numerous pairs of questions on the farmer survey to determine if the variables showed a statistical association. Using the cross tabulation example above, the probability that a case falls into the cell native *and* graduate school is the product of the probability of a respondent being a native and the probability of a respondent having attended graduate school. The table shows that 88 percent of the respondents are native and 10 percent of the respondents have attended graduate school.

Thus, if level of education and native status are independent, the probability of a respondent being a native who has attended graduate school is estimated to be:

$$P\ (\text{native})\ P\ (\text{graduate school}) = 0.88 \times 0.10 = 0.088$$

The expected number of cases in the respective cell is 6.9, which is 8.8 percent of the 78 cases in the sample. From the table, the observed number of natives who have attended graduate school is 5, which is 2 less than expected if the two variables are independent. To construct a statistical test of the independence hypothesis, the above calculations are repeated for each cell in the table.

After calculating the expected number of responses in each cell, the Pearson chi-square statistic can be used to determine whether the two variables were independent. The Pearson chi-square statistic is calculated by summing the squared residual for all cells divided by the expected frequency for all cells. The calculated chi-square is compared to the theoretical chi-square distribution to produce an estimate of how likely, or unlikely, this calculated value is if the two variables are in fact independent.

In the example of native status and level of education, the Pearson chi-square value is 6.04. If native status and level of education are independent, the probability that a random sample would result in a chi-square value of at least that magnitude is 0.048. If the probability is small enough[1], the hypothesis that the two variables are independent is rejected. Since, in the example, the statistic of 0.048 is below 0.05, the hypothesis that native status and level of education are independent is rejected. Therefore, an association is assumed to exist between whether a farmer is native to the area and the level of education they attain.

The chi-square test cannot determine whether the two variables are related or what the relationship might be. The test can only be used as a basis to infer that there exists a likelihood that the numbers in the table are not due to random sampling error alone. Small variation by the actual number from the expected could be due to mere chance. Usually a probability that the actual frequencies differ from the expected frequencies of less than 5 percent is considered strong enough to claim that the variables are not independent. This would mean that if 100 tests were done using these two variables, chance would account for the difference between expected and observed value 95 times and the other 5 times the difference would be due to some type of relationship.

Numerous chi-square tests of independence were performed on the survey data. In most cases no relationship was found or; to be more precise, the assumption of independence could not be rejected. In some cases the assumption of independence of variables could be rejected and an association between the two could be inferred. The specific situations where the assumptions of independence were rejected are discussed in Chapter 5.

Notes

1. The normally accepted values are 0.05 and 0.01. This report used the value of 0.05.

Chapter 5. Results of Analysis

Response to the Survey

Response to this survey was better than previous LCRA sponsored surveys of the farmers (see Table 5.1) Farmers in the Lakeside Irrigation District returned 40 of 102 surveys, for a rate of 39 percent. Farmers in the Gulf Coast Irrigation District responded at a lower rate with 38 of 128 returning surveys for a 30 percent total. Therefore, even though the Lakeside district is the smaller of two in population, it is represented more highly in the survey. Overall, the response was 79 of 230, for a rate of 35 percent, with 51 percent of the total responses from Lakeside and 49 percent from Gulf Coast. Results will usually be discussed with the data for the two districts combined. Only when a significant difference exists between the two districts will responses be separated.

The following sections will discuss data which is related to farming practices, farmer personal characteristics, farmer relations with the LCRA, and opinions about the new volumetric rate structure and its implementation.

Table 5.1
Response Rates for Survey

District	Response Rate	Percentage
Gulf Coast	38/128	30
Lakeside	40/102	39
Total	**79/230**	35

Source: Policy Research Project Survey.

Demographics

Most of the farmers who responded to the survey operate on a relatively small scale and do not run a farming organization. Information on the number of hired workers the farmers' employ reveals this fact. Approximately half, 45.6 percent, reported that they work their farms without the assistance of any field hands. Another 29.1 percent employ only one aid. Therefore, a total of 75 percent of the farmers employ one employee or less.

The farmers ranged in age from less than 30 years old to more than 60 years. If this range is broken down into ten year increments, the most common age group is 41-50 years old, with 28 percent of the farmers indicating they are in this age group. The distribution is bell shaped, with a slight exaggeration in the top group of *greater than 60.*

The farmers are a stable population. Most of the farmers are natives of the area. Only 11.5 percent reported that they were not native to the region. They also appear to have been rice farming their entire lives. When asked how many years they had been farming in the area, 42.9 percent reported it to be longer than 20 years and 71.5 percent had farmed there for more than 10 years. Only about one quarter of the farmers reported that they had been farming the area less than 10 years.

According to farmer responses, the group is well educated. All farmers indicated they finished high school. A majority, 52.6 percent, of the farmers responding indicated that they have completed college and 10.3 percent reported having completed graduate school. Together, these numbers indicate 62.9 percent of the farmers have completed post-secondary education. This seems rather remarkable given the rural nature of the work and the fact that a degree is not a minimum job requirement, as is often the case in urban settings. U.S. Census data indicates the average rates for the State of Texas are 19 percent for completion of college and 6.5 percent for completion of graduate school. This is a combined total of 25.5 percent. For the entire U.S., 19.3 percent have completed college and 7.2 percent have completed graduate school for a combined 26.5 percent (U.S. Census Bureau, 1990). Therefore, the survey respondents reported a higher level of education than either the average for the State of Texas or the U.S. In fact, whereas the averages for Texas and the U.S. are very close, the farmers more than double this rate.

The size of the farmer families was fairly tightly clustered around 3 persons with the average being 3.2 persons. The average size of a U.S. family is also 3.2 persons. For Texas, the average is 3.3 persons (U.S. Census Bureau, 1990). The most common size was two persons with 29.9 percent of the respondents indicating this size of family. Very few (3.9 percent) farmers reported being single; that same amount reported having a family of six or more.

Income was reported by ranges (see Figure 5.1). The most frequently cited range was $40,000-$60,000 per year. Twenty-six percent of the farmers reported over $60,000 per year of income. The total family income of the farmers may be higher than the average family income in the U.S., as the median income for a family of four in the U.S. is $35,225 per year (U.S. Census Bureau). One way to assess average income would be to work with simplified components. If the mid-point for each income range is used, except for $0-$10,000 (use $10,000), and for over $60,000 (use $70,000), the weighted average is $46,301. This amount is about 30 percent higher than that of the average U.S. The average for the state of Texas is even lower at $31,553 (U.S. Census Bureau, 1990). This situation is in contrast to statements made by many farmers in the essay portion that they were operating very close to the point of not be able to continue farming because of rising costs and shrinking profit margins.

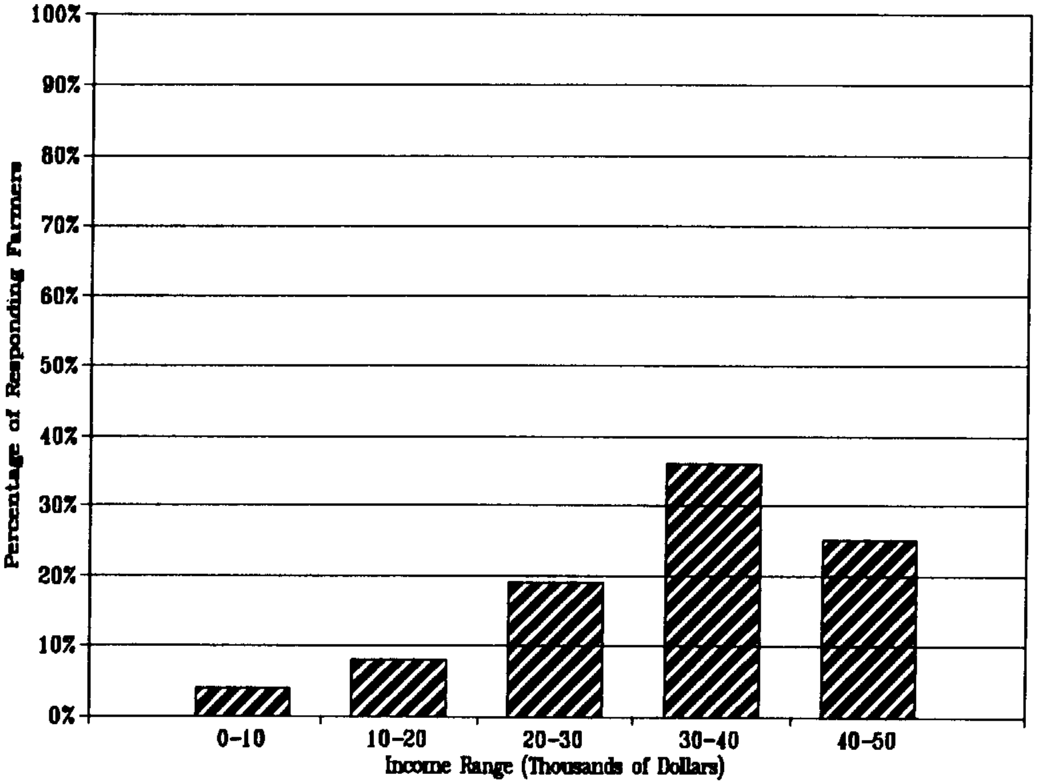
Farming Practices

Rice was, by far, the crop farmed by the most respondents with 100 percent indicating that they grew this crop. However, rice is not the only crop grown. Several other crops were reported (see Figure 5.2). The majority of these other crops were grown in the Gulf Coast district with few Lakeside farmers indicating that they farmed anything other than rice. Even in Gulf Coast the percentage of farmers raising another crop in addition to rice was never over 9 percent.

The average number of acres of rice being farmed was 554. The farms in the Lakeside district averaged about twice the size of those in the Gulf Coast district. The Lakeside district reported a larger average rice crop size at 744 acres while Gulf Coast rice farms averaged 356 acres. If other crops are included with rice for total acres farmed, the average acreage farmed is 636 for the total survey (see Figure 5.3)

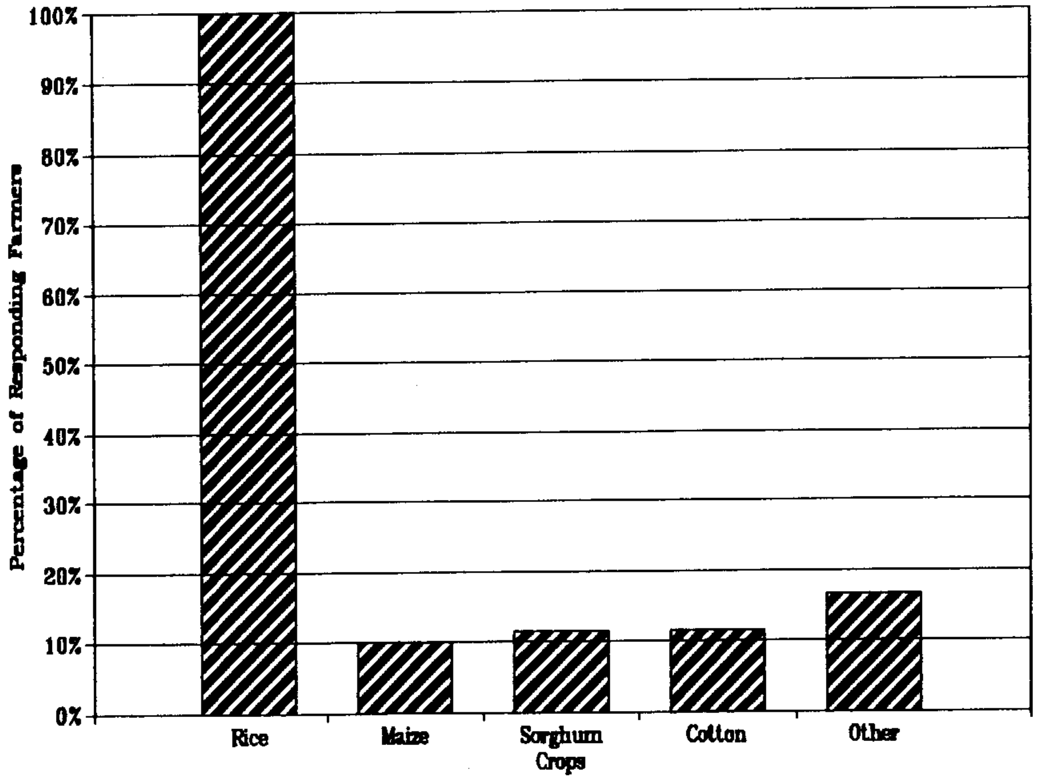
The farmers' legal relation to the land they farm, or land tenure, could have an impact on the farming practices employed by that farmer. Whether the farmer owns the land, is leasing it, or is in some type of cooperative agreement with the land owner, could very well determine the amount of capital investment the farmer is willing to make in the land. Someone who does not own a particular piece of land will not normally be willing to invest significant amounts of money in the upgrading of the land since he or she will not benefit from the increased value of the land. The only possible benefit to the leasing farmer from improvements that increase water efficiency would be if the water saved could reduce irrigation costs. In the past, the LCRA charged for

Figure 5.1
Annual Family Income



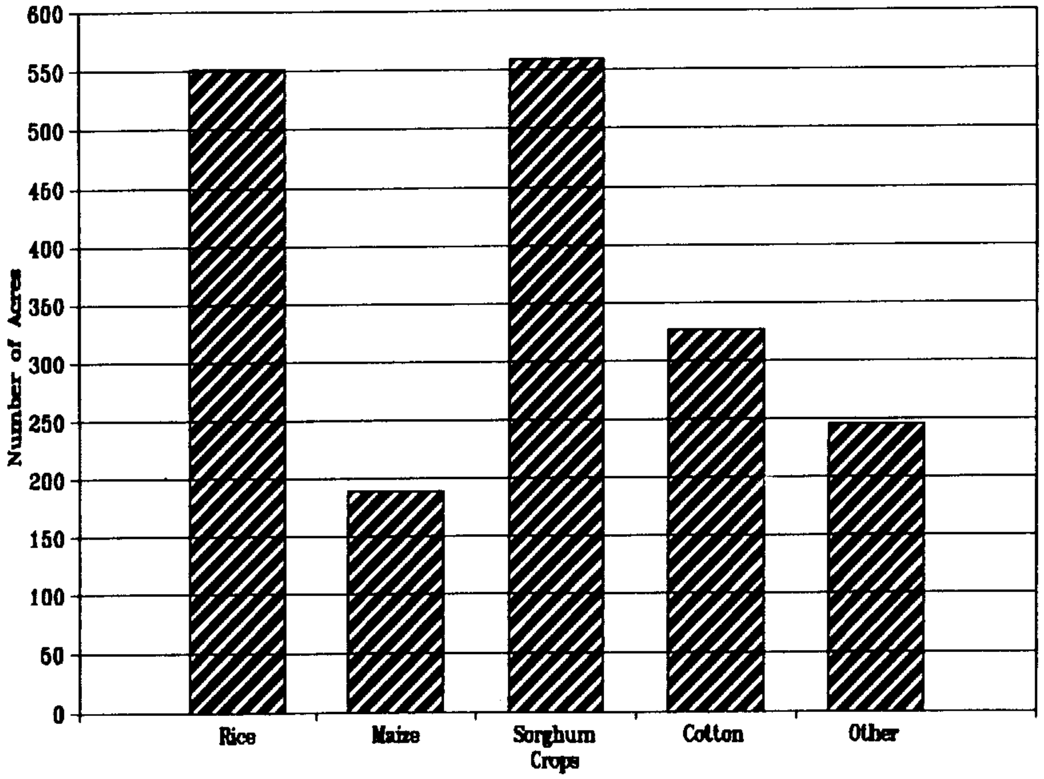
Source: Policy Research Project Survey

Figure 5.2
Farmers Raising Specific Crops



Source: Policy Research Policy Project Survey

Figure 5.3
Average Acres Farmed by Crop



Source: Policy Research Project Survey

water on a *per* acre basis not, on a volumetric basis. As a result, heretofore, neither incentive has existed for the farmers who do not own the land to make efficiency improvements.

The owners of the land that is being leased may consider investing in capital improvements to increase efficiency if they could recoup this investment through higher lease prices. However, it is unlikely that farmers would be willing to pay the increased leases if they were unable, in turn, to save money by using less water. With the traditional pricing system the farmer could not save money by using less water.

The new volumetric pricing system could give an incentive to invest in the water efficiency of the land. Land owners could charge higher lease prices for more efficient land. Both land owning and non-land owning farmers could save money on water bills if they implemented improvements.

To understand the relative importance of each of the land relationships discussed above, the farmers were asked their legal relation to the land. It appears that land ownership may historically have been a limiting factor in making capital improvements in the land, as only 28 percent reported that they owned between 81-100 percent of the land they farmed. A majority of 56.5 percent reported that they owned between 0-20 percent of the land they farmed. Of those who did not own land that they farmed, 85 percent reported that they leased it. Thirteen percent reported that they were in a cooperative arrangement with the owner of the land.

A technique employed by many of the farmers is one known as a maintenance or "cheater" stream. This technique keeps a predictable rate of water in the field at all times but is considered to be wasteful of water. The survey attempted to determine the percentage of farmers using such a stream and their motivations for doing so. A knowledge of these factors should make it easier to successfully discourage the farmers from using this technique in the future.

Fifty-five percent of the farmers reported using a cheater stream. Figure 5.4 shows the reasons given by the farmers for their use of the stream. The most frequently reported reason was that it takes too long for water to arrive once it is ordered by the farmer. Thirty percent of the farmers who use a cheater stream gave this as their reason for using them. If water delivery time could be shortened, perhaps the usage of cheater streams could be reduced.

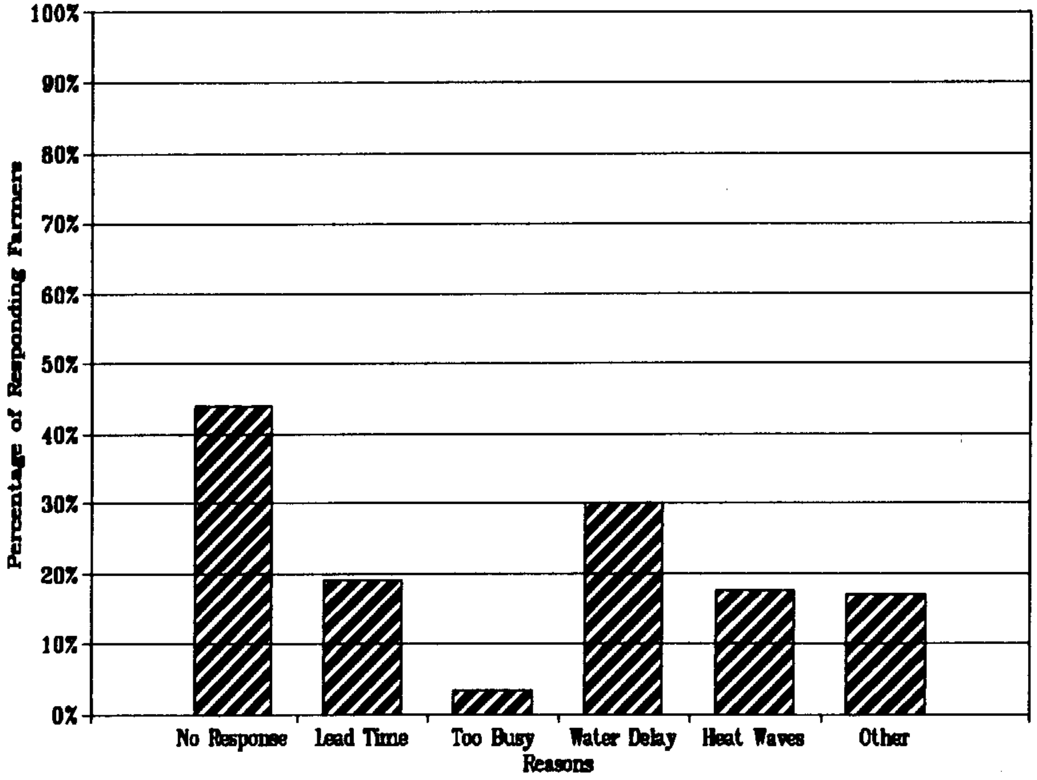
The number of miles traveled each day in order to manage the fields may be related to the number of fields farmed. Travel could affect the quality of water management since a large number of smaller fields, rather than fewer larger fields, would require more travel. A farmer may be less likely to manage the fields on a daily basis if long distances are involved.

To determine if these factors may need more attention in the future, farmers were asked for information regarding the number of fields farmed and the number of miles travelled to manage the fields. Cross tabulations were run but the results were not statistically significant. In spite of the logical connection and water boss reports that travel effects water management, it appears from the farmers' responses that travel and the number of fields may not be related.

Numerous farming techniques exist which can increase efficiency and thereby conserve water. These techniques range from those which are labor intensive to those which are capital intensive. Labor intensive techniques are ones which require relatively more time and energy on the part of the farmer. The benefit to these techniques is that they require less financial input. The main cost is the time of the farmer. An example of a labor intensive technique is field records. The only equipment required for the maintenance of field records is a notebook.

Capital intensive techniques do not require the farmer to put in many hours of labor, but they are relatively expensive. The benefit of capital intensive techniques is normally a reduction in labor inputs. An example would be the precision leveling of a field. The process may be expensive to perform; but, once done, the

Figure 5.4
Reasons for Using Cheater Streams



Source: Policy Research Project Survey

efficiency of the field is increased indefinitely without any additional farmer input. Farmers were asked to choose from a list of water conservation techniques the methods they employ in their fields. This was done in order to learn what are the more or less popular techniques. This information can be analyzed to determine future policies about the encouragement of the various techniques. The frequencies with which the farmers employ the various techniques can be seen in Figure 5.5.

The most frequently practiced techniques were canal maintenance (72.2 percent of farmers, see *canals* in figure), improved levees (72.2 percent of farmers, see *imp. levees* in figure), and multiple delivery points (70.9 percent of farmers, see *delivery* in figure).

The least popular technique listed was underground pipes at 21.5 percent (see *pipes* in figure). Other techniques used included precision leveling (see *leveling* in figure), field records (see *records* in figure), shallow flood (see *flood* in figure), and permanent levees (see *perm. levees* in figure). The farmers were also given a chance to indicate any other techniques they employed that were not listed; 5.1 percent said they used some other technique.

Perhaps the biggest surprise is that only 41.8 percent of the farmers reported using field records. Field records will not save as much water as techniques such as precision leveling and underground pipelines, but they have two benefits. Field records are an inexpensive method by which to improve farming efficiency and they help farmers examine practices in a more objective and systematic manner.

The greatest percentage of farmers reported using a total of four of the water conservation techniques listed in the survey question. The average number of techniques was 4.2.

Overall, the difference between the number of conservation techniques used in the two districts was not significant, but some differences did occur in regard to which techniques were employed in each district. In the Lakeside district, 80 percent reported they use multiple delivery points, while 60 percent of those in Gulf Coast reported their use. For precision leveling, 57.5 percent of those in Lakeside reported their use while only 26 percent in Gulf Coast use this technique. Lakeside also used underground pipes more with 30 percent reporting their use to 13 percent in Gulf Coast.

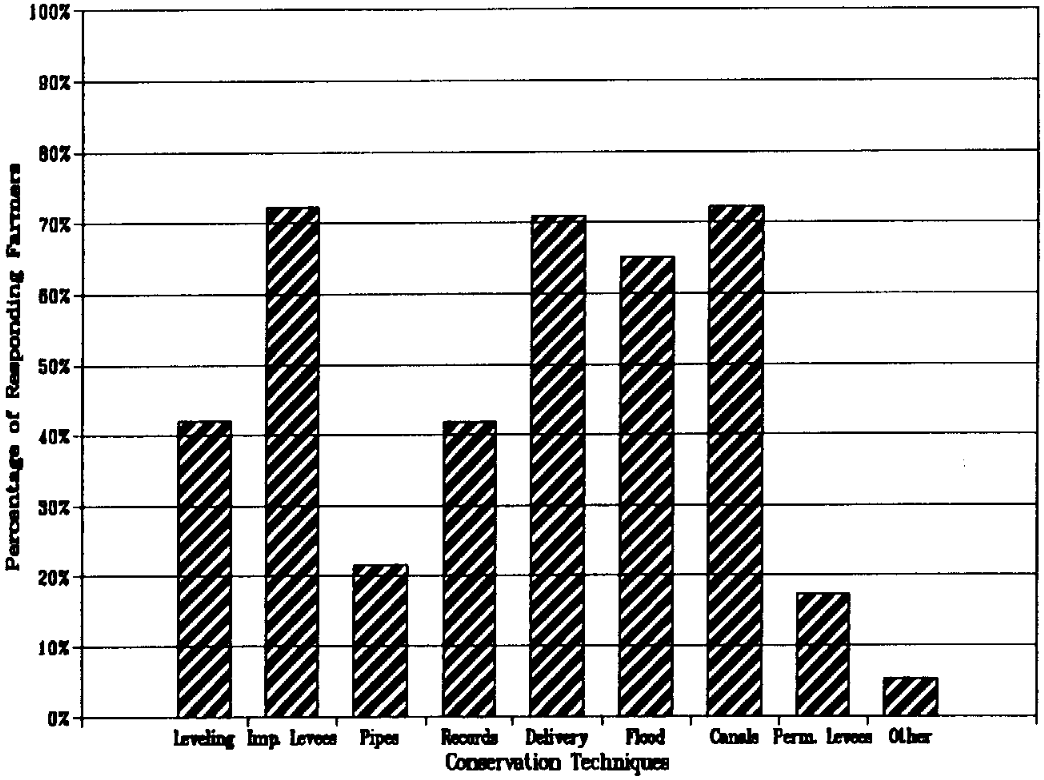
The farmers were asked to report the number of acres of land that had been precision leveled. Counting both districts, 41.8 percent indicated that they had precision leveled land. This leaves 58.2 percent who do not use this technique.

A slight discrepancy exists between the responses to the question on conservation techniques used and the number of acres precision leveled. Twenty-three percent of the farmers indicated they had between 50 and 300 acres precision leveled. Twenty-three percent also said they had over 300 acres that had been precision leveled. This gives a total of 46 percent who reported some precision leveled land versus 42 percent in the previous question. The discrepancy is small and probably the result of an oversight by a few farmers.

This data identifies three groups: those with no acres precision leveled, those with relatively few acres precision leveled, and those with many acres precision leveled. The last two groups are the same size and added together just about equal those in the first group.

To discover the current situation regarding groundwater use, the farmers were asked to estimate the portion of their irrigation water that comes from surface sources (the LCRA canal system) and the portion that comes from groundwater wells. In all, 32.9 percent of the farmers reported the use of at least some amount of groundwater in the irrigation of their crops. Of those who did report the use of groundwater, the average amount as a percentage of total water usage was 41.6 percent. The most common portion reported was 50 percent. Therefore, of those who do use groundwater, 23.1 percent use it for half of their water supply. This represents

Figure 5.5
Farmers Using Conservation Techniques



Source: Policy Research Project Survey

7.6 percent of all farmers.

A large majority of the farmers (78.1 percent) claim to experiment with new farming techniques. A cross tabulation was run on this question and the number of conservation techniques used by the farmers. It is logical to assume that farmers who use more conservation techniques would correspond to those who claim that they use new techniques. Conversely, it would seem that farmers who do not employ many conservation techniques would correspond to those who claim not to use many new techniques. Strangely, there was not a statistically significant association between the way that farmers answered both questions.

Relations with the LCRA

A major portion of the survey was aimed at determining farmer attitudes toward the LCRA. The questions in this section deal with the job performance of the LCRA as perceived by the farmers.

Farmers were asked to evaluate the job that the LCRA staff has done when the farmers have questions on various topics. One topic was billing. The farmers were asked to rate the job of the LCRA staff when they had questions about their water bill (see Figure 5.6). A combined[1] 97.2 percent of the farmers reported that the LCRA is at least *helpful* in regards to such questions and 35.2 percent said the LCRA is *very helpful.* Only 2.8 percent rated the staff as *not helpful* in this situation.

The farmers were also asked to rate the LCRA's performance when they had questions about water conservation (see Figure 5.7). A combined 89.6 percent said the LCRA was at least *helpful*, while 17.9 percent said they were *very helpful*, and 10.4 percent said the LCRA staff was *not helpful* in answering such questions.

In regards to questions about water deliveries, a combined 94.4 percent felt the LCRA was at least *helpful* with 26.4 percent feeling the LCRA was *very helpful* in answering such questions (see Figure 5.8). Only 5.6 percent reported the LCRA as *not helpful* in answering questions about water deliveries.

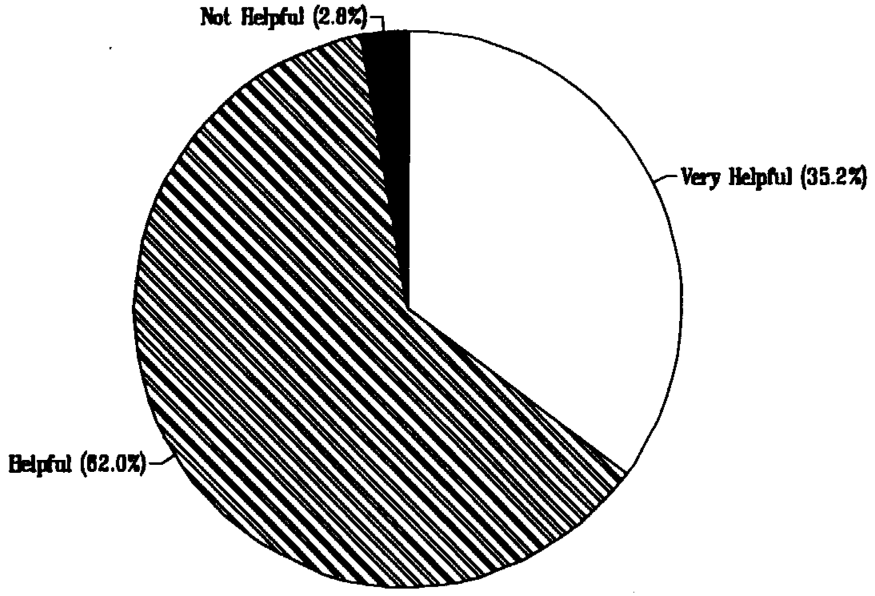
While farmers felt that the LCRA did a good job in answering questions about water deliveries, they were not so positive when it came to the deliveries themselves. Figure 5.9 shows that while a combined 54.2 percent felt the deliveries were at least *accurate*, 45.8 percent felt that they were *not accurate*. This question takes on significance with the introduction of the new volumetric pricing system for water. For the new rate structure to be fair, the amount of water delivered must be accurately measured. The farmers' concern over this issue is understandable.

The farmers were asked a series of questions about farmer meetings. The first was whether they had been invited to a farmer meeting in the past year. Nearly all, 97.4 percent, reported they had been invited and 2.6 percent reported they had not been invited. The LCRA appears to have done a good job informing the farmers of the meetings.

Farmers were then asked if they had attended the meeting. A majority, 80.3 percent, of farmers reported having attended a meeting in the past year. District of residence was also examined to determine if farmers from one district were more likely to attend the meetings. The district of residence was found to be statistically significant with farmers from the Lakeside district more likely to attend.[2] In the Lakeside district, 89.5 percent of the farmers reported attending a meeting. In the Gulf Coast district, 71.1 percent attended (see Figure 5.10).

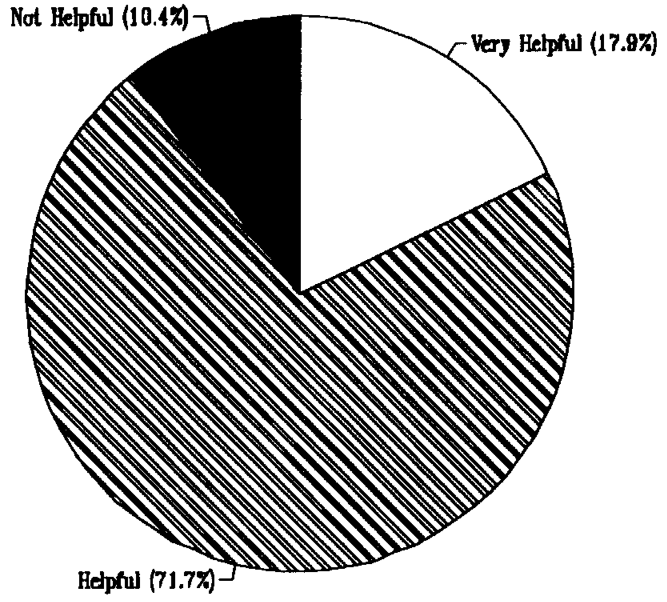
This results would seem to indicate that the farmers in the Lakeside district are more involved and politically active in relation to the LCRA than are the farmers in the Gulf Coast district. The LCRA may need to give special attention to motivating the Gulf Coast farmers to become more involved. The greater the number of farmers that can work more closely with the LCRA, the greater the chance the LCRA has of achieving its goals.

Figure 5.6
LCRA's Response to Billing Questions



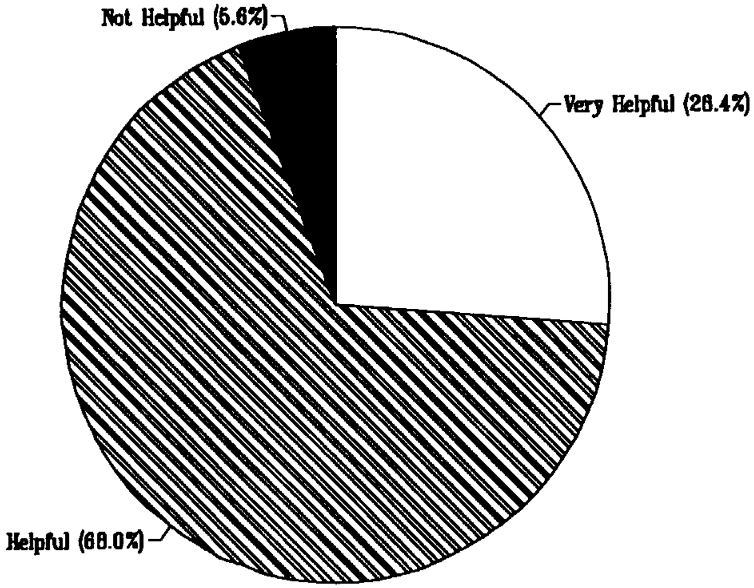
Source: Policy Research Project Survey

Figure 5.7
LCRA's Response to Conservation Questions



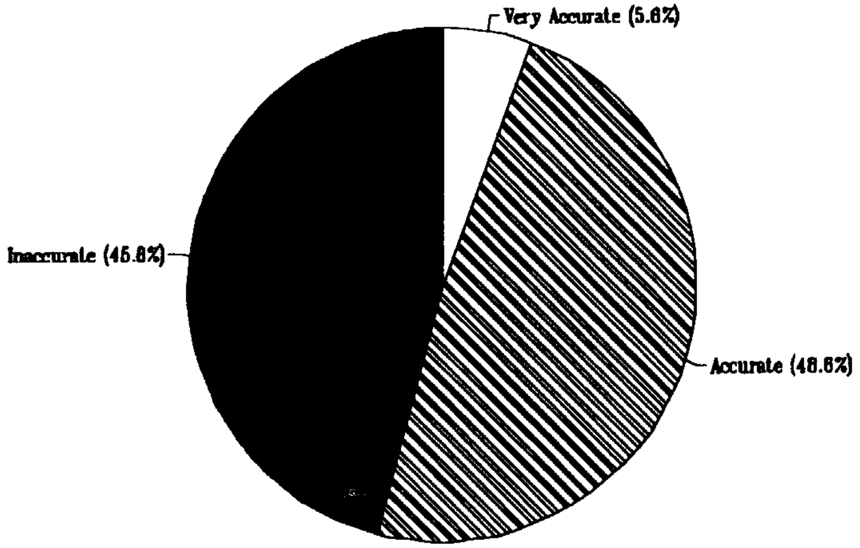
Source: Policy Research Project Survey

Figure 5.8
LCRA's Response to Water Delivery Questions



Source: Policy Research Project Survey

Figure 5.9
Accuracy of the LCRA Water Deliveries



Source: Policy Research Project Survey

Figure 5.10
Attended Farmer Meeting in the Past Year

Lakeside District

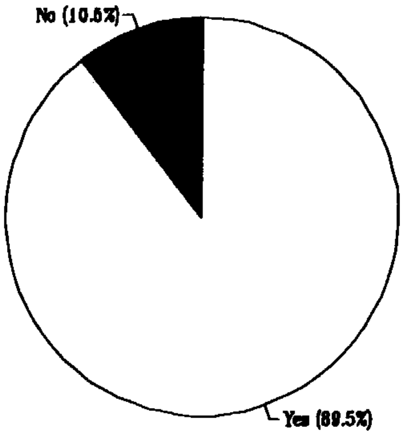
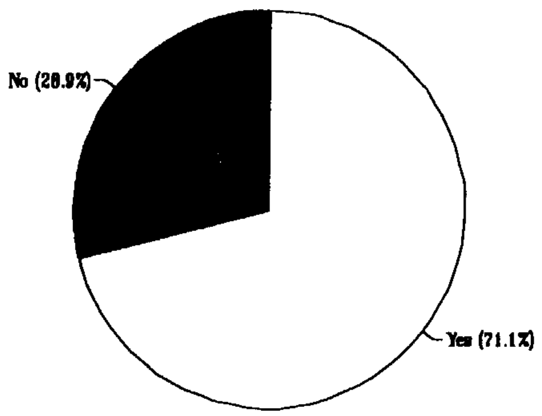


Figure 5.10 (continued)
Attended Farmer Meeting in the Past Year

Gulf Coast District



Source: Policy Research Project Survey

The final question about farmer meetings asked the farmer to rate the value of the meetings that they attended. As Figure 5.11 shows, 81.8 percent of the farmers felt that the meetings were at least *useful*, while 18.2 percent felt that they were *not useful*. In light of the positive response, every effort should be made in the future to persuade those who did not attend previous meetings to attend future meetings.

The LCRA has conducted water conservation demonstration projects in the area. Farmers were asked two questions about these projects: whether they were invited and what was their value. Most farmers, 88.2 percent, reported being invited to such a demonstration. Three-quarters (75.4 percent) of farmers who attended these demonstrations gave them favorable ratings and 9.4 percent even rated them as *very helpful* However, a significant number did report that they found the demonstrations to be *not helpful* (see Figure 5.12). The LCRA should attempt to improve such projects with the aim of relating water saving techniques to the farmers.

In a question related to the above projects, farmers were asked whether the LCRA had offered them any technical advice in the past year. One half, 50.7 percent, of the farmers reported receiving technical advice from the LCRA in the past year. There is no information on whether or not the farmers implemented any of this advice. The question stated, *"did the LCRA offer you any technical*[3] *advice . . .?"*, so the advice may have been offered as a response to questioning by the farmer and was not necessarily instigated by the LCRA.

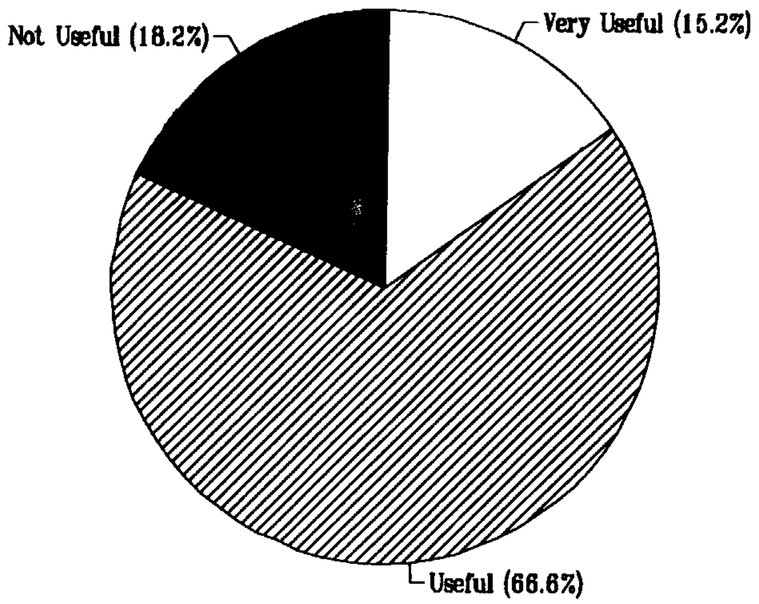
The Policy Research Group wanted to gain insight into farmer attitudes toward regulation in general. This might indicate whether the LCRA is working against a general bias against increased emphasis on water conservation as measured by attitudes on regulation. It was found that a small percentage (5.5) of farmers felt that groundwater and surface water should *always be regulated* (see Figure 5.13). In addition to those who felt the sources should always be regulated, a significant number, 69.4 percent, felt that surface water should be regulated under conditions of drought and when demand exceeds supply. Surprisingly, a total of 39.7 percent of the farmers felt that groundwater should be regulated under these same conditions. This result is surprising not because the farmers have necessarily been for the overuse of a resource but because in the State of Texas groundwater is considered part of the property rights of the surface owner.

In regard to surface water, 22.2 percent of the farmers felt that it should *never* be regulated. As was expected, a large number of farmers, 54.8 percent, felt that groundwater should *never* be regulated. A cross tabulation was run on the questions of surface water regulation and groundwater regulation to see if farmers tended to respond similarly to both questions (see Table 5.2).

A statistically significant association was found.[4] The largest group was those who felt that both groundwater and surface water should *never* be regulated. An even 50 percent of the farmers felt that even in situations when demand exceeds supply, neither groundwater nor surface water should be regulated.

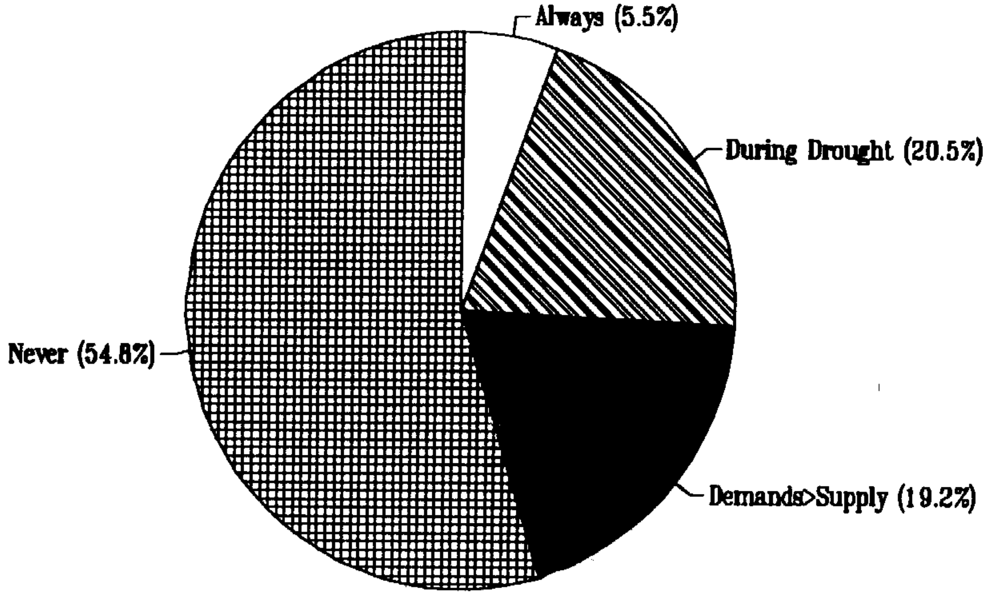
To get an impression of the overall relationship between the farmers and the LCRA, farmers were asked whether they felt that, in general, the LCRA was helpful, or not, to rice farmers. Most of the farmers, 84.4 percent, felt that the LCRA was at least *helpful* to the farmers (see Figure 5.14). Equal portions, 14.7 percent, expressed opposing opinions that the LCRA was *very helpful* or *not helpful* to rice farmers. This indicates that overall the LCRA has a good reputation with the farmers, though there is a small portion, 14.7 percent, who are unhappy with the organization. It is undetermined how much of this unhappiness is the result of the new rate structure. It is possible that some farmers are judging the LCRA's entire operations on the fact that they don't like the new rate structure. However, it is possible that this small, but significant, number of farmers have a poor opinion of the LCRA regardless of the new volumetric rate structure.

Figure 5.11
Usefulness of LCRA Farmer Meetings



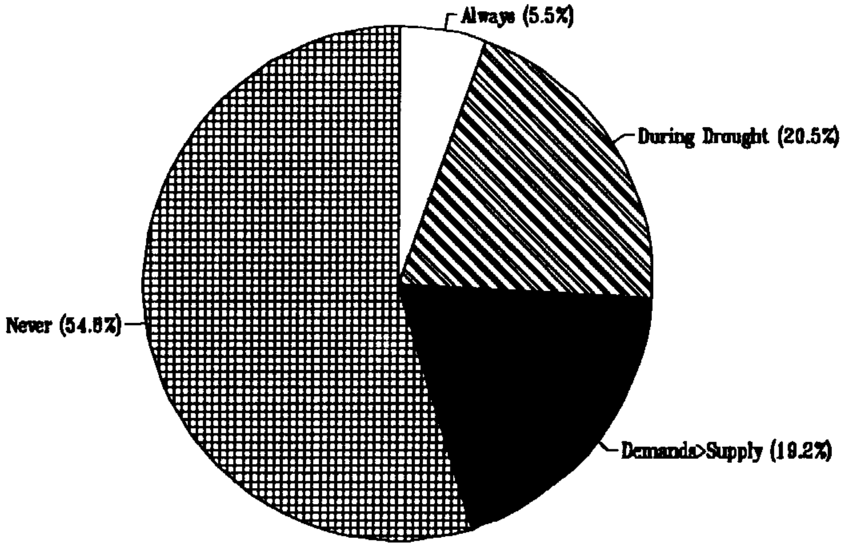
Source: Policy Research Project Survey

Figure 5.12
Value of Conservation Demonstrations



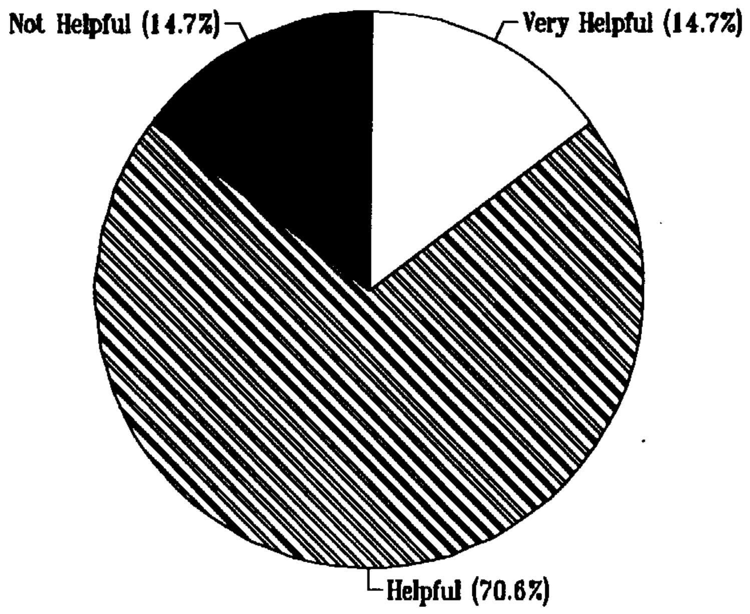
Source: Policy Research Project Survey

Figure 5.13
When Should Groundwater be Regulated?



Source: Policy Research Project Survey

Figure 5.14
Is The LCRA Helpful--Overall?



Source: Policy Research Project Survey.

Table 5.2
Cross Tabulation: Farmers' Attitudes Towards Regulation of Groundwater by Surface Water

Surface Regulation	**Groundwater Regulation**				
	Always	**During Drought**	**When Demands Exceed Supply**	**Never**	**Total**
Always	2 (0)	2 (1.3)	2 (1.3)	2 (1.3)	6 (8.6)
During Drought	2 (2.9)	9 (12.9)	3 (4.3)	9 (12.9)	23 (32.9)
When Demands Exceeds Supply	2 (2.9)	2 (2.9)	9 (12.9)	12 (17.1)	25 (35.7)
Never	0 (0)	2 (2.9)	0 (0)	14 (20)	16 (22.9)
Total	**4** **(5.7)**	**15** **(21.4)**	**14** **(20)**	**37** **(52.9)**	**70** **(100)**

Source: Policy Research Program Survey.
Note: percentages are contained within parentheses.

New Rate Structure

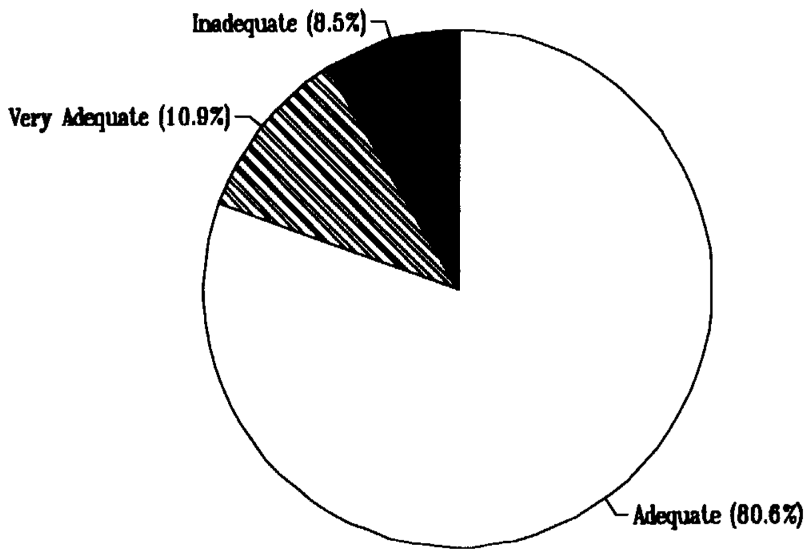
The proposed volumetric rate structure is a major departure from the past. Beginning in 1993, the farmers now have a chance to reduce water bill if they use less water. Conversely, water bills could go up if farmers use more water.

An important factor in getting farmer support for the new plan was to educate them about its design, purpose, and function. In this respect, 91.4 percent of farmers felt that LCRA had done at least an *adequate* job informing them of the new rate structure (see Figure 5.15). Some, 12.3 percent, even felt the LCRA had done a *very adequate* job of informing them of the new rate. A slightly smaller number, 9.6 percent, felt that the LCRA had done an *inadequate* job in this area.

It is interesting that given the many reservations the farmers have about the new rate structure, that over 90 percent would report the LCRA had done an adequate job informing them. This would seem to indicate that although most farmers understand the structure well, they still disagree with it.

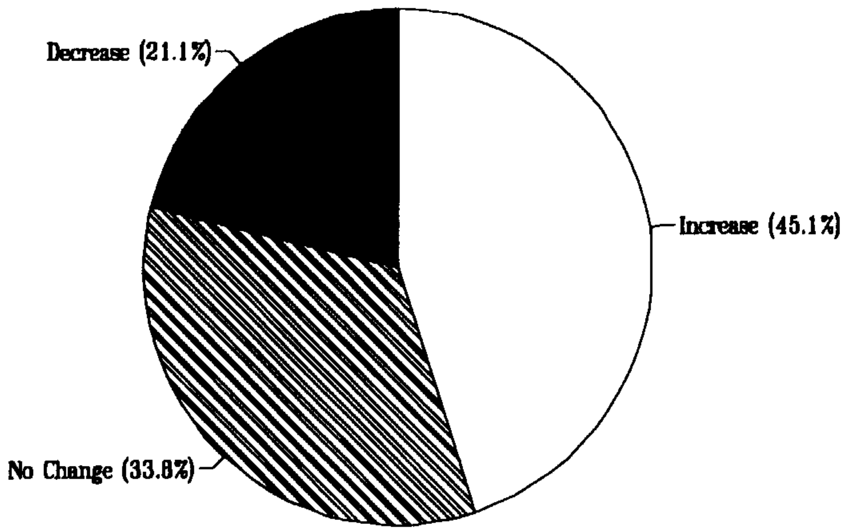
Much of the opposition comes from the belief on the part of 45.1 percent of the farmers that their water bills will increase as a result of the new structure (see Figure 5.16). One third of the farmers, 33.8 percent, predict that there will be no change in their water bill while 21.1 percent predicted that their bills would decrease.

Figure 5.15
LCRA's Explanation of Rate Structure



Source: Policy Research Project Survey

Figure 5.16
Effect on Water Bill of New Rate



Source: Policy Research Project Survey

significant number, 13.2 percent, believed their bills would increase and yet still considered the new structure to be fair.

Table 5.4
Cross Tabulation: Effect on Water Bill of New Structure and
Fairness of New Structure

Fairness of New Structure	Effect on Water Bill			
	Increase	No Change	Decrease	Total
Very Fair	1 (1.5)	1 (1.5)	3 (4.4)	5 (7.4)
Fair	9 (13.2)	19 (27.9)	11 (16.2)	39 (57.4)
Unfair	21 (30.9)	2 (2.9)	1 (1.5)	24 (35.3)
Total	**31** **(45.6)**	**22** **(32.4)**	**15** **(22.1)**	**68** **(100)**

Source: Policy Research Program Survey.
Note: percentages are contained within parentheses.

A cross tabulation was also run on the questions of fairness and the accuracy of the water deliveries (see Table 5.5). The results showed a strong statistically significant association.[7]

The largest group, 35.3 percent, thought the water deliveries were accurate and considered the new structure fair. The second largest group, 26.5 percent, felt that water deliveries were inaccurate and consequently that the new structure was unfair.

Finally, the farmers were asked whether the new rate structure provided incentive to save water (see figure 5.18). A majority, 58.3 percent, thought that the new structure did provided incentive while 20.8 percent felt it did not. A large number, 20.8 percent, had no opinion.

A cross tabulation was computed on the accuracy of water deliveries and whether the new structure provided incentive to save water but there was not found to be any statistically significant association. The largest group, 30 percent, felt that the deliveries were accurate and that the new structure did provide an incentive to save water. The second largest group, 22.9 percent, felt that water deliveries were inaccurate but that the new structure was fair nonetheless. These results are surprising, as one might expect that if the water measurements are inaccurate, then a rate structure which depends on the these measurements for its billing would not provide incentive to save water.

A separate cross tabulation was run on the questions whether the new structure provided incentive to save water and the predicted effect on water bills (see Table 5.6).

Table 5.5
Cross Tabulation: Accuracy of Water Deliveries and Fairness of New Structure

Accuracy of Deliveries	Fairness of Structure			
	Very Fair	Fair	Unfair	Total
Very Accurate	2 (2.9)	2 (2.9)	0 (0)	4 (5.9)
Accurate	2 (1.5)	24 (35.3)	6 (8.8)	32 (47.1)
Inaccurate	1 (1.5)	13 (19.1)	18 (26.5)	32 (47.1)
Total	5 (7.4)	39 (57.4)	24 (35.3)	68 (100)

Source: Policy Research Program Survey.
Note: percentages are contained within parentheses.

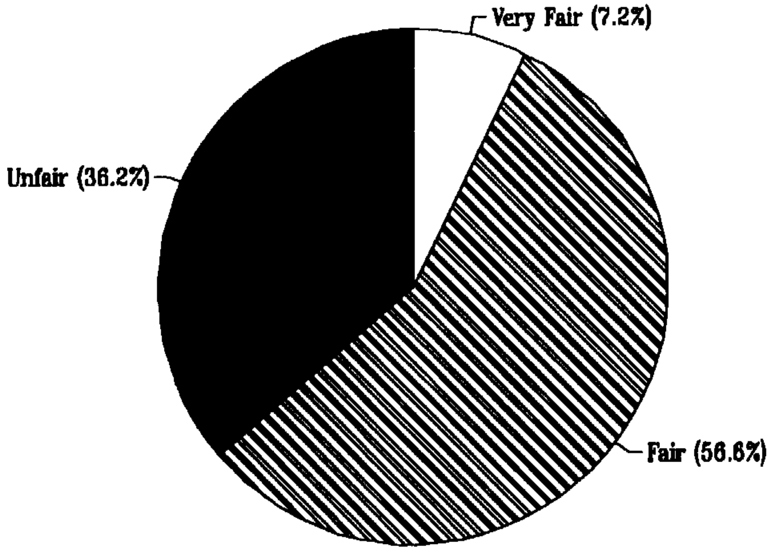
The results from this test showed a statistically significant association.[8] One-fifth of the farmers believed that the new structure did provide incentive to save water but that it would also increase their water bills. An equal number also felt that the new structure provided a water saving incentive but that it would not change their bills. The third largest group, 18.6 percent, also felt that the new structure provided water saving incentive but that it would allow their bills to decrease.

Table 5.6
Cross Tabulation: Effect on Water Bill of New Structure and, "Does New Structure Provide Incentive to Save Water?"

Effect on Bill	Agree With Statement			
	Yes	No Opinion	No	Total
Increase	14 (20)	8 (11.4)	10 (14.3)	32 (45.7)
No Change	14 (20)	6 (8.6)	3 (4.3)	23 (32.9)
Decrease	13 (18.6)	0 (0)	2 (2.9)	15 (21.4)
Total	41 (58.6)	14 (20)	15 (21.4)	70 (100)

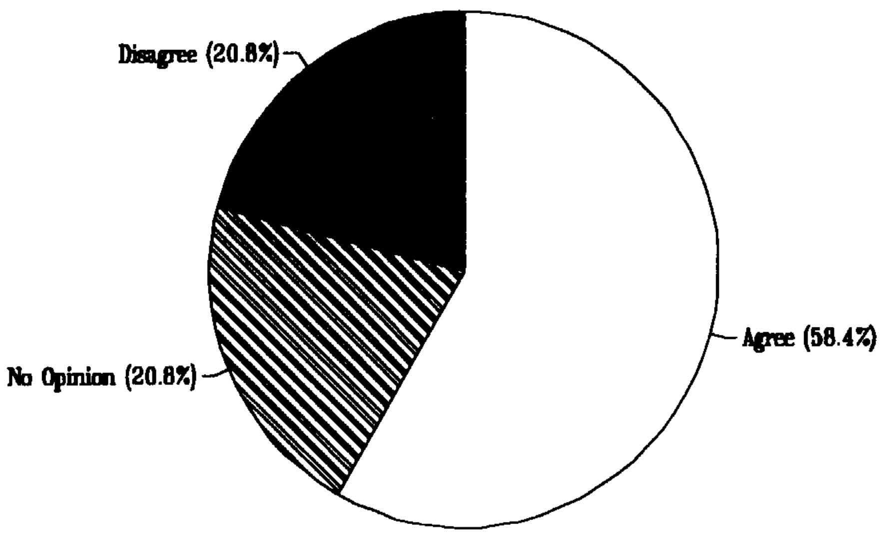
Source: Policy Research Program Survey.
Note: percentages are contained within parentheses.

Figure 5.17
Fairness of New Rate Structure



Source: Policy Research Project Survey

Figure 5.18
New Rate Structure Gives Incentive to Save Water?



Source: Policy Research Project Survey

Essay Responses

Response to the essay section of the survey was widespread as 53 percent of the respondents wrote comments.

Two issues were mentioned with much greater frequency than any others: (a) inaccuracy of the water delivery measurements by the LCRA and (b) the opinion that the LCRA is an inefficient bureaucracy.

The item most often mentioned was the inaccuracy of the water delivery measurements (see also Figure 5.8). Many farmers remain unconvinced of the LCRA's ability to charge them on a volumetric basis fairly when the method of measurement is so prone to error. While some farmers exhibited what amounts to indignant outrage over this issue, others were more moderate and voiced a reasonable concern. The main concern is that fluctuating canal depths prevent the assumed amount of water from being delivered to the fields. As one farmer states:

> Without an actual gear driven counter, the volumetric rate structure will be inaccurate. This is because the canal level fluctuates up and down, and at times (up to 36-48 hours) no water is flowing through the water box, but the clock is still ticking indicating how much water should be flowing through the opening in the water box (quoted from a respondent to the PRP Survey).

Of the farmers responding in this section of the survey, 30 percent remarked about this issue, thereby showing its importance to them. Several of these respondents noted that they agreed with the theory of volumetric pricing but felt that in practice it would not be fair since the accuracy of the water deliveries was so poor.

The second most common remark by the respondents in the essay section was the feeling that the LCRA was itself inefficient in its use and management of water. Many also felt that the LCRA was simply an inefficient bureaucracy that had become self-serving and did not respond to the farmers' needs.

Farmers suggested that a major water savings could be obtained if the LCRA would improve its own canal system. This would include better maintenance of levees, as well as removal of vegetation from the canals.

Several farmers voiced frustration over the point that while farmer water use had decreased greatly in the previous several years, the LCRA had raised water prices. The result is that much of the inefficiencies of water use have already been removed but the farmers did not benefit financially from this savings. In fact, they have paid more. Now, when increased efficiency is harder to come by, the LCRA is instituting a volumetric price structure.

Several farmers remarked in the essay section that the idea of volumetric pricing was indeed good and should constitute a larger portion of the total water bill. While they welcome the chance to save money through the conservation of water, they contend the savings will not be enough to merit the investment in capital intensive items such as underground pipelines and precision leveled fields. The volumetric portion of the bill was considered too small and the flat *per* acre fee too large. This limits the amount of money a farmer can save no matter how small the amount of water used. The farmers indicated that if the flat fee was reduced and the volumetric fee increased, this would provide more incentive to save water.

Some farmers also expressed frustration over their perceived lack of input about issues which effect them. Although in the survey the farmer meetings received an overall good rating by farmers (see Figure 5.10), several farmers remarked that they had been "taken out of the decision making loop." Generally, these types of opinions were associated with the notion that LCRA had become a self-serving bureaucracy that was not concerned about working *with* the farmers.

Numerous farmers did make positive comments. The most frequent was the sentiment that the LCRA and the farmers need to work together more. The farmers noted that they are not the only ones who benefit from their rice farming. The farmers claim to represent a large portion of the economy in their areas and to support many local businesses. The LCRA also derives income from the farmers. In light of these factors, the respondents felt it is important that the two groups cooperate to develop an arrangement which is fair to all parties.

Notes

1. In the following discussion, the term *combined* means the combination of two response groups. For example, if 10 percent of the respondents chose the options *good* and 15 percent chose the options *very good* the combined number would be 25 percent of the respondents indicating at least *good*.

2. Pearson chi-square statistic is 0.04.

3. The term *technical* was not defined in the survey and may have been misunderstood.

4. Pearson chi-square statistic is 0.01.

5. Pearson chi-square statistic is 0.0001.

6. Pearson chi-square statistic is 0.0001.

7. Pearson chi-square statistic is 0.0002.

8. Pearson chi-square statistic is 0.004.

Chapter 6. Summary and Recommendations

The report begins with a brief introduction about the irrigation districts operated by the LCRA. Following this introduction, an extensive review of existing work in the adoption of conservation practices is presented to provide a theoretical background from which to judge the practices of the farmers in this survey. The consensus of existing research is shown to be that a combination of economic and personal factors have an impact on adoption of conservation practices. This conclusion is supported by the present study.

Existing research deals almost exclusively with the factors affecting the adoption of conservation tillage among farmers. This study is important because of its examination of the factors affecting the adoption of water conservation techniques among farmers. The author knows of no other similar study performed on this topic.

The report presents a thorough discussion of survey theory and methodology. The resulting survey was a product of this extensive review. The PRP determined that a mail survey of all farmers in the two districts represented the best strategy. A short review of the steps required to accomplish this task are presented in Chapter 4.

The farmer survey attempted to gain as unbiased an assessment as possible of information in several areas. One area is the farming techniques used by the farmers. Knowledge of the techniques employed by the farmers is needed for the LCRA to understand where possible improvements could be made. The LCRA can also gain information on its performance as perceived by the farmers from the section which asks the farmer to evaluate the LCRA. The section on attitudes about the new rate structure will inform the LCRA about the factors which need to be addressed in regard to this issue.

Most of the farms are not large operations run by outside corporations but small to moderate size ones run by area natives. Three-quarters of the farmers employ one or no farm hands and the average size of farms is 636 acres if all crops are included. Farmer income was moderate with more farmers falling into the $40,000 to $60,000 annual income range than any other. A calculation was performed that showed a farmer average annual income of $46,301. This amount was 30 percent higher than the comparable figure for a U.S. family of four.

Every farmer in the survey grows rice as their main crop, though a number of other crops were also reported. Other crops raised included: corn, sorghum, cotton, and soybeans. Rice, corn, and cotton demand large amounts of water while sorghum requires less. Ten percent of the farmers reported raising a sorghum crop in 1992. The author believes that in the future, as water is charged volumetrically, sorghum may represent a larger portion of the farmers' acreage.

The farmers used a number of water conservation techniques but did not invest great effort in this area. The lack of strong commitment to water conservation techniques is not surprising given the culture and tradition of rice farming, the history of water supply in the area, and current land tenure situations. Historically, water has been provided for a flat fee which did not charge for water by the amount used. Considering that most water conservation techniques require capital investment, farmers may have had a financial disincentive to invest in water conserving methods. With the additional factor that most farmers lease or rent the land they farm on a short term basis, the farmers may not benefit financially from any investment in the land.

The most popular water conservation techniques to be used by the farmers were improved levees, multiple delivery points, shallow flood, and canal maintenance. The less popular techniques included precision leveling, underground pipes, permanent levees, and field records. The lack of popularity of this second group may reflect the high cost. The survey indicates that only 42 percent of farmers are currently using any type of field record.

Field records should be promoted as a way to improve water savings that do not require large financial inputs from the farmers. The use of field records may also assist in the changing of farmer attitudes. Keeping records of field conditions and problems aids in the solution of problems and promotes a more systematic approach to the practice of farming. A more studied and systematic approach may help many farmers improve their efficiency and become more receptive to new techniques and behaviors.

It is likely that with water being charged for on a volumetric basis, farmers will move to employ more water conservation techniques as they now have a financial incentive to save water. The LCRA can aid this change by providing technical assistance to the farmers. In addition, the LCRA should consider a program which would allow farmers to deduct the cost of certain improvements from their water bill. For example, the precision leveling of land is expensive but the returns last for many years. It may be in the public's best interest to assist in the development of such strategies.

The farmers generally had a positive impression of the LCRA, but improvements could be made. The farmers indicated that for the most part they were happy with the manner in which the LCRA responded to their questions.

Of course the major issue at hand is the new volumetric rate structure. The manner in which the implementation of this new program is handled will likely set the tone for relations between farmers and the LCRA for many years to come.

The farmers indicate a major concern over the accuracy of the water delivery measurements. Some farmers even liked the idea of volumetric pricing but refrained from endorsing the program because of perceived measurement inaccuracies. If the LCRA can prove that delivery measurements are accurate, this would make substantial progress towards an overall positive impression of the new rate structure. Demonstrations should be held to show measurement accuracy. The best type of example would be an in-field demonstration over an extended time. The extended time period is important to convince the farmers that canal fluctuations do not effect the water deliveries. Another approach is to try in-field audits of measuring equipment to confirm continuing accuracy.

The concerns expressed by many of the farmers indicate that communication between the two parties could be improved. To meet this end it is recommended that every effort be made to improve communication between the farmers and the LCRA. Improved communication could help in two areas. The first is in the effectiveness of the water measurement techniques. The farmers need to be convinced of this effectiveness. The second is in regards to the feeling by farmers that their interests do not matter to the LCRA.

While most farmers expressed a general positive attitude toward the LCRA, others felt that their concerns were not being considered with proper weight. The farmers want to feel that they are part of the decision making process. In light of the fact that a majority of farmers indicated that farmer meetings were of value, these meetings should be continued. The meetings should also be continually reevaluated to determine if they could be improved in the future.

The response rate to this survey indicates that the farmers appreciate the opportunity to express their views. To continue to monitor the farmers' practices and opinions in as unbiased a fashion as possible, future surveys should be conducted. The response achieved by this survey appears, in some part, due to the fact that it was conducted by a third party and not the LCRA. This fact apparently convinced the farmers that their opinions would be considered fairly. Future surveys could also be conducted by a third party but it would be helpful if farmers could be made aware that their participation in this survey made a difference. The precedent set by this survey should be continued to maintain and promote any positive feelings on the part of the farmers.

In general, knowledge of the farmers' attitudes on this multitude of subjects will aid policy development. The LCRA will be able to use this information to determine how the farmers may react to potential policy changes. The LCRA should take this information into account in order to choose the appropriate policy and method through which the policy may be presented and implemented. The information gained from the survey will thus help the LCRA to be a more effective agency by helping it to better understand it customers.

Appendix A. Survey Forms

This appendix includes the documents that were sent to all persons on the LCRA mailing lists for both the Gulf Coast and Lakeside districts. The first four pages represent the survey form itself. The succeeding three pages are postcards which were sent before, along with, and after the survey form.

I. We want to start by thanking you for your valuable participation in this survey. Section I focuses on your field(s) and farming practices.

Please do not write in this column

1. Which crops did you farm last year? (Please check all that apply)
____rice ____maize ____sorghum ____cotton __/__/__/__/__
____Other (please specify)______________________________ __/__/__/__/__

2. How many acres of each crop did you farm last year? (Please write in the appropriate number)
_______rice _______maize _______sorghum _______cotton __/__/__/__/__
____Other (please specify)______________________________ __/__/__/__/__

3. Do you rotate crops?
____yes (within same year) ____yes (year to year) ____no __/__/__

4. Please estimate the percentage of irrigation water you use from surface and groundwater sources.
_______ % surface water _______ % groundwater __/__/__/__

5. How many separate fields did you farm last year?
____1 ____2 ____3 ____4 ____5 or more __/__/__/__/__

6. How would you describe the soil types of your field(s)? (Please check all that apply)
_____ silty sand _____ sandy clay _____ sandy clay loam _____ loam __/__/__/__/__
_____ silt loam _____ sandy loam _____ clay _____ sand __/__/__/__/__

7. Of the land you farmed last year, what percentage do you own?
____0-20% ____21-40% ____41-60% ____61-80% ____81-100% __/__/__/__/__

8. On the land you farmed that you do not own, were you
____leasing? ____employed? ____co-oping? __/__/__

9. Do you employ any field hands?
________yes (give number) ____no __/__/__/__

10. Do you live next to the land you farm?
____yes ____no __/__

11. How many miles do you travel each day during the growing season to tend your fields (average)?
____0-10 ____ 11-30 ____ 31-50 ____more than 50 __/__/__/__/__

12. Which of the following water conservation methods are you currently using? (Please check all that apply)
____ precision leveling ____ multiple delivery points __/__/__/__/__
____ improved levees ____ shallow flood
____ underground pipelines ____ canal maintenance __/__/__/__/__
____ field records ____ permanent levees
____Other (please specify)______________________________

13. How many acres of your farm land has been precision leveled?
____0-50 ____50-100 ____100-200 ____200-300 ____ more than 300 __/__/__/__/__

14. How many flushings did you use last year?
____1 ____2 ____3 ____more than 3 (please write in the number)__________ __/__/__/__/__

15. If you use a feeder stream to maintain the water level on your field(s), please check the reasons as they apply to your situation.
____ lead time on orders is too long ____ water may not be delivered when ordered __/__/__/__/__
____ too little time to check every field ____ used only during extreme heat waves __/__/__/__/__
____Other (please specify)______________________________

II. Section II covers personal characteristics. We would like to know this information to help us with our analysis. If you do not wish to answer a question in section II, please feel free to skip it.

Please do not write in this column

16. What is your age?
____less than 30 ____31-40 ____41-50 ____51-60 ____more than 60 _/_/_/_/_

17. In which irrigation district do you farm?
____Gulfcoast ____Lakeside _/_

18. Are you a native of this area?
____yes ____no _/_

19. How many years have you been farming in this district?
____0-5 ____6-10 ____11-15 ____16-20 ____more than 20 _/_/_/_/_

20. What is the highest level of education that you have completed?
____8th grade ____high school ____college ____graduate school _/_/_/_

21. Is your formal education related to your success in farming?
____ very important ____ related ____ not related _/_/_

22. How many persons are there in your household?
____1 ____2 ____3 ____4 ____5 ____6 ____more than 6 _/_/_/_/_
_/_/_/_/_

23. Which of the following comes closest to your total family income?
____ 0-$10,000 ____ $10,000-$20,000 ____ $20,000-$30,000 _/_/_/_/_
____ $30,000-$40,000 ____ $40,000-$60,000 ____ over $60,000 _/

III. Section III is the last section. It deals with your interaction with the LCRA, your opinions on water conservation, and the proposed rate structure. We really appreciate your time and effort.

Please do not write in this column

24. Who do you most often contact at LCRA?
____water boss ____district manger ____secretary ____ supervisor
____Other (please specify)________________________________ _/_/_/_/_

25. How do you most often communicate with this person?
____ by telephone during the working day ____ by telephone in the evening _/_/_/_/_
____ by coincidental meeting in the field ____ by planned meeting _/_/_/_/_
____Other (please specify)________________________________

26. How frequently do you communicate with LCRA?
____more than once per month ____about once per month ____less than once per month _/_/_

27. Approximately how many times did you order water from LCRA during last year's growing season?
1st crop: ______1 ______2 ______3 ______4 ______more than 5 _/_/_/_/_
2nd crop: ______1 ______2 ______3 ______4 ______more than 5 _/_/_/_/_

28. Has LCRA invited you to any farmer meetings during the last two years?
____yes ____no _/_

29. Have you attended any of these LCRA farmer meetings?
____yes ____no _/_

30. If you attended any farmer meetings, how useful was the information you received from them?
____ very useful ____ useful ____ not useful _/_/_

31. Has LCRA informed you about its water conservation demonstration projects?
____yes ____no _/_

32. If you have observed these demonstration projects, how would you assess their value to you?
____ very helpful ____ helpful ____ not helpful _/_/_

33. Did LCRA offer you any technical information last year?
____yes ____no
_/_

34. Do you ever experiment with new or different farming techniques?
____yes ____no
_/_

35. How helpful are LCRA staff when you have questions about water deliveries?
____ very helpful ____ helpful ____ not helpful
_/_/_

36. How helpful are LCRA staff when you have questions about water conservation techniques?
____ very helpful ____ helpful ____ not helpful
_/_/_

37. How helpful are LCRA staff when you have questions about your irrigation water bill?
____ very helpful ____ helpful ____ not helpful
_/_/_

38. How would you rate the accuracy of LCRA's water deliveries?
____ very accurate ____ accurate ____ inaccurate
_/_/_

39. How would you rate LCRA's attempts to inform you of its proposed volumetric rate structure?
____ very adequate ____ adequate ____ inadequate
_/_/_

40. In your opinion, the proposed volumetric rate structure is:
____ very fair ____ fair ____ unfair
_/_/_

41. In your opinion, how will the proposed volumetric rate structure affect your bill?
____ increase in water costs ____ no change in water costs ____ decrease in water costs
_/_/_

42. What is your position on this statement, "LCRA's proposed rate structure will provide incentives to save water"?
____ agree ____ no opinion ____ disagree
_/_/_

43. From which of these sources have you gotten most of your farming knowledge?
(Please check all that apply)
____parents/relatives
____other farmers
____practice/experience
____agricultural extension service
____school
____trade magazines
____LCRA
____Other (please specify)____
_/_/_/_/_
_/_/_/_/_

44. Of the sources you checked above in # 43, which one is most related to your farming success?
(Please check only one)
____parents/relatives
____other farmers
____practice/experience
____agricultural extension service
____school
____trade magazines
____LCRA
____Other (please specify)____
_/_/_/_/_
_/_/_/_/_

45. When LCRA develops its water conservation policies, whose interests do they have in mind?
(Please check all that apply)
____farmers' interests
____state government
____LCRA's own interest
____municipalities
____other (please specify) ____
_/_/_/_/_
_/_/_

46. In your opinion, which of these options should be most important in the development of water conservation programs for rice farming? (Please check only one)
____farmers' interests
____state government
____LCRA's own interest
____municipalities
____other (please specify) ____
_/_/_/_/_
_/_/_

47. When should public authorities have the right to regulate surface water use?
____ all the time
____ in periods of extreme drought
____ only when there are more demands than supply
____ never
_/_/_/_/_

48. When should public authorities have the right to regulate groundwater use?
____ all the time ____ only when there are more demands than supply
____ in periods of extreme drought ____ never

__/__/__/__/__

49. Do you believe that LCRA helps rice farmers?
____ very helpful ____ helpful ____ not helpful

__/__/__

50. Please add your comments about any issues not addressed in the questionnaire.

Thank you for your cooperation. Please return the questionnaire in the postage-paid envelope as soon as possible.

If you would like a free copy of the survey results please fill out the enclosed postage-paid postcard and send it to us.

Dear LCRA Customer,

If you would like to receive a copy of the survey results, please check the box below and return this card with your name and address.

☐ Yes, I would like to be sent a copy of the survey reuslts.

Return address: ______________________
____
____

Dear LCRA Customer,

You should have received a survey form in the mail recently. If you have not completed the survey and returned it in the prepaid envelope, please take a few minutes to do this as soon as it is convenient.

If you did not receive a survey form, please phone Ms. Gail Bunce collect at (512) 471-4962, ext. 318. We will then forward one to you promptly.

Thank you for your participation.

David J. Eaton
Beth Harris Jones Centennial
Professor in Natural
Resource Policy Studies

Dear LCRA Customer,

As part of a graduate course at the LBJ School of Public Affairs at The University of Texas, my students are conducting an evaluation of the LCRA's water conservation program. An important part of this evaluation will be a survey. We will be asking farmers who use LCRA water for irrigation about their opinions on the LCRA and its water policies.

The survey should be arriving shortly. Please watch for it.

Thank you.

David J. Eaton
Beth Harris Jones Centennial
Professor in Natural
Resource Policy Studies

Appendix B. Survey Data

This appendix contains the raw data response for each question on the survey administered to the rice farmers. Following each response is the number of farmers who marked that particular response. To the right of this number is the percentage of total responses represented by this number. The total of all percentages for each question may not add up to 100. This may be due to any combination of two reasons. One reason is the rounding of percentages. The second reason is that several questions contain multiple responses. As an example of the latter, a question may ask a farmer to "check all answers that apply." In this case, the recorded data will indicate the percentage of farmers who "checked" a particular response, not a particular response's percentage out of all possible responses.

	No.	(Percent)
Surveys mailed	230	
Surveys returned	79	(35)
Surveys not returned	151	(65)

Question 1--"Which crops did you farm last year? (Please check all that apply)"

No response	0	
Rice	79	(100.0)
Maize	8	(10.1)
Sorghum	9	(11.4)
Cotton	9	(11.4)
Other	13	(16.5)

Question 2--"How many acres of each crop did you farm last year?"

(Average acreage for those who farm each respective crop)

No response	1
Rice	554.3
Maize	190.3
Sorghum	557.8
Cotton	327.3
Other	244.1

(Average total acreage cultivated by each farmer for 1992)

Total	636.2

Question 3--"Do you rotate crops?"

No response	0	
No	16	(20.3)
Yes (within same year)	5	(6.3)
Yes (year to year)	58	(73.4)

Question 4--"Please estimate the percentage of irrigation water you use from surface and groundwater sources.

(Average responses)

No response	7
Surface Water	86.8%
Groundwater	41.6%

Question 5--"How many separate fields did you farm last year?"

No response	2	
1	7	(9.1)
2	11	(14.3)
3	7	(9.1)
4	11	(14.3)
5 or more	41	(53.2)
Average	3.9	

Question 6--"How would you describe the soil types of your field(s)? (Please check all that apply)"

No response	0	
Silty Sand	3	(3.8)
Sandy Clay	23	(29.1)
Sandy Clay Loam	30	(38.0)
Loam	1	(1.3)
Silt Loam	6	(7.6)
Sandy Loam	38	(48.1)
Clay	17	(21.5)
Sand	4	(5.1)

Question 7--"Of the land you farmed last year, what percentage do you own?"

No response	1	
0-20%	44	(56.4)
21-40%	8	(10.3)
41-60%	1	(1.3)
61-80%	3	(3.8)
81-100%	22	(28.2)

Question 8--"On the land you farmed that you do **not** own, were you . . ."

No response	19	
Leasing	51	(85)
Employed	1	(1.7)
Co-oping	8	(13.3)

Question 9--"Do you employ any field hands?"

No response	0	
No (0)	36	(45.6)
1	23	(29.1)
2	8	(10.1)
3	5	(6.3)
4	3	(3.8)
5	1	(1.3)
6	2	(2.5)
7	0	(0.0)
8	1	(1.3)

Question 10--"Do you live next to the land you farm?"

No response	1	
No	60	(76.9)
Yes	18	(23.1)

Question 11--"How many miles do you travel each day during the growing season to tend you fields? (Average)"

No response	3	
0-10	12	(15.8)
11-30	24	(31.6)
31-50	20	(26.3)
More than 50	20	(26.3)

Question 12--"Which of the following water conservation methods are you currently using? (Please check all that apply)"

No response	3	
Precision leveling	33	(41.8)
Improved levees	57	(72.2)
Underground pipelines	17	(21.5)
Field records	33	(41.8)
Multiple delivery points	56	(70.9)
Shallow flood	51	(64.6)
Canal Maintenance	57	(72.2)
Permanent levees	14	(17.7)
Other	4	(5.1)

Question 13--"How many acres of your farm land has been precision leveled?"

No response	5	
0-50	40	(54.1)
51-100	5	(6.8)
101-200	5	(6.8)
201-300	7	(9.5)
More than 300	17	(23.0)

Question 14--"How many flushings did you use last year?"

No response	7	
0	24	(33.3)
1	32	(44.4)
2	11	(15.3)
3	5	(6.9)
More than 3	0	(0.0)

Question 15--"If you use a feeder stream to maintain the water level on your field(s), please check all reasons as they apply to your situation."

No response	35	(44.3)
Lead time on orders is too long	15	(19.0)
Too little time to check every field	3	(3.8)
Water may not be delivered when ordered	24	(30.4)
Only during periods of extreme heat waves	14	(17.7)
Other	13	(16.5)

Question 16--"What is your age?"

No response	1	
Less than 30	6	(7.7)
30-40	18	(23.1)
41-50	22	(28.2)
51-60	18	(23.1)
More than 60	14	(17.9)

Question 17--"In which irrigation district do you farm?"

No response	1	
Gulf Coast	38	(48.7)
Lakeside	40	(51.3)

Question 18--"Are you a native of this area?"

No response	1	
No	9	(11.5)
Yes	69	(88.5)

Question 19--"How many years have you been farming in this district?"

No response	2	
0-5	7	(9.1)
6-10	15	(19.5)
11-15	9	(11.7)
16-20	13	(16.9)
More than 20	33	(42.9)

Question 20--"What is the highest level of education that you have completed?"

No response	1	
8th grade	0	(0.0)
High school	29	(37.2)
College	41	(52.6)
Graduate school	8	(10.3)

Question 21--"Is your formal education related to your success in farming?"

No response	2	
Very important	14	(18.2)
Related	42	(54.5)
Not related	21	(27.3)

Question 22--"How many persons are there in your household?"

No response	2	
1	3	(3.9)
2	23	(29.9)
3	18	(23.4)
4	20	(26.0)
5	10	(13.0)
6	3	(3.9)
More than 6	0	(0.0)
Average	3.2	

Question 23--"Which of the following comes closest to your total family income?"

No response	6	
$0-$10,000	2	(2.7)
$10,000-$20,000	6	(8.2)
$20,000-$30,000	6	(8.2)
$30,000-$40,000	14	(19.2)
$40,000-$60,000	26	(35.6)
Over $60,000	19	(26.0)

Question 24--"Whom do you most often contact at the LCRA?"

No response	2	
Water boss	69	(89.6)
District manager	2	(2.6)
Secretary	4	(5.2)
Supervisor	0	(0.0)
Other	2	(2.6)

Question 25--"How do you most often communicate with this person?"

No response	1	
By telephone during the working day	62	(79.5)
By coincidental meeting in the field	8	(10.3)
By telephone in the evening	1	(1.3)
By planned meeting	3	(3.8)
Other	4	(5.1)

Question 26--"How frequently do you communicate with this person?"

No response	3	
More than once per month	60	(78.9)
About once per month	4	(5.3)
Less than once per month	12	(15.8)

Question 27--"Approximately how many times did you order water from the LCRA?"

1st Crop:

No response	9	
1	1	(1.4)
2	9	(12.9)
3	6	(8.6)
4	11	(15.7)
5 or more	43	(61.4)
Average	4.2	

2nd Crop:

No response	25	
1	5	(9.3)
2	15	(27.8)
3	12	(22.2)
4	7	(13.0)
5 or more	15	(27.8)
Average	3.3	

Question 28--"Has the LCRA invited you to any farmer meetngs?"

No response	2	
No	2	(2.6)
Yes	55	(97.4)

Question 29--"Have you attended any of these meetings?"

No response	3	
No	15	(19.7)
Yes	61	(80.3)

Question 30--"If you attended any farmer meetings, how useful was the information you received from them?"

No response	13	
Very useful	10	(15.2)
Useful	44	(66.7)
Not useful	12	(18.2)

Question 31--"Has the LCRA informed you about its water conservation demonstration projects?"

No response	3	
No	9	(11.8)
Yes	67	(88.2)

Question 32--"If you observed these demonstration projects, how would you assess their value to you?"

No response	26	
Very Helpfu	5	(9.4)
Helpful	35	(66.0)
Not Helpful	13	(24.5)

Question 33--"Did the LCRA offer you any technical information last year?"

No response	8	
No	35	(49.3)
Yes	36	(50.7)

Question 34--"Do you ever experiment with new or different farming techniques?"

No response	6	
No	16	(21.9)
Yes	57	(78.1)

Question 35--"How helpful are the LCRA staff when you have questions about water deliveries?"

No response	7	
Very helpful	19	(26.4)
Helpful	49	(68.1)
Not helpful	4	(5.6)

Question 36--"How helpful are the LCRA staff when you have questions about water conservation techniques?"

No response	12	
Very helpful	12	(17.9)
Helpful	48	(71.6)
Not helpful	7	(10.4)

Question 37--"How helpful are the LCRA staff when you have questions about your irrigation bill?"

No response	8	
Very helpful	25	(31.6)
Helpful	44	(55.7)
Not helpful	2	(2.5)

Question 38--"How would you rate the accuracy of the LCRA's water deliveries?"

No response	7	
Very accurate	4	(5.6)
Accurate	35	(48.6)
Inaccurate	33	(45.8)

Question 39--"How would you rate the LCRA's attempts to inform you of its proposed volumetric rate structure?"

No response	6	
Very adequate	9	(12.3)
Adequate	57	(78.1)
Inadequate	7	(9.6)

Question 40--"In your opinion, the proposed volumetric rate structure is:

No response	10	
Very fair	5	(7.2)
Fair	39	(56.5)
Unfair	25	(36.2)

Question 41--"In your opinion, how will the proposed volumetric rate structure affect your bill?"

No response	8	
Increase in water costs	32	(45.1)
No change in water costs	24	(33.8)
Decrease in water costs	15	(21.1)

Question 42--"What is your position on the statement, 'the LCRA's proposed rate structure will provide incentives to save water'?"

No response	7	
Agree	42	(58.3)
No opinion	15	(20.8)
Disagree	15	(20.8)

Question 43--"From which of these sources have you gotten most of your farming knowledge? (Please check all that apply)"

No response	4	
Parents/relatives	51	(64.6)
Other farmers	62	(78.5)
Practice/experience	63	(79.7)
Agricultural extension service	41	(51.9)
School	11	(13.9)
Trade magazines	15	(19.0)
LCRA	5	(6.3)
Other	2	(2.5)

Question 44--"Of the sources checked above in #43, which one is most related to your farming success? (Please check only one)"

No response	7	
Parents/relatives	25	(34.7)
Other farmers	13	(18.1)
Practice/experience	27	(37.5)
Agricultural extension service	6	(8.3)
School	0	(0.0)
Trade magazines	0	(0.0)
LCRA	0	(0.0)

Other	1	(1.3)

Question 45--"When the LCRA develops is water conservation policies, whose interests do they have in mind? (Please check all that apply)"

No response	4	
Farmer's interest	29	(36.7)
State Government	19	(24.1)
LCRA's own interest	49	(62.0)
Municipalities	36	(45.6)
Other	9	(11.4)

Question 46--"In you opinion, which of these options should be most important in the development of water conservation programs for rice farming? (Please check only one)"

No response	6	
Farmer's interest	67	(91.8)
State Government	1	(1.4)
LCRA's own interest	1	(1.4)
Municipalities	0	(0.0)
Other	4	(5.5)

Question 47--"When should public authorities have the right to regulate **surface** water use?"

No response	7	
Always	6	(8.3)
In periods of extreme drought	24	(33.3)
Only when more demands than supply	26	(36.1)
Never	16	(22.2)

Question 48--"When should public authorities have the right to regulate **groundwater** use?"

No response	6	
Always	4	(5.5)
In periods of extreme drought	15	(20.5)
Only when there are more demands than supply	14	(19.2)
Never	40	(54.8)

Question 49--"Do you believe that the LCRA helps rice farmers?"

No response	4	
Very helpful	11	(14.7)
Helpful	53	(70.7)
Not helpful	11	(14.7)

Question 50--"Please add your comments about any issues not addressed in the questionnaire."

(Essay style responses)

See Appendix C for text responses of question #50.

APPENDIX C:
RESPONSES TO SURVEY QUESTION #50

This appendix contains the complete text of all written responses given to question #50: "Please add your comments about any issues not addressed in the questionnaire." Written responses were given by 42 of the 79 respondents. Note that the symbols "----" indicate writing on the survey form that could not be read.

Respondent 1:
LCRA wastes more water than any farmer ever thought about. They never patrol their canals to look for leaks. They often leave canals leaking all season, resulting in pastures being flooded and roads washed out. The volumetric billing is simply LCRA figuring a way to make the farmers pay for their incompetence. The extra charge for purchase of stored water is unfair. The farmer cannot pass extra and unexpected costs through to his customer and LCRA should not either. There should be one price for water no matter where it comes from.

Respondent 2:
(questions) # 40, 41, 42: Cannot express an opinion at this time because it has not been in practice long enough or on enough fields to determine its efficiency.

Respondent 3:
How about the price of LCRA water compared to others in the state and other states? One, in my opinion, to be higher than any other.

Respondent 4:
We have farmed rice for only one year, therefore, our answers are limited in value to you. At a recent Rice Growers' Seminar in Bay City, it was shown that we are the high cost producers of rice in the nation. Water is a big part of that cost. This puts a premium on LCRA to provide lower cost water to rice farmers or lose the customers.

Respondent 5:
I can pump groundwater cheaper than I can buy from LCRA.

Respondent 6:
I think the LCRA needs to pay more attention to the quality of water being dumped into the river by cities and towns up the river.

Respondent 7:
The metering system of measuring water flowing into fields is not accurate when pushing water to high points. Canals are not checked for trash or ---- in them. Canals are not held at regular levels.

Respondent 8:
I believe LCRA, like most other public utility companies, spends too much money on new equipment. If farmers had new trucks, backhoes, tractors, etc., we wouldn't be able to afford them. I believe the average tractor in the U.S. is 19 years old. I wonder what the average price of equipment of LCRA is. Also I believe we should have a lower flat rate for water and a higher charge for the amount of water that we really use. This would make farmers conserve more water.

Respondent 9:
Any regulations placed on water that is used by the agricultural community or farmers would only lead to further regulations, to which my tax dollars, as well as other farmers, would be used to fight these usually very unfair regulations.

Respondent 10:
I believe the metering of our water is needed and has been needed in the past. There are a lot of people in Texas today and water will become a very important and costly commodity. Hopefully we will be able to answer the challenge. The only way we will be able to compete with cities for water is by using up to date methods of conserving water. This will come with the implementation of volumetric metering of our usage of water. Farmers must curtail the way they use in every way and every phase of the crop during the year. But LCRA needs to make these efforts worthwhile to the farmer. Incentive is going to have to play a big part in this project. This will have to come from LCRA. Hopefully the process of metering will also improve in 1993 over 1992. Too much difference from field to field in '92. Hope you can get something out of this. Thank you for your efforts.

Respondent 11:
LCRA has done a very good job through the years. My biggest concern is on the new measuring system that we are going to be charged by in 1993. I think there has not been enough studies done on the system for enough years to start charging us by this method, although it has been said there will be adjustments made if there is a large amount of difference in the normal amount of water used. I just think this program needs a few more years and different weather conditions in these years, such as a drought or two, to come up with fair rates to both LCRA and the farmer.

Respondent 12:
Surface water belongs to everyone, but the people in the Colorado River Water Shed should have priority. Here we share the concerns of floods, droughts, or any environmental or industrial disaster that may occur on the River or Highland lakes. The rice farmer pays for water used in the irrigation of their crops that support their families, cities, counties, and businesses along the Colorado River. Without our water so goes the rice farmer and everyone connected, including LCRA. I also feel that ground water should be regarded as a mineral and should be handled in this manner. The land owner should have some consideration in this, an important issue as well. I support a volumetric metering concept for conservation and billing purposes, but I feel that inconsistencies in canal levels, high rainfall amounts, debris in delivery points add to the problem with the method and type of metering equipment available for an accurate delivery measurement, plus or minus 10%, at this time. This is the only opposition I have, as well as many of my cohorts. Higher irrigation cost is a fear shared by all farmers. The incentive for better water conservation needs to be addressed further, the proposed Rate Tariff does not make it feasible or profitable to invest in the enormous expense involved in precision land leveling and or underground pipelines. Perhaps, lower per acre charges and higher diversion charges, and/or discounts for precision leveled land, along with higher rice prices could help enhance these incentives. We all need each other, to work together, to achieve our goals, and make this program profitable for all of us.

Respondent 13:
Thank you for this opportunity to share my thoughts and feelings regarding LCRA and the proposed water conservation program. As rice farmers dependent on water from the Colorado River we realize that we are forced to deal with, yea - at the mercy of a bureaucracy. A bureaucratic organization with little interest in irrigation. In my small farming operation, water costs have increased 21.12% in three years. In a dry year this could increase another 10% as projected by the LCRA stored water charge ($5.27 per acre foot). At each meeting for farmers and the LCRA which I have attended some farmer has asked "Are you attempting to shut down irrigation and put farmers out of business?" Volumetric billing is sound, however three boards and a yardstick in a silted lateral do not a meter make. Our water costs go up - then there is an announcement that "LCRA has frozen electric rates until the turn of the Century." AND another - "LCRA announces with pride the winning of $1.5 million in grants for Environmental Purposes" including $414,000 in <u>fact gathering</u> and report

preparation for the Colorado River under Clean Rivers Act. Also $200,000 for solid waste management planning. Folks, what are we dealing with here? Oh yes, BUREAUCRACY. A far better question - Would not LCRA employees and customers all be far better served should these assets become part of a well managed and for profit business? Again, thank you.

Respondent 14:
LCRA is a state agency - it pays no taxes - generates 0 jobs in the private sector, but can greatly effect jobs in the private sector by its decisions and policy making.

Respondent 15:
#48 - Water usage policy must be developed in a rational and objective atmosphere and environment and not as a "knee jerk reaction". The establishment of policy for water is critical and should be openly debated.

Respondent 16:
The LCRA makes no attempt to listen to, or implement any of our ideas. Sure, they have meetings down here but they are only to pacify us. It's obvious because of their attitude and we see nothing coming back our way at all. We used to have local farmers on some committee that went to Austin from time to time to voice our concerns and give suggestions to help us and LCRA see things eye to eye but this committee has not met in 2 years. We as farmers have been taken out of the decision making loop. We just do and pay as we are told with no input. Six or eight years ago we in Matagorda County were using approximately 8 to 9 acre feet per acre (AFPA). This past year I think we used an average of approximately 4.5 to 5 AFPA. We as farmers in the field are the ones for this decrease in usage by our hard work and our willingness to be conservative for environmental reasons. LCRA is getting and gladly taking all of the credit and in return we farmers are getting to pay approx. 45% more in rates. Times as they are in the rice farming business, it has become apparent that something has got to change for the better or we will be out of business soon, real soon. We have got to all work together because without us we take down lots of other businesses with us. This includes a lot of jobs employed by LCRA.

Respondent 17:
Person in charge of water, water boss: isn't working with the farmer like he should, in the last 3 year this is a little better than year ago. LCRA needs the rice farmer and rice farmer need LCRA. Some of your personnel is hard to get along with.

Respondent 18:
No one with LCRA has ever actually watered rice. They do not understand a lot of the many problems the farmer faces in his day to day watering process. This in turn costs the farmer alot of time, money, and stress. There needs to be more understanding and cooperation between the farmers' everyday needs and LCRA's employees handling the water distribution.

Respondent 19:
LCRA is becoming a self-servicing organization.

Respondent 20:
The only revenue that I can remember to pay for the dams was from the rice farmer for many years. I know it is going to cost more to meter and keep back then the small amount of water saved. It will create new jobs and cost.

Respondent 21:
Without an actual gear driven counter, the volumetric rate structure will be inaccurate. This is because the canal level fluctuates up and down, and at times (up to 36-48 hours) no water is flowing through the water box, but the clock is still ticking indicating how much water should be flowing through the opening in the water box. In

other words - we are being charged for the hole in the water box and nothing is passing through it but air. Unfluctuating canal depths to maintain constant pressure is extremely important.

Respondent 22:
This is an estate (family) operation. We have a tenant farmer, therefore cannot answer all the questions.

Respondent 23:
Thank you for giving us the opportunity to make comments on the LCRA. It is our opinion that the LCRA is working for the good of all in their attempt at volumetric metering, but there are many problems that must be worked out if it will be successful and have the approval of farmers. Two problems that have already surfaced at Gulfcoast are:

A. inaccuracies in measurement
B. lack of incentive in curtailment of usage

The LCRA staff has attempted over the last several years to obtain a better working relationship with its customers. They have organized two different "Farmer Advisory Groups", the first met only once or twice. The second group was formed only shortly before the first of the year. For the most part, members of the group feel that their opinions and suggestions fall on deaf ears with the staff at Austin. The staff uses the "Farmer Advisory Groups" to add to their recommendations to the LCRA board. At a recent board meeting in Austin the staff stated that over 50% of their irrigation customers were in support of a rate change. This could not be farther from the truth. Nearly all Texas rice farmers are feeling the effects of higher inputs and lower prices from the mills.

Respondent 24:
I believe that the volumetric rate system will not be an accurate way to charge for water use.

Respondent 25:
Re: Volumetric Rate Structure. The method of measurement is unfair. The system used is accurate when the water level in the canal is constant. Unfortunately, the water level fluctuates and therefore true water use is not fairly determined.

Respondent 26:
Out of the 650 ac. of rice, only 250 ac. on LCRA. The remainder of the rice and soybeans are irrigated by a private irrigation well.

Respondent 27:
Questions #47 and #48 need one more choice - that being a water commission of equal representation from each water user in the river basin. This is a nice questionnaire, but what is its purpose? LCRA has a monopoly and our only choice is to pay their proposed rate or do without the water, in other words, don't grow a crop that depends upon the use of irrigation water. LCRA could provide the same or better service to our area by cutting overhead, staff, ———, etc.

Respondent 28:
The G&A <u>cost</u> factored into the water division of the LCRA continued to grow as the LCRA Bureaucracy grows. This monster has grown exponentially since 1980 to date. This growth has been by Management, Board of Directors, Legislated Mandates, etc. The farmers and Water division of LCRA have taken a lot of flack from the Board and Lake People because we are not a profit center with the huge G&A expense in our budget. Which by the way continues to grow annually.

Respondent 29:
Your survey is not applicable in several ways to us as we are landowners who lease their land for a share of crop and for cash. For crop share leases for rice, we provide land, water and seed plus a portion of the other crop inputs, however the lessees provide the labor and equipment. Also the land is owned and operated by partnerships of six people so the personal questions are answered only by one partner, the managing partner. W.R.T. LCRA meetings -- they are generally on short notice and in conflict with other important meeting and at a distance. (In fact it seems that LCRA schedules meetings in conflict with some obvious events.)

Respondent 30:
Some rice farmers have abused their water rights. They were inattentive to their watering practices and did not care about using water conservatively - I appreciate the method that if a farmer conserves and manages his water he will be billed accordingly.

Respondent 31:
LCRA is overstaffed and overpaid. Too much emphasis put on recreation. Environmental input is great. Farmers will soon be priced out of business per acre ft. costs will soon outgrow our income.

Respondent 32:
The volumetric measurement was inaccurate. I had two fields side by side. One read 1.5 feet difference. It will be very good to help conserve water when it is perfected. If the water Boss would spend a little more time on the canal he could do a better job. They don't have the experience the older water bosses had.

Respondent 33:
Water is becoming a bigger farming issue every year. A farmer's conservation practice is becoming more important and mandatory. We cannot afford to experiment with too radical a farming techniques so the information LCRA and extension services provide can be very helpful.

Respondent 34:
In my opinion LCRA needs a more accurate way to measure water discharged into fields. The way water is measured to date is not accurate enough to allow them to fairly charge farmers for usage.

Respondent 35:
I have been farming rice since 1976. Water is absolutely necessary in growing rice. Since '76 LCRA has more than doubled, in fact almost tripled, the rate they charge me for water. Yet with practically no change in services - except for now a metering system which in "theory" is great but in "practice" is terribly inaccurate! Personally, I feel LCRA is selling water to the highest bid which would be municipalities and leaving the farmers hung out to dry because of the prohibitive cost of LCRA water. I think it's terrible and I can't stop it and will merely become a victim of the system.

Respondent 36:
Four years ago rates were increased by 28% spread over a four year period at 7%/year actually compounded to a 35% increase. At the same time water use by LCRA's own numbers have decreased in Gulf Coast from over 9 acre feet/acre to under 6 acre feet/acre. Actually 5.25 acre feet/acre. Over 30% savings in water usage. We were also promised there would be no more rate increases for 4-5 years after this. Now to get around a rate increase they come up with a new system of billing - volumetric rates - which in most of the farmer's opinion a very poor method of measurement. Wildly fluctuates between fields. So you tell me - do you believe that LCRA helps rice farmers? Sadly most of us feel that we will be paying 10-25% more within 2-3 years and the low prices of rice will not sustain this increase.

Respondent 37:
As a rice producer I feel like the municipalities and recreational interests have tried to take away water rights from the farmers. As a whole the farmers have cut way back on the amount of water used in the last 10 years.

But every year we pay more and more for water. While the price we receive for our crop decreases every year. I sometimes feel people are more concerned about the water level of the lake, that was built for irrigation purposes, than the crops that produce food to feed them. I also feel that after studies have been completed they will show water coming out of our rice fields are cleaner than the water we are putting in the top of our fields.

Respondent 38:
LCRA does not spend enough time or energy conserving water within their system, i.e., main canals.

Respondent 39:
Best relations between water boss and farmer in my 50 years of farming. Note I own $100,000.00 LCRA bonds.

Respondent 40:
The accuracy of LCRA measurements of water concerns me greatly. They need an independent measuring service consisting of farmers and LCRA employees that are educated in the practice of measuring water so that this will be fair for everybody. Hand held meters should be thrown away. This is not in my opinion an accurate way to measure water, especially when you are farming on the end of the canal because of canal level fluctuations. Accuracy above all is my main concern. Send me this survey a year from now and I will be able to answer your questions more accurately.

Respondent 41:
Water rate is too high in comparison to the prices we receive on our rice.

Respondent 42:
LCRA is a bureaucracy with too many folks trying to run other people's business to impress the folks above them. The water districts and their local management should be left alone to do their jobs without Austin breathing down their necks. This survey just seems to me to be another attempt by bureaucrats to look impressive. There is a point at which information becomes futile. LCRA is not and will not every be one of the rice farmers' main sources of information. That is not and should not be LCRA's responsibility except where it pertains to water conservation.

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