MP-1559
June 1984

WATER
USE AND MANAGEMENT
In The Texas Rice Belt Region

The Texas Agricultural Experiment Station, Neville P. Clarke, Director, The Texas A&M University System, College Station, Texas

WATER USE AND MANAGEMENT IN THE TEXAS RICE BELT REGION

Ronald C. Griffin*

Gregory M. Perry

Garry N. McCauley

June 1984

Department of Agricultural Economics
Texas A&M University
College Station, Texas 77843

*The authors are, respectively, Assistant Professor and Research Associate in the Department of Agricultural Economics, Texas A&M University, and Associate Professor, Texas A&M University Agricultural Research and Extension Center at Beaumont. Senior authorship is shared by the first two authors.

ACKNOWLEDGMENTS

The authors have received the support and advice of many persons and organizations during the preparation of this report. Primary thanks go to the Texas Rice Research Foundation and Texas Agricultural Experiment Station for providing the necessary financial support to complete this project.

Sixteen major water suppliers graciously shared data and information which was used extensively throughout the report. H.L. Goodwin, Ron Kaiser, Ron Lacewell, Karen Pilant, M. Edward Rister, Dudley Smith, Tom Sneed, and James Stansel provided many useful comments on the report, as did John Stoll on the initial drafts of the mail-out survey. Gerald Crenwelge and Richard Bettge made substantial contributions to the glossary. Anna Hallaran spent many hours entering the survey responses into the computer. Penny Weaver and Carla Fisher provided able assistance in the typing of the manuscript. Last, but not least, many thanks go to those rice producers who freely gave of their time to complete and return the mail-out survey. The detailed results available in this report are due largely to the efforts of the many producers who responded to the survey.

TABLE OF CONTENTS

Acknowledgments ii

Introduction 1

Study Objectives 1
Rice Water Management Study 3
Report Format 4

Executive Summary 6

Conclusions 7
Research Implications 8

History and Current Production 10

Current Production 12

Water Law and Institutions in Texas 16

Surface Water Law 16
Adjudication 17
Surface Water Management Institutions 18
Texas Department of Water Resources 19
Irrigation Water Suppliers 20
Groundwater Law 28
Groundwater Management Institutions 28
Harris–Galveston Coastal Subsidence District 29

Surface Water Use 30

Agricultural Surface Water Use 30
Private Rights 30
Canal Delivery Losses 33
Pricing Systems and Water Use 34
Nonagricultural Surface Water Use 35
Summary of Surface Water Use 37

Groundwater Use 40

Agricultural Groundwater Use 40
Energy Sources 42
Nonagricultural Groundwater Use 44

Farm Water Management 48

Cultural and Irrigation Practices 48
Preplant Activities 48

Planting, Flushing, and Flooding 49
Flooding and Flood Maintenance 51
Harvest and Ratoon Crop 53
Water Costs and Total Production Costs 53
Tenure Arrangement 58
On-Farm Water Use 62
Current Water Conservation Practices 64

Future Water Demand and Conservation Options **67**

Expected Future Surface Water Supply and Demand 67
Expected Future Groundwater Supply and Demand 68
Reactions to Decreased Water Supplies and Increased Costs 69
Reactions to Increased Water Supplies and Decreased Costs 77

References **82**

Appendix **87**

INTRODUCTION

Water continues to be an important resource in the economic development of the Texas Gulf Coast. High rainfall and the abundance of many large, quality rivers and streams have contributed to the establishment and growth of many water-intensive industries in the area. Because water resources have been so abundant, the area historically has been able to absorb continued industrial and population growth without taxing these resources. However, public concern about adequate water supplies has been mounting as demand increases, supplies become limited, and water costs increase.

Water can be obtained from two basic sources: either as surface water (rivers, lakes, bayous, etc.) or from underground aquifers. Because the natural flow of water during peak demand months has been fully allocated in most river basins along the Gulf Coast, reservoirs have been built to store water during peak runoff periods for use in periods when water is more scarce. However, the escalating cost of constructing new reservoirs is making this an increasingly expensive and unattractive way to increase water supplies (Griffin and Stoll 1983). Moreover, recent changes in national policy have substantially reduced the federal subsidization of new reservoirs.

Groundwater sources are also becoming more difficult to obtain and expensive to use. Despite fairly high recharge rates, increased withdrawal from the underground aquifer has resulted in declining water tables and land subsidence in parts of the Texas Gulf Coast area (Harris-Galveston Coastal Subsidence District 1982). Land subsidence can cause damage to bridges, roads, and buildings, as well as make areas more susceptible to flooding. The costs of pumping water increase with declines in the water table, since it requires more energy to lift water from a greater depth. In addition, saltwater intrusion is occurring more and more frequently in areas where the Gulf Coast Aquifer is overpumped (Texas Department of Water Resources 1983).

The Texas rice industry is highly dependent upon water for irrigation purposes and therefore is greatly concerned with future supply and demand conditions in the Gulf Coast area. Over 474,000 acres of rice were planted in Texas in 1982, and 99% of this acreage was located in the 18-county Texas Rice Belt region. Rice is virtually the only crop being irrigated in this region, accounting for over 90% of the total irrigated acreage. Water represented the biggest single cost of producing rice in 1980, averaging $54.39/acre or 16.4% of all variable costs of production (Texas Agricultural Extension Service 1982). The per-acre cost of water has approximately doubled since 1975. While the costs of water and other production inputs have continued to increase, prices received by farmers for their crop have remained constant or even declined (USDA 1982). Currently, water costs for rice farmers in Texas are higher than those in any other rice-producing state (Mullins et al. 1981). Coincidentally, total production costs are also highest in Texas. The current high costs of obtaining and using water and the high probability that costs will continue to increase have been the primary incentives for Gulf Coast rice producers to seek ways to conserve water, either through management practices or capital investments.

STUDY OBJECTIVES

The purpose of this study is to investigate water use in the Texas Rice Belt and, in particular, to focus on water use by rice farmers. The specific objectives of this study are as follows:

1) To identify the sources of water used for rice irrigation.

2) To examine the specific entities that manage surface water used by rice producers, identify their service areas, and briefly detail their origins and methods of operation.

3) To estimate the amount and cost of surface water used by rice producers.

4) To estimate the amount and cost of groundwater used by rice farmers. Also, to determine the number, operating depth, and capacity of wells used to obtain water for irrigation.

5) To identify nonagricultural water consumers who use significant amounts of water and determine the extent of their water use.

6) To determine where water losses can occur in rice production and identify those practices that can influence water losses.

7) To examine the important cultural and managerial practices that influence water use in rice farming. Also, to investigate how these practices vary with changes in water costs, water sources, and tenure arrangements.

8) To determine which cultural and water conservation practices rice producers would implement should changes occur in water supplies and costs.

9) To seek recommendations on potential areas of future research in the areas of water cost reduction and water conservation in rice production.

It is to be emphasized that *the primary intent of this study is to provide a descriptive picture of water use and water management* affecting rice producers of the Texas Rice Belt. Literature is reviewed and data and opinions are collected and presented with only a limited amount of data analysis being undertaken. The results of the study should prove useful to researchers, producers, and planners as a starting point for further research in the water management area. The information will also be useful in providing a better basis for private and public decision making. It requires but a brief exposure to the water-related problems faced by Texas rice producers to become aware of the current and future importance of these issues and to learn how little basic information is available for designing solutions. It is hoped that the background and data provided by this study will represent a step toward improving this situation.

Several sources of data are used throughout the report. To gain a more comprehensive perspective regarding groundwater and surface water use by agriculture, two separate surveys were designed and administered following the 1982 crop year. The single most important data source is the results from the Rice Water Management Study (RWMS) survey, conducted during the winter of 1982-83. Some summary information concerning the response to this survey is presented in the next section. The second survey consisted of personal interviews held with representatives of each of the major canal companies supplying irrigation water to rice farmers. Many of these organizations are also large suppliers of municipal and industrial water. Historical data was obtained on water withdrawals, acres irrigated, and water costs. Canal managers were also asked several general questions dealing with local water supplies, methods of management, conveyance losses, and possible future water sources. Information from these surveys is used throughout this report. The Texas Department of Water Resources (TDWR) also provided a significant amount of data and information.

RICE WATER MANAGEMENT STUDY

The objective of the Rice Water Management Study was to gather detailed information from rice producers and landowners concerning water sources, use, management, and costs. A mailing list of approximately 3,370 persons who were designated as either rice producers or landowners was obtained from the Texas A&M University Agricultural Research and Extension Center at Beaumont. This list was randomly reduced by 20% to a total of 2,693 names, and questionnaires were sent to each of these people in November 1982. A copy of the survey can be found in the Appendix. The survey was 16 pages in length and required several hours to complete for some farmers. A postcard reminder was sent to nonrespondents three weeks later, and a second questionnaire was mailed to all remaining nonrespondents in January 1983.

A total of 880 responses was received as a result of these procedures (a return rate of 32.7%). Returns are categorized as follows:

Category	Number	Percent
Rice Producer	258	29.3%
Landlord	64	7.3%
Partnership	125	14.2%
Non-Rice Producer	105	11.9%
Did Not Produce Rice in 1982	207	23.5%
Nonrespondent	121	13.8%
	880	100.0%

The "Partnership" category includes producers who farmed in partnership with another producer. To avoid duplication of information, partnerships were requested to return only one survey per partnership. The remaining partners were asked to return the survey with only the partnership box checked, thus indicating that a survey form had been completed for their partnership.

Persons who had never farmed rice nor owned rice land comprise the "Non-Rice Producer" category. Those who had been rice producers in the past, but who did not produce rice in 1982, account for 23.5% of all respondents. Of this number, 48% indicated they had retired, 25% had not farmed because of low rice prices, 6% had rice out of rotation in 1982, and 21% did not produce rice for other reasons. Within the "Did Not Produce Rice in 1982" category, 52 respondents indicated they did not produce rice because of low prices. Only 23% of the 52 respondents indicated they intended to produce rice in the future. Another 27% indicated they did not intend to produce rice again, while 46% were undecided. Undoubtedly, the prospect of continued poor rice prices at the time the survey was taken (prior to the announcement of the Payment-In-Kind program) had a significant influence on the undecided respondents.

The "Nonrespondent" category includes those persons who sent the questionnaire back unanswered or sent a note indicating that they felt that they could not complete the questionnaire accurately. The majority of respondents in this category indicated they were landowners who did not take an active role in management of their rice land.

The number and acreage of respondents are delineated by county in Table 1. Overall, total returns represented 33.3% of the rice acreage in the Rice Belt area, with county returns being above 25% in most counties. No returns were received from Orange and Hardin Counties where only a few rice producers were in operation during the 1982 crop year. Since the response rate was high in most counties, analysis of most of the results by county can be expected to produce statistically accurate approximations of actual population means. In general, the response rate was better than expected for a survey of this size, perhaps indicating a concern by rice farmers about water supplies and costs. Responses tended to be highest in counties where groundwater is an important irrigation source. This may be due in part to groundwater being, in general, a more expensive water source for rice production.

It is important to note that the percentage of acreage represented in the sample (33.3%) is larger than the percentage return rate (26%) from the 3,370 persons on the initial mailing list. This indicates that the results may be somewhat biased toward larger producers, and this should be kept in mind as the results are evaluated.

REPORT FORMAT

The following report is divided into 7 major parts. The first is a short summary of the major findings and conclusions of this study. The second section provides historical perspective regarding the development of rice production in Texas as well as identifying the level of current production. The third section is intended as a brief primer on important Texas water laws and institutions affecting rice production.

The fourth and fifth sections examine surface and groundwater use, respectively, by major sectors within the Texas Rice Belt. The sixth section focuses upon on-farm water management practices -- examining those practices which influence water consumption. The seventh and final section presents information concerning future water availability in the region and summarizes producer reactions to hypothetical changes in water supplies or costs.

TABLE 1. RESPONSE BY COUNTY TO RICE WATER MANAGEMENT SURVEY AS COMPARED TO 1982 ACREAGE LEVELS

County	Number of Surveys Received	Number of Acres Reported	1982 Planted Acres[a]	Percentage of Planted Acres Reported
Austin	3	1,697	4,000	42.4%
Brazoria	28	14,443	48,900	29.5%
Calhoun	4	4,347	12,300	35.3%
Chambers	20	12,872	44,000	29.3%
Colorado	15	15,207	44,800	33.9%
Fort Bend	5	6,476	21,500	30.1%
Galveston	3	1,613	8,600	18.8%
Hardin	0	0	1,600	0.0%
Harris	12	5,972	17,900	33.4%
Jackson	26	14,510	36,800	39.4%
Jefferson	28	11,676	43,000	27.2%
Lavaca	2	b	4,800	b
Liberty	16	8,599	34,100	25.2%
Matagorda	26	16,971	48,300	35.1%
Orange	0	0	1,400	0.0%
Victoria	3	b	5,300	b
Waller	7	6,437	13,500	47.7%
Wharton	60	32,940	79,900	41.2%
Total	258	156,978	470,700	33.3%

[a]As reported by the Texas Crop and Livestock Reporting Service (Humphries 1983).
[b]Items reported but not shown on a county basis to avoid disclosure of individual operations.

EXECUTIVE SUMMARY

Water is an essential and costly input in the production of rice in Texas. The rising price of water is one factor making it increasingly difficult for Texas rice producers to compete in U.S. rice markets. Approximately 60% of 1982 rice acreage was irrigated using only surface water supplies, and 80% of this acreage was served by 16 major water suppliers. Across these water suppliers, water withdrawals in 1980 averaged 5.4 acre-feet per acre, but it is not known how much of this water was consumed in the delivery process. Average water consumption for acreage relying on groundwater supplies is computed to be 3.8 acre-feet. Calculated groundwater consumption is somewhat greater than what is reported by the Texas Department of Water Resources and the Soil Conservation Service.

The use of groundwater resources in the Rice Belt is largely unconstrained by legal institutions except for the Harris-Galveston Coastal Subsidence District. The appropriative water rights structure predominates for surface water in Texas, and these rights are saleable. The legal process of verifying and solidifying water rights, known as "adjudication," is underway for all basins in the Rice Belt. Surface water delivery services are organized within a variety of private or public supply institutions having different backgrounds, structures, and objectives.

Legal claims to surface water amount to over 25 million acre-feet annually in the 18 counties of the Rice Belt although this much water is not believed to be available. Over 2.7 million acre-feet of surface water was withdrawn in 1980; 61% of this total went to agriculture (nearly all to rice), 31% to industry, and the remaining 8% to municipalities. Likewise, over 1.2 million acre-feet of groundwater was withdrawn in 1980 -- 53% by agriculture, 12% by industry, and 35% by municipalities.

Results from the Rice Water Management Study found that the average well operated during the 1982 crop year was 659 feet deep, served 197 acres, and operated over 2,000 hours. The most important energy source is natural gas, which accounts for 61% of the rice acreage using groundwater. Electricity was also an important energy source. Most groundwater acreage was located in the Lower Gulf Coast region.

Approximately 470,000 acres of rice were produced in 1982, of which about 68% was harvested for two crops. First crop water costs averaged $44 per acre for surface water users and $57 per acre for groundwater users. Second crop water costs averaged $15 and $31 per acre respectively for surface and groundwater users.

Sharecropping was the most common land tenure arrangement, accounting for 62% of all 1982 acreage. An additional 16% was cash leased while 22% of the acreage was operated by owners. Both one-fourth and one-half sharecrop arrangements typically had the landlord paying 100% of the water costs, while tenants usually bore all water costs for less than one-fourth share arrangements.

Producers estimated that just over half of the water they received for irrigation was evaporated or consumed in plant growth. Tailwater and field seepage were also considered to be major on-farm water use categories. Many producers were unable to make categorical estimates of on-farm water uses.

Within the study area an estimated 139,000 acres has been "water-leveled," 67,000 acres has been laser-leveled, and 29,000 acres are served by underground pipe. A disproportionate share of these water conservation investments are located on owned land rather than leased land.

The majority of Upper Gulf Coast surface water users would not react as strongly to decreases in surface water supplies as would Lower Gulf Coast surface water users. The majority of surface water users, when faced with cutbacks in water supplies, would reduce acreage and increase the use of precision leveling, water leveling, and other minor water conservation practices. The majority also indicated they would not use wells more intensively, switch to other irrigated crops, switch to sprinkler irrigation, nor drill new wells.

Groundwater users also reacted in a similiar fashion when faced with increases in groundwater costs. In the case of groundwater users, however, acreage reduction was the only alternative favored by the majority. When faced with declines in groundwater costs or increases in surface water supplies, the majority of producers indicated they would not change their modes of operations.

CONCLUSIONS

Motivation for this study was derived from important private and public concerns regarding the on-farm use of water for rice production in the Rice Belt region. These concerns stem from a growing awareness of water scarcity and the potential implications of this scarcity in future rice production and water management, as well as in further municipal and industrial development. During recent decades continually growing municipal and industrial water needs have been satisfied by tapping prevailing water surpluses and developing new surface water and/or groundwater supplies.

Prospects for further economic development guarantee that water demand in the Texas Rice Belt will continue to increase. Increased competition for limited water supplies does not imply that agriculture will "lose out" to water users with a higher willingness to pay. However, some private rights currently being exercised in water-short river basins may be lost as a result of the adjudication process, if such rights do not have firm legal backing from existing appropriative and riparian water right laws. Rights having such legal backing will continue in effect because of their early dating relative to more recent nonagricultural claims. In fact, some irrigators stand to gain as a result of owning adjudicated surface water rights which are a saleable and increasingly valuable commodity. Tenants and producers who do not own the rights to water that they are using stand to lose as water is transferred to higher valued uses.

With respect to physical groundwater limitations, the Gulf Coast aquifer contains ample water supplies for satisfying future groundwater requirements within the region. While abundant, groundwater resources are increasingly expensive to obtain. High levels of groundwater withdrawal can also result in land subsidence and saltwater intrusion, both of which are costs to society at large. Of greater direct importance to the producer, the higher costs of energy and of drilling new wells will limit groundwater use in Texas rice production.

The survey results seemed to show that producers view precision land leveling and (for groundwater users) pump and bowl repairs as the most cost-effective ways to conserve on water use. On the other hand, producers seemed to demonstrate a great deal of uncertainty and pessimism about the uses of alternative crops or sprinkler irrigation systems as means to conserve water. This result indicates that, should these alternatives prove to be experimentally viable, a great deal of work will still need to be invested to convince producers that such alternatives should be given serious consideration when seeking to conserve water.

RESEARCH IMPLICATIONS

Two procedures have been employed in deducing the research needs that are summarized below. First, in the RWMS survey producers were asked to identify research needs that they felt needed to be addressed; no explicit reference to water was made in this question. Second, on the basis of information accumulated during this study and presented in this report, it is possible to isolate information gaps which, if filled, would permit improved water management.

Physical, economic, and institutional settings pertaining to water use and management by rice producers vary widely across the Rice Belt. Physical factors include soil, climate, and surface water and groundwater resources. Economic factors certainly include water costs and the costs of substitute inputs such as labor and herbicides. Institutional factors encompass water rights and the structure and objectives of particular private or public water suppliers. The variability of these factors make it difficult, if not dangerous, to generalize very much about the water-related problems faced by rice producers or about potential solutions. Economically attractive alternatives for one geographic area will only be of passing interest in others. Therefore, a targeted research approach would be most useful in addressing water-related problems in the Rice Belt.

Research for technology enhancement need not be devoted to solving local problems. General systems for improved water delivery, application, and monitoring could be useful in many areas of the Rice Belt. Some producers responding to the RWMS survey noted a need for developing water-conserving rice varieties; this too would represent an area of general technology enhancement. Undoubtedly, there are many other researchable topics with the potential to improve general rice production technology and enable producers to take better advantage of water economics.

Regarding physical factors, one result of this study is to demonstrate how little is known regarding the amount of water which is used or lost through leaching, evaporation, tailwater, etc. Needless to say, water management could be significantly improved with better information on relative water losses to these various outlets. Within the RWMS survey some producers noted the need for research on lateral losses. Because all of these losses will vary according to cultural practices, climate, and soil type, it is necessary to adopt a targeted stance for studying this problem. Moreover, in order to best apply research results to specific physical settings, it would be desirable to identify physical factors which influence water losses and to then quantify these influences.

Economic factors affecting water use should be taken into account when assessments are performed for the relative economic viability of alternative or new rice cultural practices. Within a production context the role of economics is primarily to gauge alternative technologies and then recommend a preferred practice. This task is complicated by the diversity of available management practices as well as by the variability of physical and economic settings. Nevertheless, it is preferable for economic analysis of this type to be attentive to local conditions. For example, water-conserving investments such as relifting tailwater, underground pipe, precision leveling, and sprinkler irrigation each present several types of economic benefits and economic costs which will vary greatly with local conditions. A flexible framework for combining these benefits and costs within a single analytical procedure would be very helpful. Other potential research topics in economics include the impact of water metering on water use and the economically optimal timing of well/pump repair for rice production.

Institutional factors relating to water use and management in Texas rice production are also important and researchable topics. Surface water supply organizations have a large amount of capital pertaining to canals, diversion and storage facilities, and pumping plants. For water suppliers having a large unretired debt on these structures, the fixed costs of annual operation can be large relative to variable costs (for labor, energy, etc.). These fixed costs are quite independent of actual operations and must be spread across the service area of a water supplier. Therefore, as rice acreage declines (either due to unfavorable rice prices, government programs, or municipal and industrial development), average fixed water costs increase for remaining rice acreage and put even greater economic pressures on these producers. This can cause an even greater decline in acreage and thereby precipitate an economic failure for the water supply system as a whole. Institutionally oriented research might suggest ways in which this process might be circumvented.

A spectrum of complementary scientific, economic, and institutional research is needed to arrive at profitable solutions to present and future water resource problems in the Texas Rice Belt. Some particular research problems may in fact require research that overlaps into some or all of these areas. For example, a study of the feasibility of municipal wastewater use in rice irrigation would likely involve an examination of the effects of wastewater on plant growth and quality, the consequences of wastewater use for municipalities and those who currently use wastewater, as well as an economic study of the impacts of wastewater use. Finally, it must be acknowledged that research on any one aspect of rice culture (such as water) cannot exclude interrelationships with other management practices if such research is to be useful.

HISTORY AND CURRENT PRODUCTION

Although some rice production occurred in the U.S. as early as 1609, actual commercial production did not begin until after 1730. Rice production was centered in the Southeast during pre-Civil War times, with South Carolina being the predominant rice-producing state. Following the Civil War, production of rice shifted from the Southeast to the South Central states, particularly Louisiana (Holder and Grant 1979).

The first record of rice production under irrigation in Texas occurred in 1862 in Newton County. Until 1888 only small amounts of rice were grown in the state, mostly for home use. Farmers began to experiment with upland (dryland) rice production in 1888. Upland rice production was not found to be profitable and was soon abandoned (Taylor 1902).

Growth of the rice industry in Louisiana eventually spilled over into the Jefferson County area of Texas. In 1891 an irrigation company began pumping water from Taylor's Bayou in Jefferson County to farms in the surrounding area. By 1898 the county had 3,000 acres of rice, several miles of irrigation canals, and a rice mill (Texas Water Resources Institute 1983).

In 1899 rice was introduced into the Eagle Lake area along the Colorado River. Results were so successful that rice production quickly spread throughout the Lower Colorado River Valley. By 1902 56,000 acres in the Colorado River Valley were planted to rice. During this period the first irrigation well was put into operation on a farm near Eagle Lake (Taylor 1902).

Rice production expanded from Jefferson County and the Colorado River Valley to all parts of the Texas Gulf Coast. For a short time rice was produced even in the Rio Grande Valley. Total Gulf Coast rice acreage increased from 9,000 acres in 1899 to 140,000 acres in 1902, and to 220,000 acres by 1910. Texas annual harvested rice acreage from 1895 to 1982 is illustrated in Figure 1, as are the acreages for the Upper and Lower Gulf Coast subregions. Each subregion consists of the following counties: Austin, Brazoria, Calhoun, Colorado, Fort Bend, Galveston, Harris, Jackson, Lavaca, Matagorda, Victoria, Waller and Wharton counties in the Lower Gulf Coast region; and Bowie, Chambers, Hardin, Jefferson, Liberty, Newton, and Orange counties in the Upper Gulf Coast region.

Over 60 canal systems were built during these early years of rice production in Texas, several of which remain in operation today. Many wells were also developed to supply groundwater. By 1902 10% of the rice acreage was irrigated using groundwater. The conditions in this area of Texas were ideal for rice production. As one author of the period put it:

> Rice must have an abundant supply of fresh water, and a soil that is rich enough to nourish the rice, and compact enough to hold the water. It is being successfully grown in Texas whenever the above factors are grouped; and money and brains are grouping them [in this area] with a twentieth century effectiveness. (Taylor 1902, p. 10)

By 1909 over 50% of all irrigated crop acreage in Texas was planted to rice (Texas

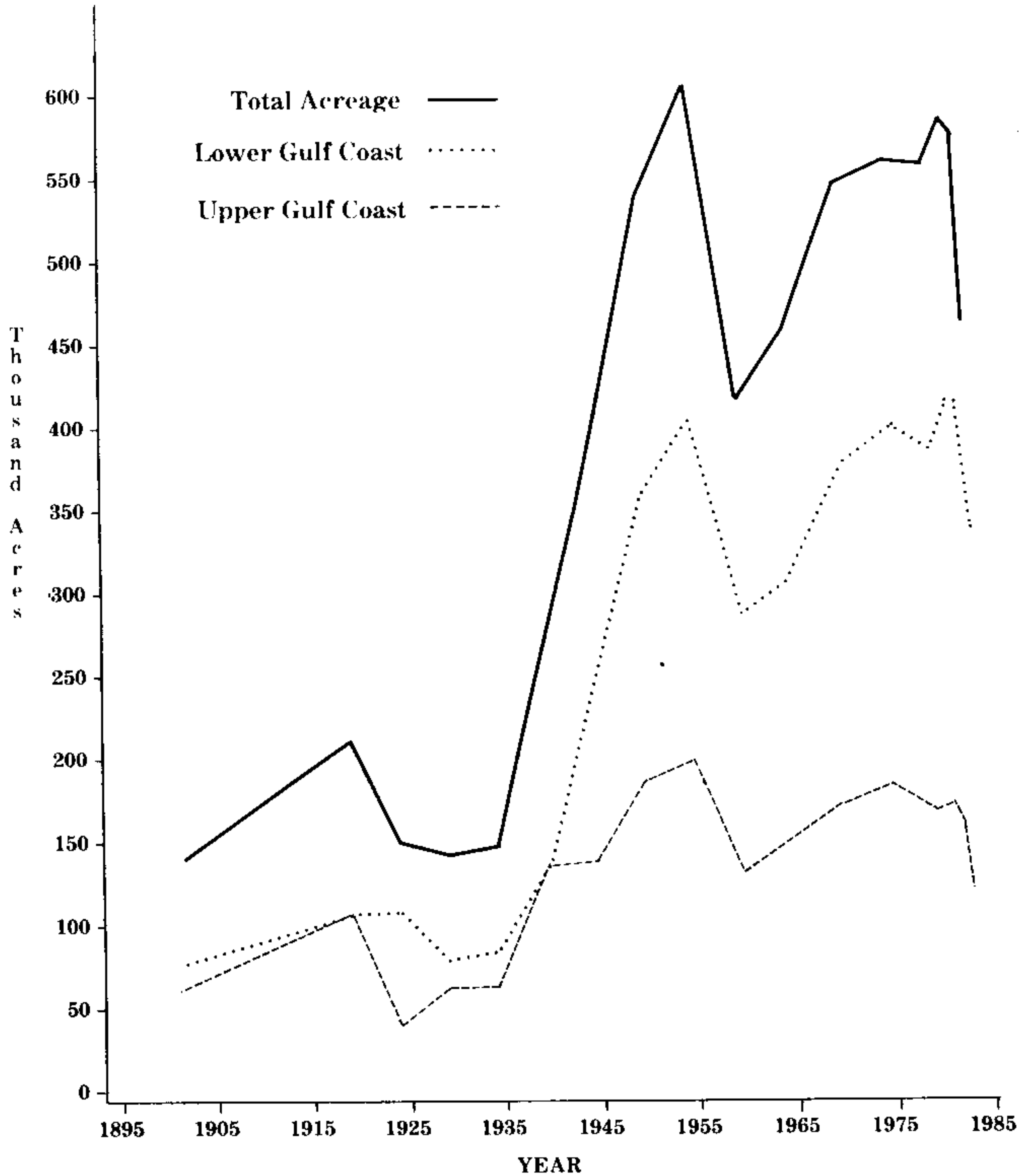

Figure 1. Harvested rice acreage in Texas, 1902-1982.

Department of Water Resources 1981a).

Rice acreage in Texas continued to increase until 1920, when 281,000 acres of rice were planted. Depressed farm prices after 1920 were largely responsible for a 20-year decline in rice acreage. Many of the major canal systems went bankrupt and were temporarily abandoned during this period. Rice acreage began to expand again in the early 1940's, particularly in the central and western portions of the Rice Belt. Some of this increase in acreage was due to the development of more efficient pumps which made groundwater a more economical water source (Texas Department of Water Resources 1981a). Some large canal systems were also built during this period.

Increases in rice acreage continued after World War II. By 1949 Texas had become the leading rice-producing state in the U.S., a position it continued to hold throughout much of the next 24 years. Rice acreage in Texas reached its peak in 1954 when 607,000 acres of rice were harvested. To prevent large crop surpluses, production controls and marketing quotas were imposed on rice producers throughout the U.S. beginning in 1955. Rice acreage declined sharply in Texas over the next several years as a result of the government actions. Marketing quotas were suspended in 1974, thereby causing great fluctuations in acreage from 1974 to the present. In recent years, low prices, high production costs, and new government programs have contributed to a large decline in Texas rice acreage (Holder and Grant 1979). In 1983 only 320,000 acres of rice were planted in Texas, the lowest acreage in production since 1941.

CURRENT PRODUCTION

Rice has been produced in at least 34 counties since its introduction to Texas in 1862. In 1982 production was located in 23 counties, with all but Bowie, Anderson, Franklin, Hopkins, and Newton Counties being located in the Gulf Coast Prairie region. This region is also known as the Texas Rice Belt. Figure 2 is a map indicating the 18-county area designated as the Rice Belt and those counties where rice was produced in 1982.

The Gulf Coast Prairie is a fairly level plain, varying in width from 30 to 80 miles. The area is humid, with rainfall averaging from 35 inches per year in Victoria to 60 inches in Orange on the Louisiana border (*Texas Almanac*). The growing season varies from 240 days on the eastern border to 300 days on the southwestern edge. The longer growing season in the western half often permits harvest of a ratoon, or second, crop of rice. The types of soils in which rice is generally grown are clayey or silt loam with a high clay subsoil. The clay subsoil is needed to minimize water percolation during flood irrigation. Typical crop rotations in the Texas Rice Belt include 1 year of rice and 1 year of grass, 2 years of rice and 2 years of grass, or 1 year of rice and 1 or 2 years of soybeans. Approximately 3.5 million acres of land are suitable for rice production on the Gulf Coast Prairie (Texas Water Resources Institute 1965), but only 560,000 acres were planted to rice in 1979.

Rice acreage in the 18 rice-producing counties for 1982 is reported in Table 2. Also indicated are the number of acres in each county being irrigated using surface water, groundwater, or a combination of both. Approximately 59% of the total acreage is irrigated using only surface water, 33% using only groundwater, and 8% using a combination

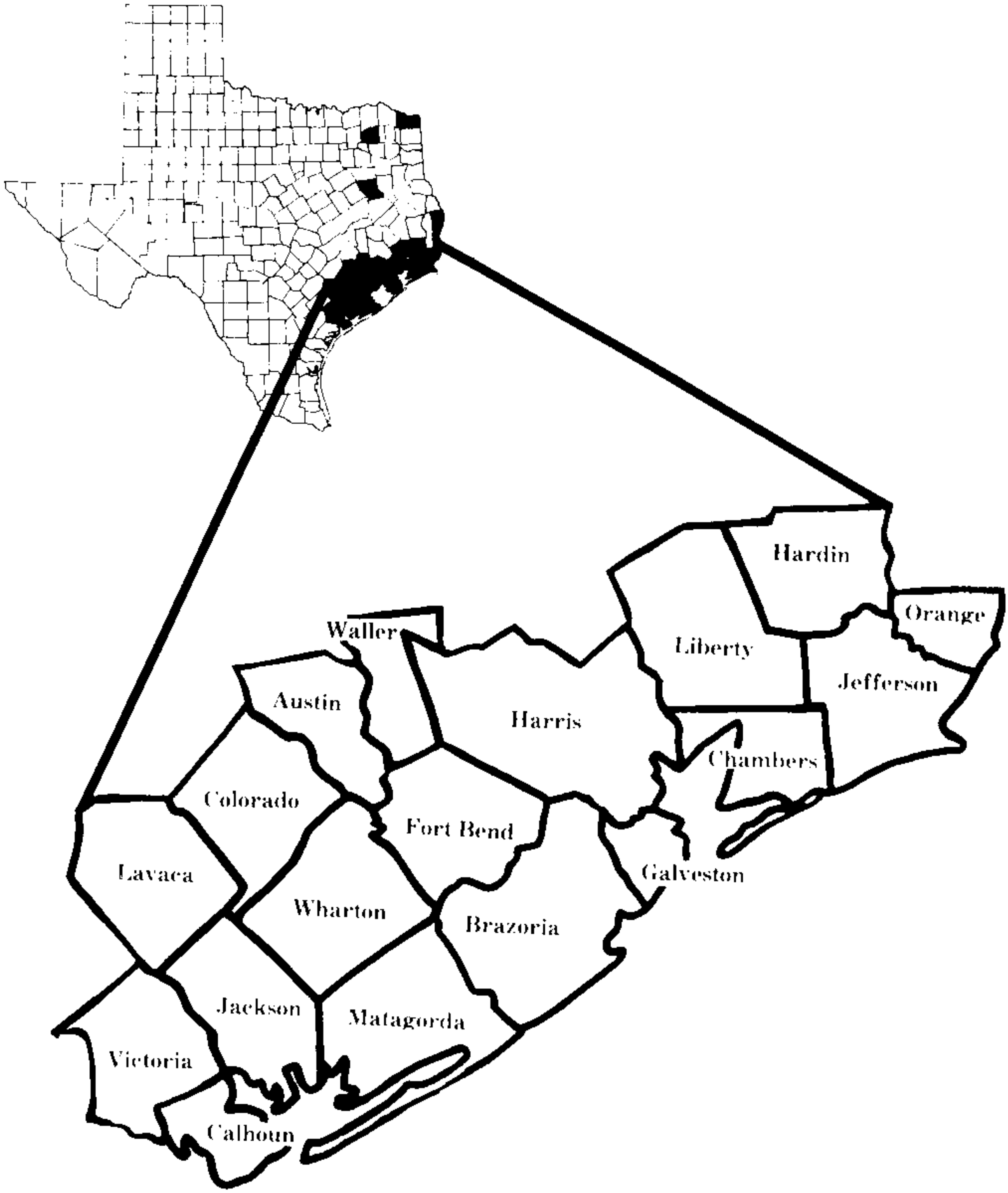

Figure 2. The Texas Rice Belt in relation to rice-producing counties .

of both sources. On average over 50% of the water used on the combination acreage is obtained from surface sources.

The most important surface water sources for rice irrigation are the Colorado, Trinity, Neches, and Brazos Rivers. Utilized for irrigation to a lesser extent are the Sabine, San Jacinto, Guadalupe, and Tres Palacios Rivers, as well as many other smaller rivers, streams, and bayous. Virtually all groundwater used in rice production is obtained from the Gulf Coast Aquifer (Texas Department of Water Resources 1983).

TABLE 2. IRRIGATION SUMMARY BY COUNTY FOR 1982 TEXAS GULF COAST RICE PRODUCTION

County	Surface Water Irrigation Only (Acres)	Groundwater Irrigation Only (Acres)	Irrigation Using Combined Supplies (Acres)	Irrigation Using Combined Supplies Surface Water (Percent)
Austin	0	2,916	1,084	10%
Brazoria	41,724	3,621	3,555	90%
Calhoun	7,622	4,678	0	-
Chambers	43,190	810	0	-
Colorado	33,261	11,155	384	30%
Fort Bend	6,555	4,945	0	-
Galveston	8,600	0	0	-
Hardin	0	1,600	0	-
Harris	2,202	12,766	2,932	30%
Jackson	0	32,687	4,113	10%
Jefferson	43,000	0	0	-
Lavaca	0	3,486	1,314	50%
Liberty	21,854	3,660	8,586	58%
Matagorda	32,998	9,645	5,657	80%
Orange	1,400	0	0	-
Victoria	0	5,300	0	-
Waller	0	10,006	3,494	20%
Wharton	33,529	37,937	8,434	29%
Total	275,935	155,212	39,553	46%

Source: Calculated from data reported in the Rice Water Management Study survey, based on county acreage figures obtained from the Texas Crop & Livestock Reporting Service (Humphries 1983).

WATER LAW AND INSTITUTIONS IN TEXAS

A review of the laws and institutions governing water use in Texas is useful in understanding the water situation in the Rice Belt. The legal right that each water-consuming entity holds varies greatly, depending on the source of the water, type of claim, age of the claim, and use of the water itself. Institutions, particularly water supply and management organizations, have a direct influence on water use, cost, and availability. While there are many institutions governing water use in Texas, the subsequent discussion will be limited to an examination of those laws that directly affect rice producers. Because institutions governing use of surface water differ greatly from those governing groundwater use, groundwater institutions will be examined later in this section.

SURFACE WATER LAW

Surface water is defined legally as "Water of ordinary flow, underflow, and tides of every river, and storm water, flood water, lakewater, and rainwater" (*Vernon's Texas Codes Annotated, Water Code* § 5.021). There are, in general, three types of surface water rights which historically have been legally recognized in Texas. The oldest legal rights are commonly known as the Spanish grants, because they are rights which were generally granted while Texas was under Spanish rule. These water rights were only assigned in connection with a land grant, and only those land grants which specifically mention water rights have rights which are legally recognized. The number of rights which date from Spanish land grants are few, most being in the San Antonio and El Paso areas (Basham 1982).

The Republic of Texas adopted the common law of England in 1840. The part of the common law dealing with water rights is known as the Riparian Doctrine. This law states that owners of riparian land, or land bordered or crossed by a stream, have a legal right to certain use of that water (Cox 1982). The water itself is not necessarily owned by the State under riparian law but is held in trust by the State for use by riparian landowners. The Riparian Doctrine is commonly used in the humid eastern states to settle legal questions dealing with water rights (Cox 1982).

The Spanish and riparian rights were adequate to deal with water controversies in Texas during much of the pre-Civil War era, due to the small demand for irrigation water. Gradually, however, dams and canal systems were developed to divert water onto nonriparian lands for irrigation purposes. To encourage further economic development, the legislature donated public lands for canal construction and sought to legalize claims on surface water made by canal operators. The result was the creation of a third type of water right, based on the Doctrine of Prior Appropriation, which was adopted by the Texas State Legislature in 1889 (Thompson 1960). This legislative act declared that all unappropriated water was the property of the State and a right to use state water was restricted to those who held approved permits.

The passage of the appropriative law immediately created a conflict with the riparian law, since the two laws were contradictory and incompatible (Caroom and Elliott 1981). Predictably, the riparian right was restricted over time in its applicability through a series of judicial opinions and legislative reforms. The State did not recognize any new riparian right water claims after 1895. In 1905, in the case of *Watkins Land Co.* v. *Clements,* the

Texas Supreme Court ruled that water utilized under riparian right was limited to domestic use, unless surplus water was available after the domestic needs of all other riparian water users along the stream had been satisfied (86 S.W. 733). Riparian rights were further limited in the 1926 case *Motl* v. *Boyd* to the "normal" flow of streams, which excluded flood flow (286 S.W. 458). Despite these rulings, some individual farmers have continued to use water for irrigation under riparian right (McNeely and Lacewell 1977).

Initially, priorities in appropriative rights were assigned according to the date of application ("first in time, first in right"). Beginning in 1931 a preference system was adopted which modified the priority system. Appropriative water rights have since been categorized and prioritized according to use as follows (§ 11.053):

(1) Domestic and Municipal
(2) Industrial
(3) Irrigation
(4) Mining
(5) Hydroelectric Power
(6) Navigation
(7) Recreation
(8) Other Beneficial Uses

Thus, a water right that is older can be superseded by a right which is higher on the preference scale. However, this can only be done by eminent domain condemnation and payment of compensation to the owner of the right being superseded (Cox 1982). In addition, any water appropriated after 1931 is subject to reappropriation by any city or town for domestic or municipal use *without* the need for compensation (§ 11.028). Approximately 94% of water appropriations in the Gulf Coast area have been dated since 1931 (Texas Department of Water Resources 1982a).

Ownership of a permanent water right can be transferred without loss of priority. That is, perfected water rights in Texas can be bought and sold independently of the land upon which these rights are exercised (§ 11.084).[1] Therefore, individuals possessing surface water rights may, depending on local or regional water scarcities and future economic development, own a valuable commodity. However, a water right can be cancelled by the Commission if it has been willfully abandoned during three successive years (§ 11.030) or has not been put to beneficial use at any time during a ten-year period (§ 11.173). These same rules apply to private and public water suppliers operating in Texas.

Adjudication

As applications for permits were processed and approved, little attempt was made to

---

[1] Changes in a permit, such as changes in location of use or changes from agricultural to industrial use, must be approved by the Texas Water Commission. In the case of a change in location, all senior water right holders which are intermediate to the old and new locations are notified of the prospective change in addition to a general public announcement (Basham 1983). In the event of protests, a hearing will be held by the Commission prior to approval or denial of the transfer (Schwartz 1983). Interbasin transfers are allowable, providing a permit has been issued from the Texas Water Commission allowing the transfer (§ 11.085). Such exchanges are not approved if it would cause stress in the originating basin within the next fifty years (Basham 1983).

verify whether the amount claimed was actually being used or if the water was even available to be used by the claimant. For example, Spanish, riparian, and appropriative rights in the Rio Grande Valley greatly exceeded the amount of water available during the drought of the 1950's. Since it was not clear who had preemptive rights to use the available water, the State filed suit against Hidalgo County Water Control and Improvement District No. 18 to prompt a court adjudication of water rights. *Adjudication* is a legal process whereby a court determines which claims of right are valid and which are invalid, and the amount of water the claimant is entitled to receive. After a decade in court and $10,000,000 in legal costs, the Lower Rio Grande water rights were adjudicated (Caroom and Elliott 1981). Recognizing that this controversy was a warning of things to come, the legislature passed the Water Rights Adjudication Act of 1967. This act gives authority to the Texas Water Commission to determine, with judicial confirmation, the nature and extent of surface water rights for each stream in Texas (§ 11.3). The constitutionality of the adjudication process was upheld in the case *Adjudication of the Upper Guadalupe River Segment of the Guadalupe River Basin* (625 S.W.2d 353).

As a first step in the adjudication process, the Department of Water Resources investigates a particular stream or stream segment and prepares a report which includes accurate mapping. The results of the report are then presented to the Hearing Examiners, who make an initial determination of water rights. If this initial determination is approved by the Commission, copies are sent to all those claiming rights, and hearings are held to air any objections. Upon completion of the hearings a final determination is made by the hearing examiners, again subject to the approval of the Commission. If there are no requests for a rehearing, this final determination is filed with a district court by the Attorney General. Should no objections be upheld in court the judgment becomes final and certificates of adjudication can then be issued by the Commission to all water users in the adjudicated area. Once a river basin has been adjudicated, only persons or entities holding certificates have a legal right to use surface water (Basham 1982).

It is important to note that the process of adjudication makes no attempt to determine how much water is available for use; rather, its purpose is to determine who has a legal right to water, and the priority of that right relative to other rights. It is possible that the total amount of water permitted to be used under adjudication in a basin may exceed the amount of water available. Currently, all river basins in the Rice Belt are at some stage of the adjudication process (Basham 1982).

SURFACE WATER MANAGEMENT INSTITUTIONS

Many public and private institutions have important roles in the management and use of surface water in the Texas Rice Belt. To better understand their roles it is useful to examine each of these institutions in more detail. The subsequent discussion is divided into two major parts; the first part deals with the Texas Department of Water Resources and the second considers surface water suppliers. While the TDWR is not directly involved in supplying irrigation water to farmers, it has an important influence on future water availability. Following a brief discussion of the TDWR's responsibilities, each of the 16 major canal systems serving Texas rice producers will be highlighted.

Texas Department of Water Resources

After adopting the Appropriative Doctrine in 1889, the legislature passed the Irrigation Act of 1895. This act gave a person permission to use state water by filing an affidavit with the county clerk detailing his intended use (TDWR 1983). Due to increasing demands and the consequent conflicts it was soon necessary for the state to assume a more active role in the management of surface water. In 1913 the state legislature created the Board of Water Engineers to "approve the appropriations, storings, and diversions of the state's waters" (Thompson 1960). The duties and responsibilities of this board were expanded over time and additional agencies were created to deal with other aspects of water use in Texas. The legislature created the Texas Department of Water Resources in 1977 to consolidate the various water agencies into one department. The TDWR is an administrative agency of the state, active in formulating and implementing water policy. In 1979 the department had a staff of 887 persons and spent $23.8 million to carry out its legislative mandates (TDWR 1979). The department is administratively divided into three units, which serve functions similiar to the legislative, executive, and judicial branches of state government (§ 5.012). Each branch is discussed in more detail below. While these units have many duties and responsibilities, only those pertinent to agriculture in the Gulf Coast area will be discussed.

Texas Water Development Board

The Texas Water Development Board (TWDB) represents the legislative branch of the TDWR. The board, appointed by the governor and confirmed by the senate, is comprised of six members who serve for staggered terms of six years. The board chairman is designated by the governor. The board's most important function is to "establish and approve all general policy of the department" (§ 5.132). The board approves all budget recommendations to the legislature and all agreements entered into by the Executuve Director. It can create and consult with various types of advisory councils to assist in carrying out its functions. The board also provides for issuance of Water Development Funds to be used in the acquisition and development of water storage facilities and water quality enhancement projects (TDWR 1981b).

The Executive Director

The Executive Director is appointed by the board to manage the administrative affairs of the department. He represents the department at hearings and contract negotiations. His office handles the processing of applications, petitions, and other documents, and the execution of rules, orders, and decisions implemented by the department (§ 5.179). He is also responsible for the preparation and formulation of a comprehensive state water plan (TDWR 1981b). The Executive Director is given responsibility to organize the TDWR staff in an efficient manner. He also appoints Watermasters over river basins that have been adjudicated.

Texas Water Commission

This commission consists of three members from different parts of Texas. The Commissioners, like the TWDB members, are appointed by the governor to staggered terms of six years. The Commissioners serve as the judicial arm of the department. The Commission is the issuing agency, having final authority for various types of permits, the most important of which (for our purposes) are permits to use state water. After the permits are processed by the department, they are referred to the Commission for final action. The Commissioners then hold a hearing to receive input on the permit applications after which a written decision of approval or denial is given. The Commission is also responsible for adjudication of water rights and oversees the actual adjudication work carried out by the Office of Hearing Examiners.

The Office of Hearing Examiners works exclusively under the direction of the Texas Water Commission. The office consists of three lawyers (and their assistants) who handle much of the daily work in the adjudication process, and make recommendations to the Commission concerning each water right being adjudicated.

Irrigation Water Suppliers

Following adjudication, all surface water users must possess a certificate of water right to be able to use water legally. For some farms the source of water is a nearby bayou or stream. In these cases the farmer himself will frequently possess a legal right to withdraw surface water. However, for most rice producers using surface water, the source of irrigation water is a canal system which is operated by a public or private concern. These concerns hold the legal right to use surface water, and they charge a price for delivering water to each farm serviced by the canal system. Although many canal systems have been developed since rice farming began in Texas, the following discussion concentrates on 16 major private companies and public entities which currently supply surface water to rice producers. Seven are state agencies (river authorities), one is a navigation district, one is a municipality, and seven are private canal companies. These suppliers provided 84% of all the surface water used for rice production in Texas in 1979 (TDWR 1982a). One of the private canal companies was acquired recently by one of the river authorities. An overview of the management and historical background for these 16 entities is given below.

Public Water Suppliers

Seven of the nine public water suppliers are river authorities. River authorities had their beginning in 1929 when the Texas State Legislature created the Brazos River Conservation and Reclamation District. These "conservation" districts as originally conceived were an attempt to create a governmental unit that would assume an overall, basin-wide perspective, as well as the authority to develop and conserve the water and soil resources of the basin (Thompson 1960). Indeed, the bill creating the Brazos River Conservation and Reclamation District indicated the district's purpose was to "provide for the conservation and development of all the natural resources ... including the control, storing, preservation, and distribution of storm and flood waters ... for irrigation, power, and all other useful purposes" (Texas House of Representatives 1929).

River authorities have broadened their responsibilities over time to include water quality control and development of recreational facilities. In general, the authorities cannot raise revenues through taxation. Rather, they depend upon support from counties and sales of electrical power and/or water to cover expenses. Due to their state agency status, river authorities are prohibited by law to make a profit; this does not prohibit authorities from using excess revenues to acquire new capital. It is important to note that the authorities can issue bonds and are tax-exempt; thus, they possess some comparative advantages over their private sector counterparts.

River authorities represent a sort of middle level of government, since their jurisdictions typically include multi-county areas. Those authorities serving less than 10 counties are subject to the supervision of the Texas Department of Water Resources (§ 12.081). The larger river authorities are more independent of the TDWR and at times have even been at odds with the TDWR over various policies (Thompson 1960). Despite this greater independence, all river authorities must hold water permits with the TDWR, must report annual water use, and are subject to the legal powers vested in the TDWR with respect to water rights (Schwartz 1982).

River authorities have developed new water sources through construction of reservoirs and have purchased rights to water already in use by others. As a result, the river authorities own the surface water rights to over half of the water used by agriculture in the Rice Belt area. By contrast only 6% of the total surface water withdrawals made in 1982 for nonagricultural use in the Texas Rice Belt area were made by river authorities (TDWR 1982a). A brief history concerning each river authority serving rice producers follows below.

Brazos River Authority

The Brazos River Authority (BRA), initially called the Brazos River Conservation and Reclamation District, was the first river authority created in the state of Texas (1929). It is also the largest river authority, with boundaries stretching from the New Mexico border on the west to the Gulf of Mexico and with jurisdiction over surface water in all or part of 65 counties.

The BRA operates two canal systems serving rice producers in Fort Bend and Brazoria Counties. The American canal begins at a point above Richmond and moves water approximately 70 miles to Texas City. This particular canal was built in 1908 and was sold to the BRA in 1967. The Briscoe canal, approximately 40 miles in length, parallels the American canal. It was built in 1941 and was also sold to the BRA in 1967.

Both canals were built initially to deliver water to rice farmers in their respective areas. Since World War II, the BRA also has been selling water to industrial users. Currently, industrial water demand accounts for approximately 50% of all water consumed within the two canal systems. Water supplies to these two canal systems are obtained from natural river flow and releases from some of the 12 reservoirs operated by the Authority for water supply purposes (Shannon 1983).

Guadalupe-Blanco River Authority

The Guadalupe-Blanco River Authority (GBRA) was created in 1935 by an act of the Texas Legislature and includes within its district all of the counties (except Kerr County) that are in the watersheds of the Guadalupe and Blanco Rivers. The GBRA is involved in several facets of water resource development and use, including hydroelectric power generation, irrigation, water supply and treatment, soil and water conservation, wastewater treatment, and recreation.

In 1963, the GBRA purchased the Calhoun Canal System from the West Side Calhoun

County Navigation District. This canal system was constructed during 1946–48 when rice production was first introduced into Calhoun County. Industrial and municipal concerns also began using water from the canal system after its acquisition by GBRA. In 1982, industrial and municipal use accounted for 21% of the total water delivered by the Calhoun Canal Division.

Canyon Dam and Reservoir, located in Comal County, is presently the only major water conservation and storage reservoir operated by GBRA. It was constructed in cooperation with the U.S. Army Corps of Engineers. At the present time, all of GBRA's municipal customers and most of its industrial customers have contracted for stored water from the reservoir. Because of the relatively high cost of this water, rice irrigators in Calhoun County are not presently contracting for water from Canyon Reservoir (Wittliff 1982).

Lower Colorado River Authority

The Lower Colorado River Authority (LCRA) was formed in 1934, consisting of the 10 lower counties on the Colorado and Pedernales Rivers. LCRA operates six dams on the Colorado River, which are used to generate electricity and for flood control. In addition, the LCRA operates three fossil fuel-powered electricity generating plants. The authority supplies electricity to approximately 900,000 people in 41 Central Texas counties. The LCRA is also a major supplier of municipal and industrial water in its service district and operates several recreational parks which are located along the reservoirs which it operates (LCRA 1982).

During the early 1900's, approximately 28 canal systems were developed along both sides of the Colorado River in Matagorda County. These 28 systems were eventually consolidated into 12 systems, each of which was purchased by V.L. Letulle during the 1930's. The 12 systems were united to form the Gulf Coast Canal Company. This company was eventually sold to the LCRA in 1960. The current canal system contains approximately 374 miles of main line canal and laterals, with water fed into the system from three pumping stations located along the Colorado River. The LCRA has recently expanded its jurisdiction over water used for rice production by purchasing Lakeside Irrigation Company.

Lower Neches Valley Authority

The Lower Neches Valley Authority (LNVA) was created in 1933. It has authority over the Neches River and its tributaries in Jefferson, Hardin, Tyler, Liberty, and Chambers Counties. In 1943, LNVA purchased its current canal system of four pumping plants and over 300 miles of canal from Texas Public Service Company. The system has since been expanded to include over 400 miles of distribution canals. Parts of this canal system have been in operation since before 1900.

Approximately 75% of the water used by the canal system is withdrawn from the Neches River, with the remaining 25% coming from Pine Island Bayou. Approximately 60% of water use is for agriculture, with 35% being used by industry and 5% allocated to municipal use. The authority, in cooperation with the U.S. Army Corps of Engineers, has also built Town Bluff and Sam Rayburn Dams to conserve excess water for periods of low flow (Harris 1982).

Sabine River Authority

The Sabine River Authority (SRA) was created in 1949, encompassing all or part of 21 counties on the eastern border of Texas. The SRA purchased the Orange County Water Company in 1954. This canal system was built during the Great Depression by the Works Progress Administration to supply water for rice production. Since its construction, agricultural water use has slowly declined in the canal system area and has been replaced by industrial water use. Currently, only about 14% of water deliveries are for rice production. An increasing amount of rice acreage has been converted in recent years to the production of crawfish.

The canal system consists of 40 miles of main line canal with an additional 40 miles of laterals. The SRA also operates the Toledo Bend, Lake Fork, and Iron Bridge Dams for conservation, flood control, and hydroelectric purposes (Perry 1982).

San Jacinto River Authority

The San Jacinto River Authority (SJRA) was formed in 1937. It comprises all territory within the watershed of the San Jacinto River except the portion of the river that lies in Harris County. After World War II the SJRA purchased a canal system that delivered water from Lake Houston to water users located along the eastern side of the San Jacinto River in Harris County. This canal system, which has earthen levees with concrete syphons and headwalls, was built during World War II by the federal government to deliver water for wartime industrial use.

Although the principal purpose of the canal has always been to deliver water to industrial customers, several rice farmers also purchase water from the SJRA for irrigation purposes. In 1982, approximately 5% of water deliveries were to rice farms. Because the amount of rice acreage on their system has always been small, the SJRA prices water on a volumetric basis. Suburban growth from nearby Houston in recent years has resulted in a decline in rice acreage available for production. The SJRA expects that this decline will continue, with rice farming eventually being phased out on their system. The SJRA also operates the Lake Conroe Dam and Reservoir (Barrett 1982).

Trinity River Authority

The Trinity River Authority (TRA) was formed in 1955 and consists of all or parts of 17 counties in the Trinity River watershed. It currently is the only river authority which can levy property taxes. The TRA, in conjunction with the City of Houston, owns and operates the Lake Livingston dam and reservoir on the Trinity River. Although TRA serves many industrial and municipal customers on the upper end of the Trinity River, approximately 90% to 95% of all water withdrawals on the lower part of the river are for agricultural use.

In about 1900, several thousand acres of land were purchased, and a canal system was built from the Trinity River to the Raywood area in Liberty County. Following its creation, the developers sent representatives to Minnesota seeking farmers who were willing to move to the Raywood area and farm rice. The venture went bankrupt soon afterwards although the canal system continued in operation. After changing hands several times, the canal system was purchased by E.W. Boyt in the 1920's. The system, renamed the Devers

Canal Company, remained in the Boyt family until 1969 when it was purchased by the TRA.

Following the purchase of the Devers Canal Company by TRA, rates were raised approximately 30% to finance the debt incurred by TRA when the canal was purchased. Because of the large increase in rates, local farmers filed suit with the Texas Water Commission, charging that the new rates were unfair. After a hearing the Commission ruled the rates were fair but water use was wasteful. The TWC ordered TRA to implement a metering system and to price water on a volumetric, rather than per-acre, basis. Water has been sold by the acre-foot since 1973. The current canal system consists of 81 miles of main canal and 125 miles of laterals (Walter Clark 1982).

In addition to the seven river authorities, two other public institutions supply water for irrigation purposes in the Gulf Coast region. Summary information on these two public institutions is presented below.

Chambers-Liberty Counties Navigation District

Navigation districts are organized to improve streams, to construct and maintain canals or waterways, to permit or aid navigation, and to issue bonds to finance these improvements (§ 61.111). These districts are under local rather than state supervision and are governed by a board of three commissioners. As is the case with river authorities, the navigation district's objective is to serve the public while being economically self-sufficient.

The Chambers-Liberty Counties Navigation District (CLCND) was organized in the 1940's. The district soon acquired the Lone Star Canal Company which was originally established in 1902. As was the case with many canal companies, Lone Star fell on hard times during the 1920's and was unable to continue operations after 1927. In 1932, four men purchased the canal and resumed operations, again under the name Lone Star Canal. The canal was sold to the CLCND in 1947.

Currently, the CLCND operates approximately 100 miles of main line canal in Chambers and Jefferson Counties. Approximately 60% of the water withdrawals are obtained from the Trinity River and the remaining 40% are from White's and Turtle Bayous. Industrial and mining uses currently account for only 2% of total water withdrawals (Warren Clark 1982).

The City of Houston

The City of Houston operates a municipal water district to supply water for industrial and household use within its area of jurisdiction. To improve its service abilities and to ensure a continued water supply in the future, the city purchased two canal systems, known as the West canal and the Southern canal.

The West canal is a sister canal to the canal system operated by the SJRA. This canal delivers water to industrial users on the west side of the San Jacinto River. The city purchased the canal system and its associated water rights from the federal government following World War II. Only 2% of the water delivered in this canal system goes to agricultural users. Much of the remaining amount is used for domestic consumption.

The Southern canal was developed during 1902-1904 to serve rice farmers in western Chambers, southern Liberty, and eastern Harris Counties. It was purchased by the City of Houston in cooperation with the Coastal Industrial Water Authority (CIWA) in 1975. Although the water rights are owned by the city, much of the maintenance and management of the canal system is handled by CIWA. Industry is the predominant water user on the Southern canal, accounting for almost 60% of all water withdrawals. Much of the water used is obtained from the Trinity River and is delivered to the system by way of the CIWA canal system (Seward 1982).

Private Water Suppliers

Seven major private companies delivered water for rice production in the Gulf Coast region during the 1982 crop year. Although the number of acres served varied widely (3,200 to 30,000 acres), most of the companies had several things in common. All the private canals have existed for 50 years or more and most date back to the early 1900's. Most have been owned by the same family for generations. Almost all of the private canal company owners also own rice acreage, and some supply water as part of sharecrop tenure agreement. Only a few of the seven companies serve industrial users.

While only the seven largest private companies will be discussed below it is worth noting that there are several other smaller canal systems that sell some of their water to other rice farmers. Among these are Lovell Lake Canal Company and J. H. Taylor of Jefferson County, and the Tigner and Farrer Irrigation Company and Henry Munson Estate of Brazoria County.

Chocolate Bayou Water Company

Chocolate Bayou Company was created in 1969 through a merger with Houston Farms. Chocolate Bayou purchased the South Texas Water Company in 1973. The company, in combination with the canal system already owned by the company, was organized as the Chocolate Bayou Water Company (CBWC). The CBWC and its subsidiaries are currently owned by I.P. Farms, Inc.

Chocolate Bayou Company is a vertically integrated company involved in rice research, production, and marketing. The company owns about 53,000 acres which is generally farmed in a 50% sharecropping arrangement with local farmers. Only about 13,000 acres were used to produce rice in 1982, with water for this acreage supplied by the CBWC. Some water is also purchased from Brazos River Authority and resold to rice producers on the CBWC system.

Approximately 75% of the water used by the CBWC is obtained from the Brazos River, with the remaining 25% coming from the Chocolate Bayou. The company operates approximately 75 miles of main canals and 150 miles of laterals. Industrial use accounts for about 5% of all water withdrawals (Holesovsky 1983).

Dayton Canal Company

Shortly after 1900 a few men representing the combined interests of numerous landowners in the southwestern part of Liberty County initiated a feasibility study of the potential for irrigated crops in the area. After selecting a diversion point on the Trinity

River, a gravity flow irrigation system was platted. The proposal for the system was approved and water deliveries began in 1910. However, damage from a hurricane combined with low rice prices caused water deliveries to be terminated after 1919.

A group of rice producers purchased the canal system and resumed operations in 1936. Ownership and operation of the canal system is currently in the hands of the Dayton Canal Company, a wholly-owned subsidiary of American Rice Growers Cooperative Association, Dayton Division (ARG-D). In addition to operating the canal system, the ARG-D leases approximately two-thirds of the acreage served by the canal system and, in turn, farms this acreage in a sharecropping arrangement with its co-op members (McQuhae 1983).

Farmers Canal Company

Located on the Tres Palacios Creek and only a few miles from the Tres Palacios Bay, Farmers Canal Company, in Matagorda County, is a unique canal system in some respects. The Cooperative Canal Company was organized in 1909 to develop a canal system for rice irrigation. A canal system was constructed soon afterwards and rice production commenced. Salt intrusion from the bay into the creek in 1911 forced the company to suspend pumping. As a result, the crop failed that year and the cooperative went bankrupt. The Farmers Canal Company Corporation was formed in 1913 and purchased the canal system. The Trull family eventually bought out the other stockholders. The canal company has been owned by the Trull family since 1932.

The Tres Palacios Creek has a very small watershed of about 40 miles in length. Therefore, the system is highly dependent on summer rainfall to maintain sufficient flow in the creek for irrigation use. Because the canal's pumping station is located along a low gradient of the creek near the river mouth, water can be pulled upstream by the canal company's pumps when downstream flow is not sufficient for irrigation demands. Water samples are taken periodically when water is being pulled upstream to avoid pumping water with high salt content into the canal system. The canal system also has nine wells that are used to supplement water supplies during peak demand periods. These wells generally provide about 10% of total water supplies used during a production year.

Garwood Irrigation Company

In November 1900, construction began on a canal system just north of Garwood in Colorado County. Initially named the Red Bluff Rice Company, the system is now known as Garwood Irrigation Company. William S. Lehrer and son purchased the canal company in about 1920. Since that date the company has remained under the ownership of the Lehrer family. Since its creation the Garwood Irrigation canal system has continued to expand. Currently, it operates over 200 miles of canals. The pumping plant was moved in 1941 from its original site near Garwood to its present site, several miles farther upstream.

Water for the canal company is obtained from the Colorado River. Approximately two-thirds of the water used by the company is purchased from the LCRA. The company built a small dam across the river in 1980 to ensure a sufficient river depth for pumping at the withdrawal site (Lehrer 1982).

Lakeside Irrigation Company

In 1899 Captain William Dunovant irrigated 250 acres of rice near the town of Eagle Lake in Colorado County. The results were so successful that several canal systems were built in the area the following year. In particular two systems were built in the Eagle Lake area, one by Captain Dunovant and the other by the Eagle Lake Rice Company. Both systems were under the ownership of O.J. Wintermann by 1910. Ownership of the entire canal system remained in the Wintermann family until after the 1982 crop year, when it was sold to the LCRA.

Lakeside Irrigation pumps water from the Colorado River into Eagle Lake. A pumping plant on Eagle Lake then pumps water into part of the 300 miles of canals operated by the company. There is also a relift plant north of Eagle Lake that furnishes water for approximately one-third of the total acreage irrigated each year. Although Lakeside owned some water rights, most water was purchased from the LCRA in accordance with a contract which was enacted in 1937 (Davidson 1983).

Pierce Ranch

Abel Head "Shanghai" Pierce arrived in the Gulf Coast area in 1853 and over the next 20 years built a cattle empire consisting of tens of thousands of acres and thousands of head of cattle. At one time his holdings stretched from Columbus, Texas to the Gulf of Mexico. Shanghai died in 1900 and the Pierce Estate, as it was called, remained intact until 1956 when the surface interests were divided among his heirs. One part of the Estate has come to be known as Pierce Ranch, located in Wharton County.

A pumping plant and canal system were constructed on the current ranch shortly after Shanghai Pierce's death and was originally designed to irrigate up to 50,000 acres. About 50 miles of canal are currently operated by Pierce Ranch. The ranch produces several thousand acres of rice as well as soybeans, corn, and grain sorghum.

Although Pierce Ranch owns all of the irrigated acreage, the land is farmed under a sharecropping system. Water is provided at no charge to the producer as part of the sharecropping agreement (Armour 1982).

Richmond Canal Company

The Richmond canal system, located in Fort Bend County, was developed by William S. Lehrer in 1927. After a few years of operation the canal was sold to the Richmond Rice Association cooperative. This cooperative held ownership from 1944 to 1977 at which time the cooperative was dissolved and reorganized as a partnership named Richmond Irrigation Company, Ltd. Part of the system was purchased by Houston Lighting & Power Company to supply water to their Smithers Lake Power Plants.

The Richmond Irrigation Company operates a relatively small system consisting of approximately 30 miles of main line canals and 20 miles of laterals. The water source for the system is the Brazos River. Industrial use constitutes approximately 50% of total water withdrawals. It is expected that water use for rice production in the area will continue to decline and industrial use will increase since the Richmond area is being rapidly absorbed into the Houston metropolitan area. The land served by the company is leased from local and out-of-state landowners and is farmed in a 50% sharecrop arrangement (Schlicher 1982).

GROUNDWATER LAW

Groundwater is defined in the State Water Code as "Water percolating below the surface of the earth ... but does not include defined subterranean streams or the underflow of rivers" (§ 52.001). Presently, the Absolute Ownership Doctrine is recognized as the legal definition of groundwater ownership in Texas. This doctrine is based on the concept that each landowner has complete ownership and control over water beneath his land just as he does in the case of other natural resources (Cox 1982). This right includes freedom to exploit this water resource, if the use is not wasteful[2], regardless of the effect one person's water use has on neighboring water users (*Pecos County Water Control and Improvement District No. 1* v. *Williams*, 271 S.W.2d. 503). The Absolute Ownership Doctrine evolved when little was known about water behavior in underground reservoirs (Cox 1982). Since most of the underground reservoirs in Texas are only slowly replenished by percolation, water withdrawals have caused a gradual depletion of aquifers throughout Texas.

GROUNDWATER MANAGEMENT INSTITUTIONS

In response to demands that something be done about groundwater problems, the legislature passed the Underground Water District Act of 1949. This legislation provides for creation of districts covering all or parts of major underground aquifers which exist throughout the state. The districts can be created by one of two methods (§ 52.021). One way is by legislative mandate at the state level. The second and most common method used is initiated by the Texas Water Commission. The Commission undertakes a study of a particular aquifer. Public hearings are then held to determine how groundwater is used within the area served by the aquifer. Following this hearing the Commission attempts to delineate subregions served by the aquifer, based on cropping patterns and political and geological boundaries. After a region is outlined, another hearing is held to determine whether the region's residents desire that an underground water district be created. If there is sufficient interest in creation of the district, a temporary board of directors is appointed by the Commission, and elections are scheduled to ratify creation of the district and to approve a tax levee.

The districts are given authority to require permits for any new wells drilled within district boundaries (§ 52.112) and to regulate new well spacing and production (§ 52.117). They are also empowered to regulate wasteful use of water pumped from wells drilled prior to creation of the district (§ 52.101). The majority of the underground water districts currently in operation are located over parts of the Ogallala Aquifer in northwestern Texas.

---

[2] "Wasteful" water use as defined in Section 52.001 of the Texas Water Code means water produced that is not used for a beneficial purpose or water which is allowed to escape from the land of the well owner.

It is generally agreed that, despite the limitations of these districts, they have been successful in slowing the depletion of aquifers and the subsidence of land. The districts have also been useful in the dissemination of water conservation information to water consumers. In fact, in a recent study for the governor, it was recommended that: (1) the state develop and enforce rules regulating the withdrawal of groundwater in areas where local people have chosen not to organize districts; and (2) that water used in areas currently being regulated by districts be exempt from such state regulation (Massey 1982).

Harris-Galveston Coastal Subsidence District

During the past 75 years, extensive pumping of groundwater from the aquifer in the Houston metropolitan area has caused water levels in some areas to decline more than 400 feet. One of the effects of this water withdrawal has been land subsidence, which is the sinking of the land's surface due to compaction of the underground water-bearing formations. In parts of the Houston area land subsidence in excess of 9 feet occurred from 1906 to 1978. The result of subsidence has been to render the already flat terrain more susceptible to temporary flooding, permanent inundation, and storm surge during periods of high rainfall (Harris-Galveston Coastal Subsidence District 1982).

To better combat the subsidence problem, the legislature created the Harris-Galveston Coastal Subsidence District in 1975 to "provide for the regulation of the withdrawal of groundwater . . . for the purpose of ending subsidence . . ." (Texas House of Representatives 1975). The district has jurisdiction over all groundwater usage within the borders of Harris and Galveston Counties. It is currently the only underground water district in operation in the Texas Rice Belt.

The subsidence district requires that all well owners have a permit from the district stipulating the amount of water that can be withdrawn from each well in operation. These permits must be renewed every 5 years and are revocable. The board of directors which oversees operation of the subsidence district may also, after a hearing on the subject has been held, reduce permitted levels of groundwater withdrawal from any particular well.

To finance operation of the district and to further encourage water conservation, the subsidence district levies a fee based on the amount of water withdrawn from each well. In 1982 this amount was $3.50 per one million gallons for agricultural users and $5.00 per one million gallons for municipal and industrial users (one million gallons equals 3.07 acre-feet).

The subsidence district has also encouraged industrial water users to convert to the use of surface water whenever possible. As a result, groundwater accounted for 49% of total 1981 water consumption for the two counties involved, down from 62% just 5 years previously. These groundwater conservation measures have combined to greatly reduce subsidence rates in the eastern half of the district. Subsidence problems continue to exist in the western half of Harris County (Wilkinson 1983).

SURFACE WATER USE

Surface water withdrawals by all water users in the 18-county area comprising the Texas Rice Belt amounted to over 2.7 million acre-feet in 1980, or 68% of all surface and groundwater withdrawals. While most of the surface water used is obtained from major rivers, there are also bayous, public and private reservoirs, streams, and drainage ditches that serve as important sources of water.

AGRICULTURAL SURFACE WATER USE

Agriculture accounted for 60% of all surface water diverted in the Rice Belt during 1980. Virtually all of this water was used in rice production. Surface water was the sole source of water for 59% of the rice acreage in 1982, with an additional 8% of the acreage served by a combination of surface and groundwater. Large acreages of rice were irrigated using surface water in Brazoria, Chambers, Colorado, Jefferson, Liberty, Matagorda, and Wharton Counties. Table 2 on page 15 presented a summary by county of acres served by surface water, groundwater, or combination of the two sources.

The 16 largest canal systems supplied water to approximately 80% of all rice acreage using surface water in 1982. A summary of information concerning these suppliers, including 1982 water withdrawals and first crop acreages, is given in Table 3. Withdrawals varied from 2.6 to 7.4 acre-feet per acre, with an average of 5.4 acre-feet per acre. Several factors are responsible for the large variation in withdrawals among systems including system size, management, irrigation practices, delivery costs, and legal constraints. The Colorado River is the single most important surface water source, supplying over 600,000 acre-feet of water in 1982.

When examining the maximum serviceable acreage figures shown in Table 3, it is easy to delineate three subgroups within the table: those systems having a capacity above 30,000 acres, those systems with capacity between 20,000 and 30,000 acres, and those systems with a capacity of less than 10,000 acres. The reason why such a large gap exists between the medium and small systems is not clear. One casual observation about the third group is that it consists of (1) public suppliers which obtain a substantial portion of operating revenues from industrial water sales and (2) private companies which are used as a service arm to deliver water to land the company also owns or operates. Several managers of both public and private suppliers in this third group commented during the personal interviews that the agricultural irrigation portion of their systems was losing money. In general, public suppliers in this third group tend to view agriculture as a "sideline" business to their principal purpose of supplying water to industrial and municipal water users. The private companies in this third group tend to view their canal systems as complementary to their farming operations.

Private Rights

Water diverted under privately owned surface water rights was used to irrigate approximately 62,000 acres of land in 1982. This acreage is decomposed by county in Table 4. Survey results from Calhoun, Fort Bend, Galveston, and Victoria Counties did not indicate any acreage irrigated using private rights. They were therefore not included in the "Others" category.

TABLE 3. WATER WITHDRAWALS AND ACREAGE SERVED IN 1982 BY PRINCIPAL CANAL SYSTEMS

Canal System	Counties Served	Water Withdrawals (Acre-feet)	First Crop Rice Acreage (Acres)	Water Source(s)	Maximum Acres Serviceable[a]
Lower Neches Valley Authority	Jefferson Chambers Liberty	235,231	36,763	Neches River, Pine Island Bayou	70,000
Lower Colorado River Authority	Matagorda Wharton	289,625	39,310	Colorado River	42,000
Chocolate Bayou Water Company	Brazoria	145,915	30,373	Brazos River, Chocolate Bayou	38,000
Brazos River Authority	Brazoria Galveston	66,500	17,489	Brazos River	28,500[b]
Lakeside Irrigation Company[c]	Colorado Wharton	139,325	27,232	Colorado River	28,000
Trinity River Authority	Liberty Chambers Jefferson	54,504	18,900	Trinity River	25,000
Garwood Irrigation Company	Colorado Wharton	129,271	23,188	Colorado River	24,000
Chambers-Liberty Cos. N. D.	Chambers	82,965	16,671	Trinity River	23,500
Dayton Canal Company	Liberty	33,389	8,178	Trinity River	9,600
Guadalupe-Blanco River Authority	Calhoun	47,846	7,647	Guadalupe River	9,000
City of Houston	Chambers Harris Liberty	10,937	4,147	Trinity River	7,500
Richmond Irrigation Company	Fort Bend	25,183	6,200	Brazos River	7,100

(continued)

TABLE 3. (CONTINUED)

Canal System	Counties Served	Water Withdrawals (Acre-feet)	First Crop Rice Acreage (Acres)	Water Source(s)	Maximum Acres Serviceable[a]
Pierce Ranch	Wharton	42,797[d]	4,816	Colorado River	7,000
Farmers Canal Company	Matagorda	16,210	3,206	Tres Palacios River, Groundwater	3,300
Sabine River Authority	Orange	7,129	1,348	Sabine River	2,000
San Jacinto River Authority	Harris	2,991	947	San Jacinto River	2,000
TOTAL		1,329,818	246,415		334,000

[a]As estimated by respective system based on water supplies and maximum acreage expected to be planted to rice in any particular year.
[b]Brazos River Authority could not estimate a maximum acreage figure but felt that it was less than acreage served in 1978 (28,500 acres).
[c]Purchased by the LCRA in 1983.
[d]Includes water used to irrigate approximately 1000 acres of other crops.

Sources: Public information obtained from surface water use reports filed with the Texas Department of Water Resources (Buckingham 1982). Maximum acres serviceable obtained during interviews conducted with representatives from each of the systems represented.

Further analysis of this information illustrates a sharp contrast between the eastern and western parts of the Rice Belt. In the eastern counties (Jefferson, Chamber, and Liberty), bayous were the water source used to irrigate 72% of the "private" acreage; lakes and private reservoirs supply water for another 21.9% of the acreage. By contrast, the western counties (Wharton, Brazoria, Austin, Harris, Walker, Colorado, Jackson, and Matagorda) obtained 41.6% of their private surface water from rivers or streams, 28% from drainage ditches and miscellaneous sources, and only 23.4% from bayous.

The survey results appear to indicate that when bayous were used as a water source they were used without supplement from groundwater sources. Rivers and streams were, in general, also used without supplemental groundwater, as were private lakes and reservoirs. By contrast other sources, such as drainage ditches, were used as a supplement to groundwater and generally accounted for only 10% to 20% of the total water used. The results also indicate that well water is not used when a dependable source of surface water

TABLE 4. ACREAGE IRRIGATED USING PRIVATELY OWNED SURFACE WATER RIGHTS

County	Estimated 1982 Acreage Irrigated Using Private Rights	Percentage of Total Surface Water Acreage Served by Private Rights
Jefferson	12,339	30.2%
Chamber	10,216	24.3%
Wharton	10,185	12.9%
Brazoria	7,860	16.5%
Liberty	4,787	14.1%
Others	16,860	-
Total	62,247	13.5%

is available.

Much of the private surface water use, in contrast to most water diverted by the 16 major water suppliers, is in fact tailwater from other rice fields that has found its way into the bayou or stream from which it is reused. Thus, while excessive tailwater on a particular farm is costly to the farm operator, it may at the same time be beneficial to many producers using the tailwater farther downstream.

Canal Delivery Losses

Canal delivery losses, considered to be water consumed between the point of diversion from the water source to the farm gate, can account for a substantial portion of total water consumption. There are two major types of delivery losses: steady state losses and transient losses. *Steady state* losses are those losses that are continuous in nature and include such things as seepage, surface evaporation, and transpiration from weeds growing in the canal. *Transient* losses are more irregular in occurrence and include initial canal wetting-up losses, short-term breakouts, and dead water losses or water left in the system after irrigation is complete (Trout and Bowers 1981).

Conveyance losses are greatly influenced by the physical properties of the canal system, including the system design, canal length, width, and composition. Management also is a major factor influencing conveyance losses. Canal maintenance and rodent and vegetation control in and along the canal system are ways in which conveyance losses can be affected by canal managers.

Information concerning water use by farms is not available for most systems since water is generally priced by the acre rather than by the acre-foot. As a result, the proportion of total water withdrawals lost in the conveyance process cannot be separated from the amount of water used by irrigators. Interviews with the various canal managers showed that, while most did not know how much water they lost in the delivery process.

most felt such losses were not "excessive." The managers also felt they were doing a good job of minimizing conveyance losses.

Most canal systems were built using clay soil and in some cases were also lined with a heavier clay soil to minimize seepage. Seepage can therefore be expected to be a less severe problem than it otherwise would be. Deadwater losses would be expected to be low for canal systems delivering water throughout the year to industrial customers. Initial wetting-up losses and dead water losses are, on the other hand, estimated by most managers to be substantial in systems not serving industry. Rodents, such as gophers, nutria, and muskrats, and alligators are considered to be a major cause of breaks in canal systems. Such breaks are costly to the water suppliers, both in terms of water losses as well as the physical cost of repairing the breach. Major breaks can also inconvenience water users.

To date no broad-based engineering studies have been done to estimate canal losses for systems operating in the Rice Belt. Because of their unique situations, a few canals do have estimates of conveyance losses. Trinity River Authority is required by law to sell water in their Devers canal system on a volumetric basis. Their records indicate that conveyance losses in a normal year amount to 12-18% of total water withdrawals (Walter Clark 1982). The Sabine River Authority, while pricing its water on a per-acre basis, uses sample measurements to estimate water deliveries to rice and crawfish farms. Based on these estimates, conveyance losses amounted to almost 30% of total water diverted (Perry 1982). Part of the difference between these figures is probably due to whether or not lateral losses are included in main canal losses.

Pricing Systems and Water Use

Historically, surface water has been sold on a per-acre basis rather than by the volume of water used. Although per-acre pricing would seem to give producers no incentive to manage their water resource so as to minimize consumption, the water suppliers do use various procedures to discourage excessive water use by rice producers. The suppliers try to monitor the amount of tailwater being lost in each field served. The supplier usually will threaten to do one of two things if the amount of tailwater being released is repeatedly judged to be excessive; either charge the producer an additional amount for the water used, or cut off the producer's water supply for a period of time. The desire to avoid either outcome is considered by canal operators to be sufficient motivation for producers to regulate water use.

As was indicated in the section on surface water management institutions, the Trinity River Authority and the San Jacinto River Authority operate the only two canal systems where water use is measured and water is priced on a volumetric basis. The SJRA has, since purchase of its present canal system in the 1940's, priced water on a volumetric basis for rice farmers. The SJRA uses a metered gate and calculates water use by measuring the head on both sides of the gate and using those figures in conjunction with a table of standards to calculate water use. The principal advantage in using a metered gate is that, in general, it is the least expensive method available to meter water. The principal disadvantage is that the metered gates require a minimum flow in order to accurately measure water use (Reddell 1983).

The Trinity River Authority began volumetric water pricing in 1973, using impeller-driven meters to measure water. Due to the high investment cost required to implement a metering system, meters were first installed on a community basis, with water to several fields being measured by one meter and averaged over the acreage involved. The community meters were replaced over the next 4 years by individual meters for each field. In addition to the high cost of purchase and installation, a disadvantage of impeller-driven meters is that they can be obstructed by vegetation or floating objects, thus not registering the flow of water. Impeller-driven meters, when operating properly, are considered to be more accurate in measuring water use than metered gates.

The resulting effect of metering on water withdrawals by TRA has been dramatic. Per-acre water withdrawals on the Devers system averaged a little over 5 acre-feet in the years previous to the installation of meters. Withdrawals dropped to 4.38 acre-feet in 1973, the first year water was metered. Withdrawals continued to drop over the next 6 years, reaching a low of 2.68 acre-feet in 1979. Since 1979 water withdrawals have averaged about 3 acre-feet.

Although it appears that transferring the responsibility for water conservation to the rice producers has in itself had a tremendous effect on reducing water use, economists argue that there may be other factors that have also contributed to the decline in water use. As is the case with many water suppliers, TRA sets its water prices based on the total operating cost of the canal system, divided by the amount of water sold (known as average cost pricing). Water suppliers have many fixed costs independent of the quantity of water sold. A decrease in the amount of water sold, resulting from a transfer in water conservation responsibility, will usually cause an increase in the effective per acre-foot price of water. Producers react to the higher water price by decreasing water use further.

Metering water to each producer required that TRA make a large investment in impeller-driven meters. Currently, the cost of a new metering system on the TRA system is estimated to be $700 for a meter plus $1300 for the gate and pipe on the lateral into which the meter is placed (Walter Clark 1982). The cost of installing and monitoring the meters during the growing season was also passed on to water users in the form of higher per acre-foot water costs. Again, the higher water costs undoubtedly caused per-acre water use to decline.

It can be concluded then that a change in water conservation incentives and increases in water costs are both responsible for the dramatic declines in water usage witnessed on the TRA canal system. This conclusion is supported by statistical studies made by Griffin and Perry (1983) and Ellis, Griffin, and Ziemer (1984).

NONAGRICULTURAL SURFACE WATER USE

Municipal and industrial users account for the remaining 40% of all surface water diverted in the 18-county area comprising the Texas Rice Belt. Estimates of 1980 surface water withdrawals (by county) for industrial, municipal, and agricultural categories are presented in Table 5. Included in the industrial category is water used in mining, which accounts for less than 2% of the total industrial water use. Included in the agricultural total is water consumption by livestock, which accounts for less than 1% of the total agricultural use.

Most municipal surface water use is located in the Houston metropolitan area (Harris

TABLE 5. ESTIMATES OF SURFACE WATER WITHDRAWALS BY COUNTY AND USE FOR 1980

County	Municipal	Industrial	Agricultural	Total
	------------------Acre-Feet------------------			
Austin	0	0	1,112	1,112
Brazoria	1,455	238,235	267,778	507,468
Calhoun	2,078	14,176	43,587	59,841
Chambers	304	8,854	195,898	205,056
Colorado	0	0	163,527	163,527
Fort Bend	1,595	13,526	36,064	51,185
Galveston	14,633	44,806	54,064	113,503
Hardin	0	0	42	42
Harris	178,144	256,720	12,290	447,154
Jackson	0	0	4,083	4,083
Jefferson	30,571	159,490	351,846	541,907
Lavaca	0	0	2,099	2,099
Liberty	0	0	99,265	99,265
Matagorda	0	4,238	270,016	274,254
Orange	0	44,745	9,962	54,707
Victoria	0	51,818	766	52,584
Waller	260	0	373	633
Wharton	0	0	140,379	40,379
18-County Total	229,040	836,608	1,653,151	2,718,799

Source: Bill Moltz. Planning and Development Department, Texas Department of Water Resources, Austin. Personal Communication, 9 March 1983.

and Galveston Counties) and the Beaumont metropolitan area (Jefferson County). Harris County's municipal water supply is obtained predominantly from Lake Houston while that for Galveston County is diverted from the Brazos River. The City of Beaumont obtains much of its water supply from the Neches River. The municipal figures include water used by businesses for drinking and sanitation purposes (Moltz 1983).

Industrial surface water use accounted for almost 31% of total water withdrawals in 1980 for the 18-county area. As with municipal water consumption, industrial water consumption is centered in the Houston and Beaumont metropolitan areas. The principal industries using large amounts of water in the Gulf Coast area are the bulk chemical and petroleum refining industries. Large amounts of water are also used in steam-electric power plants for cooling purposes. Only a small portion of water used for cooling is actually consumed (TDWR 1983).

In addition to industrial, municipal, and agricultural water withdrawals, smaller amounts of water are used for other purposes. Use of water for recreational purposes amounted to less than 10,000 acre-feet of water in 1980. Toledo Bend Dam released over 3 million acre-feet in 1980 to generate electricity. Most of this use was nonconsumptive. Marine biologists have indicated a certain minimum level of flow is necessary for all rivers emptying into the Gulf of Mexico in order to maintain coastal estuaries.

SUMMARY OF SURFACE WATER USE

When examining surface water use, it is essential to be specific about the term "use." Permitted, withdrawal, and consumptive uses differ substantially from one another. Figure 3 highlights the differences between the amount of water permitted to be used and that actually withdrawn in 1980 is illustrated in Figure 3. Permitted use, or the amount of water for which a legal claim has been established, is approximately 25.7 million acre-feet. Although water supplies vary greatly from year to year, experts feel permitted use far exceeds water actually available for withdrawal and consumption (Crittenden 1982). Many of these permitted rights have never been fully exercised because water has not been available. As can be seen in Figure 3, over 86% of the water claimed is for industrial use. It is notable that most of this water has been claimed since 1964. In contrast, over half of the permitted agricultural use relates to water rights dated before 1915. Therefore, while permitted agricultural use is much less than permitted industrial use, most industrial permits are much newer than the agricultural permits. Because of the priority rule established when the appropriative law was adopted in Texas ("first in time, first in right"), industrial permit holders pose little immediate threat to current agricultural surface water use in the Gulf Coast area.

The second bar in Figure 3 shows the amount of water diverted by use in 1980. Agricultural users constitute the predominant diverters of water. Much of the water diverted by agricultural, industrial, and municipal users was returned back to the environment in a reusable form. The TDWR estimates that approximately 35% of all surface and groundwater used in rice irrigation is return flow. The department also estimated return flows for industrial and municipal users in the 18-county study area for 1980 at 481,000 and 453,000 acre-feet respectively (Moltz 1983). This represents approximately 49% of all surface and groundwater withdrawals for industrial use, and 68% of all withdrawals for municipal use. Based on these figures, consumption of surface and

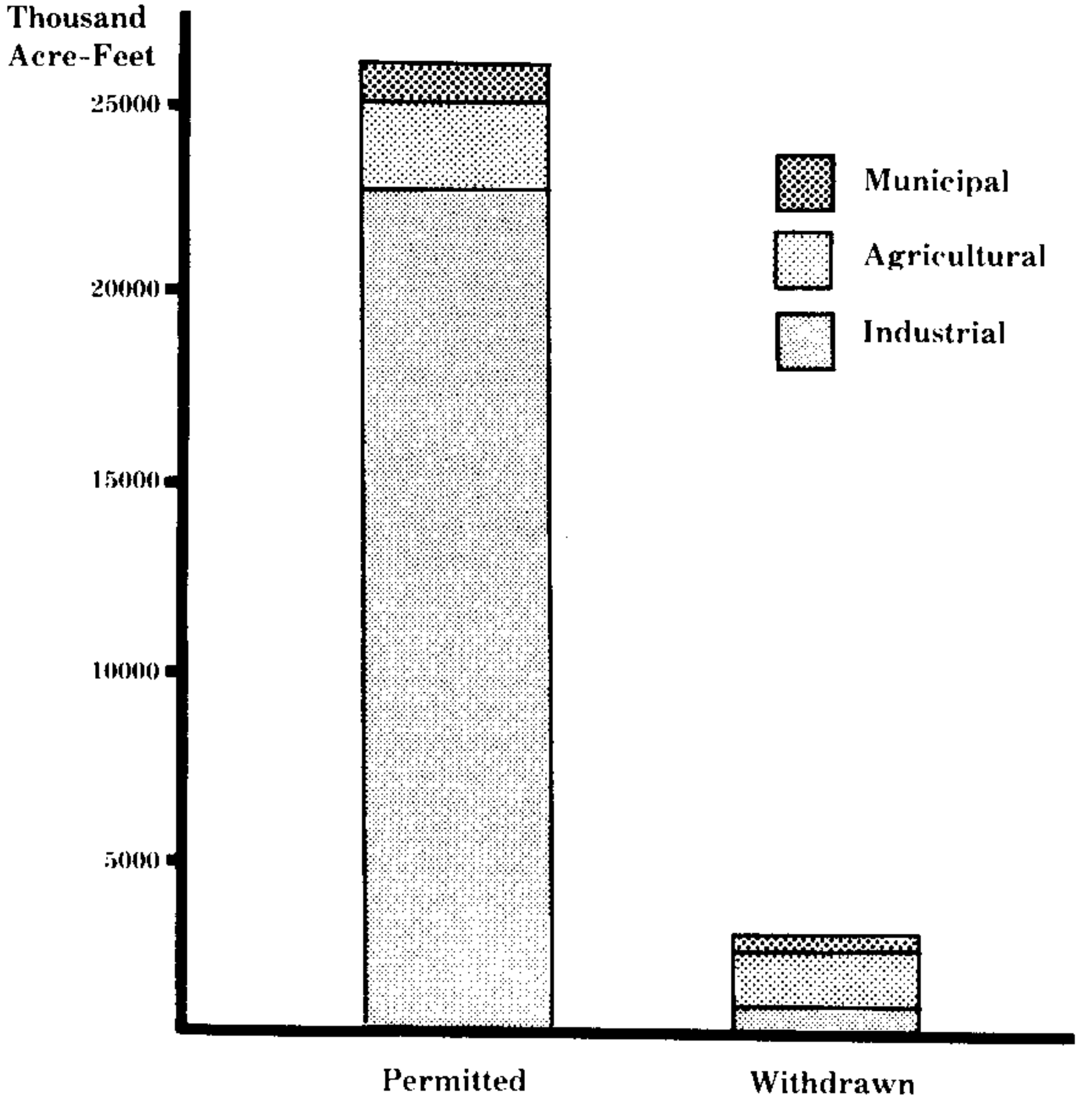

Figure 3. Surface water permits relative to withdrawals for the Texas Rice Belt, 1980.

groundwater in 1980 for the Rice Belt region was approximately 2.2 million acre-feet. Approximately two-thirds of this amount was consumed by agricultural users.

GROUNDWATER USE

Groundwater continues to be an important water source for agricultural, municipal, and industrial users in the Texas Gulf Coast region. In 1980, groundwater withdrawals in the Texas Rice Belt region were in excess of 1.2 million acre-feet, or 32% of all surface and groundwater withdrawals. Virtually all groundwater is obtained from the Gulf Coast Aquifer. This aquifer underlies most of the coastal plain from the Rio Grande Valley northeastward into Louisiana, extending about 100 miles inland from the Gulf. In parts of the aquifer fresh water occurs at depths of more than 3,000 feet, with large capacity wells in some areas yielding as much as 4,500 gallons per minute (TDWR 1983). Water withdrawals by specific use group are discussed below.

AGRICULTURAL GROUNDWATER USE

Agricultural use in 1980 accounted for just over half (53%) of all groundwater withdrawals in the Rice Belt area. As with surface water, virtually all groundwater utilized by agriculture was used to irrigate rice. Livestock use accounted for less than 1% of total agricultural groundwater use.

As part of the RWMS survey, rice farmers using groundwater were asked to give detailed information for each well they operated in 1982. This information included the drilled depth of the well, the depth at which the well bowls were located, the estimated pumping capacity of the well (in gallons per minute), the number of hours the well was operated during the 1982 crop year, the number of acres served by the well, and the most recent year in which major repairs on the pump were made. The year in which the pump was installed was to be entered if no major repairs had ever been performed on the pump. Information for a total of 346 wells was received, and summary information by county is reported in Table 6.

The average bowl depth by county varied from 185 feet in Wharton County to 345 feet in Lavaca County. Average drilled depth by county was much deeper, ranging from 501 feet in Wharton County to 894 feet in Waller County. The much deeper drilled depth indicates that few if any wells would need to be redrilled should water tables continue to fall.

Upon further inspection the survey results indicated that approximately one-third of the well bowls were located in the 200-249 foot range. A second third of the well bowls were set at depths of less than 200 feet, with the remaining third set at depths of 250 feet or more. Reported bowl depths ranged from 50 feet to 650 feet. The reported drill depths ranged from 60 feet to 1,600 feet. Unlike the bowl depth data, the drilled depth data was unevenly distributed over this range. While the average drilled depth was 659 feet, about 44.5% of the wells reported had drilled depths between 600 feet and 900 feet. Another 34% of the drilled depths were evenly distributed between 100 feet and 600 feet. Only 27% of the wells could be considered shallow wells, or wells with a drilled depth of less than 500 feet. This is very close to results obtained for Texas by Mullins et al. (1981) in a survey of major U.S. rice-producing areas.

The average last year of repair was 1978 for the wells surveyed. The optimal time of repair depends upon the lift, the amount of water pumped, the rate of decline in

TABLE 6. IRRIGATION WELL INFORMATION BY COUNTY AS REPORTED IN THE RWMS SURVEY

County	Number of Wells Surveyed	Average Acreage Served	Average Well Depth (feet)	Average Bowl Depth (feet)	Average Pump Capacity (Gallons/min.)	Average Hours Operated 1982	Average Last Year of Repair
Austin	6	285	859	249	2083	2687	1978.0
Brazoria	13	234	665	201	2108	1466	1972.7
Calhoun	4	a	a	a	a	a	a
Colorado	30	138	666	271	1648	1850	1976.7
Fort Bend	21	249	547	213	2380	2326	1978.6
Harris	18	181	690	304	1481	2675	1979.9
Jackson	70	197	714	232	2039	2258	1979.5
Lavaca	6	182	717	345	1667	2600	1979.5
Liberty	9	158	573	218	1367	1822	1980.8
Matagorda	25	251	828	234	1985	1328	1980.1
Victoria	14	212	740	269	2164	2512	1980.7
Waller	32	197	894	302	1678	1864	1979.3
Wharton	98	181	501	185	2071	2018	1978.1
OVERALL[b]	346	197	659	233	1966	2009	1978.6

[a]Data withheld to avoid disclosure of information for individual operations.
[b]Averages are unweighted by acreage.

operating efficiency, the cost of fuel, the value of the crop being irrigated, and other factors. For example, a well pumping a significant amount of sand will experience a much faster yearly decline in operating efficiency than will a well pumping little or no sand. Consequently, the well pumping sand will need to be repaired more frequently to keep operating costs at a minimum.

Using the survey data and the data contained in Table 1 on page 5, county estimates were made for the number of wells used in 1982, the number of acres irrigated using these wells, average per-acre water pumpage, and total water pumpage. These results are given in Table 7. It is important to observe that the figures include acreage irrigated by a combination of surface and groundwater sources. For counties where large acreages exist that use groundwater as a supplement to a surface water source, the inclusion of this combination acreage has the effect of reducing the per-acre groundwater use figures.

One surprising result from this table is the high per-acre water pumpage figures. These figures were calculated using the average pump capacity, hours operated, and acres served for each county reported in Table 6. Ignoring the figures for Brazoria, Liberty, and Matagorda Counties (where significant amounts of combination acreage using a high percentage of surface water exist), average pumpage is above 45 inches per acre. This is high when compared to calculations made by the Texas Department of Water Resources (in cooperation with the Soil Conservation Service). For example, calculations from the survey indicate that groundwater pumpage in Victoria County averaged 4.73 acre-feet per acre in 1982. This compares with per-acre pumpage figures calculated by the Soil Conservation Service (SCS) and the TDWR of 3.40 acre-feet in 1980, 3.33 acre-feet in 1979, and 3.31 acre-feet in 1974 (TDWR 1981a; Moltz 1983).

Why a discrepancy exists between the two data sources exists is not clear. It is possible that producers answering the survey consistently overestimated the pumping capacity of their wells. Wells that have not been serviced for several years may have become less efficient than their original rated capacity. However, calculations made from surveyed wells which had been repaired in 1982 again showed water pumpage as being significantly higher than TDWR and SCS estimates, although somewhat lower than the figures shown in Table 7.

The water pumpage figures estimated by the SCS were made based on experience gained by SCS personnel while working with farmers during the pumping season. Because the figures were not obtained using a survey technique, it is possible that water use was underestimated. However, evidence from Harris County seems to substantiate the figures reported by the SCS. In 1979, the SCS calculated that 42,758 acre-feet of groundwater was used by agriculture, or 2.05 acre-feet per acre (TDWR 1981a). The Harris-Galveston Coastal Subsidence District, which keeps a record of electricity used by each pump in the county for purposes of estimating groundwater withdrawals, estimated that in Harris County 44,813 acre-feet of groundwater were used by agriculture in 1979, or 2.15 acre-feet per acre (Harris-Galveston Coastal Subsidence District 1982). In 1982, the Subsidence District estimated agricultural groundwater use at 3.42 acre-feet per acre, approximately 15% lower than the per acre pumpage figure for Harris County given in Table 7.

Energy Sources

Irrigation wells operated in 1982 in the Texas Rice Belt utilized one of the four

TABLE 7. ESTIMATED NUMBER OF WELLS IN OPERATION, ACRES SERVED, AND TOTAL WATER PUMPED IN 1982

County	Number of Wells	Acres Served by Wells	Average Pumpage Per acre (acre-feet)[ab]	Total Groundwater Pumped (acre-feet)
Austin	17	4,000	3.62	14,467
Brazoria[c]	30	7,176	2.43	17,462
Calhoun	19	4,678	2.50	11,695
Colorado	86	11,539	4.07	46,925
Fort Bend	69	14,945	4.09	61,150
Hardin	NA	NA	NA	NA
Harris	87	15,698	4.03	63,315
Jackson	184	36,800	4.30	158,240
Lavaca	21	4,800	4.38	21,040
Liberty[c]	49	12,246	2.90	35,513
Matagorda[c]	66	16,347	1.93	31,604
Victoria	22	5,300	4.73	25,043
Waller	64	13,500	2.93	39,488
Wharton	253	46,371	4.25	197,077
Total	966	195,860	3.69	723,019

[a]Includes acreage using both surface and groundwater (see Table 2 on page 15).
[b]Calculated from survey data using county averages of pump capacity, hours operated, and acres served:

inches per acre = [pump capacity (gallons/minute) x 60 (minutes/hour) x hours operated] / [325,849 (gallons/acre-feet) x acres served].

[c]Counties having a significant amount of acreage using a combination of surface and groundwater sources.
NA - Not Available.

following fuel types: Natural Gas, Electricity, Liquid Propane (L.P.) Gas, or Diesel. Based on results obtained from the RWMS survey, approximately 60% of all 1982 groundwater acreage was irrigated using natural gas as the energy source. Another 29% of the acreage used electricity as the energy source, with diesel and L.P. gas accounting for the remaining 11%. A percentage breakdown by county of the acreage served by wells utilizing each energy source is given in Table 8.

Natural gas, L.P. gas, and diesel fuels are all utilized through use of an internal combustion engine. The engine is connected to a well gearhead to which the well bowls are connected. By contrast, an electric pumping plant consists solely of an electric motor, to which the bowls of the well are directly attached. Because the investment cost of the engine and gearhead is large relative to the electric motor, the use of internal combustion engines as a power source is cost efficient only if the cost of fuel is substantially less than the cost of electricity on a thermal basis (Knutson et al. 1981). Many rice producers using natural gas obtain the fuel from a natural gas well located on their farm or from a natural gas pipeline which passes through the farm. In many cases the natural gas is often obtained free of charge, or at a price that is substantially below the price charged to other nonagricultural customers.

A comparison between wells that use the various energy sources indicates there does not seem to be much difference in well depths or pumping capacity. The average natural gas well operated in 1982 tended to be used to irrigate more rice acreage than did the average electric or diesel-powered wells. Using data from the RWMS survey and the formula used to calculate the figures in Table 7, average per-acre pumpage in 1982 was 4.17 acre-feet for diesel-powered wells, 3.83 acre-feet for natural gas-powered wells, 3.5 acre-feet for electric wells, and 2.5 acre-feet for propane gas-powered wells. The average number of years since repair was longest for wells using electricity and shortest for the L.P. gas-powered wells.

NONAGRICULTURAL GROUNDWATER USE

Aside from agriculture, municipalities are the largest consumers of groundwater. In 1980, municipal water use accounted for 35% of all groundwater withdrawals. Groundwater use by municipal, industrial, and agricultural users in 1980 for the 18 Gulf Coast rice-producing counties is given in Table 9 and depicted in Figure 4. As with surface water, most municipal groundwater consumption is concentrated in and around Houston. Although subsidence has historically been a problem in the Houston area, municipal groundwater withdrawals have continued to increase in recent years. Withdrawals increased 30% during the period 1976–1980 (Harris–Galveston Coastal Subsidence District 1982). The construction of three water treatment plants in the Houston area is expected to help reduce dependence on groundwater as a municipal water source.

Industrial groundwater use accounted for only 12% of total groundwater withdrawals in 1980. Groundwater has become a relatively minor source of water for industrial users in the Gulf Coast area, accounting for 15% of total industrial water consumption. Industrial groundwater use in the Houston area has been reduced by approximately 100,000 acre-feet during the period 1976–1980, due largely to the completion of the CIWA canal (Harris–Galveston Coastal Subsidence District 1982).

TABLE 8. WELLS OPERATED AND ACRES SERVED BY TYPE OF ENERGY SOURCE

County	Percentage of:	Natural Gas	Electricity	Propane	Diesel
Austin	Wells	50.0%	33.0%	0.0%	12.0%
	Acreage	41.0%	44.4%	0.0%	14.6%
Brazoria	Wells	46.2%	46.1%	0.0%	7.9%
	Acreage	45.6%	51.9%	0.0%	2.5%
Calhoun	Wells	a	a	a	a
	Acreage	a	a	a	a
Colorado	Wells	23.3%	63.3%	6.7%	6.7%
	Acreage	30.4%	53.1%	5.1%	11.4%
Fort Bend	Wells	47.6%	52.4%	0.0%	0.0%
	Acreage	49.3%	50.7%	0.0%	0.0%
Harris	Wells	58.8%	41.2%	0.0%	0.0%
	Acreage	59.1%	40.9%	0.0%	0.0%
Jackson	Wells	73.5%	5.9%	1.5%	19.1%
	Acreage	76.3%	5.4%	0.3%	17.9%
Lavaca	Wells	a	a	a	a
	Acreage	a	a	a	a
Liberty	Wells	55.6%	11.1%	11.1%	22.2%
	Acreage	60.1%	16.5%	12.6%	10.8%
Matagorda	Wells	68.0%	28.0%	4.0%	0.0%
	Acreage	72.7%	22.0%	5.3%	0.0%
Victoria	Wells	92.9%	7.1%	0.0%	0.0%
	Acreage	93.6%	6.4%	0.0%	0.0%
Waller	Wells	65.6%	18.8%	0.0%	15.6%
	Acreage	67.6%	16.6%	0.0%	15.8%
Wharton	Wells	41.4%	38.4%	3.0%	17.2%
	Acreage	53.3%	35.9%	1.1%	9.6%
Unweighted Average	Wells	54.5%	31.1%	2.3%	12.0%
	Acreage	60.5%	28.9%	1.4%	9.1%

[a]Data withheld to avoid disclosure of information for individual operations.

TABLE 9. ESTIMATES OF GROUNDWATER WITHDRAWALS BY COUNTY AND USE FOR 1980

County	Municipal	Industrial	Agricultural	Total
	Acre-Feet			
Austin	2,621	75	10,252	12,948
Brazoria	21,009	5,905	23,228	50,142
Calhoun	699	1,750	12,281	14,730
Chambers	2,408	10,293	295	12,996
Colorado	3,050	6,993	61,978	72,021
Fort Bend	21,057	6,772	45,638	73,467
Galveston	19,818	4,353	147	24,318
Hardin	5,582	294	5,028	10,904
Harris	302,609	68,029	57,608	428,246
Jackson	3,080	181	132,381	135,642
Jefferson	7,674	7,402	277	15,353
Lavaca	2,944	581	27,224	30,749
Liberty	6,565	14,661	30,347	51,573
Matagorda	5,912	2,044	30,597	38,553
Orange	11,813	8,777	44	20,634
Victoria	10,265	3,762	26,512	40,539
Waller	3,160	931	26,601	30,692
Wharton	5,836	9,405	165,730	180,971
18-County Total	436,102	152,208	656,168	1,244,478

Source: Bill Moltz, Planning and Development Department, Texas Department of Water Resources, Austin. Personal Communication, March 9, 1983.

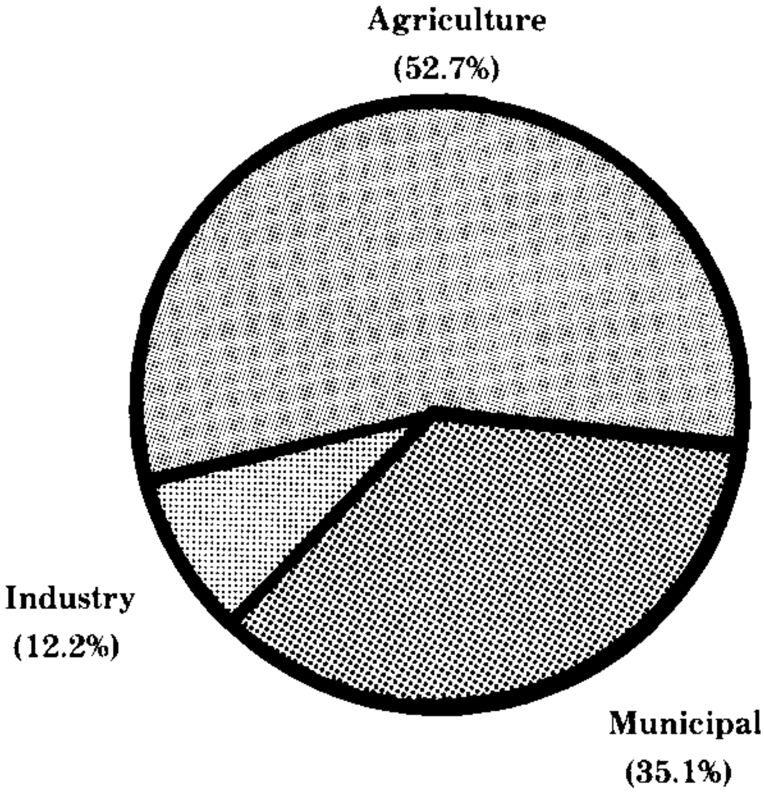

Figure 4. Groundwater consumption in the Texas Rice Belt by type of use, 1980.

FARM WATER MANAGEMENT

To this point the principal focus of this report has been to provide an overall view of water use in the Texas Rice Belt region. It is the purpose of this section to examine the farm-level factors which have significant influence on the use and management of water. Five major categories influencing the amount of water used by a rice producer can be identified. These are:

(1) The particular cultural practices the producer employs,
(2) The cost of obtaining irrigation water,
(3) The type of tenure arrangement under which the land is farmed,
(4) The physical characteristics of the farm, and
(5) The type of water conservation practices used to reduce on-farm water losses.

It is the purpose of this section to examine each of these major categories and identify the practices, costs, and factors that currently exist in the Rice Belt.

CULTURAL AND IRRIGATION PRACTICES

Rice is one of the most intensively managed crops in the nation. Aside from the large labor costs and capital investment necessary for rice production, the cultural practices involved also make rice the highest per-acre water user of any major crop in the U.S. While particular management practices vary across the Texas Rice Belt region, the overall organization of production activities is generally the same. A synopsis of the cultural practices commonly followed by Texas rice farmers are outlined below, with practices employed in irrigation and water management discussed in greater detail. It should be kept in mind that producers in particular areas of the Rice Belt may not employ all of the procedures outlined here.

Preplant Activities

Rice producers prefer to begin land preparation in the fall immediately following harvest. During the fall the ground is generally disked once to break up crop residue and to aerate the soil. Plows are seldom used in ground preparation since they tend to break up the soil plowpan. The plowpan is important in minimizing irrigation water loss through percolation. Levees are normally built in the fall in areas with heavy clay soils that will be aerially seeded. Heavy clay soils must have months of wetting and drying to form a relatively watertight retainer. Fields in which levees are built in the fall must be land-planed prior to levee construction. Future land preparation will be performed between the existing levees. Levees may be plowed and pushed again in the spring, but care is taken to not damage the seasoned base.

If weather and ground conditions are favorable, the ground will be disked in January. Following the last disking in the spring a field cultivator will sometimes be used to break up clods and soil crust and to kill weeds. In fields without levees a land plane will then be brought in to level any high spots in the field and to fill in any remaining rut traces left after the previous year's harvest. This assures a fairly equal distribution of water during irrigation.

Once land planing is complete, fields are ready to have the levees rebuilt. Several levees are built across each field, following the contour of the land, so that an irrigation flood can be held. Rice producers build a levee for every 0.2 to 0.3 foot drop in land elevation, depending on slope. Because levees follow the natural contour of the land in non-precision-leveled fields, they tend to be irregular in shape. Levees are destroyed each year by the rice producer during field preparation, except in some areas of aerial seeding when the field will be in rice the following year.

It is generally necessary to mark the location of levees in fields that have never been used for rice production, have been out of production for several years, or have been land planed. This is generally done using levee-lasering equipment. The laser equipment emits a beam that guides a tractor and ridger across the field along each contour, leaving a small ridge marking where the levee is to be placed. For land in regular rice rotation which has not been extensively land-planed it is generally unnecessary to mark levees since traces from the previous year's levees provide a sufficient guide for placement of the current year's levees.

Following the marking of levees, preplant fertilizer is applied. This is done either from the air or by use of ground rigs. Levees are usually built using a tractor and levee plow. Sometimes a levee pusher will also be used on lighter soils. At times it will be necessary that the operation be done twice to ensure that the levees are of sufficient height. In general producers try to build levees so that they will be at least 18 inches high throughout the growing season (Parker 1983).

While building the levees, the farmer also creates a ditch (commonly called a bar ditch) which is approximately 6 inches deep on both sides of the levee. The ditch on the upper side of the levee is essential when draining the field. In addition, one or more ditches (quarter drains) are also carved through the low points of each cut (or paddy) to carry water down and out of the field. A levee gate or drain pipe is installed before flushing or flooding the field at points where these ditches cross each levee. The gate or pipe is then closed off and will only be reopened when the producer desires to drain the field.

To permit movement of water between cuts, one or more levee gates or boxes are installed in each levee in the field. The boxes are also used to control the water depth in each paddy. A gate is sometimes located at the lowest point in the field's bottommost levee to allow for release of excess water and for use when the field is drained. A diagram of a typical rice field is given in Figure 5.

Planting, Flushing, and Flooding

Planting of rice in Texas is generally carried out beginning in the second week of March and continuing through the third week in April. Planting east of Houston generally starts about a week later than west of Houston. As with fertilization, planting can be done from the air or on the ground. Ground seeding is done using a grain drill.

Two different techniques are used to seed from an airplane. The first technique, called water seeding, requires that the field be flooded prior to planting. The planting flood will be held for 3 to 5 days until the rice begins to sprout. The water will then be drained off slowly to minimize seed movement. The second technique, called dry air

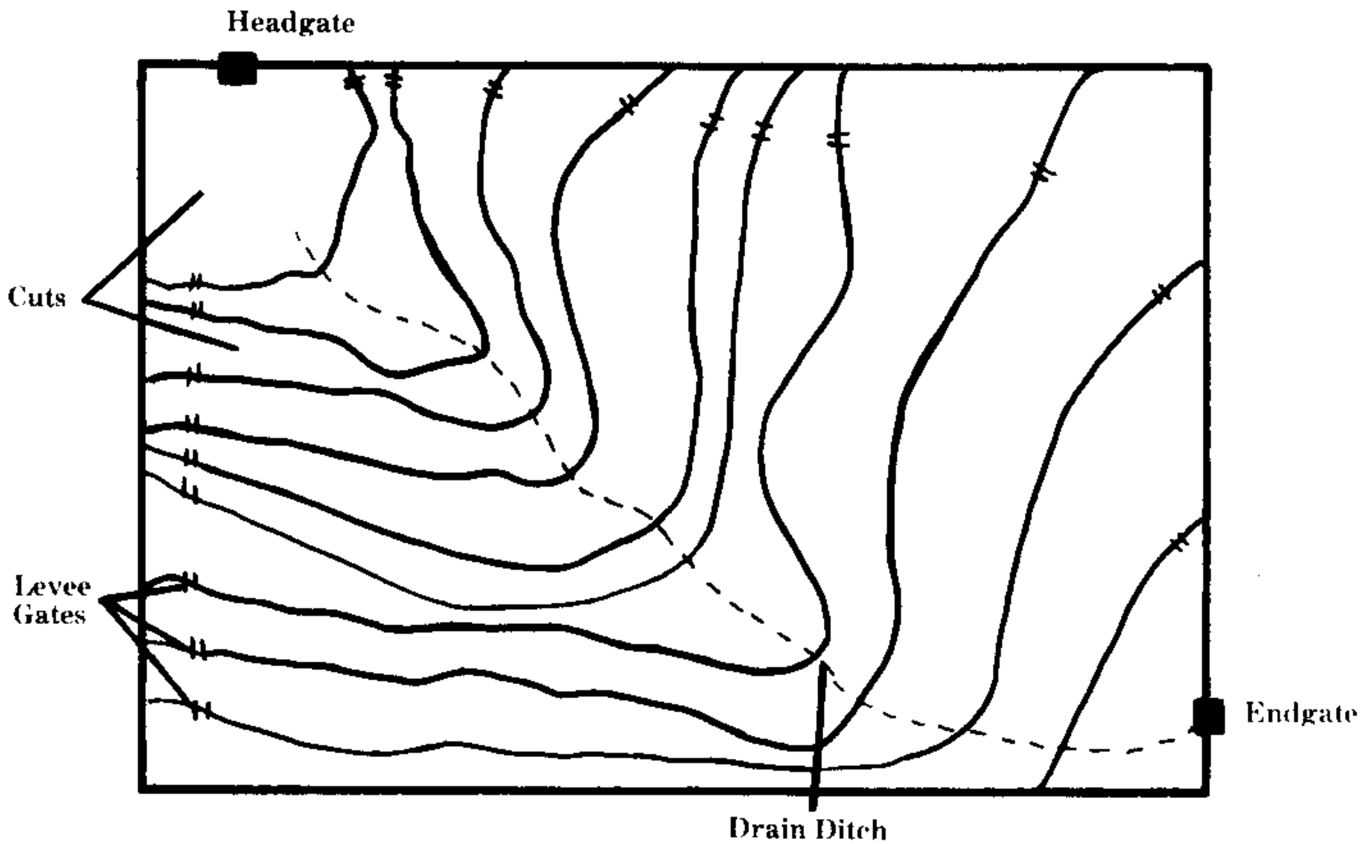

Figure 5. A representative rice field.

seeding, involves broadcasting seed onto dry ground. Areas of aerial seeding onto dry ground are flushed immediately after planting. The flood will be held for 24 to 36 hours to completely wet the seed bed. Drill seed rice is not usually flushed but depends on soil moisture and rainfall for emergence. The construction of levees occurs immediately after planting for acreage which has been seeded using a grain drill. Levees are built either before or after seeding for acreage which has been seeded by airplane onto dry ground.

It is useful at this point to examine in further detail the use of flushing in Texas rice production. Strictly speaking, flushing is a flood irrigation technique whereby only the top several cuts are flooded before the inflow is stopped. By contrast, an irrigation flood involves the entire field being covered with water. Producers, however, will sometimes refer to a flood held for a short period of time as a flush. A flush is generally held for about 12 hours. The water is then drained into the next cuts and the procedure repeated. Table 10 exhibits the timing of flushes on Texas rice farms as reported in the RWMS survey. Responses are also broken down into the Upper and Lower Rice Belt regions to show the contrast in flushing practices between the two regions.

As the table indicates, approximately one-third of the producers surveyed in the Upper Rice Belt indicated that they water-seeded some acreage (flushed before planting), while only 1% of the producers in the Lower Rice Belt indicated use of water-seeding. Another 51% of the farms in the Upper Rice Belt flushed immediately after planting, while 65% of the Lower Rice Belt farms flushed after planting. Overall, 9% of all farms surveyed flushed before planting and 59% flushed immediately after planting. Since only 2% of producers surveyed flushed both before and after planting, it can be concluded that approximately two-thirds of the farms (59% + 9% - 2% = 66%) used flushing as an aid to seed germination and stand establishment.

After the rice has been planted the first herbicide application is usually made when the weeds reach the two-to-three-leaf stage. The first application will consist of contact and preemerge chemicals depending on the specific weed pressure. The rice may be flushed before or after herbicide application depending on the level of moisture stress. Subsequent applications of herbicides may be made depending on weed pressures with the last application just prior to flood. In most cases it is recommended that the field be flushed 24 hours after herbicide application (Texas Agricultural Extension Service 1983). Table 10 indicates that approximately half of the rice producers responding to the survey did flush after herbicide application. The total fertilizer requirement will be divided into two to three applications. The first is generally done before planting. If three applications are made, the second occurs immediately prior to flood establishment, preferably on dry ground. The final application is made at panicle differentiation. New varieties may require an additional application during heading if nutrient stress is apparent.

Flooding and Flood Maintenance

Approximately 24-42 days after plant emergence, when the rice plant is actively tillering, a flood is established. The principal purpose of this flood is to control weeds that may compete with the rice plant for sunlight and nutrients. Optimally, the established flood will be a minimum of 2 inches deep at the highest point in the cut. This will ensure adequate weed control and yet minimize water use.

Because of evaporation, plant use, and field losses it is necessary from time to time

TABLE 10. SURVEY RESULTS ON TIMING OF FLUSHES IN RICE IRRIGATION

Indicated Times When Fields Were Flushed	All Farms		Upper Rice Belt		Lower Rice Belt	
	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total
(a) Before working the ground in the spring	0	0%	0	0%	0	0%
(b) Before planting	22	9%	20	34%	2	1%
(c) Immediately after planting	142	59%	30	51%	112	65%
(d) Before applying herbicide	31	13%	10	17%	21	12%
(e) After applying herbicide	123	51%	39	66%	84	49%
(f) Immediately after harvest	95	39%	20	34%	75	44%
(g) Other	13	5%	7	12%	6	4%
(h) No response or None	17	-	0	-	17	-
Number of Respondants	230	-	59	-	171	-
Average Number of Times Flushed	-	1.9	-	2.1	-	1.8

to add additional water to the field. Rice producers prefer to have a continuous flow of water into the field to replace daily losses and use. Usually this is not practical, either because of weather or institutional constraints, or because of excessive cost. For example, most water suppliers do not supply water on a continuous basis to all rice producers they serve. Instead the producers rotate turns taking water, and there may be a minimum waiting period between turns. The RWMS survey indicated that over 50% of the Gulf Coast rice producers using surface water received three or fewer releases into their field to produce the first crop of rice. These survey results are contained in Table 11. Producers in the Lower Rice Belt tended to use more releases to maintain a flood than did producers in the Upper Rice Belt, probably due to less rainfall, higher evaporation, and higher soil porosities in the western region.

Once the flood has been established, it generally will be maintained until preparation for harvest. The only time a field will be intentionally drained during the growing season is when conditions are such that the rice is subject to straighthead. Straighthead results in sterile florets and blank panicles and only affects rice growing in particular types of soils. The flood level is also allowed to drop prior to application of a broadleaf herbicide in order to expose more leaf surface to the herbicide (Texas Agricultural Extension Service 1983).

Harvest and Ratoon Crop

Approximately 7 to 12 days before harvest the field is drained. This allows the land to firm up for harvesting equipment while allowing the field to stay moist enough to keep the rice plant alive. Harvest generally begins in mid-July and continues through most of August, with the Upper Gulf Coast rice producers beginning harvest operations a couple of weeks later than their counterparts in the Lower Gulf Coast region. If the rice is harvested early enough, it is possible for a ratoon crop of rice to also be produced. Table 12 shows ratoon rice acreage in 1982. Ratoon acreage is consistently higher in western counties due primarily to the drier fall conditions. Ratoon acreage in eastern counties was generally higher in 1982 than it has been for the past several years, probably due to the low price of rice and better weather conditions.

To get maximum ratoon crop production, it is important that water and fertilizer be put on the rice stubble immediately after the first crop has been harvested. Approximately 40% of the producers surveyed indicated that they flushed their fields immediately after harvest. Generally, one release in the Upper Rice Belt and two releases in the Lower Rice Belt were used in 1982 to maintain flooded conditions on the ratoon crop.

WATER COSTS AND TOTAL PRODUCTION COSTS

Tables 13 and 14 present 1982 average per-acre water costs for surface and groundwater users, respectively. Surface water costs were lowest in Harris and Jefferson Counties. The results compare quite favorably with rates actually charged in 1982 by public water suppliers and private companies for irrigation water. Actual charges made by the 16 major water suppliers for irrigation of first crop rice ranged from $21/acre to $65/acre. Based on survey results, costs for producers using water under private rights averaged $32.22/acre during 1982.

TABLE 11. NUMBER OF SURFACE WATER RELEASES USED TO MAINTAIN IRRIGATION FLOOD ON FIRST CROP RICE

Number of Releases	All Farms		Upper Rice Belt		Lower Rice Belt	
	Number	Percent	Number	Percent	Number	Percent
1	12	9%	3	6%	9	11%
2	24	18%	15	31%	9	10%
3	33	24%	18	37%	15	17%
4	25	19%	7	14%	18	21%
5	15	11%	4	8%	11	13%
6	14	10%	2	4%	12	14%
7	2	1%	0	0%	2	2%
8	3	2%	0	0%	3	4%
9	1	1%	0	0%	1	1%
10	5	4%	0	0%	5	6%
11	0	0%	0	0%	0	0%
12	1	1%	0	0%	1	1%
Total	135	100%	49	100%	86	100%

TABLE 12. 1982 RATOON CROP RICE ACREAGE IN THE TEXAS RICE BELT

County	1982 Ratoon Crop Acreage	Percent of First Crop Acreage
Austin	3,764	94.1%
Brazoria	8,977	18.4%
Calhoun	11,551	93.9%
Chambers	31,401	71.4%
Colorado	39,194	87.5%
Fort Bend	5,469	25.4%
Galveston	0	0.0%
Hardin	NA	NA
Harris	12,400	69.3%
Jackson	32,093	87.2%
Jefferson	14,442	33.6%
Lavaca	3,486	72.6%
Liberty	19,347	56.7%
Matagorda	43,283	89.6%
Orange[a]	368	26.3%
Victoria	5,173	97.6%
Waller	12,139	89.9%
Wharton	75,176	94.1%
17–County Total	318,263	67.8%

[a]Figure obtained from Sabine River Authority (Perry 1982).
NA – Not available.

TABLE 13. 1982 AVERAGE PER-ACRE SURFACE WATER COSTS

County	Number of Observations	First Crop Water Costs	Percentage of First Crop Costs	Ratoon Crop Water Costs	Percentage of Ratoon Crop Costs
Austin	1	a	a	a	a
Brazoria	15	$45.64	14.8%	$ 9.27	12.9%
Calhoun	3	54.73	10.5%	a	a
Chambers	18	39.99	11.9%	10.42	13.1%
Colorado	7	51.58	15.2%	15.35	16.7%
Fort Bend	0	NA	NA	NA	NA
Galveston	3	54.62	13.3%	a	a
Harris	3	31.01	9.3%	a	a
Jackson	1	a	a	a	a
Jefferson	21	27.96	9.4%	11.20	11.8%
Liberty	9	44.23	11.5%	11.81	16.2%
Matagorda	19	44.69	13.5%	17.55	13.0%
Orange	0	NA	NA	NA	NA
Waller	0	NA	NA	NA	NA
Wharton	24	50.83	21.8%	22.00	15.0%
Unweighted Average	124	$44.17	13.8%	$15.35	14.1%

[a]Data withheld to avoid disclosure of information for individual operations.
NA – Not Available

TABLE 14. 1982 AVERAGE PER-ACRE GROUNDWATER COSTS

County	Number of Observations	First Crop Water Costs	Percentage of First Crop Costs	Ratoon Crop Water Costs	Percentage of Ratoon Crop Costs
Austin	2	a	a	a	a
Brazoria	4	$39.04	10.3%	a	a
Calhoun	1	a	a	a	a
Colorado	4	70.50	18.5%	$31.75	20.3%
Fort Bend	3	53.51	20.3%	NA	NA
Hardin	0	NA	NA	NA	NA
Harris	5	70.94	35.0%	31.50	26.6%
Jackson	19	64.14	19.2%	33.44	26.3%
Lavaca	1	a	a	a	a
Liberty	0	NA	NA	NA	NA
Matagorda	6	51.96	14.1%	33.20	37.0%
Victoria	3	47.07	10.0%	27.33	48.8%
Waller	5	62.60	9.8%	56.75	26.1%
Wharton	25	49.00	14.0%	23.87	21.2%
Unweighted Average	78	$56.57	15.6%	$30.96	26.6%

[a]Data withheld to avoid disclosure of information for individual operations.
NA – Not Available

As a comparison between Tables 13 and 14 indicates, groundwater costs in 1982, on the average, were higher in all counties than surface water costs. Overall, first crop groundwater costs were about 28% higher than first crop surface water costs. Groundwater costs ranged from $18 per acre to $120 per acre for the farms surveyed. Costs were highest in the central portion of the Rice Belt (Brazoria, Harris, and Waller Counties) and, in general, seemed to be higher in those counties where the well bowls are set at a greater depth (see Table 6 on page 41).

One surprising result from the survey was the large difference between groundwater and surface water costs for ratoon crop production. In fact, the difference in costs between the two water sources was greater for ratoon crop water prices than it was for first crop water prices. Surface water costs for ratoon cropping averaged $15.35 per acre, while groundwater costs averaged $30.96 per acre. Rice producers reported ratoon crop surface water costs as high as $24 per acre, while ratoon crop groundwater costs were as high as $85 per acre.

Producers responding to the RWMS survey were also asked to estimate what percentage first and ratoon crop water costs were of their respective first and ratoon crop production costs. Estimated total costs to produce the first crop of rice averaged $320 per acre for surface water users and $362 per acre for groundwater users. Ratoon crop costs averaged $109 per acre for surface water users and $116 per acre for groundwater users. These results compare favorably with Table 15, which provides an itemized account of average production costs for 1982.

TENURE ARRANGEMENT

The type of tenure or land use arrangement under which a producer operates can have a significant influence on water management. For example, consider the following information on wells summarized from the RWMS survey:

	Leased	Not Leased
Number of Wells	99	247
Average Acreage Served	192	199
Average Well Capacity (gals/minute)	2097	1912
Average Hours Operated	2173	1948

Using the formula presented with Table 7 and the above data, the average leased well pumped 4.4 acre-feet per acre, while the average non-leased well pumped only 3.5 acre-feet per acre, or 21% less water. While these two water-use figures are not statistically different from one another, a larger sample size would probably indicate that tenure arrangement influences the amount of water used by rice producers.

Information on the percentage of acres operated under the three principal types of tenure arrangements (owned, sharecrop, and cash rent) is displayed in Table 16. As the table indicates, sharecrop is the most common type of tenure arrangement used by Gulf Coast rice producers. Crop share arrangements tend to represent a larger proportion of total acreage in the Lower Gulf Coast area as opposed to the Upper Gulf Coast area.

TABLE 15. 1982 ESTIMATED PER-ACRE COSTS OF PRODUCTION

Item	Upper Gulf Coast First Crop Only	Lower Gulf Coast First and Ratoon Crop
Variable Cost:		
Seed	$ 30.00	$ 26.00
Fertilizer	44.24	61.30
Chemicals	51.14	59.40
Custom Aerial	27.90	25.00
Tractor	21.77	29.63
Equipment	20.41	19.61
Labor	64.91	62.45
Irrigation	65.98	56.49
Drying	31.59	48.04
Hauling	9.23	22.42
Commission	3.05	4.03
Interest and Other	11.56	18.83
Total	$381.78	$417.12
Fixed Cost:		
Tractor	$ 28.23	$ 36.21
Equipment	60.10	62.41
Share Rent	44.15	73.90
Total	$132.48	$172.52
Total All Costs	$514.26	$589.64

Source: Texas Agricultural Extension Service. *1983 Rice Production Guidelines.* College Station, Texas.

TABLE 16. 1982 TENURE ARRANGEMENTS BY COUNTY

	Percentage of Acreage		
County(s)	Owned	Sharecrop	Cash Rent
Austin/Waller	22.1%	15.7%	62.2%
Brazoria/Galveston	21.9%	38.8%	39.3%
Calhoun	28.0%	70.3%	1.7%
Chambers	34.1%	25.8%	40.0%
Colorado	7.7%	89.6%	2.8%
Fort Bend	43.6%	54.2%	2.2%
Hardin	NA	NA	NA
Harris	23.7%	40.2%	36.1%
Jackson	5.7%	91.9%	2.4%
Jefferson	30.4%	60.6%	9.0%
Lavaca/Victoria	18.8%	81.2%	0.0%
Liberty	39.4%	53.2%	7.4%
Matagorda	14.9%	76.6%	8.4%
Orange	NA	NA	NA
Wharton	17.9%	79.5%	2.7%
Weighted Average	22.1%	62.2%	15.7%

NA - Not Available

The distribution of sharecropped acres farmed in 1982 by particular sharecropping arrangements is shown in Table 17. The table indicates that approximately half of all sharecropped acres were farmed under a one-half sharecrop arrangement. A typical one-half sharecrop arrangement contract specifies that the landowner pay all water costs, all seed costs, and 50% of all chemical costs, including fertilizer, herbicides, insecticides, etc. In exchange, the landowner receives half of the crop. Approximately one-third of the acreage farmed under one-half sharecrop arrangements is owned by private canal companies.

Other common sharecrop arrangements (one-tenth, one-eighth, one-seventh, one-sixth) usually do not require that the landlord pay any of the water costs. In fact, the landowner will generally not pay any of the costs of production in these four situations. When the landlord does pay some of the production costs, it is usually in proportion to the share of the crop, such as paying one-sixth of the variable production costs and receiving one-sixth of the crop. This proportional sharing of production costs, when it does occur, is typically confined to the one-eighth, one-seventh, one-sixth, and one-fifth sharecrop arrangements.

A breakdown of acreage that is cash rented by the amount of rent paid is displayed in Table 18. In almost all cases the landowner pays no costs as part of the rental

TABLE 17. NUMBER OF ACRES FARMED AND PERCENT OF WATER EXPENSES PAID BY LANDLORD FOR COMMON SHARECROP ARRANGEMENTS

Percent of Crop to Landlord	Number of Acres	Percentage of Total Sharecropped Acreage	Number of Observations	Mean Percentage of Water Costs Paid by Landlord	Median Percentage of Water Costs Paid by Landlord
one-tenth	39,581	13.6%	31	9.1%	0%
one-ninth	6,694	2.3%	4	0.0%	0%
one-eighth	30,850	10.6%	33	13.0%	0%
one-seventh[a]	30,268	10.4%	37	0.0%	0%
one-sixth	16,588	5.7%	14	0.0%	0%
one-fifth	3,201	1.1%	5	8.6%	0%
one-fourth	11,641	4.0%	6	36.0%	100%
one-half	140,276	48.2%	108	99.0%	100%
other	11,932	4.1%	10	-	-
Total	291,031[b]	100.0%	248	-	-

[a]Includes 15% sharecrop arrangements.
[b]Does not include acreage in Hardin or Orange Counties.

TABLE 18. 1982 CASH RENT ACREAGE

Cash Rent	Number of Acres	Percentage of Rented Acreage	Number of Observations	Average Rent per Acre
$ 0-$10	2,146	2.9%	5	$ 9.53
$11-$20	20,941	28.3%	8	15.62
$21-$29	19,758	26.7%	22	24.89
$30-$39	15,763	21.3%	17	32.62
$40-$49	7,844	10.6%	12	42.24
$50-$100	7,548	10.2%	12	64.04
Total[a]	74,000	100.0%	76	$29.30

[a]Does not include acreage for Hardin or Orange Counties.

agreement. As the table indicates, smaller acreage arrangements tended to rent for a higher price than did the larger acreage arrangements.

ON-FARM WATER USE

On-farm water use, as the term is used here, means all water received by groundwater users at the well outlet or, for surface water users, water used from the point where the water supplier no longer has control over the water resource. Once the water is under the control of the farmer it will either be consumed through plant transpiration and evaporation, or lost from the producer's control in the irrigation process. Water losses in the irrigation process are unavoidable and in some cases may even be desirable. Studies have shown that the actual evapotranspiration (evaporation plus transpiration) requirements for rice production are about 2 acre-feet per acre during the growing season (*Rice Farming* 1982). As the data presented in both the surface water use and groundwater use sections have indicated, on-farm water use is substantially higher than this figure. The difference between water deliveries to the farm and evapotranspiration needs is an approximation of water lost in the irrigation process. It is important to note that rainfall may reduce the amount of irrigation required to produce the crop if the rainfall comes at a time when it can utilized by the producer. This rainfall will generally have little effect on the water needs of the rice plant but can replace much of the water lost in the irrigation process. Such was the case in 1979, when groundwater use for irrigation in the Rice Belt averaged less than 3 acre-feet per acre (TDWR 1981a).

On-farm water losses can be broken down into the following categories: tailwater, levee breakage and seepage, lateral losses, and field seepage (leaching). *Tailwater* losses refer to water which is lost out the end of the field. This can occur after a heavy rainfall or when an excessive amount of irrigation water is let into the field. Tailwater loss may also be intentional, such as when the field is drained prior to harvest. Therefore, some tailwater losses are expected in rice production. The TDWR has estimated that approximately 35% of all water used for irrigation in the Rice Belt was returned to the environment as surface water rather than consumed (TDWR 1983).

Levee breakage and seepage losses, as the term implies, occur when the levees in or around a field break, allowing water from one or more cuts to escape. These breaks are generally a result of more water in the cut (possibly due to heavy rainfall) than the levees have the strength to hold. A levee which has been weakened as a result of rodent activity may also break under otherwise normal conditions. Some water seepage through levees also occurs during the irrigation season. Levee losses can be minimized only by continual monitoring of each field by the rice producer.

Laterals are smaller ditches used to convey water from its source (well or canal system) to the field being irrigated. *Lateral losses* are in most cases due to seepage through the bottom and sides of the lateral. Studies in other parts of the world have shown that seepage losses in laterals often range from one-fourth to one-third of the total water diverted (Kruse, Humphreys, and Pope 1981). The amount of water lost through laterals is highly dependent on the wetted area of the lateral, the length of the lateral, and the type of soil used to form the lateral. Thus, percentage lateral losses will be zero for instances when water is being pumped directly into the field but can be very high for water transported long distances in laterals which are made of very porous materials. Preliminary results from a study currently underway found lateral losses ranging from 13% to 49% on six Gulf Coast rice farms. The laterals being studied range from 1,200 to 10,000 feet in length (Bettge et al. 1983).

Field seepage occurs when a field's soil profile is held at its water holding capacity for a period of time. Some field seepage does occur in rice production since the soil is held in a flooded condition throughout much of the growing season. The presence of a thick soil hardpan greatly reduces field seepage losses.

To learn more about farmers' perceptions regarding on-farm water use, producers participating in the RWMS survey were asked to estimate the percentage of use attributed to the above-mentioned categories. The survey results are presented in Table 19. Evapotranspiration was estimated to be the largest water use category, averaging 57% of on-farm water use. When comparing the results for surface water users with groundwater users, the principal difference is the much higher percentage of tailwater losses reported by surface water users. This observation is consistent with the hypothesis that groundwater users engage in greater water conservation because of the higher costs of groundwater as compared to surface water.

The range of responses to this question illustrate large differences in perceptions from producer to producer for each category of on-farm consumption. Percentages for tailwater losses ranged from 0% to 90% for surface water users and from 0% to 70% for groundwater users. Levee losses were considered to be small by all producers, ranging between 0% to 30% for surface water users and 0% to 10% for groundwater users. Evapotranspiration ranges were 2% to 96% and 10% to 100% for surface and groundwater

TABLE 19. FARMERS' ESTIMATES OF WATER USES AND LOSSES

Use/Loss Category	All Users	Surface Water Users	Groundwater Users
Tailwater	15.6%	19.0%	10.5%
Levee Breakage	4.9%	5.8%	3.5%
Evapotranspiration	57.1%	52.3%	64.3%
Lateral Losses	7.3%	6.9%	7.9%
Field Seepage	9.1%	9.1%	9.0%
Other	6.0%	6.9%	4.8%
Total	100.0%	100.0%	100.0%

respectively. The range for lateral losses was 0% to 40% for surface water and 0% to 45% for groundwater. Seepage losses varied from 0% to 50% for surface water users and 0% to 80% for groundwater users. The frustration some farmers felt at trying to answer the question was evident in the ranges for the "Other" category, which were 0% to 84% for surface water and 0% to 65% for groundwater. This frustration was also expressed by the many farmers who only partially completed the question, or who wrote that they could not or would not complete the question.

It is interesting to note that, assuming evapotranspiration was 2 acre-feet per acre in 1982 and assuming the average percentages shown in Table 19 are correct, rough estimates of on-farm water consumption can be made that are fairly close to water use figures estimated by public agencies. For groundwater users, water use is estimated at 3.11 acre-feet per acre, while surface water users estimated water use as 3.81 acre-feet per acre. While no data is currently available for on-farm surface water consumption, estimates made by the Harris-Galveston Coastal Subsidence District indicated groundwater agricultural pumpage was about 3.41 acre-feet per acre of rice (Harris-Galveston Coastal Subsidence District 1983). By this measure the estimates made by farmers of total water use on the average seem to be fairly close. It should be stressed, however, that the proximity of these two figures to one another may only be coincidental. Obviously, more research needs to be done to determine what the average percentages are for all uses and losses for the typical Texas Gulf Coast rice farm.

CURRENT WATER CONSERVATION PRACTICES

There are three major types of land improvements used by Texas rice farmers to improve water management and conservation. These methods include: water leveling, precision leveling, and installation of underground pipe. Table 20 identifies the number of acres of owned and leased land on which the above-mentioned land improvements have been implemented. It is important to note that the acreages given in Table 20 include acreage that was out of rice production in 1982.

TABLE 20. ACRES OF LAND USING SPECIFIC METHODS OF WATER CONSERVATION

County	Laser-Leveled		Water-Leveled		Underground Pipe Water Delivery	
	Owned	Leased	Owned	Leased	Owned	Leased
Austin	0	0	1,329	2,192	0	0
Brazoria	3,513	11,488	2,778	3,486	0	0
Calhoun	0	0	0	0	0	0
Chambers	0	2,911	16,510	18,268	0	0
Colorado	0	0	0	12,960	2,209	1,178
Fort Bend	0	0	0	0	0	0
Galveston	0	0	0	0	0	0
Hardin	NA	NA	NA	NA	NA	NA
Harris	2,157	1,782	5,512	20,567	0	0
Jackson	380	6,019	0	0	8,445	1,084
Jefferson	276	5,990	13,822	25,233	0	0
Lavaca	0	0	0	a	0	0
Liberty	0	0	1,984	297	0	0
Matagorda	228	5,534	0	0	0	3,722
Orange	NA	NA	NA	NA	NA	NA
Victoria	0	0	0	a	0	0
Waller	186	3,293	1,752	9,857	838	0
Wharton	11,073	13,752	703	3,169	2,767	9,345
Total	17,807	50,769	44,390	96,029	14,259	15,329

NA - Not Available
[a]Data withheld to avoid disclosure of information for individual operations.

The most common form of land improvement for water conservation is land leveling. The use of land leveling has several advantages. The principal advantage is that some levees are eliminated from the field while others are straightened. This allows for more efficient use of equipment in crop operations and permits establishment of permanent levees. Land leveling improves efficiency of irrigation water use and reduces labor requirements. It also improves field drainage and thereby improves yields of rotation crops.

The most common land-leveling practice is *water leveling*, used predominantly in the upper part of the Rice Belt. Water leveling, a form of bench leveling, is accomplished by surveying to determine where levees can be eliminated and straightening those levees that remain. New levees are then built, the areas between the levees are flooded, and the farmer uses his tractor and water leveling blades to level the land between the levees. The principal advantages of water leveling are that the farmer typically has on hand the equipment needed to carry out the leveling process, and wet soil conditions do not hamper the leveling operation.

Precision leveling is a major land-leveling process carried out with the objective of creating a smooth drop in elevation across a field. This is accomplished in a two-step process. In the first step major high and low points in each field are pinpointed, and earth-moving equipment is used to move soil from the high points to the low points. In the second step, a land plane (usually laser-guided) is employed to provide the finishing touches to the leveling process.

The principal advantage of precision leveling over water leveling is that the field can be made to slope at a more uniform rate and allow for even more straightening of levees than is possible with water leveling. Major disadvantages include the high initial cost of precision leveling, and the creation of "hot spots" in some fields. These "hot spots" are caused by a previous accumulation of salts in the former high points of the field and may require several years to dissipate.

Underground pipe has also been used to replace lateral delivery systems on some farms. The principal advantage of underground pipe is the elimination of lateral losses. Installation of underground pipe also permits land formerly used for laterals to be put into production of rice. An underground pipe system may also be designed to deliver water to each cut in a field, thereby providing a more efficient means of regulating water levels in each cut. Although not yet proven, such control should reduce water use and increase crop yield. The principal disadvantage to underground pipe is its high cost. This high cost has limited the use of underground pipe to farms where well water is used for irrigation.

Table 20 indicates that in 1982 water leveling was the most common of the three water conservation methods, accounting for approximately 140,000 acres of land. Precision (laser) leveling had been done on approximately 66,000 acres, while just over 29,000 acres were served using underground pipe water delivery systems. When comparing this table with Table 16 on page 60, the survey results indicate that a higher percentage of these water conservation practices have been implemented on owned land rather than on leased land. While 22.1% of the acreage farmed in 1982 was owned by rice producers, 48.2% of the land served by underground pipe, 31.6% of the water-leveled land, and 26% of the laser-leveled land was also owned by rice producers.

FUTURE WATER DEMAND AND CONSERVATION OPTIONS

Although surface water and groundwater supplies are presently adequate to meet the needs of Texas Gulf Coast rice producers, the future availability of such supplies remains uncertain. Moreover, it is not clear what limiting role water supplies would have on acreage expansion should rice production become more profitable. If, as many producers, planners, and researchers suggest, future water supplies available for rice production do decline and water costs increase, it is not clear what water conservation alternatives would be pursued by producers in order to continue producing rice. It is the purpose of this section to discuss anticipated future water supplies and costs, and examine how producers would react to changes in water supplies and costs.

EXPECTED FUTURE SURFACE WATER SUPPLY AND DEMAND

Surface water supplies in the Rice Belt have been, in recent years, more than sufficient to meet demand. This is due partly to the development of several reservoirs on the major river systems that traverse the Rice Belt and partly to the decline in rice acreage due to decreased profitability. The interviews conducted with the major irrigation water suppliers indicated various factors limited expansion of acreage on each system. Legal limitations on water permits placed a ceiling on future expansion for most private companies. Public and private water suppliers located near Houston indicated that available rice land, rather than water, limited acreage. Water stored in reservoirs by some public suppliers can be purchased for use by rice producers. However, such water is generally too expensive to use in agricultural production. A few suppliers were limited by the size of their canal systems and/or pumping facilities. There were also a few river authorities whose limits were well above actual acreage figures.

Because most agricultural water rights predate industrial and municipal rights, the latter users could increase their share of current water supplies only by purchasing the older rights or through the eminent domain process. In general, federal, state, and local units of government have chosen instead to construct dams and improve conveyance facilities in order to make better use of existing supplies. As long as new sources of water can be developed economically, the industrial and municipal users will not likely attempt to change the status of water rights currently being exercised for agricultural purposes.

Several projects to increase dependable water supplies and improve utilization of present supplies in the Rice Belt currently are under construction or are in the planning stages. These projects include the Wallisville, Cleveland, Rockland, Millican, Lower Lake Creek, Columbus Bend, and Baylor Creek Reservoirs; the Luce Bayou Diversion and Houston Conveyance System; and the East, Northeast, and Southeast water treatment plants in Harris County.

The Wallisville Reservoir, currently under construction, is being built on the Trinity River near Anahuac by the City of Houston. Expected completion date is 1984-85. Cleveland Reservoir will be built near Cleveland by the San Jacinto River Authority, with scheduled date of completion in 1996-97. The SJRA is also planning construction of the Lower Lake Creek Reservoir near Conroe Reservoir around the year 2000. Rockland Reservoir is scheduled to be built on the Neches River by the years 2004-2005. The cost of construction will be shared by the LNVA and the City of Houston.

The Millican Reservoir and Dam will be built on the Navasota River and is scheduled for completion in 1986–87. Construction will be financed by the Brazos River Authority. The Columbus Bend and Baylor Creek Reservoirs, also known as the Colorado Coastal Project, are scheduled for completion in 1996–97. These two reservoirs will be built by the LCRA and will be located in Colorado and Fayette Counties.

The Luce Bayou Diversion (currently under construction) and the Houston System are both being built by the City of Houston to more effectively utilize water from Lake Livingston. Currently, the City is also building the East and Northeast water treatment plants so that more surface water can be used for municipal and industrial purposes in the Houston metropolitan area. The lack of treatment plants is the principal reason the City of Houston has not been able to phase out groundwater as a municipal water source. It is expected that these projects will be sufficient to meet the anticipated increases in water demand over the next 20 years (TDWR 1983).

EXPECTED FUTURE GROUNDWATER SUPPLY AND DEMAND

The U.S. Geological Service (USGS) has estimated that the Gulf Coast Aquifer can supply 2.5 million acre–feet per year of water without causing a decline in the aquifer level (U.S. Department of the Interior 1976). The USGS also estimated that the Gulf Coast Aquifer contained 450 million acre–feet of recoverable storage within 400 feet of the land's surface, with an additional 1,150 million acre–feet of recoverable storage located below 400 feet. In terms of recoverable storage, this aquifer is the largest in Texas (U.S. Department of the Interior 1976).

Despite a high recharge rate, different parts of the aquifer have experienced declines in the water table. Table 21 highlights those regions where withdrawals exceeded estimated aquifer recharge in 1980. Figure 6 shows the location of the river basins referred to in Table 21. As can be seen in the table, the largest recharge deficits are in the Houston area and the area lying between the Colorado and Lavaca Rivers.

This result is supported by results from the water management survey. In response to the question "Have you noticed a decline in the water table during the past five years?", the percentage of rice producers responding in the affirmative was highest in Harris and Jackson Counties. The specific percentages by county were: Harris, 100%; Jackson, 80%; Matagorda, 75%; Victoria, 67%; Wharton, 67%; Colorado, 43%; Waller, 43%; Brazoria, 38%; Austin, 33%; and Liberty, 33%.

While the depletion (or mining) of the aquifer is not in itself different than the consumptive use of any other exhaustible natural resource, such depletion does have economic consequences for groundwater users. As mentioned before, subsidence in the Houston area has resulted in damage to homes, roads, and bridges. Subsidence has also occurred to a lesser degree in the Jackson County area, with some locations showing declines in elevation of more than one foot between 1952 and 1973 (TDWR 1982b). As water tables have declined, saltwater encroachment has occurred in some municipal wells used by coastal cities. Once saltwater has infiltrated into the water table the well no longer can be used as a source of fresh water. A new well must be drilled which is farther from the saltwater source, and new conveyance facilities may have to be developed.

TABLE 21. ESTIMATED GROUNDWATER WITHDRAWALS AND RECHARGE FOR SELECTED BASINS IN THE GULF COAST AQUIFER

River Basin	Estimated 1980 Withdrawals (acre-feet)	Average Annual Recharge (acre-feet)	Estimated Water Mined from Aquifer (acre-feet)
Sabine	21,000	54,000	0
Neches	80,100	101,000	0
Neches-Trinity	9,800	11,000	0
Trinity	30,900	61,400	0
Trinity-San Jacinto	27,000	42,000	0
San Jacinto	463,100	337,000	126,100
San Jacinto-Brazos	75,200	110,500	0
Brazos	55,500	72,500	0
Brazos-Colorado	101,200	68,000	33,200
Colorado	33,600	26,000	7,600
Colorado-Lavaca	125,300	8,000	117,300
Lavaca	220,500	86,000	134,500
Lavaca-Guadalupe	58,200	48,000	10,200
Total	1,301,400	1,025,400	428,900

Source: *Water For Texas - Planning for the Future*. Draft. TDWR 1983.

Of particular concern to the agricultural user is the effect the falling water table has on water costs. As the water table falls, the distance water has to be lifted increases, resulting in greater energy use and higher pumping costs. In addition, it is sometimes necessary to reset the depth of the bowls or replace the pumping plant altogether to ensure an adequate supply of irrigation water during the growing season. The rising water costs also make it more and more difficult for the rice producer to produce rice at a profit.

In summary, the supply of groundwater seems adequate to meet any immediate future demand. The cost of obtaining groundwater likely will continue to increase, however, as both increasing energy prices and falling water tables contribute to an increase in pumping costs.

REACTIONS TO DECREASED WATER SUPPLIES AND INCREASED COSTS

Several questions dealing with hypothetical changes in water supplies and costs were posed to those producers who received the RWMS survey. Four questions were asked requesting the respondents to indicate what water conservation alternatives they would pursue, might pursue, and would not pursue in light of long-term decreases in water supplies or increases in water costs. Questions dealing with changes in water supplies were directed at those persons using surface water, while groundwater users were asked to

Figure 6. Major river basins in the Texas Rice Belt.

respond to questions dealing with changes in groundwater costs.

Initially, surface water users were asked to indicate which of 10 alternatives they would pursue if surface water supplies were decreased 15%. A total of 50 rice producers from the Upper Gulf Coast and 75 from the Lower Gulf Coast responded to the question. The aggregated responses are displayed in Table 22. The respondents indicated they would most likely rely on other, unspecified water conservation practices, such as precision land leveling and lined lateral ditches, to decrease total water use. Specific alternatives which were highly ranked included reducing irrigated acreage and increasing the use of tailwater.

The use of wells to supplement surface water was considered to be a more viable alternative to Lower Gulf Coast rice producers than to producers in the Upper Gulf Coast Region. This was undoubtably due to the limited use of groundwater by the Upper Gulf Coast producers. The installation of underground pipe was also looked upon with greater favor by Lower Gulf Coast producers. Switching to sprinkler irrigation, other irrigated crops, or drilling wells were alternatives that very few indicated they would pursue, while over two-thirds of the respondents indicated that these were alternatives which they would *not* pursue.

Groundwater users were asked to indicate which of 11 alternatives they would pursue when faced with a permanent 15% increase in groundwater costs. Responses from 124 producers are given in Table 23. It is important to note that a 15% increase in groundwater costs does not imply that water availability or usage would decline by 15%. Thus, percentages in Tables 22 and 23 are not directly comparable.

As was the case with surface water users, groundwater users felt that the use of miscellaneous water conservation practices was the most likely alternative they would pursue when faced with an increase in water costs. Specific alternatives receiving high approval were servicing of pump and bowls to improve pumping efficiency, increasing the use of tailwater, and reducing rice acreage. Alternatives considered least viable included switching to sprinkler irrigation or other irrigated crops.

Following these initial hypothetical situations, more severe situations were presented to the producers to ascertain what major changes, if any, they would make in their water conservation practices. Surface water users were asked to indicate alternatives they would pursue when faced with a 30% reduction in surface water supplies. A total of 46 Upper Gulf Coast and 72 Lower Gulf Coast rice producers responded to the question. Their responses are summarized in Table 24.

When comparing Tables 22 and 24, perhaps the most surprising result is that Lower Gulf Coast producers would not implement many new water conservation alternatives should supplies be reduced by 30% rather than 15%. The largest changes that they would make would be to reduce irrigated acreage further and switch to other irrigated crops. This seems to indicate that producers felt most water conservation alternatives, short of acreage reductions, would be in place by the time a 15% reduction was made in water supplies. On the other hand, many more Upper Gulf Coast producers would implement additional water conservation practices under the larger water supply reduction. In particular, use of other water conservation measures, increased use of tailwater, and switching to other irrigated crops would receive highest priority. Again, most alternatives which required high capital investments (such as sprinkler irrigation and drilling new wells) received the smallest

TABLE 22. POTENTIAL WATER CONSERVATION ALTERNATIVES PURSUED BY PRODUCERS IN RESPONSE TO A 15% DECREASE IN SURFACE WATER SUPPLIES

	Alternative	Gulf Coast Region	Would Pursue	Might Pursue	Would Not Pursue
(a)	Use Wells More Intensively	Upper	10%	0%	90%
		Lower	16%	17%	67%
(b)	Reduce Irrigated Acreage	Upper	48%	20%	32%
		Lower	39%	26%	35%
(c)	Switch to Other Irrigated Crops	Upper	0%	28%	72%
		Lower	6%	27%	67%
(d)	Switch Some Acreage to Sprinkler Irrigation	Upper	2%	20%	78%
		Lower	9%	20%	71%
(e)	Drill Wells	Upper	0%	12%	88%
		Lower	7%	17%	76%
(f)	Switch All Acreage to Sprinkler Irrigation	Upper	2%	12%	86%
		Lower	1%	13%	86%
(g)	Install Underground Pipe	Upper	8%	16%	76%
		Lower	20%	33%	47%
(h)	Reduce Ratoon Cropping	Upper	20%	26%	54%
		Lower	16%	36%	48%
(i)	Increase Use of Tailwater	Upper	32%	38%	30%
		Lower	44%	32%	24%
(j)	Use Other Water Conservation Practices	Upper	52%	28%	20%
		Lower	44%	32%	24%

TABLE 23. POTENTIAL WATER CONSERVATION ALTERNATIVES PURSUED BY PRODUCERS IN RESPONSE TO A 15% INCREASE IN GROUNDWATER COSTS

	Alternative	Would Pursue	Might Pursue	Would Not Pursue
(a)	Reduce Rice Acreage	29%	29%	42%
(b)	Switch to Irrigated Crops Using Less Water	8%	27%	65%
(c)	Install Underground Pipe	18%	36%	46%
(d)	Switch Some Acreage to Sprinkler Irrigation	2%	23%	75%
(e)	Switch All Acreage to Sprinkler Irrigation	1%	6%	93%
(f)	Reduce Ratoon Cropping	19%	41%	40%
(g)	Reduce Non-Rice Irrigated Acreage	10%	20%	70%
(h)	Increase Use of Tailwater	32%	31%	37%
(i)	Use Other Water Conservation Practices	41%	32%	27%
(j)	Have Pump and Bowls Serviced	40%	35%	25%
(k)	Other	7%	3%	90%

TABLE 24. POTENTIAL WATER CONSERVATION ALTERNATIVES PURSUED BY PRODUCERS IN RESPONSE TO A 30% REDUCTION IN SURFACE WATER SUPPLIES

	Alternative	Gulf Coast Region	Would Pursue	Might Pursue	Would Not Pursue
(a)	Use Current Wells More Intensively	Upper	12%	4%	84%
		Lower	23%	18%	59%
(b)	Reduce Irrigated Acreage	Upper	50%	26%	24%
		Lower	48%	18%	34%
(c)	Switch to Irrigated Crops Using Less Water	Upper	12%	34%	54%
		Lower	15%	24%	61%
(d)	Use Some Sprinkler Irrigation	Upper	6%	32%	62%
		Lower	10%	20%	70%
(e)	Drill (more) Wells	Upper	6%	10%	84%
		Lower	8%	18%	74%
(f)	Switch to Using only Sprinkler Irrigation	Upper	4%	24%	72%
		Lower	6%	8%	86%
(g)	Install Underground Pipe	Upper	14%	18%	68%
		Lower	22%	34%	44%
(h)	Reduce Ratoon Cropping	Upper	20%	30%	50%
		Lower	21%	30%	49%
(i)	Increase Use of Tailwater	Upper	46%	26%	28%
		Lower	48%	24%	28%
(j)	Use Other Water Conservation Measure	Upper	68%	18%	14%
		Lower	52%	26%	22%

support from the producers surveyed. No doubt the poor economic situation facing rice producers at the time the survey was taken left many farmers doubtful about the ability of these capital improvements to pay for themselves. Several comments made by survey respondents also indicated they were not sure that sprinkler irrigation was a viable water conservation alternative for them under any conditions.

Table 25 summarizes the actions which would be pursued by 117 rice producers should groundwater costs permanently increase 30%. A comparison of this table with Table 23 indicates that the major response by rice producers to increases in groundwater costs to above present levels would be to reduce irrigated acreage. Virtually all other alternatives would be pursued at the same level as when groundwater costs were increased only 15%.

Using the acreage figures reported by each producer, calculations were made to determine the total number of acres operated by surface and groundwater users who indicated that they would, might, or would not reduce rice acreage. In performing these computations, explicit consideration was given to the amount of acreage being cultivated by each respondent. A summary of these results is given in Table 26.

Some interesting information can be obtained when comparing Table 26 with the previous four tables. For example, when comparing Tables 26 and 25, the results indicate that while 55% of the rice producers would definitely reduce rice acreage in response to a 30% increase in groundwater costs, these producers only accounted for 19% of the 1982 acreage reported in the RWMS. So, while many farms using groundwater would reduce acreage under this type of a scenario, the majority of these farms would be small. Similiar results are obtained when comparing Table 26 with Tables 22-24, particularly for groundwater users.

Producers indicating that they would or might reduce acreage under any one of the four scenarios were also asked to estimate the approximate percentage acreage reduction they would implement in their operations. Approximately one-half of the groundwater users and two-thirds of the surface water users who indicated that they would or might reduce acreage did in fact estimate the percentage they would decrease irrigated acreage. When weighted by farm size, the figures indicated that groundwater users who definitely planned to reduce acreage estimated that their acreage reductions would average 33% and 54%, respectively, for the 15% and 30% increases in groundwater costs. By contrast, 15% and 30% hypothetical decreases in surface water supplies resulted in estimated acreage decreases of 22% and 33% respectively.

Multiplying these percentages by the percentages given in Table 26, the 15% and 30% increases in groundwater costs would result in a minimum respective decrease of 4% (.33 x .11 = .04) and 10% (.54 x .19 = .10) in total groundwater acreage in production. For surface water users, 15% and 30% decreases in supplies would result in 9% and 19% decreases in total surface water acreage, respectively. These figures should be considered minimum acreage reductions since they do not include the "Might Reduce Acreage" category.

In summary, a 100% increase in water costs or decrease in water supplies would result in more than a 100% decrease in irrigated acreage. Farms irrigating small acreages with groundwater would cut acreage much more severely than large acreage farms. Many of the small farms using only groundwater indicated that they would in fact discontinue

TABLE 25. POTENTIAL WATER CONSERVATION ALTERNATIVES PURSUED BY PRODUCERS IN RESPONSE TO A 30% INCREASE IN GROUNDWATER COSTS

	Alternative	Would Pursue	Might Pursue	Would Not Pursue
(a)	Reduce Rice Acreage	55%	21%	24
(b)	Switch to Irrigated Crops Using Less Water	13%	20%	67%
(c)	Install Underground Pipe	19%	27%	54%
(d)	Reduce Non-Rice Irrigated Acreage	9%	18%	73%
(e)	Reduce Ratoon Cropping	23%	29%	48%
(f)	Increase Use of Tailwater	33%	27%	40%
(g)	Switch Some Acreage to Sprinkler Irrigation	3%	21%	76%
(h)	Switch All Acreage to Sprinkler Irrigation	2%	6%	92%
(i)	Use Other Water Conservation Practices	40%	27%	33%
(j)	Have Pump and Bowls Serviced	42%	25%	33%
(k)	Other	8%	1%	91%

TABLE 26. RICE ACREAGE AS RELATED TO PRODUCER'S RESPONSES TO INCREASING COST/DECREASING SUPPLIES OF IRRIGATION WATER

			Percentage of Acreage Operated		
Water Source	Percent Increase in Cost	Percent Decrease in Supply	Would Not Reduce Acreage	Might Reduce Acreage	Would Reduce Acreage
Surface	-	15%	28%	31%	41%
	-	30%	28%	16%	56%
Ground	15%	-	60%	29%	11%
	30%	-	60%	21%	19%

Note: These percentages represent total acres operated by producers in each of the indicated categories. They do *not* represent percentage acreage which would be reduced as a result of the indicated changes in water supplies and costs.

rice production altogether. Thus, adverse changes in water supplies and costs would result in an increase in the average rice farm size, particularly for farms using groundwater.

REACTIONS TO INCREASED WATER SUPPLIES AND DECREASED COSTS

Following the aforementioned questions dealing with decreases in water supplies and increases in water costs, two additional hypothetical questions were posed to farmers in which contrasting scenarios were presented. Producers using surface water were asked to indicate what alternatives they would pursue if their water supplies increased 10%, assuming that the cost of these additional supplies was the same as present supplies. A total of 49 Upper and 72 Lower Gulf Coast producers responded to the question. Their responses are summarized in Table 27.

Only 10% of both Upper and Lower Gulf Coast producers felt that they would increase rice acreage as a result of increased surface water supplies. This seems to indicate that water is not a major factor limiting increases in Texas rice acreage. Again, however, it should be kept in mind that rice producers were facing poor economic conditions when the survey was taken. Many of the farmers might very well have been reacting to the economic conditions of the time when answering this question.

Groundwater users were asked to indicate what alternatives they would pursue if groundwater costs permanently decreased 10%. A summary of their responses from 123 producers can be found in Table 28. As was the case with surface water users, the majority of groundwater users felt that they would make no change in their operations as a result of a decrease in costs.

TABLE 27. POTENTIAL WATER USE ALTERNATIVES PURSUED BY PRODUCERS IN RESPONSE TO A 10% INCREASE IN SURFACE WATER SUPPLIES

	Alternative	Gulf Coast Region	Would Pursue	Might Pursue	Would Not Pursue
(a)	Plant More Acreage into Rice	Upper	10%	31%	59%
		Lower	10%	43%	47%
(b)	Use Less Supplemental Well Water	Upper	12%	4%	84%
		Lower	35%	7%	58%
(c)	Use More Water to Control Weeds	Upper	12%	33%	55%
		Lower	25%	26%	49%
(d)	No Change in Farming Operation	Upper	68%	14%	18%
		Lower	53%	26%	21%
(e)	Spend Less Time Minimizing Lateral Losses	Upper	10%	12%	78%
		Lower	8%	17%	75%
(f)	Other	Upper	2%	4%	94%
		Lower	8%	3%	89%

TABLE 28. POTENTIAL WATER USE ALTERNATIVES PURSUED BY PRODUCERS IN RESPONSE TO A 10% DECLINE IN GROUNDWATER COSTS

	Alternative	Would Pursue	Might Pursue	Would Not Pursue
(a)	Plant More Acreage to Rice	13%	23%	64%
(b)	Use More Water to Control Weeds	12%	27%	61%
(c)	No Change in Farming Operation	59%	26%	15%
(d)	Spend Less Time Minimizing Lateral Losses	4%	16%	80%
(e)	Other	4%	2%	94%

Two questions were included in the survey to obtain more information on farmer's perceptions concerning water as a factor limiting expansion of rice acreage on their respective farms. In the first question producers were asked to estimate the maximum number of acres they would farm given their current land and water resources and assuming that rice was the most profitable crop in their operation. They were also asked to include only acreage that they owned or were currently leasing. Following this question, producers were again asked to estimate the maximum acres they would farm under the same circumstances, except that they were to assume they could get all the water they needed at current prices. A county-by-county summary of the responses to these questions is given in Table 29.

The results from Table 29 seem to indicate that water supplies are not a major factor limiting increases in rice acreage. In fact, most of the difference in acreage between the two scenarios is in Colorado and Wharton Counties. As can be noted in Table 3 on page 31, most canal systems operating in these counties in 1982 were at or near the maximum acreage limit imposed by surface water availability. Generally, these limits were due to legal restrictions placed on the maximum amount of water which the supplier could divert for irrigation.

TABLE 29. MAXIMUM POTENTIAL ACREAGE WITH AND WITHOUT CURRENT WATER SUPPLY CONSTRAINTS

County	1982 Acreage	Maximum Acreage With Current Water Supplies	Maximum Acreage With Unlimited Water Supplies
Austin	4,000	4,553	5,412
Brazoria	48,900	67,610	72,837
Calhoun	12,300	23,362	23,362
Chambers	42,000	83,384	83,384
Colorado	44,800	91,009	111,366
Fort Bend	21,500	44,085	44,085
Galveston	8,600	14,506	14,506
Hardin	1,600	NA	NA
Harris	17,900	23,654	26,843
Jackson	36,800	48,192	48,997
Jefferson	43,000	68,037	68,037
Lavaca	4,800	a	a
Liberty	34,100	62,074	71,263
Matagorda	48,300	67,271	68,827
Orange	1,400	a	a
Victoria	5,300	6,405	6,405
Waller	13,500	35,189	44,853
Wharton	79,900	175,662	187,889
Total	470,700	825,480	888,722

NA - Not Available
[a]Data withheld to avoid disclosure of information for individual operations.

REFERENCES

Armour, Lawrence. General Manager, Pierce Ranch, Pierce, Texas. Personal Interview, 10 January 1983.

Barrett, Ike. San Jacinto River Authority, Conroe, Texas. Personal Interview, 17 December 1982.

Basham, George V. III. Hearings Examiner, Texas Water Commission, Austin. Personal Interview, 21 September 1982.

Bettge, R., G. McCauley, W. Weiderhold, and G. Crenwelge. "Status Report of Water Monitoring Project." Presentation made at the 1983 Gulf Coast Water Management Conference and Tour, Dayton, Texas. 13–14 June 1983.

Caroom, Doug and Paul Elliott. "Water Rights Adjudication–Texas Style." *Texas Bar Journal* 44 (November 1981): 1183–1190.

Clark, Walter. General Manager, Devers Canal Division, Trinity River Authority, Devers, Texas. Personal Interview, 21 December 1982.

Clark, Warren. General Manager, Chambers–Liberty Counties Navigation District, Anahuac, Texas. Personal Interview, 21 December 1982.

Cox, William E. "Water Law Primer." *Proceedings of the ASAE* 108 (March 1982): 107–122.

Crittenden, Bob. Planning and Development Department, Texas Department of Water Resources, Austin. Telephone Interview, 9 July 1982.

Davidson, Frank. Surveyor, Lakeside Irrigation Company, Eagle Lake, Texas. Personal Interview, 10 January 1983.

Ellis, John R., Ronald C. Griffin, and Rod F. Ziemer. "A Supply–Demand Analysis of Irrigation Water Use in the Texas Rice Belt." To be presented at the 1984 Western Agricultural Economics Association Meeting. San Diego, July 1984.

Grant, Warren G. Agricultural Economist, ERS, United States Department of Agriculture, College Station, Texas. Personal Communication, April 1983.

Griffin, Ronald C. and John R. Stoll. "The Enhanced Role of Water Conservation in the Cost–Benefit Analysis of Water Projects." *Water Resources Bulletin* 19 (June 1983): 447–457.

Griffin, Ronald C. and Gregory M. Perry. "Alternative Water Rate Structures for Rice Irrigation." Natural Resources Working Paper Series. Department of Agricultural Economics, Texas A&M University, College Station. 4 August 1983.

Harris–Galveston Coastal Subsidence District. *Subsidence '82.* Friendswood, Texas, 1982.

Harris-Galveston Coastal Subsidence District. *Annual Report Data.* Friendswood, Texas, 1983.

Harris, Robert. General Manager, Lower Neches Valley Authority, Beaumont, Texas. Personal Interview, 22 December 1982.

Hodges, Frank. "Law Relating to Water." In *Facets of Hydrology,* pp. 315-330. Edited by John Rodda. 1976.

Holder, Shelby H. Jr. and Warren R. Grant. *U.S. Rice Industry.* Washington, D.C.: USDA Economics, Statistics, and Cooperatives Service, Agr. Econ. Rep. 433, Aug. 1979.

Holesovsky, Buddy. Water System Manager, Chocolate Bayou Water Company, Alvin, Texas. Personal Interview, 10 January 1983.

Humphrey, M. David, Jr. Statistican, Texas Crop and Livestock Reporting Service, Austin. Personal Communication, January 1983.

Hutson, William F. *Irrigation Systems in Texas.* United States Geological Survey, Water Supply and Irrigation Paper Number 13. Washington, D.C.: Government Printing Office, 1898.

Knutson, Gerald D., Robert G. Curley, and Blaine R. Hanson. *Cutting Energy Costs for Pumping Irrigation Water.* Division of Agricultural Sciences, University of California, Leaflet 21188. Berkeley, California, February 1981.

Kruse, E.G., A.S. Humphreys, and E.J. Pope. "Farm Water Distribution Systems." In *Design and Operation of Farm Irrigation Systems,* pp. 395-439. Edited by M.E. Jensen. St. Joseph, Michigan: American Society of Agricultural Engineers, September 1981.

Lower Colorado River Authority. *Annual Report 1982.* Austin, Texas.

Lehrer, William. President, Garwood Irrigation Company, Garwood, Texas. Personal Interview, 2 December 1982.

Massey, Tom S. Lawyer and Former State Representative, San Angelo, Texas. Telephone Conversation, 23 September 1982.

McNeely, John G. and Ronald D. Lacewell. *Surface Water Development in Texas.* Texas Agr. Exp. Sta. Bull. No. B-1177, Texas A&M University, May 1977.

McQuhae, Charles. Manager, Dayton Canal Company, Dayton, Texas. Personal Interview, 21 December 1982.

Moltz, Bill. Planning and Development Department, Texas Department of Water Resources, Austin, Texas. Personal Communication, 9 March 1983, 12 August 1983.

Muller, D.A. and R.D. Price. *Groundwater Availability in Texas: Estimates and Projections through 2030.* Austin: Texas Department of Water Resources. Report 238.

Mullins, Troy, Warren R. Grant, and Ronald D. Krenz. *Rice Production Practices and Costs in Major U.S. Rice Areas, 1979.* Arkansas Agr. Exp. Sta. Bull. No. 851, University of Arkansas, March 1981.

Parker, Michael G. Master's Student, Department of Ag. Economics, Texas A&M University, College Station, Texas. Personal Communication, April 1983.

Perry, Leo. Division Manager, Gulf Coast Division, Sabine River Authority, Orange, Texas. Personal Interview, 22 December 1982.

Reddell, Donald L. Professor, Department of Agricultural Engineering, Texas A&M University, College Station, Texas. Telephone Conversation, 1 April 1983.

Rice Farming. "Is Sprinkler Irrigation a Viable Alternative for Rice?" January 1982, pp. 14–15.

Schlicher, Dan. General Manager, Richmond Irrigation Company, Richmond, Texas. Personal Interview, 20 December 1982.

Schwartz, Suzanne. Attorney, Texas Department of Water Resources, Austin. Personal Interview, 21 September 1982.

Schwartz, Suzanne. Attorney, Texas Department of Water Resources, Austin. Telephone Conversation, 9 March 1983.

Seward, Lewis B. Deputy Assistant Director, Water Division, Department of Public Works, City of Houston, Texas. Personal Interview, 17 December 1982.

Shannon, Gene. Manager, Canal Division, Brazos River Authority, Alvin, Texas. Personal Interview, 10 January 1983.

Taylor, Thomas U. *Rice Irrigation in Texas.* University of Texas Bulletin No. 16, 1902.

Texas Agricultural Extension Service. *Texas Enterprise Budgets, Irrigated Rice.* B-1241(C21,C22) College Station, Texas.

Texas Agricultural Extension Service. *1983 Rice Production Guidelines.* College Station, Texas, 1983.

Texas Almanac. Fiftieth Edition, 1980–1981. Dallas: A.H. Belo Corporation.

Texas Department of Agriculture. *Texas Historic Crop Statistics 1866-1980.* Austin, Texas, 1981.

Texas Department of Water Resources. *Annual Financial Report For the Year Ended August 31, 1979.* Austin, Texas, 1979.

Texas Department of Water Resources. *Inventories of Irrigation in Texas 1958, 1964, 1969, 1974, and 1979.* Austin, Texas, October 1981a.

Texas Department of Water Resources. *Report of the Texas Department of Water Resources, For the Biennium September 1, 1979 through Aug. 31, 1981.* Austin, Texas, 1981b.

Texas Department of Water Resources. *Data Tape of Surface Water Use Reports Through 1982.* College Station, Texas: Department of Agricultural Economics Texas A&M University, 1982a.

Texas Department of Water Resources. *Groundwater Resources of Colorado, Lavaca, and Wharton Counties, Texas.* Report 270. Austin, Texas, July 1982b.

Texas Department of Water Resources. *Texas Water Facts.* Austin, Texas, February 1982c.

Texas Department of Water Resources. *Water For Texas, Planning for the Future.* Draft, Austin, Texas, February 1983.

Texas House of Representatives. *An Act to Create the Brazos River Conservation and Reclamation District.* Forty-First Legislature, Ratoon Called Session, H.B. 197, 1929.

Texas House of Representatives. *An Act to Create the Harris-Galveston Coastal Subsidence District.* Sixty-Fourth Legislature, Regular Session, H.B. 552, 1975.

Texas Water Resources Institute. *Agricultural Resources Related to Water Development in Texas, Preliminary Report to the Texas Water Development Board.* College Station, Texas: Texas A&M University, September 1965.

Texas Water Resources Institute. *Texas Water Resource* 9(5):2, Texas Agricultural Experiment Station, College Station. Sept/Oct 1983.

Thompson, John T. *Public Administration of Water Resources in Texas.* Institute of Public Affairs Series, No. 43, Austin, The University of Texas, 1960.

Trout, T.J. and S.A. Bowers. "Operational Evaluation of Village Level Irrigation Conveyance Systems." *Transactions of the ASAE* 24(1981): 636-642.

Treude, Norman. Manager, Gulf Coast Water Division, Lower Colorado River Authority, Bay City, Texas. Personal Interview, 11 January 1983.

U.S. Department of Agriculture; Crop Reporting Board, Statistical Reporting Service. *Agricultural Prices, Annual Summary 1981.* Washington, D.C., June 1982.

U.S. Department of Interior, U.S. Geological Survey. *Summary Appraisals of the Nations Ground-Water Resources -- Texas-Gulf Region.* Professional Paper 813-F. Washington, D.C.: Government Printing Office, 1976.

Vernon's Texas Codes Annotated, Water Code. 3 Volumes, 56 Sections. St. Paul, Minn.: West Publishing Company, 1972.

Wilkinson, Susan. Harris–Galveston Coastal Subsidence District, Friendswood, Texas. Telephone Conversation, 9 March 1983.

Wittliff, Herbert. Manager, Calhoun Canal Division, Guadalupe–Blanco River Authority, Port Lavaca, Texas. Personal Interview, 3 December 1982.

APPENDIX

THE RWMS SURVEY

RICE WATER MANAGEMENT STUDY

Department of Agricultural Economics
Texas A&M University
College Station, Texas 77843
November 1982

RICE WATER MANAGEMENT STUDY

The purpose of this survey is to identify current and potential problems relating to the profitable use of water in rice production. In order to eliminate the possibility of double counting, land farmed in partnership should be reported on one questionnaire only. Please coordinate your response to this questionnaire with your partner(s) so that two or more different questionnaires do not contain information on the same unit of farmland. If you farm some land in partnership and some singly and you have not been designated to represent the partnership, complete the survey and omit that acreage which you farm in partnership. If all your acreage is farmed in partnership and you have not been designated to represent the partnership, please check the box below and return the questionnaire unanswered.

[] I farm all my land in partnership with others. One of my partners has agreed to fill out a questionnaire representing our partnership.

Directions

For your convenience this questionnaire is separated into five parts. The following directions indicate which sections apply to you.

- If you did not produce any rice in 1982 please fill out Part A only.
- If you leased land to others please fill out Part A.
- If you did farm rice in 1982, please fill out Parts B and E.
  - a) If you used surface water to irrigate, fill out Part C also.
  - b) If you used groundwater to irrigate, fill out Part D also.
  - c) If you used a combination of surface water and groundwater, fill out both Parts C and D.
- Please answer Part F irregardless of your production situation.

In most cases you will be filling out more than one section. For example, if you leased land out and also farmed some land using surface water you would complete Parts A, B, C, and E. Please be sure to read each question carefully before attempting to answer.

PART A - GENERAL AND FARM TENURE INFORMATION

1. If you did not produce rice in 1982 and did not lease land to others to produce rice, please answer the following questions. Otherwise, skip to 2.

   (1a) Have you ever been a rice producer?
   [] Yes [] No

   (1b) If you answered 'No' to question (1a), you have completed the questionnaire. If you answered 'Yes', please indicate why you did not produce rice in 1982.

   [] Retired
   [] Prices were too low
   [] Rice is out of rotation this year
   [] Other ______

   (1c) Do you intend to produce rice in the future?
   [] Yes [] No [] Undecided

   (1d) If you answered 'No' to question (1c), indicate why you do not plan to produce rice in the future.

   [] Plan on retiring
   [] Sold my rice acreage
   [] Other crops more profitable
   [] Other ______

2. Answer the following questions if you leased land to others for rice production in 1982.

   (2a) In the table below, indicate by county the number of acres leased to others whereon the indicated water conservation practices have been implemented.

County	Underground Pipe	Laser Leveled (field)	Water Leveled
(1) ______	______	______	______
(2) ______	______	______	______
(3) ______	______	______	______
(4) ______	______	______	______
(5) ______	______	______	______

   (2b) What percentage of the above listed water conservation practices did you pay for? ______%

If you leased land to others please answer the following questions.

3. Each of the following instructions describes the information needed in particular columns of table A.3. Make a separate entry on the table for every irrigated field of land which differs from other fields in terms of either (i) county, (ii) crop produced in 1982, (iii) water supply source or (iv) tenure arrangement. If a question does not pertain to your particular farming situation it should be left blank. If two fields do not differ in any of the above four categories, they should be added together and reported on <u>one</u> line of the table.

(3a) For each field differing in terms of (i-iv) above, enter location by county, number of acres irrigated in 1982, and crop being produced in 1982. Include crops (and acreage) not being irrigated in 1982 but which are grown in rotation with irrigated crops.

(3b) Indicate for each field the source of surface water (the name of the river authority or canal company). If you own rights by permit with the state enter "private rights".

(3c) For each field differing in terms of (i-iv) above, indicate the appropriate tenure situation by (a) indicating under "Cash Rent" the dollars/acre you receive for cash rent or (b) indicating under "Crop Share" the percentage of the crop you receive as rental payment. If your tenure arrangement is a combination of cash rent and crop share, indicate your arrangement on <u>both</u> lines.

(3d) For each field differing in terms of (i-iv) above, indicate the percentage of cash water costs (canal charges, energy costs, etc.) paid by you.

(3e) For each field differing in terms of (i-iv) above, indicate the percentage of cash crop expenses (except water) which were paid by you.

(3f) For each field differing in terms of (i-iv) above, indicate the percentage of surface water used. If surface water is the only water source, put '100'. If wells are the only water source, put '0'. If the water source is a combination of surface and ground water, indicate what percentage is surface water.

(3g) Indicate for each field the number of wells servicing this acreage.

NOTE: Two example entries are included for illustrative purposes.

TABLE A.3

	(3a)			(3b)	(3c)		(3d)	(3e)	(3f)	(3g)
	County	Irrigated Acreage in 1982	Crop Being Irrigated	Surface Water Supplier	Indicate: Cash Rent	Indicate: Crop Share	Percent of Water Costs	Percent of Cash Crop Expenses	Percent of Surface Water	Number of Wells
ex. 1	Brazoria	220	Rice	Choc. Bayou	$ 100 /ac	____ %	100 %	0 %	75 %	2
ex. 2	Brazoria	75	Soybeans	Choc. Bayou	$ ____ /ac	33 %	- %	33 %	- %	0
1.					$ ____ /ac	____ %	____ %	____ %	____ %	
2.					$ ____ /ac	____ %	____ %	____ %	____ %	
3.					$ ____ /ac	____ %	____ %	____ %	____ %	
4.					$ ____ /ac	____ %	____ %	____ %	____ %	
5.					$ ____ /ac	____ %	____ %	____ %	____ %	
6.					$ ____ /ac	____ %	____ %	____ %	____ %	
7.					$ ____ /ac	____ %	____ %	____ %	____ %	
8.					$ ____ /ac	____ %	____ %	____ %	____ %	
9.					$ ____ /ac	____ %	____ %	____ %	____ %	
10.					$ ____ /ac	____ %	____ %	____ %	____ %	

NOTE: Please read question #3 carefully before attempting to fill out this table

PART B - GENERAL LAND AND WATER INFORMATION

If you produced rice in 1982, please answer the following questions.

4. Record the answers to the following questions in Table B.4 located on the following page. Please make a separate entry for every irrigated field on your farm that differs from other fields in terms of either (i) county, (ii) crop produced in 1982, (iii) water supply (groundwater or surface water) or tenure arrangement (owned or leased). For example, if you had two different fields of land in the same county, under the same tenure arrangement, receiving water from the same river authority, and both fields were in rice, you would add the information for both fields together and enter this information on one line.

Each of the following instructions describes the information needed in particular columns of the table. If a question does not pertain to your particular farming situation, it should be left blank.

(4a) For each field differing in terms of (i-iv) above, enter location by county, number of acres irrigated in 1982, and crop being produced in 1982. Include fields not being irrigated in 1982 but which are sometimes used to produce rice.

(4b) For surface water supplies, enter the supplier from which you purchased your water (the name of the river authority, canal district, or cooperative). If you were exercising private water rights held by you or your landlord, simply enter "private rights".

(4c) For each field differing in terms of (i-iv) above, indicate the appropriate tenure arrangement as follows: (a) If you own or are purchasing the land, check the box under "Own". (b) If you are share cropping this field, enter the percentage share of the crop which goes to the landlord under the heading "Crop Share". (c) If you are cash leasing the land, enter the cost per acre of renting this field under the heading "Cash Rent".

(4d) If you leasing this field of land, please enter the percentage (0-100%) of water costs (canal charges, energy costs, etc.) being paid for by the land owner.

(4e) For each field differing in terms of (i-iv) above, enter the percentage of irrigation water which came from surface sources. For example, if all your water came from surface sources, enter '100'. If all your water came from wells, enter '0'. If you received water from both sources, enter what percentage surface water was of the total water used.

TABLE B.4

		(4a)		(4b)	(4c)			(4d)	(4e)	(4f)	(4g)
					Indicate						
	County	Irrigated Acreage in 1982	Crop Being Irrigated	Surface Water Supplier	Own	Crop Share	Cash Rent	Percent of Water Provided by Landlord	Percent of Surface Water	Acre Inches Used 1982	Ratoon Acreage in 1982
ex. 1	Wharton	500	Rice	LCRA	[X]	____%	$____/ac	- %	100 %	65	250
ex. 2	Wharton	250	Rice	LCRA	[ ]	33 %	$____/ac	100 %	50 %	60	50
1.					[ ]	____%	$____/ac	____%	____%		
2.					[ ]	____%	$____/ac	____%	____%		
3.					[ ]	____%	$____/ac	____%	____%		
4.					[ ]	____%	$____/ac	____%	____%		
5.					[ ]	____%	$____/ac	____%	____%		
6.					[ ]	____%	$____/ac	____%	____%		
7.					[ ]	____%	$____/ac	____%	____%		
8.					[ ]	____%	$____/ac	____%	____%		
9.					[ ]	____%	$____/ac	____%	____%		
10.					[ ]	____%	$____/ac	____%	____%		
11.					[ ]	____%	$____/ac	____%	____%		

NOTE: Please read question #4 carefully before attempting to fill out this table.
If you run out of room on this table, please continue on a separate piece of paper

(4f) For each field enter the amount of water applied in <u>inches per acre</u> to this field of land in 1982, to the best of your knowledge. (1 acre-inch = 27,150 gallons). If you are very uncertain about the amount of water, enter "unknown".

(4g) For each field differing in terms of (i-iv) above, enter the number of acres of second crop which you harvested in 1982.

NOTE: Two example entries are included for illustrative purposes.

Please answer the following questions on the lines provided.

5. If you indicated in question (4b) that you obtained surface water from private sources, indicate below the specific source(s) from which this water was drawn.
   [] (a) Bayou
   [] (b) River or Stream
   [] (c) Lake or Private Reservoir
   [] (d) Other (please specify) ______________________________

6. What percentage of your water use consists of tail (drainage) water which you are relifting from either your farm of your neighbor's farm? _____%

7. What percentage of your water needs <u>could</u> be "reasonably" supplied by relifting tail water on your farm? _____%

8. In a typical production year, when do you flush (run water across) your fields?
   [] Before working the ground in the spring
   [] Before planting
   [] Immediately after planting
   [] Before applying herbicide
   [] After applying herbicide
   [] Immediately after harvest
   [] Other (please indicate) ______________________________

9. Do you check the weather outlook before flushing? [] Yes [] No

10. Given an average year, indicate below the percentage of water used on your farm which you estimate is consumed or lost by the following categories:

(1) Tailwater	_____%
(2) Levee Breakage	_____%
(3) Evaporation or Plant Transpiration	_____%
(4) Lateral Losses	_____%
(5) Field seepage or Leaching	_____%
(6) Other	_____%
Total	100 %

PART C - SURFACE WATER INFORMATION

If you produced rice in 1982 using surface water, please answer the following questions on the lines provided.

11. On fields where only surface water is used, how many acre inches of water per acre do you estimate you would use in a typical year to produce your first crop of rice? _____in.

12. a) What do you estimate your cost per acre in 1982 will be for surface water to produce your first crop only? $_____

    b) What percentage do you estimate this cost will be of you total 1982 costs of producing this first crop? _____%

13. a) What do you estimate your cost per acre in 1982 will be for surface water to produce your second crop only? $______

    b) What percentage do you estimate this cost will be of your total 1982 costs of producing this second crop? ______%

14. After establishing your flood, how many times do you take water to maintain the flood?
    a) First Crop _______releases
    b) Second Crop _______releases

15. Assume that 15% of your yearly surface water supplies were lost for a period of 10 years. Please indicate your reaction to the following alternatives by placing a 2 beside the alternative(s) that you would pursue, a 1 beside the alternative(s) that you might pursue, and a 0 beside the alternative(s) you would not pursue.

    ____(a) Use current wells more intensively
    ____(b) Reduce irrigated acreage (By what percentage? ____%)
    ____(c) Switch to irrigated crops which use less water
    ____(d) Use some sprinkler irrigation combined with current irrigation practices
    ____(e) Drill (more) wells
    ____(f) Switch to sprinkler irrigation on all fields
    ____(g) Install underground pipe
    ____(h) Reduce ratoon cropping
    ____(i) Increase use of tail water
    ____(j) Use other water conservation practices (lined ditches, precision level fields, etc.)

16. Now assume that 30% of your yearly surface water supplies were lost for a period of 10 years. Again rank the following alternatives as before, placing a 2 beside the alternative(s) you would pursue, a 1 beside the alternative(s) you might pursue, and a 0 beside the alternative(s) you would not pursue.

____(a) Use current wells more intensively
____(b) Reduce irrigated acreage (By what percentage? ____%)
____(c) Switch to irrigated crops which use less water
____(d) Use some sprinkler irrigation combined with current practices
____(e) Drill (more) wells
____(f) Switch to sprinkler irrigation on all acreage
____(g) Install underground pipe
____(h) Reduce ratoon cropping
____(i) Increase use of tail water
____(j) Use other water conservation measures (lined ditches, precision level fields, etc.)

17. What actions would you take if your surface water supplies were <u>increased</u> 10% during the next 10 years, assuming the cost of this water was the same as present surface water supplies? Indicate your response to each alternative by placing a 2 beside the alternative(s) that you would pursue, a 1 beside the alternative(s) that you might pursue, and a 0 beside the alternative(s) you would <u>not</u> pursue.

____(a) Plant more acreage into rice
____(b) Use less well water to supplement surface water
____(c) Use more water to control weeds better
____(d) No change in farming operation
____(e) Spend less time and money minimizing water losses from laterals
____(f) Other ____

PART D - GROUND WATER INFORMATION

If you produced rice in 1982 using groundwater, please answer the following questions.

18. Please record the answers to the following questions in the table below. Use the back of this page if you need more room.

    (18a) For each operational well enter location by county, number of acres irrigated in 1982, and crop being irrigated in 1982. If no crops are being irrigated, enter 'none'. If you are leasing the land, put a check in the box after the well number.

    (18b) Enter the drilled depth of each well in feet.

    (18c) Enter the depth at which the bowls of each well are set.

    (18d) Enter the total number of hours you operated each well in 1982.

    (18e) Enter the pumping capacity of each well. Include the unit of measurement if other than gallons per minute (gpm).

    (18f) Enter the energy source (electricity, diesel, natural gas, etc.) used in 1982 to pump water.

    (18g) Enter the year in which the last major repair was performed on each pump. If the pump has never had any major repairs performed on it since installation, enter the year installed.

	(18a)			(18b)	(18c)	(18d)	(18e)	(18f)	(18g)
Well	County	Acres Irr.	Crop	Drill Depth	Bowl Depth	Hours 1982	Pump Cap.	Energy Source	Last Repair
ex. []	Waller	120	Rice	450	400	2600	1500 gpm	Diesel	1980
1) []									
2) []									
3) []									
4) []									
5) []									
6) []									
7) []									
8) []									

	(18a)			(18b)	(18c)	(18d)	(18e)	(18f)	(18g)
Well	County	Acres Irr.	Crop	Drill Depth	Bowl Depth	Hours 1982	Pump Cap.	Energy Source	Last Repair
9) []									
10) []									
11) []									
12) []									
13) []									
14) []									
15) []									
16) []									
17) []									
18) []									
19) []									
20) []									

If you used groundwater to produce rice in 1982, please answer the following questions.

19. Have you noticed a decline in the water table during the past five years?

    [] Yes.
    [] No.
    [] None of my wells have been in place for 5 years.
    [] I don't know.

20. a) What do you estimate you cost per acre will be for groundwater to produce your first crop only? $______

    b) What percentage do you estimate this cost will be of your total 1982 costs of producing this first crop? ______%

21. a) What do you estimate your cost per acre in 1982 will be for groundwater to produce your second crop only? $______

    b) What percentage do you estimate this cost will be of your total 1982 costs of producing this second crop? ______%

22. Assume that your groundwater cash costs permanently increase 15% starting in January 1983. Indicate your reaction to the following potential alternatives listed below. Place a 2 beside the alternative(s) that you would pursue in your operation, a 1 beside the alternative(s) that you might pursue, and a 0 beside the alternative(s) you would not pursue.

    ____ (a) Reduce rice acreage (By what percentage? ____%)
    ____ (b) Switch to irrigated crops which require less water
    ____ (c) Install underground pipe
    ____ (d) Use some sprinkler irrigation combined with current irrigation practices.
    ____ (e) Switch to sprinkler irrigation on all acreage
    ____ (f) Reduce ratoon cropping
    ____ (g) Reduce non-rice irrigated acreage
    ____ (h) Increase use of tail water
    ____ (i) Use other water conservation practices (lined ditches, precision level fields, etc)
    ____ (j) Have pump and bowls serviced to improve pumping efficiency
    ____ (k) Other (please indicate) ______________________________

23. Now assume that groundwater costs permanently increase 30% starting in January 1983. Please indicate your reaction to the following alternatives by placing a 2 beside the alternative(s) that you would persue, a 1 beside the alternative(s) that you might pursue, and a 0 beside the alternative(s) you would not pursue.

____(a) Reduce rice acreage (By what percentage? ____%)
____(b) Switch to irrigated crops which require less water
____(c) Install underground pipe
____(d) Reduce non-rice irrigated acreage
____(e) Reduce ratoon cropping
____(f) Increase use of tail water
____(g) Use some sprinkler irrigation combined with current irrigation practices
____(h) Switch to sprinkler irrigation on all acreage
____(i) Use other water conservation practices (lined ditches, precision land leveling, etc.)
____(j) Have pump and bowls serviced to improve pumping efficiency
____(k) Other (please indicate) ______________________________

24. Assume that your groundwater costs permanently decreased 10% beginning in January 1983. Indicate your response to each alternative by placing a 2 beside the alternative(s) that you would pursue, a 1 beside the alternative(s) that you might pursue, and a 0 beside the alternative(s) you would not pursue.

____(a) Plant more acreage into rice
____(b) Use more water to control weeds better
____(c) No change in farming operation
____(d) Spend less time and money minimizing water losses from laterals
____(e) Other ____

PART E - MANAGEMENT INFORMATION

If you produced rice in 1982, please answer the following questions.

25. How do you perceive water availability during the next decade? (check one only)

    [] I do not anticipate it being a problem for my operation.
    [] A problem, but not a serious one for my operation.
    [] A serious problem facing my operation.
    [] The most important problem facing my operation.

26. How do you anticipate water cash costs will change in the next decade? (check one only)

    [] Their percentage of my total costs of production will decline.
    [] Their percentage of my total costs of production will remain about the same.
    [] They will become an increasingly larger percentage of my total production costs.

27. Given your current land and water resources and assuming that rice is the most profitable crop for your operation, what are the maximum number of acres of rice that you would farm (not including additional leased acreage)? _____acres

28. Given your current land resources but assuming that you could obtain all the water you would need at current prices, what is the maximum number of acres of rice you would farm (excluding additional leased acreage)? _____ acres

29. Using the table below indicate by county and tenure arrangement the number of acres you operate whereon you have made the following water conservation investments.

County	Underground Pipe		Laser Leveled (field)		Water Leveled	
	Own	Lease	Own	Lease	Own	Lease
(1) _________	_____	_____	_____	_____	_____	_____
(2) _________	_____	_____	_____	_____	_____	_____
(3) _________	_____	_____	_____	_____	_____	_____
(4) _________	_____	_____	_____	_____	_____	_____
(5) _________	_____	_____	_____	_____	_____	_____

30. (a) Indicate how many acres you farm in partnership. _____ acres
    (b) Is this acreage included in the results of this survey?
    [] Yes [] No

PART F - GENERAL COMMENTS

31. What did you think of this survey in general?

32. Do you have any particular research needs you would like to see addressed?

WE WANT TO THANK YOU FOR TAKING THE TIME TO RESPOND TO THIS SURVEY. WE ANTICIPATE THE RESULTS OF THIS RESEARCH EFFORT WILL BE PUBLISHED IN AN AGRICULTURAL EXPERIMENT STATION BULLETIN DURING THE SUMMER OF 1983.

GLOSSARY

Adjudication - A legal process whereby a court determines the legality and priority of water rights and the amount of water which may be legally used under each right.

Aquifer - A water-bearing stratum of permeable rock, gravel, or sand.

Bench Leveling - A form of precision leveling where the field is divided into segments (benches). This is usually performed where slope prohibits a single, precision-leveled plain. Levees are located at each stepdown when using the contour levee method of irrigation.

Canal - An artifical waterway used to conduct water to irrigated land. In the Texas Rice Belt, this term refers primarily to the large arterials which deliver water to farm laterals.

Field Lateral - A small lateral used to convey water from a main lateral to a particular field.

Flood - Irrigation under the contour levee method whereby water is maintained above the soil surface for more than 48 hours. Differs from flushing in that the water is held longer on the field and the entire field is underwater at one time.

Flush - Irrigation technique similiar to flood irrigation except that only parts of a field are inundated, with inundation being less than 48 hours in length. Flushing is typically done to enhance moisture conditions so as to promote seed germination or seedling growth.

Groundwater - Water available in or acquired from an underground aquifer.

Land Smoothing - A method of roughly smoothing the field surface with a land plane without altering the slope of the field. The purpose is to fill ruts and small holes, and level off mounds left from the preceding season.

Lateral - A side ditch or conduit used to transport water from a canal to one or more irrigated fields. Laterals may be owned and maintained by the canal operator or by the field owner.

Precision Leveling - The reshaping or modification of the land surface to a planned grade. Laser-guided machinery is used in most cases. The purpose is to provide a more efficient irrigation environment.

Prior Appropriation Doctrine - Water right law in which legal entitlement to water is based on the seniority of the claim. Senior rights must be satisfied before junior rights can be served. Water use is limited to a specified amount under this type of right.

(continued on inside back cover)

GLOSSARY

(continued from inside front cover)

Ratoon Crop – Rice crop harvested from tillers which become productive after the harvest of the initial crop. Although not strictly considered as such, a ratoon rice crop is sometimes referred to in the Rice Belt as a second crop of rice.

Riparian Doctrine – Water right law which states that owners of riparian land (land that is bordered or crossed by natural surface water) have legal rights to use water as long as that use is beneficial and "reasonable." Riparian water rights do not identify a legal right to a specific quantity of water, and available water is shared by all riparian landowners.

Surface Water – Water contained in streams, rivers, lakes, or bayous.

Tailwater – Water exiting or acquired from an irrigated field by way of the surface water drainage system.

Water Consumption – Water which is no longer available for use as a result of its withdrawal and use. (1) In a physical sense, water consumption in rice irrigation is limited to evaporation and plant transpiration and does not include seepage and tailwater. (2) In an economic sense, water consumption in rice irrigation includes all water which is not recoverable for reuse as a result of its use for irrigation; this includes evaporation and transpiration and some portion of seepage and tailwater.

Water Leveling – A form of bench leveling in which water is used as a suspension vehicle to assist in transporting soil.

Water Seeding – A technique for seeding rice where the cultivated seed bed is flooded and the seed, either presoaked or dry, is aerially applied.

Water Use – A broad term referring to both withdrawal and nonwithdrawal water activities for purposes which may or may not consume the water resource.

Water Withdrawal – Removal of water from its natural site. Refers to removal of either surface water or groundwater.