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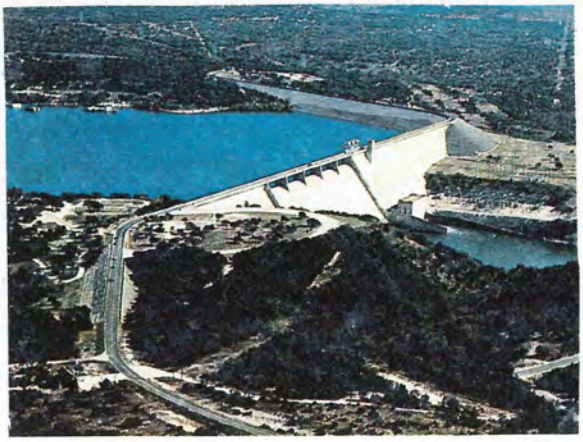

WATER MANAGEMENT STUDY

of the

LOWER COLORADO RIVER BASIN

TEXAS

DRAFT

SPECIAL REPORT

November 1992

LCRA
THE POWER TO MAKE A DIFFERENCE.

LOWER COLORADO
RIVER AUTHORITY
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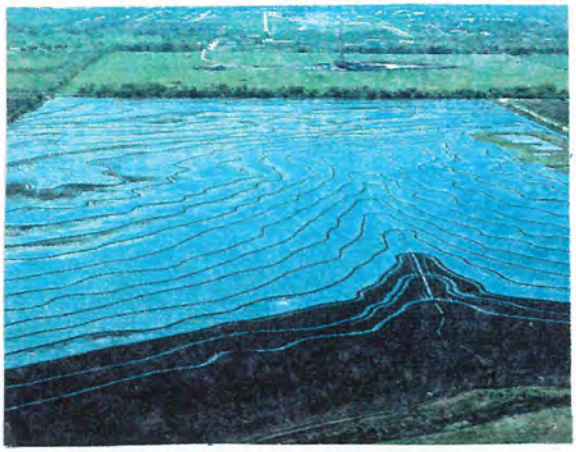
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
GREAT PLAINS REGION



SPECIAL REPORT

on

WATER MANAGEMENT STUDY

of the

LOWER COLORADO RIVER BASIN, TEXAS

November 1992

Prepared by

Bureau of Reclamation
Austin Reclamation Office
Austin, Texas

and

Lower Colorado River Authority
Austin, Texas

MISSION OF THE DEPARTMENT OF THE INTERIOR

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

MISSION OF THE BUREAU OF RECLAMATION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

MISSION OF THE LOWER COLORADO RIVER AUTHORITY

Our company provides public services that improve the quality of life for Central Texans. We provide reliable electric service at the lowest possible rates. We lead the way to protect and conserve the energy, land and water resources of the lower Colorado River basin. We manage floodwaters to safeguard people and property. We supply water for beneficial use throughout the district. We are dedicated to the preservation of the environment and natural resources. We are committed to the health, safety and well-being of the public, our customers and our employees.

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WATER MANAGEMENT STUDY OF THE LOWER COLORADO RIVER BASIN

INTRODUCTION

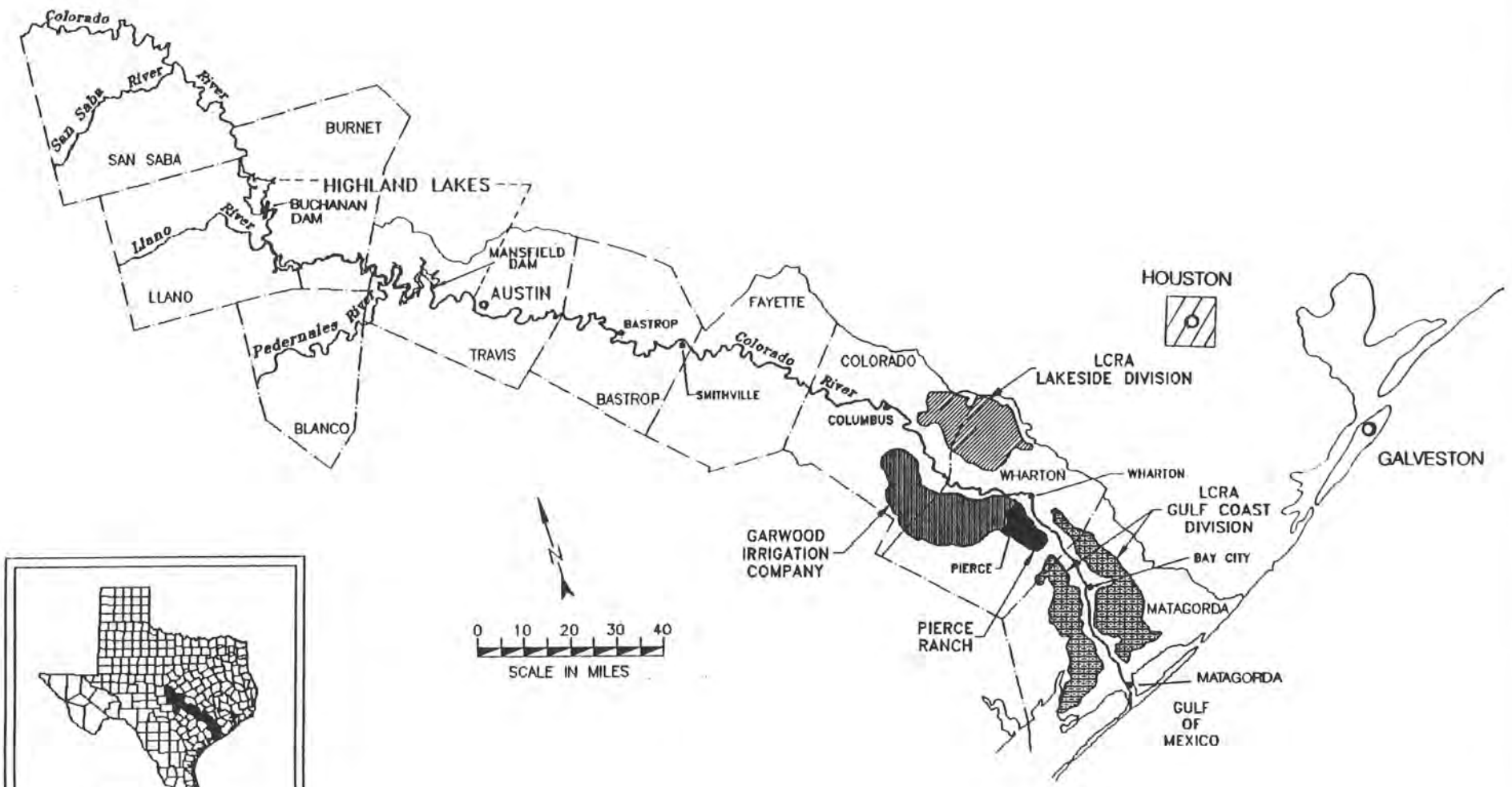
Purpose and Objectives of the Study

This special study is a joint effort by the Bureau of Reclamation (Reclamation) and the Lower Colorado River Authority (LCRA) to evaluate the viability of implementing certain mandated water conservation measures that would improve LCRA's management of the water, land, and energy resources of the lower basin of the Colorado River in Texas. The LCRA is an entity created by the State of Texas, in 1934, to manage these resources. The lower basin contains about 292 river miles and 150 miles of tributaries beginning at Lake Buchanan northwest of Austin, Texas, and ending at the Gulf of Mexico near the community of Matagorda. (See map 1.) The LCRA owns and operates six main-stem storage reservoirs supplying electrical power, municipal and industrial water, and irrigation water to a large area covering 10 counties in south-central Texas. Its headquarters are located in Austin, the State capitol of Texas.

This study is just one of several efforts that LCRA is undertaking to obtain the goals of its *Water Management Plan for the Lower Colorado River Basin* (LCRA, 1989). This plan enjoins all the water management institutions to ". . . adopt a balanced, flexible, and feasible approach that gives due weight to all the conflicting demands on the water, including the heavy economic dependence of the rice farmers on historic uses of irrigation water, rapidly emerging public interest in recreation, and environmental values. The challenge is to recognize both the historic uses and the forces of change, transform emerging problems into new opportunities, and guide the institutions of water resources management toward a new era where clean water in Central Texas is recognized as a scarce commodity." LCRA's mandate to prepare and implement a water management plan is a provision of the State's adjudication of the water rights for the lower Colorado River Basin.

This effort and the direction LCRA is taking toward managing its water resources are also consistent with Reclamation's *Strategic Plan* (Reclamation, 1992) for meeting the growing water demands and resource management needs of the West. One of Reclamation's goals is to achieve a balanced approach to the stewardship of the West's scarce water and associated land and energy resources. Full recognition will be given to the primacy of State water rights laws and State water allocation responsibilities. To this end, Reclamation must be innovative and farsighted. Opportunities for building partnerships with other Federal and non-Federal entities will be pursued to meet these challenges and to promote cooperative, effective stewardship of the Nation's natural resources.

The LCRA also prepared a *Drought Management Plan* (LCRA, 1990) in support of the water management plan. The drought management plan was



Map 1. Location of the Lower Colorado River Authority District and the Lakeside and Gulf Coast Water Divisions.

required by the Texas Water Commission upon approval of the water management plan in September 1989.

The water management and conservation initiatives being pursued by LCRA are consistent with the State of Texas' policy toward agriculture water conservation which is addressed in the 1984 State water plan and the 1992 updated recommendations of the plan.

Reclamation's role in this study was to provide technical expertise in evaluating management techniques that would help achieve the goals of LCRA's water management plan. Following the initiation of this study in fiscal year (FY) 1989, Reclamation conducted field inspections of LCRA's irrigation systems and held onsite work training sessions with field crews concerning water measurement and management, and operation and maintenance practices. Subsequent to those discussions, a pilot water measurement program was identified and has been implemented by LCRA. Reclamation conducted laboratory studies to calibrate LCRA's water measurement delivery structures and evaluated the feasibility of constructing a diversion dam at the Eagle Lake site.

Other assistance provided by Reclamation included developing an irrigation data collection/management program to account for water used and for billing purposes. Reclamation also provided technical consultation and engineering support regarding LCRA's evaluation of a low-head hydropower site. Reclamation provided peer review of LCRA's technical memoranda which were prepared to support various elements of their total water management plan.

Purpose of the Special Report

This report presents the results of a 3-year investigative program by LCRA and Reclamation to evaluate the various water management techniques described above. Included in the presentation are summaries of current and recent investigations performed by LCRA and Reclamation that focus on overall water conservation, water measurement, improved management of LCRA water delivery systems, and energy-related assessments. The scope and findings of each study are summarized in this report under the heading "Current Programs and Investigations."

Nothing in this report is intended to represent the approval or disapproval of the Secretary of the Interior. The sole purpose of this report is to provide technical information to LCRA, the State of Texas, other Federal agencies, and interested publics.

Study Authority

The authority to conduct this study is provided by Federal Reclamation laws (Act of June 14, 1902, 32 Stat. 388, and amended and supplementary acts). Federal funding for the study was obtained through Reclamation's General Investigations (GI) program. The LCRA provided in-kind services (over 70 percent of the study cost) as a cost-sharing partner in the study. These in-kind services included expenditures for staff and programmed amounts from LCRA's FY90-94 budget for the water measurement and rehabilitation programs. The Texas Water Development Board also provided LCRA with a $50,000 grant for this study.

Study Organization

A study management team was established using personnel from LCRA and Reclamation. Overall coordination of the work was performed by Reclamation's Area Planning Officer located in the Austin Reclamation Office, Austin, Texas. Technical specialists from both entities performed the analysis of water conservation devices and methods. Technical assistance was also provided by the U.S. Geological Survey (funded by Reclamation), and the Texas Water Development Board contributed funds to LCRA for purchasing water measuring equipment.

Study Background

This section presents a history of Reclamation's involvement with LCRA that led to the current studies.

Reclamation began investigating potential surface water developments in the Colorado River Basin as early as 1935. These studies led to the construction of Marshall Ford Dam and Lake Travis. Additional studies were initiated in 1954 under the Texas Basins Project which proposed developing the Columbus Bend damsite (Reclamation, 1960). A bill was introduced in the 87th Congress to authorize the project for construction. Public hearings were held; however, the project was found to be unacceptable because of the large amounts of land required.

In 1975, Reclamation initiated a study of the Colorado Coastal Plains Project (Reclamation, 1986). This study evaluated and compared 21 dam and reservoir sites in the lower basin between Austin and the Gulf Coast. Early in the study, it became apparent that two main-stem sites on the Colorado River at La Grange and Columbus, as well as two tributary sites at Clearview and Cummins Creek, had potential and warranted further study. The tributary sites, however, did not prove viable because of relatively high costs, low yield, and the absence of a regulation capability on the main stem. The La Grange site provided a sufficient yield; however, this site in comparison to the Columbus location was much more expensive due to several factors including the presence of a lignite formation, costly relocations, and the elimination of prime farmland. These comparisons of damsites were documented in Reclamation's December 1981 *Status Report* and also discussed with the LCRA Board of Directors early in 1982.

Subsequent studies of five alternative sites near Columbus revealed that the Shaws Bend site would be the most economical and efficient site to help meet the impending water shortage in the basin. An alternative including six small dams, in lieu of the one large dam, was also investigated but was not pursued because of higher cost, environmental quality problems, and operational inefficiencies.

In summary, some 32 alternatives were evaluated by Reclamation before Shaws Bend dam and reservoir was selected as the preferred plan. After carefully reviewing the data, the LCRA Board of Directors in 1986 voted not to support the Shaws Bend plan and requested their staff to explore other possibilities. Although not identified as a project benefit, Shaws Bend dam would have improved LCRA's water operations by providing re-regulation of upstream releases and effectively reducing the travel time of irrigation water to the user in the lower basin.

As a result of a 1986 decision by LCRA, Reclamation prepared a concluding report (Reclamation, 1986) on the study. The findings of Reclamation's study along with the Texas Water Plan (Texas, 1984) did, however, identify the need to accomplish water conservation in the lower basin. Conservation of water would be a way of making existing water available for meeting a portion of the future water needs of the basin.

LCRA is now seeking ways to reduce water use and to improve management and efficiency in their overall operations. To help achieve this goal, the Executive Administrator of the Texas Water Development Board in March 1987 requested assistance from Reclamation under its program for Technical Assistance to States. In response to this request, Reclamation conducted a study of the operational and physical features of the delivery system for the Gulf Coast Water Division (GCWD), Westside System. Included in the analysis was an estimate of flow losses in the Westside main canal. Deficiencies noted by the study were poor vegetative maintenance, no in-canal and onfarm water measurement capability, poor onsite water management, inflexibility of operation due to the long travel time of water, possible excessive seepage losses, low efficiency due to the above factors, and physical constraints of the system.

A general conclusion of the study was that existing facilities were antiquated and that modernization of the delivery system would help achieve LCRA's goals of conserving water and reducing pumping costs. The findings of the study were documented in a technical memorandum (Reclamation, 1987).

During the period January to April 1988, Reclamation and LCRA staffs discussed followup work needed to implement operational changes recommended in the 1987 technical memorandum. Because of limited funds available under the Technical Assistance Program, Reclamation decided that any future work should be programmed under its GI Program. A budget request was submitted to Congress, and funds to begin this water management study were appropriated in FY89.

In addition to Reclamation activities, LCRA also received technical assistance from other agencies. A joint investigation entitled *Cooperative Rice Irrigation Study* was conducted by the U.S. Soil Conservation Service (SCS, 1987), Texas A&M University, Texas Agricultural Experiment Station, Texas Rice Research Foundation, and local soil and water conservation districts, including LCRA. Commonly referred to as the "Less Water, More Rice" program, the purpose of the study was to establish a database on irrigation water use and management practices and develop rice irrigation techniques to reduce onfarm water use and lower crop production costs. The results of the study indicate that an average 25 percent onfarm water savings could be achieved with good irrigation water management practices. Additional water savings could be achieved through the use of precision land leveling, closer levee spacing, in-field multiple inlet water delivery, and intensified water management by the rice producer.

DESCRIPTION OF THE STUDY AREA

Colorado River Basin

The Colorado River rises in west Texas near the town of Lamesa and flows in a

southeast direction across central Texas to the Gulf of Mexico. The upper basin (above Lake Buchanan) has limited water supplies and is controlled by three structures on the main stem of the Colorado River. The main stem of the lower basin is controlled by seven structures, of which six are owned and operated by LCRA. Other off-channel reservoirs provide storage for powerplant cooling water and irrigation.

The lower basin is generally defined by LCRA's jurisdictional boundary which begins with Lake Buchanan and ends at the mouth of the Colorado River. The six dams and reservoirs operated by LCRA are known as the Highland Lakes chain and provide over 2.3 million acre-feet of storage capacity at the top of the operation pools. This storage capacity is used for developing water supplies and to provide water for hydropower production.

Mansfield Dam and Lake Travis, constructed by LCRA and Reclamation in the early 1940's, is the only facility specifically designed to provide flood control for the lower basin. Lake Travis also serves as a major reservoir in the system for developing irrigation water supplies to the lower basin.

Water released for irrigation from the upper reservoirs can take up to 7 days to flow the length of the river and reach the diversion pumps for the Gulf Coast Division. An additional 2 days is needed for the water to flow through the laterals and reach the farm turnouts. The flow of water through the lateral system is controlled and operated by the judgment of water bosses (ditch operators). Although most structures appear to be well maintained, the canals and laterals generally lack vegetative control in the Gulf Coast Water Division.

Uncontrolled vegetation growth along a canal in the Gulf Coast Water Division.

LCRA Water Delivery Systems

LCRA owns and operates two canal systems which together supply water to irrigate about 60,000 acres of rice each year. These water delivery systems are the Lakeside Water Division (LSWD) and the Gulf Coast Water Division. The LSWD is located in Colorado and Wharton Counties and the GCWD is located in Wharton and Matagorda Counties. (See map 1.)

Rice irrigation is the largest user of water within the area served by LCRA, accounting for approximately 75 percent of the total annual surface and groundwater demand. In an average year, about 30 percent of surface water supplied to rice irrigation is satisfied with water releases from storage in the Highland Lakes. During a severe drought, the demand for stored water could be as much as 70 percent of the annual rice irrigation demand.

The study area for the water measurement element of this investigation focused on limited acreage within the two divisions. The test area (pilot program) in LSWD covers about 3,000 acres and in GCWD about 6,000 acres.

A concern to LCRA was the apparent excessive use of water by its GCWD. This division has annually used as much as 9.50 acre-feet per acre, while the other water division uses only about 5.50 acre-feet per acre. Soil and climatic conditions in the GCWD do not differ enough from LSWD to support the need for the additional water. A second concern was the water right adjudication by the State of Texas (Texas, 1988)

Rice is a major farm commodity of the lower basin.

limiting the farm use of water for irrigation to 5.25 acre-feet per acre. Without improved operations, meeting the State's water requirement limitation could result in the reduction of irrigated acreage, which would be unacceptable to the individual owners of the irrigated farms. A reduction in the annual water requirement, however, would result in a savings of pumping cost to LCRA. Therefore, LCRA is investigating ways to improve the efficiency of the irrigation systems that include the evaluation of water needs, pumps and energy use, delivery systems, improving operation and maintenance, and better measurement and control of water.

Historical and Projected Water Uses

Under a high-case scenario (LCRA, 1988), municipal water needs in the lower basin (10-county area) are projected to increase from a 1980 use of about 116,000 acre-feet to about 434,000 acre-feet by the year 2030.

Manufacturing use is projected to increase from a use of about 11,000 acre-feet to about 89,000 acre-feet during the same period. Irrigation water use in 1980 (for primarily rice production) was about 846,000 acre-feet and is projected to increase to 915,000 acre-feet by 2030. Table 1 provides a summary of the projected water uses by category for the 10-county area managed by LCRA.

CURRENT PROGRAMS AND INVESTIGATIONS

This section presents a discussion of the investigations conducted by Reclamation and LCRA under the program initiated in 1989.

Water Measurement and Accounting

Technical Feasibility of Irrigation Water Measurement.—The objective of this study (LCRA, 1991a) was to evaluate the technical and economic feasibility of measuring the amount of water delivered to the individual rice farms of LSWD and GCWD. If potential water measurement techniques are found to be effective, then a full-scale measurement system could be implemented for both water divisions. An effective and accurate method for measuring water delivery would permit LCRA to initiate water pricing incentives based on volumetric charges.

This study consisted of two components: a field study and a laboratory study. The field study collected data from existing canal and farm turnout structures. Flow measurement from existing structures was compared to calibrated devices such as Parshall flumes or direct flow measurement. The laboratory analysis calibrated the typical LCRA devices in a controlled environment (Reclamation, 1990a).

A wide variation of main canal and farm delivery structures exists throughout the two irrigation systems. However, the overshot structure is the predominant canal flow-control device, and the undershot box is the predominant farm delivery structure. The test sections selected for this study provide a good representation of the different types of structures. Minor modifications were made to the flow-control structures within the test sections to permit flow measurement in addition to their primary use of flow control.

For overshot main canal structures, electronic water-level recorders were

Table 1.—Projected 10-county water use for the lower Colorado River Basin
[In acre-feet, numbers rounded to 100's]

Year	1980	1990	2000	2010	2020	2030
Base case						
Irrigation	846,400	779,900	758,100	745,000	736,200	736,200
Municipal	116,500	157,800	182,400	204,600	226,700	248,900
Steam electric	25,200	51,000	67,600	79,600	85,700	88,200
Manufacturing	11,300	21,800	30,300	43,000	57,800	70,800
Mining	21,200	25,700	27,600	30,400	33,200	36,100
Livestock	11,600	13,500	15,400	15,400	15,400	15,400
Total	1,032,200	1,049,700	1,081,400	1,118,000	1,155,000	1,195,600
High case						
Irrigation	846,400	970,000	942,500	926,000	915,000	915,000
Municipal	116,500	198,300	261,900	319,100	376,300	433,500
Steam electric	25,200	51,000	70,100	82,100	88,200	90,700
Manufacturing	11,300	23,100	34,800	50,300	71,300	89,300
Mining	21,200	25,700	27,600	30,400	33,200	36,100
Livestock	11,600	13,500	15,400	15,400	15,400	15,400
Total	1,032,200	1,281,600	1,352,300	1,423,300	1,499,400	1,580,000
Low case						
Irrigation	846,400	621,000	604,000	593,800	587,000	587,000
Municipal	116,500	150,200	155,200	160,400	165,300	170,200
Steam electric	25,200	51,000	61,000	66,100	78,100	84,200
Manufacturing	11,300	17,100	17,300	17,500	17,600	17,800
Mining	21,200	25,700	27,600	30,400	33,200	36,100
Livestock	11,600	13,500	15,400	15,400	15,400	15,400
Total	1,032,200	878,500	880,500	883,600	896,600	910,700

Source: LCRA, 1988.

View of a canal "overshot" flow-control device.

View of a "undershot" farm delivery structure.

installed to measure depth-of-flow only at the upstream side of the structures. For undershot main canal structures, both upstream and downstream water depths were recorded by the water-level recorder. In addition to the electronic water-level recorders, staff gauges were installed for recording water surface elevations in the canals.

Two types of instruments were used for flow measurements at farm delivery structures. For structures with pipe turnouts, direct flow measurement through the pipe was made by propeller-type meters. Depth-of-flow through the concrete and wooden water boxes were made using staff gauges. In addition, Parshall flumes were installed on the farm ditches immediately downstream of selected farm-delivery structures for determining the accuracy of estimating flow using measurements from the structure itself. An electronic recorder was also installed at each Parshall flume site to record water levels. Field calibration of the main canal structures was conducted by the U.S. Geological Survey with funds provided by Reclamation.

Laboratory calibration was made using working models of LCRA's water turnout boxes which were built and tested by Reclamation staff in the Research and Laboratory Service Division, Denver Office. The LCRA asked Reclamation to study the implementation of rectangular stop-plank style turnout structures for measurement. A full-scale model of a 4-foot water box and a 2/3-scale model of a 6-foot water box was calibrated in the Denver Office laboratory for both weir and orifice modes of operation. It was determined that metal edges should be installed on the stop planks if the structures are to be used for water measurement. Metal edges were

A LCRA employee recording flow data at a Parshall flume.

designed that could be installed and still allow the tongue-and-groove planks to be used for shutoff. The weir calibration was generalized in terms of unit discharge and can be applied for all box sizes. The orifice calibration was generalized in dimensionless form and can be used for all orifice lengths, openings, and elevations to within one orifice dimension of the box bottom (Reclamation, 1990a).

Using the results of these test models, the staff was able to develop formulas for computing flow rates through structures operating in the field. The overshot (weir flow) devices produced a calibrated version of the standard weir equation.

The undershot (orifice flow) devices are basically a submerged orifice, but calibration is complicated by the practice in the field of varying both the sill height and opening size. A family of curves was developed to compensate for variability.

Both types of devices perform better and have more consistent calibrations when the original wood-edge weir plate or orifice opening is replaced with a metal-edge plate.

On the basis of field data collected during the 1990 irrigation season and the laboratory study, the following conclusions were made:

- Use of existing farm-delivery structures for flow measurements is technically feasible.
- Use of main canal structures for estimating flow in the canal is not technically feasible.
- Better flow measurement is available using metal weir plates and orifice openings.
- Staff gauges located at strategic points along the canal system would be useful to the operators for maintaining desired water levels.
- Collecting and recording large volumes of water measurement data would be time consuming.

On the basis of the above conclusions, these recommendations for future action were made:

- If economically feasible, implement a water measurement program for onfarm deliveries to LSWD and GCWD. Develop a volumetric water rate that promotes the water conservation goals of the water management plan.
- Improve the accuracy of water measurements by converting all farm delivery structures to standard concrete boxes.
- Redesign the main canal structures to improve flow control and flow measurement.
- Develop a database and computer software package for performing all hydraulic computations and water accounting.
- Maintain a calibration check measurement program to identify unusual flow conditions and deteriorating structures.

Water Accounting Database.—On the basis of the previous recommendation, a PC-based water accounting software package was developed by Reclamation (Reclamation, 1991a and

1991b). The software system consists of a set of database computer programs and data files which field personnel use to enter farm turnout data (heads, velocities, openings, etc.) and canal data from selected structures. The program calculates flow of the various devices using the previously generated calibrations and standard curves for standard devices. The program presents a schematic of the canal system and is menu driven.

The software retains a hydrograph of all farm turnouts and selected canal devices. Reports of water use can be generated using categories of field, turnout, and farm for first and second crop, a variable time period, and the full irrigation season. Canal waterflow reports can also be generated. Presently, the program is only being used for data logging and reporting of farm turnout deliveries.

System Rehabilitation and Modification

Canal Rehabilitation.—As previously noted, LCRA water division canals have poor efficiency due to various factors. Rehabilitation of the canal system was studied (LCRA, 1991c) as a possibility for improving efficiency. A complete rehabilitation program would consist of reshaping and lining of canals and reconstruction of all flow-control and farm-turnout devices. A program of this magnitude would be extremely expensive.

A less intensive program was developed which consists of the mechanical clearing of vegetation, selective use of herbicides for vegetative maintenance, replacement of dysfunctional water-control and delivery structures, and the reshaping of canal prisms. A multiyear program was

A canal being cleared of vegetation to promote water conservation.

initiated in 1987 to rehabilitate the GCWD system. It is expected that the program will be completed in 1996. An improved maintenance program should keep the canals near optimum operating efficiency.

Reducing Pumping Requirements.—Studies were also conducted to investigate the feasibility of decreasing the pumping costs for the water divisions. The cost of electrical power for pumping represents about 50 percent of the annual operation cost of the two water divisions.

Potential Eagle Lake Diversion Dam.—In 1990, Reclamation conducted a recon-naissance study (Reclamation, 1990b) of the feasibility of building a diversion dam at the Eagle Lake site with the objective of reducing pumping cost. This dam would provide water for the LSWD canal system. A 10-foot-high concrete overflow diversion dam was considered. The study determined that the dam would not be economically justifiable until the cost of electricity increases to $0.1611 per kilowatt hours (kWh). The cost of electricity in 1990 was $0.0557 per kWh.

Bay City Dam.—Several studies to modify Bay City Dam (source of water for GCWD) have been conducted. Problems with the diversion structure include operational procedures that require flashboard risers and stop boards to be manually installed by operators during mean or normal riverflows. This procedure is considered dangerous and jeopardizes the safety of the operators. In addition, the left wingwall of the dam has been damaged by floods and presents the risk for complete dam failure.

LCRA retained a consultant, Freese and Nichols Inc., to prepare a preliminary design for modifying the dam. Several

View of the Bay City Dam which provides water to the GCWD.

alternative design configurations were evaluated by Freese and Nichols (F&N, 1991) that would achieve the desired results. The preferred plan provided these improvements:

- Raises the existing pumping pool elevation 4 feet.
- Provides for a simplistic raising and lowering of the pumping pool.
- Minimizes personnel for routine operations.
- Has only one gate section to maintain.
- Gates that are located next to the right abutment for easy installation.
- A fixed concrete weir wall that would be resistant to debris damage.

LCRA also conducted an analysis (LCRA, 1991e) of adding power generation at the dam. Their analysis showed that a 1-megawatt unit is feasible and warranted further study.

As a followup investigation to LCRA's preliminary study on Bay City Dam, Reclamation conducted a feasibility design for a 1-megawatt low-head hydropower plant (Reclamation, 1991c). Reclamation considered three types of power producing units: (1) an inline submersible turbine/generator, (2) a pit-type turbine, and (3) an S-type turbine. The S-type was later eliminated because of the large amount of steel required in the draft tube. The submersible unit was ultimately recommended because of its lower overall cost ($2.2 million), shorter delivery time for the unit, and it would be less susceptible to problems created by flooding. The study also pointed out that close coordination must occur between the powerplant designers and those designing the modifications to the dam to ensure compatibility of the structures.

The final study to date is a model study on the scour effects of various dam modification scenarios. The Water Research Laboratory at Utah State University (USU) developed an analog model to test the operation of the dam using the proposed modifications. These tests (USU, 1992) should provide sufficient data to enable LCRA and Freese and Nichols to develop the final design for modifying the dam.

LCRA has programmed funds to complete the engineering design work and to begin construction of modifications to the dam beginning in its FY93 (July 1 to June 30).

Benefit and Cost Analysis of the Canal Rehabilitation and Water Measurement Programs

Estimated Water Savings.—This study (LCRA, 1991c) was conducted for the purpose of estimating water savings from ongoing canal rehabilitation and proposed water measurement programs. The LCRA canal rehabilitation project is focused on improving the efficiency of water distribution at the GCWD. While some degree of improvement in efficiency is expected at LSWD, it is believed that this system currently operates at or near its maximum efficiency. As such, water-saving estimates for canal rehabilitation were only developed for the GCWD. Comparing the low-acreage water use scenario with the base and high-acreage scenarios, a range of water savings

between 1.50 and 2.05 acre-feet per acre is projected. This represents a water savings of up to 70,000 acre-feet per year.

The implementation of an irrigation water measurement program would further reduce operational losses. Water savings can be expected as a result of improved accuracy in estimating "real time" water diversion requirements and better management of water distribution within the delivery system. The reliability of irrigation service should also improve as a result of better system management.

The LSWD has been using a system of volumetric water management over the last 50 years. This system is based on a unit of measure known as the "water box," which is defined as a flow rate of 3,000 gallons per minute (6.68 cubic feet per second). Irrigators order water by this measure, and water diversions are estimated according to the total number of "boxes" required to meet the customer's water demand at any given time. Similarly, all water-control and field-delivery structures are managed to deliver the required boxes to a given canal segment or field. This system provides a crude but effective form of inventory control which enhances both efficiency and equity in the distribution of water.

Implementation of a water measurement program and its associated water accounting system would provide for more precise volumetric water management at the LSWD. However, resulting water savings are likely to be relatively small.

The GCWD, however, has not been operated with a comparable volumetric water management system. Rather, current management practices are based largely on the experience and judgment of field personnel. As a consequence, canal water losses from spills have been greater at GCWD than at LSWD. It is therefore expected that the implementation of a water measurement program would significantly improve water distribution efficiency and the quality of water service at the GCWD.

A water measurement program would also provide data useful for identifying canal segments that are experiencing high water losses. This information would allow better targeting of limited resources for canal maintenance and rehabilitation.

A precise estimate of potential water savings resulting from improved system operations and water measurement is difficult to make. However, it appears that the water conservation potential is greatest at the GCWD. As such, a conservative estimate of a 10-percent reduction in water use is projected for LSWD, while a 25-percent reduction is considered reasonable for GCWD. Comparing the low-acreage water use scenario with the base and high-acreage water use scenarios, an annual water savings of between 9,600 and 12,500 acre-feet is projected for LSWD. Similarly, an annual water savings of 23,800 to 38,000 acre-feet is projected for GCWD.

Rehabilitation of the GCWD is an on-going program. This work primarily involves the removal of vegetation, replacing water-control structures, and reshaping the canal prism. During FY91, approximately 106 miles of canal were rehabilitated representing a

conservation savings in water of 162,500 acre-feet. The remaining 420 miles of canal are programmed for rehabilitation through the end of FY93. By the end of FY96, the GCWD is projected to be near 80-percent efficient representing attainment of the 5.25 acre-feet per acre State limitation for rice irrigation.

Value of Water Savings.—The purpose of this study (LCRA, 1991d) was to estimate the value of projected water savings associated with the rehabilitation and water measurement programs. The value of water saved was examined both in terms of direct cost savings to LCRA and in terms of less tangible and perhaps nonquantifiable benefits associated with agricultural water conservation. Direct benefits were derived from:

- Cost savings that result from reduced electrical power requirements.
- Reduced demand for stored water from the Highland Lakes.

Historically, electric power costs have represented the largest single cost component associated with the operation of the two water divisions, accounting for about 40 to 50 percent of annual operations and maintenance expenses. Using water-savings estimates determined in the study discussed above, LCRA developed a computer model to calculate power costs using with and without water savings for three conservation scenarios; i.e., low-acreage, base, and high-acreage water use. The difference between with and without water savings represents the projected power cost savings for each year evaluated. For LSWD, the range of power cost savings for the three scenarios over a projected 18-year period was between $1.04 million and $1.36 million. For GCWD, the range of power cost savings for the three scenarios over a projected 20-year period was between $3.56 million and $7.03 million.

In addition to electric power cost savings, reduced diversions at LSWD and GCWD also provide direct benefits in the form of reduced demands for stored water from the Highland Lakes. Stored water is divided into two categories:

- "Firm" water which is supplied from the combined firm yield of the reservoir system.
- "Interruptible" water which is water that can be supplied from the reservoir system without placing firm water uses at risk.

Firm water is sold by LCRA for municipal, industrial, and steam-electric use. With the exception of golf courses, very little firm water is provided for irrigation.

The availability of interruptible water varies with hydrologic conditions and is determined annually by LCRA. This type of water is used primarily to supplement run-of-the-river water for rice irrigation. However, during drought conditions, the amount of stored interruptible water needed for irrigation purposes can increase significantly.

LCRA used its Reservoir Response Model to quantify the stored water diversion reductions associated with projected water savings for both water divisions. Again the results were compared for the three scenarios; low-acreage, base, and high-acreage water use for each water division. For LSWD, the range of stored

water savings over a 18-year period was between 137,000 and 201,000 acre-feet.

For GCWD, the range of stored water savings over a 20-year period was between 687,000 and 1,404,000 acre-feet.

In addition to direct benefits, other non-monetary benefits would also occur through canal rehabilitation and water measurement programs. These non-monetary benefits include:

- Compliance with the State limitation of 5.25 acre-feet per acre for irrigated rice.
- Extend the available supply of stored water and lessen the risk of supply curtailment during drought. Similarly, reduced irrigation demand would also lessen the impact of drought on reservoir levels and associated lake recreation and tourism values.
- Improved quality and reliability of irrigation water delivery service.
- Increased potential for more run-of-the-river water to meet instream flows and bay and estuary inflow requirements.

Economic Feasibility of Irrigation Water Measurement.—On the basis of findings developed by the water savings and value of water savings studies, LCRA prepared two sets of benefit/cost analyses (LCRA, 1991b). One analysis was for a combined canal rehabilitation and water measurement program and the second was for a water measurement program alone. For the analyses, present worth of all costs and benefits were computed by LCRA using a discount rate of 5.9 percent and a term of 20 years.

The results of the analyses for each set show that for all three scenarios (low-acreage, base, and high-acreage water use), the benefit/cost ratio exceeds unity. (See figures 1 and 2.)

Therefore, a favorable recommendation for implementation of the water measurement program may be made.

LCRA Cost Allocation Methodology.—This section presents the findings of Reclamation's review of LCRA cost allocation methodology.

Basic Allocation.—The LCRA cost allocation methodology establishes allocation percentages based on original investment costs and facilities primary use. Dams with electric generating facilities and no water storage function have the entire cost of the dam, reservoir, and the specific power generation facilities assigned to the power function. This methodology is consistent with Reclamation allocations for single purpose facilities.

For LCRA dams that have both water supply and power generation, specific power facilities are assigned to power, and the dam and reservoir are assigned to water storage. This approach is known as a "priority of use" method of allocation and is consistent with Reclamation methodology for most projects built prior to the mid-1950's. Since the 1950's, Reclamation has used the separable cost-remaining benefit (SCRB) allocation method which results

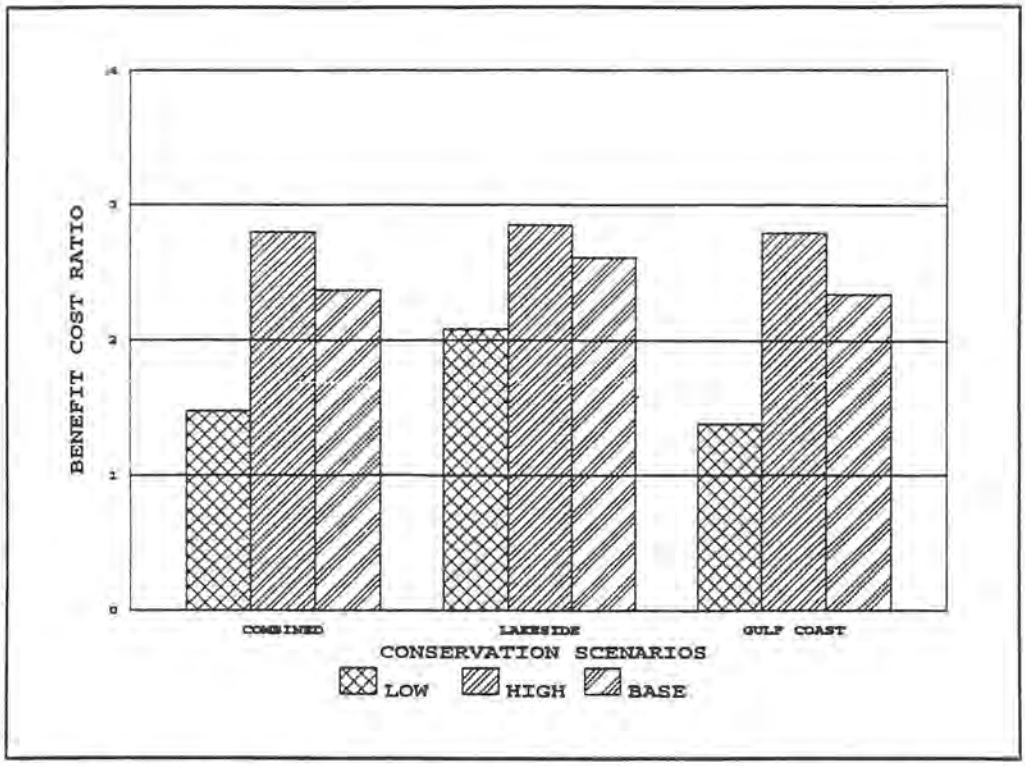


Figure 1.—Benefit/cost ratios for combined canal rehabilitation and water measurement projects (LCRA, 1991b).

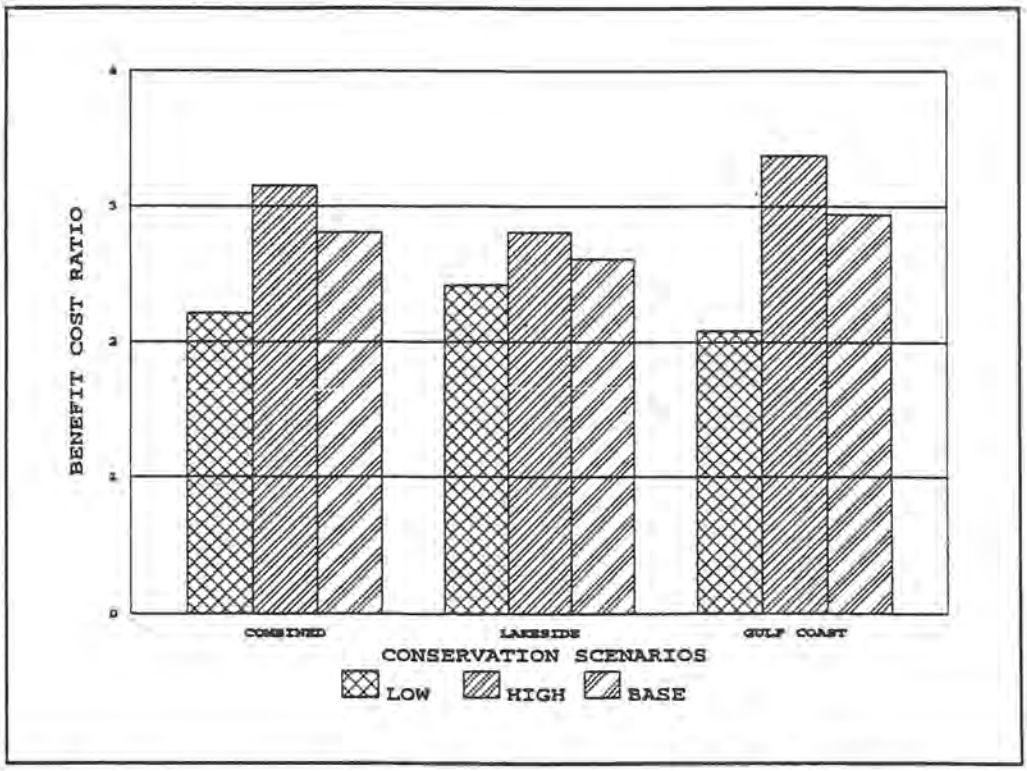


Figure 2.—Benefit/cost ratios for water measurement project alone (LCRA, 1991b).

in a more equitable allocation on multipurpose projects.

Allocation of Operation and Maintenance Expenses.—Once the base allocation is established by recognized methods consistent with the authorizing legislation, specific and joint operation and maintenance (O&M) expenses are allocated.[1] Specific O&M is assigned 100 percent to the appropriate function, and joint O&M is allocated on the same basis as the joint capital costs. LCRA is following this practice in their allocation procedures.

LCRA allocates its river management expenses to power and water supply or as joint costs, which is consistent with Reclamation policy. Reclamation and other Federal entities such as the U.S. Army Corps of Engineers have always recognized reservoir operations and river management as joint O&M costs to be allocated among the functions according to the cost allocation methodology in effect at the time of project authorization. Thus, power customers and water users should incur these costs in proportion to the established cost allocation for capital expenditures.

Recreation potential on LCRA facilities is recognized in the original authorization, although no specific provisions are established for allocation of costs to recreation or repayment by recreation interests. Under existing Reclamation methods of cost allocation, reservoir supported recreation can have joint costs of the dam and reservoir allocated to it in proportion to its share of remaining benefits, but these costs are nonreimbursable under current law. For Federal facilities, joint costs allocated to recreation are borne by the taxpayers.

There is no provision in LCRA authorization for joint recreation costs to be paid from tax revenues. Therefore, these costs would have to be covered from revenues produced by the reimbursable functions, since the authorizing legislation does charge LCRA with setting rates for water and power sufficient to pay "all expenses necessary to the operation and maintenance of the properties and facilities of the District." Since rates established by LCRA are cost-based, the appropriate allocation of these expenses would be accomplished by using the percentages established for the two revenue producing functions.

This same principle is applicable to water quality, soil conservation, and other expenses of LCRA that are mandated by law. Lacking any other revenue sources to support such activities, these purposes appear to be appropriate O&M expenses to be charged proportionally to the revenue generating project activities.

[1] In older allocation methodologies, the capital costs were allocated first and then the O&M expenses were allocated after the proper percentages were derived. Specific O&M expenses such as maintenance of an electric plant went 100 percent to that function. To these was added a proportionate share of joint O&M expenses for the total O&M assignable to that function. In a SCRB allocation, capitalized O&M expenses are part of the allocation process and determine O&M allocations "simultaneously" with the allocation of capital costs.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE ACTIONS

General

Water in south central Texas is a scarce resource. The projected population growth for the 10-county LCRA service area will impose additional demands on the limited water resources of the area. LCRA facilities, which are located along the Colorado River Highland Lakes System, provide benefits to numerous water users. These facilities provide water for recreation, fish and wildlife, flood control, hydropower generation, powerplant cooling, and municipal and irrigation needs. These competing water uses present a challenge and the opportunity for LCRA to explore innovative water management and conservation options. This challenge will require the continuous evaluation of a combination of solutions, along with the identification of tradeoffs and environmental issues, under current public views and values.

LCRA's initiatives, in connection with the *Water Management Plan* for the Lower Colorado River Basin, are indicative of its commitment towards meeting the challenge to manage water resources in a responsible manner. The current Federal position towards water resources management for the future is reflected in Reclamation's *Strategic Plan*. Recent planning documents and actions by the State also reflect this position concerning water management and conservation principles. The State has taken various actions in terms of legislation, Governor's Executive Orders, State grants, loan programs, research funds, requirements for identification and implementation of conservation plans, and other programs/policies that promote, support, and encourage water conservation.

The joint effort by LCRA and Reclamation on this study provided an excellent opportunity to explore, develop, and implement ideas by the respective technical staffs and for Reclamation to make its research laboratory facilities in Denver available. This effort covered various technical aspects, all related to the goal of overall improvement and management of water resources. In doing so, this joint effort also covered several elements of Reclamation's *Strategic Plan*. This study is a good example of what can be accomplished under a joint partnership in which both entities have mutual interests and commitments.

Specific Conclusions

- The use of farm delivery structures for flow measurement is technically and economically feasible with reasonable accuracy. The margin for error in such measurements was less than 10 percent as verified through laboratory and Parshall flume measurements in the field.

- Canal operation has improved due to the installation of staff gages at strategic locations on the main canals. The ability to make accurate measurements has resulted in daily water surface fluctuations in these canals dropping from more than 1 foot to 2 - 3 inches. The need for frequent measurement was eliminated due to the reductions in canal water surface fluctuation.

- Water savings can be achieved through vegetation removal and improved canal hydraulics.

- Water savings can be realized through implementation of improved accounting of water, including daily accounting of farm delivery turnouts using improved water measurement data and a PC database. These tasks also provide a means of billing water users on a volumetric basis.

- It is economically and technically feasible to build a low-head hydroelectric facility at Bay City Dam. Revenues from electrical power production would be realized, and pumping costs would be reduced.

- The use of existing main canal structures for the estimation of flow in the main canal is not technically feasible due to the large volume of leakage through the flash boards and the difficulty of using weir blades.

- Calculating a water balance for canal sections is not technically feasible due to the inability to accurately measure canal flows and other parameters.

- On the basis of the cost of electrical power in 1990, it is not economically feasible to build a diversion dam for the Lakeside Water District.

Specific Recommendations

- The implementation of the water measurement program should be undertaken by LCRA. Since the benefit/cost ratio of the Water Measurement Project is significantly higher than one, a recommendation to the LCRA's Board of Directors may be made for implementation of volumetric billing for both Lakeside and Gulf Coast Water Districts.

- LCRA should gradually convert all farm delivery structures to standard concrete boxes to obtain uniformity and more accurate flow measurements.

- Flow measurements at the farm delivery structures should be made when a change in the flow conditions occurs either due to a change in water surface in the canal or due to a change in the orifice opening of the structure.

- As a long-term goal, consideration should be given to redesigning the main canal structures for achieving improved control of flow and flow measurement. Improving the main canal structures will help develop a water balance approach of accounting for flows by reaches of the canal.

- LCRA should implement an ongoing calibration program for flow measurement devices. This program would catch unusual approach flow conditions attributable to unattended sediment deposits. Such a program would also monitor the effects on accuracy of measurements due to deterioration of the box structures, structural fabrication differences or inconsistencies, and/or

settlement and movement of the box structures.

- LCRA should make vegetative control and clearing a part of it's ongoing maintenance program. If left unattended, it becomes a rehabilitation problem.

- LCRA should pursue activities leading to the final design and construction of the low-head hydropower facilities at Bay City Dam.

- Since LCRA is considering a multifaceted approach (water conservation, energy, system improvements, etc.) to achieving the goals of the *Water Management Plan* for the Lower Colorado River Basin, it is recommended that LCRA consider exploring Reclamation's loan program under the Small Reclamation Projects Act (Public Law 84-984), as amended.

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