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A Study of the Effects of Institutions on the Distribution and Use of Water for Irrigation in the Lower Rio Grande Basin

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ABSTRACT

Water users in the Lower Rio Grande Basin of Texas have depended on the flow of the Rio Grande to supply water for agricultural as well as municipal and industrial purposes. Although the area is a major agricultural production region, it faces continuing problems associated with use of irrigation water from the Rio Grande. Periodic water shortages threaten to limit the potential growth and economic well-being of the area. Inefficient use of available water supplies as a result of inadequate and/or antiquated distribution facilities and inefficient management of water on farms contributes to the depletion of available water supplies for irrigation and other uses.

The objectives of this study were: (1) to study the effects of water rights as allocative devices for water; to determine the impact on cropping patterns and water use efficiency of a change which would make rights negotiable, and (2) to study the influence of Water Control and Improvement Districts on the distribution and use of water; to determine whether the ways in which these districts are organized and operated may cause them to act as facilitating or obstructing elements in the efficient development and use of water resources in the Valley.

To meet the first objective, parametric linear programming was used to analyze the impact of negotiable water rights on cropping patterns and enterprise combinations. If the institution of water rights were changed so as to make annual allotments negotiable,

market forces could be expected to move the resource into uses in which it has a higher value. Water price was varied from $9.60 per acre foot to $96.00 per acre foot. At a price of $9.60, which is approximately the present cost of irrigation water delivered at the farm gate, producers could profitably use almost 2,000,000 acre feet of water per year. At this price, 83 percent of the irrigable lands and 77 percent of the water used in the Valley would be devoted to the production of cotton and grain sorghum. At a water price of $18.65 per acre foot or higher, grain sorghum production in the Valley reverts dryland and water use for irrigation drops to 1,363,300 acre feet per year. At a price of $32.45 or above, the land devoted to cotton would be switched to dryland grain sorghum production and water use would decline to 407,900 acre feet annually.

The use of parametric programming with variable water pricing allowed the derivation of a value-in-use or "conditional demand" curve for water.

To meet the second objective of the study, data on the Valley Water Control and Improvement Districts were analyzed using multiple regression analysis. The dependent variable was delivery cost per acre irrigated. Size of district, acre feet pumped per acre irrigated, and percent of operating revenues derived from water deliveries were the independent variables. It was found that the optimum size district, from a least-cost standpoint, was 42,355 acres. However, other institutional problems associated with District policy and organization would seem to more than offset cost advantages of reorganization and consolidation. Therefore, it does not seem likely that local water users would seek changes in the organizational structure of districts simply to take advantage of economies of size associated with consolidation.

Rehabilitation of district facilities was analyzed using data from the parametric programming model for five levels of development. It was found that rehabilitation of district facilities is economically feasible, at least to the present level of water use in the Valley.

KEY WORDS: Institutions, Water Resources Planning, Irrigation, Water Rights, Irrigation Districts.

ACKNOWLEDGMENTS

The research reported herein represents the conclusion of a study of problems of irrigation development and management in the Lower Rio Grande Valley. It is based on previous analyses of the impacts of various institutions on land and water use in irrigation. The earlier studies were done by Thomas Casbeer, Abdullah Thenayan and the project director, Warren Trock.

This research focused on particular institutional arrangements (water rights and irrigation districts) and the analysis required the expert assistance of James Dozier, College of Business Administration, Bill Green, Manager, Donna Irrigation District, Harry Burleigh and his staff, Bureau of Reclamation, Austin, Louis McDaniels, Texas Water Rights Commission, and Chan Connolly with his colleagues at the Weslaco Research and Extension Center. The contribution of these persons is gratefully acknowledged.

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SECTION I

INTRODUCTION

As the population and economy of the Lower Rio Grande Basin have expanded, the demands for water resources have grown, both for agricultural and municipal-industrial purposes.

Agricultural production, primarily from irrigated land, with an annual gross value of over $104 million, is the primary source of revenue in the Valley economy. Principal crops include cotton, grain sorghum, vegetables and citrus. Oil, gas, and building materials production are significant to the basin economy and have increased in value from $17 million in 1954 to over $43 million in 1964. Value added by manufacturing has increased from $25.5 million in 1954 to over $40 million in 1966. The Port of Brownsville Authority maintains a medium depth channel from the intra-coastal canal into the city of Brownsville which has become a significant transportation hub for the Valley and northeastern Mexico [37].

Population of the basin more than doubled from 165,043 in 1930 to 352,086 in 1960. Population projections, developed by the Texas Water Development Board, show that population of the basin is expected to increase to over 486,000 in 1980, 642,700 in 2000,

The citations on the following pages follow the style of the American Journal of Agricultural Economics.

and to over 848,000 by the 2020 [30]. This means that the resources of the area will have to support 38 percent more people in 1980, 82 percent more in 2000, and 141 percent more in 2020 than in 1960 if these projections are accurate. A population growth of this magnitude will accelerate the pressures exerted on the available water supply, especially by domestic, municipal, and industrial users and can be expected to generate additional conflicts among competing uses for water.

While manufacturing, trade, and transportation are important segments of the area's economy, irrigated agricultural production remains the principal source of income and employment in the Valley. In 1960, over 32,000 employees of a total area work force of 110,892 were employed directly in agriculture or in related processing industries [37].

The annual gross value of agricultural production increased from 98 million in 1964 to over 104 million in 1968. Average income per farm increased from $11,600 in 1949 to $18,900 in 1964. The annual gross value of agricultural production is projected to continue to increase. It is projected to reach a level of 127 million in 1980, 152 million in 2000, and 169 million in 2020 [37].

The cities, industry and agriculture have depended almost entirely on diversions from the Rio Grande for their water supply. In the upper reaches, from the source of the river to El Paso, the contributing drainage area for the river is United States territory. In 1906, a treaty was ratified between the United States and Mexico relating to the water of the Rio Grande above Fort Quitman, Texas. Under terms of the treaty, the United States agreed that it would deliver 60,000 acre feet of water annually to the Acequia Madre Canal situated above the city of Juarez, Mexico. Mexico agreed to waive any and all claims to water between the Acequia Madre Canal and Fort Quitman [28].

The Rio Grande extends 1120 miles from Fort Quitman to the Gulf and although numerous attempts were made to promulgate a treaty dividing the water between the two nations, none were successful until the international treaty of 1945 was adopted, dividing the waters of the Rio Grande, the Colorado, the Tijuana Rivers between the two countries. The treaty provided for a 58 percent (U.S.) and 42 percent (Mexico) division of the Rio Grande waters. Three proposed storage dams were mentioned in the treaty. Provision was made for the omission of one or more of the proposed dams by agreement of the parties and the construction of such additional dams as might be determined by the International Boundary and Water Commission with the approval of the contracting governments. Falcon Dam and Reservoir, situated between Laredo and Roma, Texas and Amistad Dam and Reservoir situated below the confluence of the Devils River and the Rio Grande, have been completed. The size and storage capacities of the Reservoirs created by these dams are shown in Table 1 [28].

The 1945 treaty vested the International Boundary and Water Commission with extensive authority over the Rio Grande waters including the measuring, storage, and release of reservoir waters for flood prevention purposes or to meet the water needs of the contracting nations.

The completion of Falcon and Amistad Reservoirs has provided water users with considerably more water than had been previously available for irrigation due to the storage of flood waters. They have also helped to regulate river flow. However, periodic water

Table 1. Size and storage capacities of Falcon and Amistad Reservoirs

<u>Falcon Reservoir</u>	
Maximum design flood stage	4,150,000 acre feet
Conservation storage space (winter)	2,771,000 acre feet
Conservation storage space (summer)	2,710,000 acre feet
Division of conservation storage	(U.S. - 58.6%) (Mexico - 41.4%)
U.S. conservation storage (winter)	1,620,000 acre feet
<u>Amistad Reservoir</u>	
Maximum design flood stage	5,660,000 acre feet
Conservation storage space	3,550,000 acre feet
Division of conservation storage	(U.S. - 56.2%) (Mexico - 43.8%)
U.S. conservation storage	1,995,000 acre feet

Source: [28].

shortages during critical periods, inefficient use of existing water supplies, and inadequate drainage have influenced the potential growth of the area and pose the continual threat of serious effects on the economy of the Basin. Factors which continue to affect the quantity of available water from the river are drouths, increased irrigation development along the Mexican tributaries of the Rio Grande, and the increased use by Mexico of its share of the Rio Grande below Falcon Reservoir.

In 1956, the State of Texas filed a suit in the 93rd Judicial District Court to obtain an adjudication of the water rights relative to the American share of the waters of the Rio Grande. The suit named as defendents approximately three thousand water users who claimed the right to use water from the Rio Grande for a variety of uses, including the irrigation of over 850,000 acres of land located in Starr, Willacy, Hidalgo and Cameron counties.

In a judgment rendered by Judge J. H. Starley in 1966, the District Court allotted a maximum of 2.5 feet of Rio Grande water per acre per year at point of diversion for irrigation use on all lands which he found had water rights. Agricultural lands were grouped into five priority classes for allocation of water. The priorities were weighted in reference to a base of 1.0 for the lowest priority lands and greater weights for higher priorities up to 1.7 for the highest priority. Priorities were based on the appropriation of water rights perfected under certified filings, issuance of permits, and the development of water use [29].

In 1969, the Court of Civil Appeals for the Thirteenth Judicial District of Texas upheld much of the trial courts decision but changed the priority classes by eliminating three of the minor priorities and adopting two classes of weighted priorities which were designated as Class A and Class B. Under the above classification, most of the previous Class I to Class IV priority holders were grouped into Class A. Other users which the Court found had been making a "good faith" use of the waters of the Rio Grande for irrigation but who did not qualify as Class A holders were grouped into Class B. Class A holders, under this decision, are entitled to the use of 1.7 times the amount of water of Class B holders. A summary of water rights by use in the three counties is shown in Table 2. Table 3 shows the acres of Class A right by water districts.

The first major irrigation developments in the Basin took place around 1905 and were initiated by large land and irrigation companies. Those companies built the irrigation system, cleared and divided the land and sold it to individual land buyers. These land companies did not last long and many of them were bankrupt by 1915. With operation and maintenance of the irrigation water distribution system left to the farmers of the area, irrigation districts were organized under the first Conservation Amendment of 1904. Since the passage of this amendment, new water district legislation has simply been tacked onto the old. Texas general law now provides for the creation of 13 different types of water districts with virtually no limit on the number which may be created by legislative act [34].

Districts created under the 1904 act were authorized to issue bonds and levy taxes to retire them subject to: (1) a debt limitation of one-fourth of the assessed valuation of real property within the district, and (2) approval of two-thirds of the property tax-paying voters of the district. This amendment was superseded by the more liberal Conservation Amendment of 1917 which authorized creation

Table 2. Summary of water rights in Hidalgo, Willacy, and Cameron Counties

Allottee	Recognized acres	Allotment ac.ft./year
1. Domestic and municipal reserve		60,000.0
2. Research	198.0	990.0
3. Texas Highway Department	2,124.3	2,124.3
4. Industrial users		400.6
5. Irrigation rights		
Class A	684,443	-
Class B	40,685	-
Total irrigation rights	725,128	1,812,822
6. Municipal use		125,954

Source: [29, p. 93].

Table 3. Acreages with class A rights in irrigation water supply districts

District	Acreage
Cameron County WCID #1	40,133
Cameron County WID #2	58,196
Cameron County WCID #5	19,979
Cameron County WCID #6	21,912
Cameron County WID #10	4,085
Cameron County WID #11	7,024
Cameron County WID #12	1,025
Cameron County WCID #13	3,650
Cameron County WID #15	1,750
Cameron County WID #17	1,414
Cameron County WCID #19	7,600
Donna Irrigation District, Hidalgo County #1	37,625
Hidalgo County WCID #1	34,746
Hidalgo and Willacy WCID #1	69,910
Hidalgo County WCID #2	65,000
Hidalgo County WCID #3	7,941
Hidalgo County WCID #5	5,693
Hidalgo WID #6	9,238
Hidalgo County WCID #6	21,578
Hidalgo County WCID #7	19,732
Hidalgo and Cameron Counties WCID #9	72,060
Hidalgo County WCID #13	1,942
Hidalgo County WCID #14	13,452
Hidalgo County WCID #15	30,872
Hidalgo County WCID #16	13,579
Hidalgo County WCID #19	4,710
LaFeria WCID - Cameron County #3	30,645
Santa Maria WCID - Cameron County #4	4,073
Valley Acres WD	9,000

Source: [28].

of Conservation and Reclamation districts for the broad purposes of:

> The conservation and development of all of the natural resources of this State, including the storage, preservation and distribution of its storage and flood water, the waters of its rivers and streams, for irrigation, power and all other useful purposes, the reclamation and irrigation of its arid, semi-arid, and other lands, needing irrigation, the reclamation and drainage of its overflowed lands, and other lands needing drainage, the conservation and development of its forests, water and hydro-electric power, the navigation of its inland and coastal waters. The preservation of all such natural resources of the State are each and hereby public rights and duties and the Legislature shall pass all such laws as may be appropriate thereto. [34]

The Amendment further provided that the legislature "shall authorize all such indebtedness as may be necessary. . . to the achievement of the purposes of the amendment." Subject to a single requirement that bonded indebtedness be incurred only after approval of a majority of the property tax-paying voters of the district, no constitutional tax or debt limitation of any kind were placed on districts organized under the sweeping authority of this legislation. Districts organized under authority of the 1904 amendment were known as Irrigation Districts and those created under the 1917 amendments were known as Water Improvement Districts. At the present time approximately thirty-four irrigation water supply districts are operating in the Valley, ranging in size from less than 2000 acres to over 65,000 acres. In 1918 the Canales Act authorized water improvement districts to convert, without change of name, to Conservation and Reclamation districts in order to take advantage of the more liberal taxing powers authorized under the 1917 amendment. Although the 1917 act is still in effect, it too has been superseded by the more generous provisions of the Water Control and Improvement District Law of 1925 under which most of the districts now operate [34].

These districts are governed by a board of five non-salaried directors who comprise the policy making body of the district. Most districts in the Valley employ a full-time manager whose responsibility is to carry out the day to day operation of the district under the general direction of the Board.

While all Districts in the Valley finance capital expenditures through the issuance of bonds, the annual operations, maintenance, and administrative funds are secured from two sources. First, each district charges a flat rate per acre irrigated. This charge is not related to the quantity of water delivered and is used primarily to cover the fixed costs such as maintenance and salaries of full-time employees. Second, a charge is levied each time that irrigation water is delivered. While revenues from this source are generally thought of as being related to the quantity of water delivered to the farm, the facts are that only three districts have facilities for metered delivery of water. Therefore, they are actually a direct function of the number of applications of irrigation water delivered each year. This levy is designed to cover pumping costs and other expenses which vary annually with the quantity of water delivered.

Statement of the Problem

Irrigation farmers in the Rio Grande Basin of Texas have been confronted by and continue to face many problems associated with use of the waters of the Rio Grande for crop production. Problems of water availability affected by drouth, increased irrigation development along the Mexican tributaries of the Rio Grande and the increased use by Mexico of its share of the Rio Grande water below Falcon reservoir have led to proposals by water development agencies to divert additional water for irrigation purposes into the area from points as distant as the East Texas drainage basins. The quantities of water which are available for irrigation have also been affected by inefficient distribution and application of existing water supplies. Inefficiencies are a result of (1) use of irrigation water in the production of relatively low value crops, (2) unmeasured and uncontrolled application of irrigation water on farms, and (3) obsolete and inefficient distribution facilities within irrigation districts [6]. Increased salinity of the Rio Grande waters has become more of a problem as Mexico has developed irrigation projects along the Rio Grande and its tributaries and has used the River for return flows. This practice has also contributed to problems of land and water management in the area of the study. Another related problem associated with the use of Rio Grande waters, and one that is related to the salinity problem, is that of inadequate drainage facilities and a rising ground water table within the Basin. In an attempt to solve the drainage and flood problems of the area, local authorities and a "Comprehensive Study" of the basin was undertaken [37]. This agency recommended that a three-phase flood control and drainage plan be undertaken to solve these problems at a cost of over $144 million dollars.

Several studies of water supply and drainage problems in the Region, including the comprehensive study of the Soil Conservation Service, have recognized that institutional arrangements--legal, cultural, economic and political--have tended to perpetuate certain inefficiencies in the use of the land and water resources in the area. Casbeer and Trock identified some institutions that have had significant effects on land and water use in the Valley [6]. They pointed out the seriousness of the water problem in the area, and suggested several alternatives to the organizational and administrative arrangements which presently influence water resource development and use. Among these was the suggestion that water rights and annual allocations be made freely negotiable among users, thus allowing free market forces to more nearly allocate the scarce water resource to its higher uses. Another suggestion involved reorganization and consolidation of the water supply districts into one or more major conservancy districts with responsibility for supplying irrigation water, draining lands, and related conservation and utilization measures. Changes in water pricing policies were also suggested as a means to improve efficiency of water use. It was recommended that in-depth study be given to these possibilities for change in existing institutions [6]. Such studies would allow water users and resource planners to have a greater insight into the possibilities of developing the water and related resources of the Valley.

Objectives of the Study

The general purposes of this study are (1) to study the effects of water rights as allocative devices on water use; to determine the impact of a change in present institutional arrangements to facilitate the purchase and sale of water rights and/or annual water allotment on water use efficiency, and (2) to study the influence of special purpose districts (Water Control and Improvement Districts) on the distribution and use of water in the Rio Grande Basin and to determine whether the particular ways in which these districts are organized and function may cause them to act as facilitating or obstructing elements in the efficient development and management of water resources in the Valley.

The more specific objectives of the study are to:

(1) Project the effects of the transfer of water rights or annual allotments on water use in crop production in the Valley.

(2) Determine the effects of varying water prices on quantities of water used, cropping patterns, and enterprise combinations.

(3) Appraise the operational efficiency of districts with varying sizes and levels of development.

(4) Analyze alternative institutional arrangements which would allow and facilitate changes in district organization, structure, and management that would improve operational efficiency.

(5) Determine the effects on water use and hence on the economy of the area of the rehabilitation of water distribution facilities within the area.

(6) Evaluate the possibilities for rehabilitation of district facilities and the merger or combination of districts.

The Study Area

The area of this study covers the three counties at the southern tip of Texas: Hidalgo, Willacy, and Cameron. These three counties constitute what is known as the Lower Rio Grande Valley. The area is bounded by the Gulf of Mexico to the East and the Rio Grande River on the South. The largest population center in the area is the city of Brownsville situated in Cameron County with a population of over 50,000. Other principal population and trade centers are Harlingen, McAllen, Edinburg, Weslaco and San Benito. The total land area of the Basin is 2,209,000 acres. This consists of 1,038,000 acres of cropland, 694,000 acres of grassland, 270,300 acres of large water areas and 206,400 acres of land in urban and other uses. Normally, about 689,800 acres of cropland and 60,200 acres of pasture are irrigated [37].

Land Resources

The entire Basin lies within the Rio Grande Plain Land Resource Area which is characterized by nearly level to gently undulating topography. The soil resources of the area are a valuable natural resource. Most are level, high in natural fertility, easily cultivated and suitable for irrigation. There are two distinct soil associations in the Valley (Figure 1). These are the clay soil group which occupies primarily a narrow strip of land along the river and the Gulf in Hidalgo and Willacy counties and constitutes the major soil type in Cameron County and a loam group which occupies the majority of the areas covered by Hidalgo and Willacy counties. These two soil groups are characterized by somewhat different yield responses, water requirements, and management. Therefore, different budgets were developed for crops grown on these two soils and the same crop, when grown on different soils, are considered as different activities for the purposes of this study.

Water Resources

Water resources of the area are limited primarily to diversions from the Rio Grande because of the poor quality of ground water in the area.

The topography of the area with its flat terrain practically precludes the economical storage of any substantial amounts of water within the area. However, two off channel reservoirs and one natural lake are used for temporary storage of water diverted from the River. Monte Alto Reservoir in east-cental Hidalgo County has a capacity of 25,000 acre feet and is owned and operated by the Hidalgo and Willacy County WCID No. 1. Valley Acres Reservoir, North of Mercedes, has a

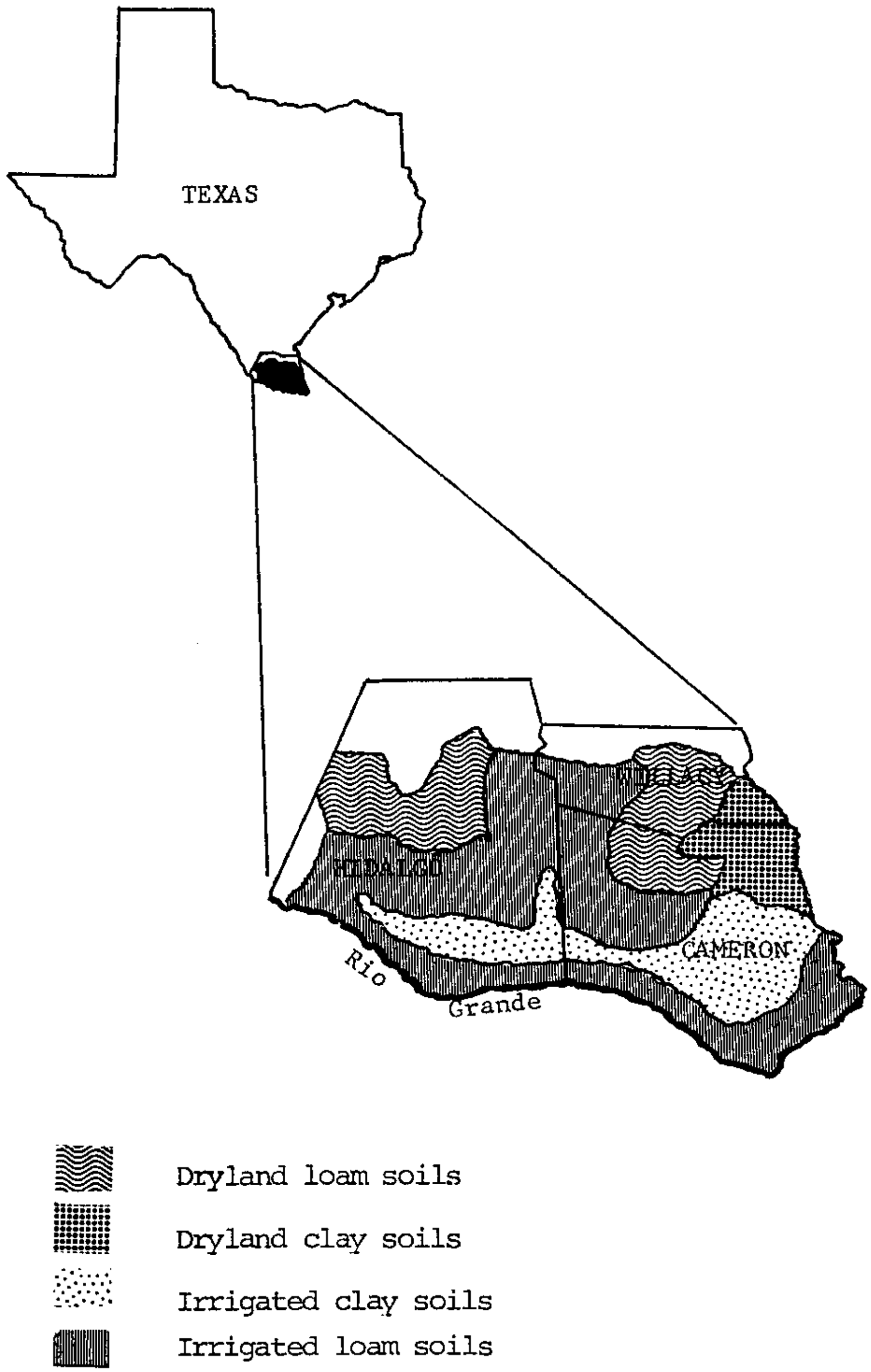

Figure 1. Lower Rio Grande Valley: location and soil types

capacity of 7800 acre feet and is owned and operated by the Valley Acres District. Loma Alto Lake in Cameron County is a natural lake which is owned and operated by the Brownsville Navigation District. Its capacity is being increased to store 26,500 acre feet. Some of the other water supply districts, primarily in Cameron County, use the natural drains and resacas for temporary storage and transfer of water but the capacity of these is limited in most cases.

Ground water of the Basin is characterized by wide variations in chemical composition and very little of it can even be considered as fresh water (less than 1,000 ppm total solids) and none meets the U. S. Public Health Service recommendations for drinking water (less than 500 ppm total solids).

The U. S. share of the Rio Grande water measured at Falcon Dam site for the period 1900 to 1964 has varied from an annual low of 478,000 acre feet in 1956 to a high of 4,025,000 acre feet in 1932. During this period the 10 year moving average declined from 1,833,000 in 1932 to 1,322,000 acre feet in 1956 and to 1,306,000 in 1964.

When the U. S. share of 1,306,000 acre feet annually is multiplied by a coefficient of 0.94 to account for river losses between Falcon Reservoir and the Valley and by a coefficient of 0.75 to account for distribution system losses, the actual water available for irrigation at the farm gate is approximately 958,230 acre feet. Table 4 shows the U. S. share of Rio Grande water measured at Falcon Dam, 1900-1964. According to observers in the Valley and others interested in water development in the State, the primary reason for the decline in the average U. S. share of the Rio Grande waters has been the development of irrigation projects on the Mexican tributaries

Table 4. United States share of Rio Grande water measured at Falcon Dam, 1900-64

Year	Annual discharge	10-year moving average	Year	Annual discharge	10-year moving average
	-------(1,000)-------			-------(1,000)-------	
	ac. ft.	ac. ft.		ac. ft.	ac. ft.
1900	2,827	-	1933	1,727	1,823
1901	1,266	-	1934	933	1,763
1902	1,106	-	1935	3,389	1,846
1903	1,758	-	1936	2,137	1,899
1904	2,248	-	1937	1,108	1,893
1905	2,555	-	1938	2,095	1,958
1906	2,822	-	1939	1,201	1,977
1907	1,593	-	1940	1,458	1,959
1908	1,707	-	1941	3,142	2,122
1909	1,588	-	1942	2,224	1,941
1910	1,238	1,947	1943	1,210	1,890
1911	1,148	1,776	1944	1,499	1,946
1912	1,087	1,774	1945	1,183	1,528
1913	1,632	1,762	1946	1,451	1,657
1914	3,150	1,852	1947	1,139	1,660
1915	1,660	1,763	1948	1,776	1,628
1916	1,354	1,616	1949	2,225	1,738
1917	1,362	1,593	1950	1,087	1,694
1918	1,173	1,539	1951	838	1,463
1919	3,675	1,748	1952	444	1,285
1920	2,901	1,914	1953	596	1,224
1921	1,051	1,905	1954	3,326	1,407
1922	2,380	2,034	1955	1,310	1,419
1923	1,833	2,054	1956	478	1,322
1924	1,530	1,892	1957	2,000	1,408
1925	2,558	1,982	1958	2,030	1,433
1926	1,613	2,008	1959	1,460	1,357
1927	1,166	1,988	1960	1,200	1,368
1928	1,441	2,015	1961	1,330	1,417
1929	1,010	1,748	1962	825	1,456
1930	1,660	1,624	1963	680	1,464
1931	1,498	1,669	1964	1,750	1,306
1932	4,025	1,833			

Source: "The Water Situation in the Lower Rio Grande Valley of Texas," Tate Dalrymple, McAllen, Texas, 1965.

of the River. This trend toward development and utilization of water upstream is expected to continue or even to accelerate in the years ahead, according to Louis McDaniels of the Texas Water Rights Commission. These trends bring into even sharper focus the need for more efficient use of available water supplies if the economy of the area is to be maintained or improved.

SECTION II

THEORETICAL APPLICATION

The theoretical framework for the section of this study concerned with water allocations among enterprises is that of the multi-product firm in a partial equilibrium framework with both product and resource markets in short run equilibrium.

According to Marglin, the conditions which must be approximately satisfied in order to use a competitive partial equilibrium framework in the analysis of water resource problems are (a) that producers are unfettered in their pursuit of profit maximization, (b) that the marginal utility of income is constant for all consumers over the ranges affected by the project, (c) that prices throughout the economy approximate marginal costs, (d) that the scale of water resource development is too small to influence prices generally throughout the economy, and (e) that no important external effects arise in the consumption of water resource output [22].

The theoretical framework for the section of the study concerned with irrigation district efficiency is that of a single product firm.

Here, the concern will be, not with optimum resource allocation among enterprises but with the economies and diseconomies associated with firm size for firms (water supply districts which are governmental entities) engaged in the production of a single commodity (the distribution of irrigation water).

The Efficiency Objective

One of the primary functions of an economic system is the allocation of scarce resources among competing uses. A test of the performance of this function is the "economic efficiency" criterion which corresponds roughly to the maximization of national income. A necessary condition for an efficient allocation of resources is that the values of the marginal products of the resource be equal in all uses. In stating the problem mathematically, the firm is faced with a production function for each enterprise which is continuous, differentiable, and with nonzero first and second partial derivatives. Each production function, furthermore, exhibits a decreasing marginal rate of substitution between any two inputs, a decreasing marginal product for all input-output combinations and an increasing marginal rate of product transformation. This may be written in the general form as follows:

(2.1) $L(Y_i, Y_2 \ldots. Ym; X_j, X_2, \ldots X_\eta) = 0$

where $i = 1,2, \ldots m$; (m = number of products or enterprises)

$j = 1,2, \ldots n$; (n = number of variable resources)

A price function of the form:

(2.2) $Pi = Pi(Y_1, Y_2 \ldots. Ym)$

is associated with each commodity or enterprise output. In the case of the less than competitive market, this price is a function of the quantity produced of the salable commodity. In the case of the competitive market, the price is a parameter and is not related to the quantity of the commodity produced by any individual firm. In either case, the general form of the revenue function can be characterized as

(2.3) $$r = \sum_{i=1}^{m} P_i Y_i$$

The same assumptions hold for a set of input prices which can be written

$$(2.4) \qquad P_j = P_j\ (X_1,\ X_2\ \ldots.\ X_n).$$

The cost of production can then be characterized as

$$(2.5) \qquad C = \sum_{j=1}^{n} P_j X_j$$

where C is limited to a given level of expenditure for inputs. And finally net revenue is defined to be

$$(2.6) \qquad \pi = \sum_{i=1}^{m} P_i Y_i - \sum_{i-1}^{n} P_j X_j$$

From equation 1 to 6 the net revenue is seen to be a function only of the inputs X and the outputs Y. The objective of the firm is to find that set of X and Y for which π is a maximum. That is, it is required to find a stationary value of equation 2.6 subject to equation 2.1 and to conditions on the second derivatives which will guarantee a maximum rather than a minimum or a point of inflection. This problem can be solved by the use of the Lagrangean multiplier. In this case, form the equation

$$(2.7) \quad G = \sum_{i=1}^{m} P_i Y_i - \sum_{i=1}^{n} P_j X_j + \lambda[\sum_{j=1}^{n} P_j X_{jY_i} - C]$$

and calculate the partial derivatives with respect to each of the inputs, outputs and the multiplier λ. Performing the differentiation, one obtains

$$\frac{\partial G}{\partial Y_i} = fP_iY_i - f\lambda_iP_i = 0 \qquad i = 1,2 \ldots.m$$

(2.8)
$$\frac{\partial G}{\partial X_{jy_i}} = fP_jX_j - f\lambda_jg_j = 0 \qquad j = 1,2 \ldots.n$$

$$\frac{\partial G}{\partial \lambda} = f(-\sum_{j=1}^{n} P_j X_{jy_i} - C) = 0$$

The first order, or necessary conditions for the constrained maximum are that all first order partial derivatives of equation 2.7 equal zero.

Eliminating λ from the set of equations in expression 2.8 one obtains

$$\frac{MVP_{X_1Y_i}}{P_{X_1}} = \frac{MVP_{X_2Y_i}}{P_{X_2}} = \frac{MVP_{X_jY_i}}{P_{X_j}} \qquad (2.9)$$

which embodies the principle that the optimal combination of inputs is obtained at the production point where the marginal rate of technical substitution between every pair of inputs is equal to the price ratio prevailing between that pair of inputs, in other words, a dollars worth of any input allocated in an output must be the same.

Alternatively, equations (2.8) may be simplified and expressed as

$$\frac{MVP_{(1)X}}{P_X} = \frac{MVP_{(2)X}}{P_X} \ldots. \frac{MVP_{(m)X}}{P_X} \qquad (2.10)$$

which embodies the principle that the optimum output combination is attained at the production point where the marginal value product for any resource in alternative uses is the same. That is, the marginal value product of a dollars worth of resource used in any one activity must equal the marginal value product of a dollars worth of the same resource in any other use.

Second order conditions require that the relevant bordered Hessian determinants alternate in sign. This implies an increasing marginal rate of product transformation between any two outputs, a decreasing marginal product for each input-output combination and a decreasing rate of technical substitution between any two inputs [11].

The complexity of the above model with its continuous non-linear production function, difficulty in parameter estimation, and the infeasibility of solving a large system of non-linear equations limits use of the model to firms having few inputs and few outputs. In addition, the marginal analysis requires the firm to have a continuous production function for the Lagrangean differential gradient method to be applicable. Because of these problems, consideration of alternative models of the firm is necessary. One practical alternative is that of linear mathematical programming.

A Linear Programming Model of the Firm

Linear mathematical programming, as opposed to the calculus embodied in the Lagrangean differential gradient technique, is applicable to problems involving the maximization of a linear function subject to a set of linear inequalities. A linear programming model of the multiple-factor, multiple product firm can be viewed as an alternative to the short-run Hicksian Model in which the smooth production function with continuous first and second derivatives is replaced by a discrete linearly homogeneous production function characterized by a set of independent linear activities. An activity is characterized by a set of ratios of variable factors from the market and fixed factors on hand to the output of a particular product. These ratios are constant and independent of the level of activity. Activities are additive with respect both to resource use and product output. The firm's short-run profit maximizing problem thus becomes one of selecting that feasible set of combination of activities which maximizes the earnings of the fixed factors [9].

A mathematical model of the multiple factor-multiple product firm amenable to solution by linear programming methods is discussed below. The firm's production function is given by

$$V_{jk} = G_{jk}X_j \quad (j = 1,2\ldots,n;\ \ k - 1,2\ldots r) \tag{2.11}$$

$$B_{ij} = A_{ij}X_j \quad (i = 1,2\ldots,m;\ \ j = 1,2\ldots n) \tag{2.12}$$

and

$$\sum_{j=1}^{n} B_{ij} \leq B: \quad (i = 1,2\ldots,m) \tag{2.13}$$

where G_{jk} is the quantity of the variable factor k required to produce a unit of product j, A_{ij} is the quantity of the fixed factor i required to produce a unit of the product j, and B_i is the quantity of the i^{th} fixed factor available for use in production activities.

The firm's profit function is given by

$$\pi = \sum_{j=1}^{n} R_jX_j - \sum_{k=1}^{r} P_kV_k \tag{2.14}$$

which is equivalent to (2.7). The profit function can be simplified by letting C_j ($j = 1,2 \ldots,n$) be the profit to the firm from the production and sale of the j^{th} product. Thus, (2.7) and (2.13) can be restated as

$$Z = \sum_{j=1}^{n} C_j X_j \tag{2.15}$$

The firm's objective of maximizing profit subject to the technical restraints imposed by the production function is

$$\text{Max } Z = \sum_{j=1}^{n} C_j X_j \tag{2.16}$$

Subject to

$$\sum_{j=1}^{n} A_{ij} X_j \leq B_i \qquad (i = 1,2...,m) \tag{2.17}$$

and

$$X_j \geq 0 \qquad (j = 1,2...,n) \tag{2.18}$$

where the final restriction limits the production of outputs and non-negative levels.

The foregoing problem can be solved by one of several variations of Dantzig's "simplex algorithm." The criterion for the linear programming optimal solution is the change in profit associated with introducing one unit of a product not in the current solution. This can be expressed as

$$\Delta Z = \sum_{i=1}^{n} C_i \frac{\Delta X_i}{\Delta X_k} - C_k \tag{2.19}$$

where the i^{th} product is in the current solution and the k^{th} product is not. If the profit foregone by introducing a unit of X_k is less than the amount of profit added by producing a unit of X_k, profit would be increased by making the change [9].

The existence of numerous computer routines, many of them embodying the Revised Simplex Method, allows efficient solution of large linear programming problems. An example of such a procedure built into a programming special language is the IBM Mathematical Programming System for use on the IBM Model 360 Computer. In addition to finding optimal solutions to large linear programming problems, such routines usually contain post-optimal procedures useful in testing the sensitivity of the optimal solution to the values assumed for particular parameters in the model. Ranging procedures allow the user to readily determine the effects of individual changes in the coefficients C_j (j = 1,2...,n) and B_i (i - 1,2...,m). Parametric procedures allow the user to study the effects of simultaneously changing coefficients of C_j, A_{ij} or B_i over specified intervals. In this study, the price of the variable input water is varied to determine (1) the quantity of water which would be used in the optimal solution by farms in the area at various prices, (2) the effects on net farm income to the area of such changes in water use and cropping patterns, which could occur if water rights were freely negotiable and (3) the effects on net farm income of the rehabilitation of existing water distribution system in the Basin.

The optimality conditions for linear programming models of the firm similar to the one presented above are somewhat different from those of the traditional marginal analysis. Naylor has summarized the optimality conditions of a linear programming model of the firm into decision rules by which to compare it with the Hicksian marginal analysis model [24]. The rules which are appropriate for the above linear programming model follow:

Rule one states that the unit price of each activity must be less than or equal to the sum of the imputed costs of the fixed and variable factors used to produce one unit of that activity.

Rule two states that for each variable factor-activity (product) combination the unit price of the given variable factor must be greater than or equal to the marginal value imputed to the variable factor with regard to the given activity.

Correlation and Regression Analyses

Correlation and regression analyses are closely linked both in concept and in use by researchers although the two techniques serve distinct purposes. Correlation measures the degree of relationship among variables while regression estimates the parameters of that association. These techniques are used in this study to analyze the relationship between variables which it is hypothesized may affect or be affected by operation within the Valley water supply districts and to estimate the parameters of the relationships.

The regression of the dependent variable Y on the independent variable X is defined as the expected value or theoretical mean of Y for each given class of X. Therefore, it describes how the average Y changes with changes in X in the joint distribution of X and Y. This regression may be expressible in functional form if the bivariate distribution of X and Y are known. Since this is usually not practical, some functional form is assumed and the regression is estimated under fairly restrictive hypotheses about the underlying variable relationship. The regression, then, is a function of mathematical variables, but the relationship estimated is between statistical variables [2].

In standard linear regression models, three assumptions are made about the relationship between the dependent variable (Y) and the independent variables (X's). The assumptions are: (1) for each selected X, there is a normal distribution of Y from which the sample value of Y is drawn at random, (2) the population of values of Y corresponding to a selected X has a mean μ that lies on a straight line $\mu = \alpha + B(X - \overline{X}) = \alpha + Bx$ where α and B are parameters and, (3) in each population, the standard deviation of Y about its mean $\alpha + Bx$ has the same value, usually denoted by $\sigma_{y.x}$.

The statistical model is specified by the equation

$$Y = \alpha + BX + E$$

where E is a random drawn from $N(0,\sigma_{y.x})$.

The regression of Y on a single independent variable is often inadequate.

Two or more X's may be available which will give additional information about Y by means of a multiple regression on the X's. Among the principal uses of multiple regression are: (1) to construct an equation in the X's that gives the best prediction of the values of Y, and (2) to discover which variables are related to Y, and, if possible, to rate the variables in order of their importance.

The correlation coefficient (r) is a measure of the degree of relationship between two variables. Two properties of r can be noted: (1) r is a pure number without units nor dimension because the scales of its numerator and denominator are both the products of the scales in which X and Y are measured, and (2) r always lies between -1 and +1. Positive values of r indicate a tendency of X and Y to increase together. Where r is negative, large values of X are associated with small values of Y.

Economies of Size

While there has been much written on the economies of scale, this subject is still one of the major areas of confusion among economists. These misunderstandings center primarily around the problems associated with the empirical possibility of increasing the quantities of all resources in exactly the same proportion as required in a true study of scale economics. According to Boulding:

> Frequently what appears to be variable returns to scale turns out to be nothing but a subtle example of variable physical marginal productivity. For instance, it is often the case that doubling the size of a factory, the number of machines in it, the number of men and the quantities of material more than doubles the output..... What we have really done is to hold constant the quantity of one input, management, and vary the quantities of all others [3].

Cost economies may be either internal or external to the individual producing unit. They may also be of a monetary (pecuniary or market) nature or of a physical (technological) nature [17]. Internal economies are those realized from size adjustment within the individual firm; they occur irrespective of adjustments in the industry. External economies are those realized entirely outside of the producing unit. They depend on adjustments of the industry and relate to the firm only as it is a part of the industry.

Internal market economies are realized as the firm becomes large enough to purchase inputs in large scale lots. Internal physical economies arise mainly as the indivisibility of factors is overcome when size and output is increased. Physical economies occur as size is expanded by use of different levels or forms of fixed factors. A larger volume in a plant of a given size causes declining average costs as long as the decline in per unit fixed cost is greater than the increase in per unit variable cost.

In the case of water supply districts, the larger units can pay a higher wage to management and by having these management costs spread over a larger number of acres, still have a lower per unit management cost than the smaller district. The efficiencies of large pumps and motors for lifting water from the river should allow larger districts to have lower operating costs per unit than smaller districts. And finally, it is also likely that maintenance cost of canals and ditches do not rise proportionally to the size and water carrying capacity of these facilities.

Benefit-Cost Analysis

Decisions as to the commitment of resources to public water resource development projects depend on an evaluation of benefits and costs and ultimately fit into the more general question of what constitutes an efficient use of resources by an economic system. Analysis of the question of economic efficiency in water resource development falls essentially into the realm of welfare economics. As project evaluation is currently carried out by various agencies, it is essentially the application of some postulates of welfare economics to a particular project [10]. On the basis of such benefit-cost analyses, the agencies determine the economic feasibility and priority of projects which are then recommended to Congress. The primary discussions concerning the "welfare" aspects of benefit-cost analysis center around two major questions. First, the question of the income redistribution effects of public resource development have been virtually ignored in the analysis of benefits and costs and very little account is taken of the fact that ordinarily a large portion of the costs of a project are not borne by the direct project beneficiaries [19]. Second, a somewhat different criticism has been presented by Stephen Marglin [22]. His criticism is based on the proposition that benefit-cost evaluation, by attempting to maximize a future income stream implicitly posited a social goal that is only partially acceptable. He feels that because the populace is interested not only in the absolute magnitude of national income but with its composition, a condition which embodies only the criterion of absolute size will lead to a choice of projects which again is not optimum from the standpoint of national welfare.

SECTION III

METHODOLOGY AND PROCEDURE

The Valley, defined here as Hidalgo, Willacy and Cameron Counties, will be considered as a single agricultural enterprise. It has the potential of producing various products with the available complement of resources. Throughout this analysis neither product nor resource prices will be allowed to change, with the exception of cost per acre inch for irrigation water which will be varied from $9.60 per acre foot to $96.00 per acre foot.

The Linear Programming Model

The basic model used in this analysis is constructed within the framework of the deterministic linear programming model of the firm described previously in Section II. Fixed factors of the model are the basic technology and operating environment of the Valley, land for both the clay and loam resource areas, regular hired and operator labor, crop allotments by resource areas, and market restrictions for certain specialty crops by resource areas. Variable factors include capital, water and seasonal labor supply.

The Land Resources

For purposes of this study, the land resource base of the Valley has been defined as that land which is shown in the conservation need inventories of the three counties as land presently under cultivation in the area and in land capability Class I, II, and III. Because of the nature of the study, and the fact of possible water importation and variation in the flow of the River, it was not felt feasible nor desirable to limit the land resource area to presently irrigated acreage. The total land resource base used in the study is 990,017 acres, of which 649,447 acres are in the loam resource area and 340,570 acres are in the clay resource area.

Because of differences in resource requirements and enterprise returns between the loam and clay soils of the area, separate sets of budgets were prepared for the crop enterprises grown on the two soil types.

The land devoted to citrus is included in the land resource base. It is recognized that citrus orchards are long range investments, and charges are not made annually in the level of citrus production. However, this crop is included in the study because it is one of the more important enterprises in the area agricultural income base and is one of the heavier users of irrigation water.

Alternative Enterprises

Thirty-nine activities or enterprises make use of the land and water resources of the Valley. Of these, twenty-two are found in the loam soil area and seventeen in the clay soil area. Alternative enterprises by soil areas are shown in Table 5.

Resource Coefficients

The quantities of resources used with one acre in each activity were determined by a farm budgeting procedure. The

Table 5. Alternative enterprises, Lower Rio Grande Valley, Texas

Loam	Clay
Dryland cotton	Dryland cotton
Cotton, preplant + 1 irrigation	Cotton, preplant + 1 irrigation
Cotton, prelant + 2 irrigation	Cotton, preplant + 2 irrigation
Dryland grain sorghum	Dryland grain sorghum
Irrigated grain sorghum	Irrigated grain sorghum
Citrus	Citrus
Beets	Beets
Lettuce	Cabbage
Cabbage	Carrots
Green beans	Pepper
Tomatoes	Lettuce
Green pepper	Onions
Honeydew melons	Sweet corn
Watermelons	Tomatoes
Cantaloupes	Cucumbers
Snap beans	Broccoli
Sweet corn	Cow-calf operation
Carrots	
Cow-calf operation	
Onions	
Cucumbers	
Broccoli	

budgets were constructed so as to estimate production requirements and costs and returns for each major crop enterprise in the Basin. The budgets reflect a level of management which is considered by agency personnel and others familiar with the area as being near average or slightly above. The production coefficients for each enterprise reflect, as near as possible, this management level. The monthly irrigation water use coefficients were determined by using data generated by the Texas Water Rights Commission and reflect precipitation and other climatological data for the period 1904 to 1956 [31]. The coefficients as used in this analysis have been increased above the Commission data to reflect an on-farm, water use efficiency of 65 percent. Prices used in the model for cotton, livestock and grain sorghum are based on 1970 levels while those for vegetable crops and citrus represent a five-year (1964-1969) average.

Resource Availabilities

Capital requirements are taken directly from the budgets and reflect only those costs required for annual operation. No charges are included for long-run capital investments as there was no way to conceptually allocate them to a particular enterprise. Three types of labor are considered in the model. Skilled labor is considered to be provided by the operator and farm workers who are hired for a longer time period than workers hired to provide seasonal assistance with irrigation and hoeing. The price for this labor was assumed to be $1.50 per hour and was set up in the model in four time periods (Dec.-Feb., Mar.-Apr., May-Aug., and Sept.-Nov.) according to the appropriate planting and harvesting schedule for the area. Seasonal labor is included in the model as a buying activity with irrigation labor assumed to cost $1.30 per hour and hoeing and thinning labor $1.21 per hour. It was assumed that operating capital was available and that its cost would be 6 percent. Water price in the model was parametrically varied from $9.60 per acre foot to $96.00 per acre foot. It was assumed that there was no restriction on water quantity so that as long as the price of water was below the marginal value product of water in any activity, the activity remained in the solution.

Enterprise Restrictions

Since this is a regional rather than a single firm study, the usual assumption of a perfectly elastic demand function for output of specialty crops could not be expected to hold unless some adjustments were made. Therefore, upper limits were imposed on the production of these specialty crops in order to maintain the validity of the assumed price set. This upper limit was set at 20 percent above the 5-year (1964-1969) average acreage harvested of all vegetable crops and citrus. Table 6 shows the maximum quantities of these crops which could enter the optimal solution. Institutional constraints in the form of government programs are important in determining the cropping pattern of the Valley. For this model, the amount of cotton allotment for the three counties in the Valley was secured from the Agricultural Stabilization and Conservation Service of the U. S. Department of Agriculture. The 1970 allotments were used in this study. The allotment for the loam area was 268,280 acres and for the clay area was 154,978 acres. Although there is a Government Feed Grain Program which could

Table 6. Upper limit restrictions on vegetable and citrus acreage

Loam area		Clay area	
Crop	Acreage	Crop	Acreage
Snap beans	3,000	Broccoli	750
Beets	1,200	Cucumbers	220
Broccoli	1,800	Tomatoes	3,500
Carrots	15,000	Sweet corn	600
Cucumber	2,500	Onions	1,700
Cabbage	7,500	Lettuce	200
Lettuce	3,500	Green pepper	700
Green pepper	6,500	Carrots	1,800
Onions	17,500	Cabbage	900
Tomatoes	12,000	Beets	200
Potatoes	4,000	Citrus	20,000
Sweet corn	3,000		
Honeydew melons	2,500		
Watermelons	7,000		
Cantaloupes	15,000		
Citrus	90,000		

conceivably limit the production of grain sorghum in the Valley, no limit was put on grain sorghum production because the program is voluntary and less than 5 percent of the farms in the area have been participating in the program [35].

Derivation of Demand for Water

The demand for a factor of production, like any other demand, is a function which relates price to quantity purchased. The function has two major parameters: the magnitude of the demand and the elasticity of the demand. Both of these parameters are determined by three principal conditions [3]. The first is the proportion which the cost of the factor bears to the total cost of the product. The second is the nature of the demand for the product produced with the factor. The third is the degree to which the factor has good substitutes. In this study, the following assumptions are made concerning input demand: (1) the firm operates in perfectly competitive input markets, (2) there is a given production function whose first derivatives are positive and decrease over the relevant range of input quantities, (3) the conditions for aggregation of individual farm demand functions are met, and (4) the firm operates in a purely competitive market for its output, that is, either the Valley contributes a small enough proportion to the national supply of the commodity not to affect its price or, in the case of specialty crops, the production of these commodities is limited in the model to those ranges for which it is assumed that national prices will not be affected.[1]

The assumptions underlying the model, in addition to those mentioned above are (1) the agricultural process of production can be divided into separate, independent activities; (2) each production activity is characterized by constant returns to scale and fixed proportions among inputs, and (3) fractions of activities can be used.

From the linear programming model, it is possible to estimate the demand function for water. In a 1970 study, Gisser used parametric linear programming to estimate the agricultural demand function for imported water in the Pecos River Basin of New Mexico [14]. In this study, he parametrically varied the price of imported water from 0 to $38.55 per acre foot while holding the price of local water constant and setting an upper limit on local water availability at 401,522 acre feet. He found that at prices greater than $38.55 per acre foot the use of imported water declined by 40 percent.

In this model, the price of water is parametrically varied from a level of $9.60 per acre foot, the approximate present cost at the farm gate for water, to $96.00 per acre foot.

In the parametric linear programming model with varying water price, assuming no other restriction is exceeded, an activity or crop will stay in the solution so long as the price of water is

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[1] This theorem states that grouping of demand function for individual farms is free of bias if (1) individual farms have identical input-output matrices and (2) individual farms have qualitatively homogeneous outputs-vectors. Given the nature of the agricultural economy of the Valley, it would seem that the similarity of input use and farm organization would allow the reasonable acceptance of the conditions for the situation under study.

less than or equal to the marginal value product of water used in that enterprise. When the price of water rises above the marginal value product of water used in the particular activity, the optimal solution is changed and that particular activity is replaced by some other in the optimal solution. This procedure will, therefore, reveal the value of water in competing uses and the potential price of water in these uses as the optimum solution varies with changes in water price and available water supply.

Analysis of Irrigation District Operations

In order to analyze the influence of the water supply districts on the distribution and use of water in the Valley, it was necessary to review the financial and other records of the thirty-four districts with respect to size of operation, operating procedures, debt and repayment capabilities, water sales policies, and quantity of water delivered annually to users.

Data used in analyzing district operation were collected from interviewing district managers, reviewing district records and reports as to the quantities of water pumped and acres irrigated annually and from audits prepared annually by the districts and filed with state agencies. Among the statistics which were collected and analyzed were: (1) total value of district assets, (2) net district debts, (3) number of acres irrigated annually within the district, (4) quantity of water pumped annually by each district, (5) district revenue derived from water sales, (6) district revenue derived from flat rate assessments, and (7) operation, maintenance, and administrative costs.

Regression Model and Hypothesis

The irrigation district data were evaluated statistically using multiple regressing analysis. The model fitted was of the form:

$$X = \alpha + \beta_1 X_1 + \beta_2 X_1^2 + \beta_3 X_2 + \beta_4 X_3$$

where

Y = annual operation, maintenance and administrative cost per acre irrigated

X_1 = Number of acres irrigated in each district

X_2 = Assets per acre

X_3 = Percent of operating revenues derived from water sales.

The hypothesis tested was that district operating efficiency, as measured by the per acre cost of supplying irrigation water, is related to size of district, financial structure of the district, and district water pricing policies. If economies of size are present in district operations, it was felt that they would be revealed by this procedure.

Benefits to System Rehabilitation

One of the objectives of this study is to determine the direct benefits and costs of rehabilitation of the water supply distribution systems in the Valley. This analysis is confined to the identification and quantification of direct benefits attributable to the rehabilitation of the systems. No attempt is made to determine the existence nor magnitude of secondary benefits. The primary benefits are, quite simply, the value of the goods and services which result directly from rehabilitation. It is the value of additional farm crops and livestock which can be produced with the water saved by rehabilitation above associated production cost.

The income, or residual, approach is currently being used in evaluation of irrigation benefits on federal reclamation projects. This procedure involves income analysis by budgeting farm situations projected with and without project conditions. The residual income is assumed to measure the economic value of the project, in this case, the value of a specified quantity of irrigation water. One of the major problems with this approach is that it requires the assumption that water use patterns by crops will be unchanging irrespective of water quantity availability and regardless of water pricing policies. The technique used in this analysis avoids this problem by assuming that producers will, in attempting to maximize net farm income, change the pattern of water use by crops with changes in either or both of these variables. In this case the change in the value of the objective function (return to land, fixed capital items, and management) will vary with changes in either of these critical variables. This variation can be measured and imputed as the gross benefits to rehabilitation.

In studies conducted by the Bureau of Reclamation in four districts in the Valley where rehabilitation of facilities has been carried out, it was found that the project has saved an average of 0.507 acre feet of irrigation water per year [31]. The linear programming model, with parametric water pricing, was run and various levels of water use were selected for the "with project" situation for the determination of benefits to rehabilitation. The "without project" situation was simulated by reducing the quantity of water available at the various levels and rerunning the model with the reduced water quantities. The difference in net revenues was taken as gross benefits to rehabilitation.

The estimated costs of rehabilitation were secured from the Bureau of Reclamation and were assumed to be the same for all districts as for the four previously rehabilitated [40].

The benefits were discounted at 5 percent and 7-1/2 percent for an anticipated project life of 40 years for comparison with project costs.[2]

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[2]The present value formula used for calculating discounted net benefits was:

$$PV = \frac{[1-(1+r)^{-n}]}{r}$$

which is the formula for the present value of an annuity of 1.0.

SECTION IV

WATER RIGHTS, WATER PRICING AND ECONOMIC EFFICIENCY

An institution which is very important to the allocation of water resources and thus to the efficiency of water use in the agriculture of the Rio Grande Basin is the system of "water rights."

The Texas Water Rights Commission defines a water right as "a right to use of water accorded by law." A necessary element of the right to use is the right to divert the water--to take possession and reduce it to physical control. As a right to do things is involved, the term has legal significance and the present law is concerned with both the taking of water from natural source and the use made of water. In Texas, as in other states which operate generally under the appropriative doctrine, the farmer is not a free agent in using whatever quantity of water he desires from a stream. The question of whether or not he may use the water, the quantity which he may divert for use, and even the time he may take it depends upon the nature of his water right. These water rights also determine priorities of use and afford legal protection to those who divert and use water pursuant to their rights.[5]

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[5] For a good discussion of the history of water rights and of water rights adjudication in the Rio Grande Basin see the 1968 Departmental Technical Report #1, Texas Agricultural Experiment Station, by Thomas J. Casbeer and Warren L. Trock entitled "A Study of Institutional Factors Affecting Water Resource Development in the Rio Grande Valley, Texas."

These water rights are appurtenant to the land for which they are granted and their ownership is one of the most important factors determining the market value of individual land holdings in the region as the difference in the value of irrigated and dry land crop production has been capitalized into land values.

It is hypothesized that this institutional arrangement which ties the available water supply to particular tracts of land in specified quantities has caused rigidities in water uses in the Lower Rio Grande which have resulted in a less than efficient allocation of this scarce resource. Some change in the institution of water rights to allow for improvements in the efficiency of water use would seem to be in order; but the change must be carefully considered for it might result in major changes in land values and shifts in income distribution throughout the Basin. Such changes would be vigorously opposed by those adversely affected by such actions. However, one way in which water might be directed into more efficient uses is through the use of a "market system" for water in which water right holders could buy, sell, or transfer either the water right or the annual allocation of water accorded to his water right. In this way, the resource could move to uses in which it has a higher value and the major problem of changing property values could be avoided by the fact of compensation for the loss of the water right.

One of the primary objectives of this study was to determine the impact of changes in present institutional arrangements which would improve the efficiency of water use. The change proposed above, i.e., a negotiable water right, would affect the price of water (by exchange among users) and the use of water in crop enterprises. To discover the impact of the change, prices for water used in agriculture in the Valley were varied and estimates of effects on (1) quantities of water used, (2) enterprise combinations, (3) cropping patterns and (4) water use efficiency, were developed. Parametric linear programming was the analytical tool used for this examination. Prices for water were varied from $9.60 per acre foot, the present average cost of water within the districts, to $96.00 per acre foot for water delivered to the farm gate. The analysis was not constrained by any limitation on the water supply. Land use is limited to the available 990,017 acres of irrigable land.

With the linear programming model used, the enterprises giving the lower returns will be eliminated from the solution whenever the price of water exceeds the marginal value product or "shadow price" for water in that use. Therefore, as water price increases, the quantity of water used and the acres of land irrigated in the Basin decrease.

The optimum combination of enterprises with acreages and water use by enterprise (or crop) when the price of water is $9.60 per acre foot is shown in Table 7.

When water is priced at $9.60 per acre foot, the entire 990,017 acres of irrigable lands in the model are irrigated and 1,948,805 acre feet of irrigation water could be profitably used. Irrigated cotton, occupying 423,258 acres and using 928,673 acre feet of water was the heaviest user of both land and water resources within the Basin. The crop with second highest acreage and water use was grain sorghum, produced on 372,089 acres and using 572,299 acre feet of water. At this price per acre foot, 83 percent of the

Table 7. Enterprise combination and water use by crops when the price of water is $9.60 per acre foot

Enterprise		Acreage	Irrigation water use ac. ft.	Net returns to land and management
Snap beans	(loam)	3,000	3,887	
Cotton - 3	(loam)	268,280	582,168	
Beets	(loam)	1,200	1,755	
Cabbage	(loam)	7,500	13,206	
Carrots	(loam)	15,000	18,150	
Green pepper	(loam)	6,500	12,450	
Lettuce	(loam)	3,500	5,232	
Onions	(loam)	17,500	26,162	
Sweet corn	(loam)	3,000	4,442	
Broccoli	(loam)	1,800	2,371	
Potatoes	(loam)	4,000	5,543	
Honeydew melons	(loam)	2,500	3,975	
Cantaloupes	(loam)	15,000	23,850	
Citrus	(loam)	90,000	261,825	
Grain sor. - 1	(loam)	210,667	326,534	
Citrus	(clay)	20,000	58,966	
Cotton - 3	(clay)	154,978	346,505	
Grain sor. - 1	(clay)	161,422	245,765	
Beets	(clay)	220	416	
Pepper	(clay)	700	1,265	
Lettuce	(clay)	200	483	
Onions	(clay)	1,700	3,441	
Sweet corn	(clay)	600	1,293	
Broccoli	(clay)	750	1,355	
Irrigated acreage		990,017	1,948,805	$72,642,620

irrigable lands and 77 percent of the water used in the Valley are devoted to these two enterprises. At this price, the entire cotton allotment for the area was irrigated. The $9.60 per acre foot price for irrigation, the lowest price included in the model, is above the average annual operating costs of $9.47 per acre foot of the Valley water supply districts and the quantity of water which could be profitably used at this price is well above the average quantity available from the Rio Grande. This points out very plainly why Valley producers continue to feel that there is a water shortage in the area relative to the demand for this resource.

According to the analysis, this combination of enterprises and quantity of water used for irrigation purposes did not change appreciably until the price of water reached $17.48 per acre foot. At this price the irrigated acreage declined to 771,850 acres with 1,609,065 acre feet of irrigation water being demanded. The combination of enterprises and quantities of water used at this price are shown in Table 8. The primary change in the model between the optimum combinations at water prices of $9.60 and $17.48 is that grain sorghum is no longer produced under irrigation on loam soils. Other crops remain in the solution at previous levels of both land and water use. At a water price of $18.65 per acre foot, grain sorghum on the clay soils reverted to dryland. This reduced the irrigated acres to 610,428 and water use to 1,363,300 acre feet (Table 9). The entire cotton allotment for the area would still be irrigated at this price and this crop would use 68 percent of the water diverted within the Basin for irrigation.

When the price of water rises to $27.90 per acre foot, the

Table 8. Enterprise combination and water use by crops when the price of water is $17.48 per acre foot

Enterprise		Acreage	Irrigation water use ac. ft.	Net returns to land and management
Snap beans	(loam)	3,000	3,887	
Cotton - 3	(loam)	268,280	582,168	
Beets	(loam)	1,200	1,755	
Carrots	(loam)	15,000	18,150	
Green pepper	(loam)	6,500	12,450	
Lettuce	(loam)	3,500	5,232	
Onions	(loam)	17,500	26,162	
Sweet corn	(loam)	3,000	4,442	
Broccoli	(loam)	1,800	2,371	
Potatoes	(loam)	4,000	5,543	
Honeydew melons	(loam)	2,500	3,975	
Cantaloupes	(loam)	15,000	23,850	
Citrus	(loam)	90,000	261,825	
Cotton - 3	(clay)	154,978	346,505	
Citrus	(clay)	20,000	58,966	
Grain sor. - 1	(clay)	161,422	245,765	
Beets	(clay)	220	416	
Pepper	(clay)	700	1,265	
Lettuce	(clay)	200	483	
Onions	(clay)	1,700	3,441	
Sweet corn	(clay)	600	1,293	
Broccoli	(clay)	750	1,355	
Irrigated acreage		771,850	1,609,065	$69,970,482

Table 9. Enterprise combination and water use by crops when the price of water is $18.65 per acre foot

Enterprise		Acreage	Irrigation water use ac. ft.	Net returns to land and management
Snap beans	(loam)	3,000	3,887	
Cotton - 3	(loam)	168,280	582,168	
Grain sor. DL	(loam)	218,167	-0-	
Beets	(loam)	1,200	1,755	
Carrots	(loam)	15,000	18,150	
Green pepper	(loam)	6,500	12,450	
Lettuce	(loam)	3,500	5,232	
Onions	(loam)	17,500	26,162	
Sweet corn	(loam)	3,000	4,442	
Broccoli	(loam)	1,800	2,371	
Potatoes	(loam)	4,000	5,543	
Honeydew melons	(loam)	2,500	3,975	
Cantaloupes	(loam)	15,000	23,850	
Citrus	(loam)	90,000	261,825	
Cotton - 3	(clay)	154,978	346,505	
Citrus	(clay)	20,000	58,966	
Grain sorg. DL	(clay)	161,422	-0-	
Beets	(clay)	220	416	
Pepper	(clay)	700	1,265	
Lettuce	(clay)	200	483	
Onions	(clay)	1,700	3,441	
Sweet corn	(clay)	600	1,293	
Broccoli	(clay)	750	1,355	
Irrigated acreage		610,428	1,363,300	$67,745,441

154,978 acres of clay soils which at lower water prices had been devoted to irrigated cotton is converted to dryland grain sorghum and the irrigated acreage in the area drops to 435,100 with irrigation use declining to 990,120 acre feet (Table 10). The 990,120 acre feet of water used in this combination of enterprises is very close to the average flow of the Rio Grande which is available for irrigation. This points out the possibilities for the transfer of water allotments from use on grain sorghum and cotton on clay soil to enterprises which provide a greater return to water. This transfer by sale of water allotments would increase the efficiency of water use and raise the income of the region.

When the price of water rises to $32.46 per acre foot, irrigated cotton on loam soils is replaced by dryland grain sorghum in the optimum solution (Table 11). At this point irrigated acreage in the Valley declines to 166,820. The model also reveals that only 407,953 acre feet of irrigation water could be profitably used at this price. At this price, citrus is the major user of the irrigated acreage and irrigation water supply, occupying 65 percent of the irrigated acreage and using 78 percent of the water diverted within the basin for irrigation purposes.

The demand for water to irrigate citrus is relatively insensitive to price, within these ranges, with no further change affecting this crop occurring in the optimum solution, until the price of irrigation water reaches $59.48 per acre foot (Table 12). At this point, the use of irrigation water to produce citrus on clay soils becomes unprofitable and this enterprise is dropped from the solution. The demand for irrigation water for citrus on loam soils is even less sensitive to price changes with this enterprise remaining in the

Table 10. Enterprise combination and water use by crops when the price of water is $27.90 per acre foot

Enterprise		Acreage	Irrigation water use ac. ft.	Net returns to land and management
Snap beans	(loam)	3,000	3,887	
Cotton - 3	(loam)	268,280	582,168	
Grain sor. DL	(loam)	237,167	-0-	
Beets	(loam)	1,200	1,755	
Green pepper	(loam)	6,500	12,450	
Lettuce	(loam)	3,500	5,232	
Onions	(loam)	17,500	26,162	
Sweet corn	(loam)	3,000	4,442	
Broccoli	(loam)	1,800	2,371	
Honeydew melons	(loam)	2,500	3,975	
Cantaloupes	(loam)	15,000	23,850	
Citrus	(loam)	90,000	261,825	
Citrus	(clay)	20,000	58,966	
Grain sor. DL	(clay)	317,750	-0-	
Beets	(clay)	220	416	
Pepper	(clay)	700	1,265	
Lettuce	(clay)	200	483	
Onions	(clay)	1,700	3,441	
Irrigated acreage		435,100	990,120	$61,030,112

Table 11. Enterprise combination and water use by crops when the price of water is $32.46 per acre foot

Enterprise		Acreage	Irrigation water use ac. ft.	Net returns to land and management
Snap beans	(loam)	3,000	3,887	
Grain sor. DL	(loam)	505,447	-0-	
Beets	(loam)	1,200	1,755	
Green pepper	(loam)	6,500	12,450	
Lettuce	(loam)	3,500	5,232	
Onions	(loam)	17,500	26,162	
Sweet corn	(loam)	3,000	4,442	
Broccoli	(loam)	1,800	2,371	
Honeydew melons	(loam)	2,500	3,975	
Cantaloupes	(loam)	15,000	23,850	
Citrus	(loam)	90,000	161,825	
Citrus	(clay)	20,000	58,966	
Grain sor. DL	(clay)	217,750	-0-	
Beets	(clay)	220	416	
Pepper	(clay)	700	1,265	
Lettuce	(clay)	200	483	
Onions	(clay)	1,700	3,441	
Irrigated acreage		166,820	407,953	$47,723,531

Table 12. Enterprise combination and water use by crops when the price of water is $59.48 per acre foot

Enterprise		Acreage	Irrigation water use ac. ft.	Net returns to land and management
Grain sor. DL	(loam)	510,247	-0-	
Beets	(loam)	1,200	1,755	
Green pepper	(loam)	6,500	12,250	
Lettuce	(loam)	3,500	5,232	
Onions	(loam)	17,500	26,162	
Sweet corn	(loam)	3,000	4,442	
Honeydew melons	(loam)	2,500	3,975	
Cantaloupes	(loam)	15,000	23,850	
Citrus	(loam)	90,000	259,534	
Grain sor. DL	(clay)	339,870	-0-	
Green pepper	(clay)	700	1,265	
Irrigated acreage		139,900	338,465	$44,489,889

solution until the water price reaches $85.75 per acre foot (Table 13).

A complete schedule of prices, quantities, acreage irrigated and associated net revenues are given in Table 14.

Table 15 shows the upper limit on water price which may not be exceeded, if the various crop enterprises are to remain in the model. Theoretically, a farmer could pay up to this price for water used in the various enterprises.

Changes in Water Release Policies at Falcon Reservoir

An interesting prospect for change in another institutional arrangement, the policy for managing the releases from Falcon Reservoir, was revealed in a review of seasonal water uses (necessary to the foregoing linear programming model). As is shown in Table 16, water price increases cause significant declines in the use of water in the months of May, June and July. This means that a high percentage of the irrigation water presently used in these months is for crops with a relatively low return to water. If releases could be redirected, especially during years of relatively low storage, toward the months of August through December, an improvement in the efficiency of water use could be realized. With negotiable water rights and/or annual allocations, such a redirection of releases would be demanded by users. Without freely exchangeable allotments and rights, the existing water management policy would be difficult to change. Right holders dictate releases by their requests for deliveries within districts. Perhaps a policy for conservation of water in periods of short supply could be implemented by agreement of rights holders and

Table 13. Enterprise combination and water use by crops when the price of water is $85.75 per acre foot

Enterprise		Acreage	Irrigation water use ac. ft.	Net returns to land and management
Grain sor. DL	(loam)	619,447	-0-	
Green pepper	(loam)	6,500	12,200	
Lettuce	(loam)	3,500	5,198	
Onions	(loam)	17,500	26,062	
Honeydew melons	(loam)	2,500	3,925	
Grain sor. DL	(clay)	339,870	-0-	
Green pepper	(clay)	700	1,265	
Irrigated acreage		30,700	49,093	$23,046,446

Table 14. Irrigation water use at various water prices and projected acres irrigated with associated returns

Price ac.ft.	Quantity ac. ft.	Acres irrigated	Net returns to land and management and fixed factors
$ 9.60	1,948,805	990,017	72,642,620
13.54	1,947,224	990,017	72,636,396
17.48	1,609,065	771,850	69,970,482
18.65	1,363,300	610,428	67,745,441
18.76	1,362,000	609,828	67,733,591
23.10	1,343,857	594,828	67,488,458
25.62	1,342,502	594,078	67,466,738
25.91	1,336,625	590,078	67,370,882
27.90	990,120	435,100	61,030,112
32.45	407,953	166,820	47,723,531
32.64	404,065	163,820	47,633,966
35.72	403,649	163,600	47,623,104
35.91	401,278	161,953	47,560,707
42.77	397,837	160,100	47,446,554
47.50	397,432	159,900	47,431,209
59.48	338,465	139,900	44,489,889
63.25	314,615	124,900	43,210,305
68.53	312,672	121,900	43,095,832
72.13	310,917	120,700	42,986,090
85.75	49,093	30,700	23,046,445
76.85	22,930	13,200	20,884,845
96.00	22,930	13,200	20,884,845

Table 15. Upper limit on water prices for enterprises in the linear programming model

Enterprise	Price
Grain sorghum - loam	$17.48
Grain sorghum - clay	18.65
Sweet corn - clay	18.76
Carrots - loam	23.10
Broccoli - clay	25.62
Potatoes - loam	25.91
Cotton - clay	27.90
Cotton - loam	32.45
Snap beans - loam	32.64
Beets - clay	35.72
Broccoli - loam	35.91
Onions - clay	42.77
Lettuce - clay	47.50
Citrus - clay	59.48
Cantaloupes - loam	63.25
Sweet corn - loam	68.53
Beets - loam	72.13
Citrus - loam	76.85
Onions - loam	85.75

Table 16. Water use by months with selected water prices and optimum enterprise combinations

Month	$9.60/ ac.ft.	$17.48/ ac.ft.	$18.65/ ac.ft.	$27.90/ ac.ft.	$32.46/ ac.ft.	$59.48/ ac.ft.	$85.75/ ac.ft.
Jan.	15,048	15,048	15,048	15,048	15,048	11,809	4,112
Feb.	252,071	162,186	115,239	84,420	23,386	20,332	3,410
March	51,963	46,713	46,713	36,787	36,787	31,136	7,990
April	242,630	142,620	58,411	50,653	50,653	42,349	4,959
May	538,740	408,906	312,456	205,862	38,187	33,843	1,685
June	339,494	328,083	309,923	194,495	46,905	38,250	-
July	347,064	347,064	347,064	250,113	44,208	35,625	-
August	67,964	67,964	67,964	67,964	67,964	54,406	10,937
Sept.	19,869	19,869	19,869	19,869	19,869	18,703	-
Oct.	29,133	29,133	29,133	29,133	29,133	22,990	1,448
Nov.	19,037	19,037	19,037	19,037	19,037	14,890	7,350
Dec.	25,785	22,435	22,435	16,769	16,769	14,131	5,532
Total	1,948,805	1,609,065	1,363,300	990,120	470,953	338,465	49,093

users who are informed of the benefits of such a change in policy.

Water Imports and the Demand for Irrigation Water

The above relationship of the price of water to the various uses of water makes possible an evaluation of a prospective water development that would affect the availability of water in the Valley. One of the primary features of the Texas Water Plan is a proposed diversion of water for irrigation from the East Texas Basins into the Rio Grande Valley. Part of this water is scheduled to replace water which is to be diverted from the Rio Grande below Amistad Reservoir into the Winter Garden area, with producers in that area paying the cost of imported water in the Valley. In addition it would provide insurance that presently irrigated acreage would have adequate water in years of low river flow. One of the primary questions which must be answered if an importation plan is undertaken is whether the agricultural economy of the area can produce sufficient returns above the cost of water transfer and thus pay for the imported water.

The results of this study indicate that the quantity of irrigation water demanded at a price of $9.60 per acre foot would be 1,948,805 acre feet. If the price of water were to rise to $17.48 per acre foot, 1,609,065 acre feet could be profitably used by producers within the region; and if the price were to rise further to $18.65 per acre foot, the demand for water for irrigation would fall to 1,363,300 acre feet annually. At any price for irrigation water above this level, it would not be profitable to produce irrigated grain sorghum on either of the two major soil types in the Valley. When the price of water rises to $27.90 the quantity demanded falls to 990,120 acre feet annually, which is approximately the average share of the Rio Grande flow which can be used by U. S. producers for irrigation purposes. This implies that any additional water imported into the Valley must be at a lower cost and selling price than $27.90 to Valley users if such water is to be bought and used within the region, assuming that the average flow of the Rio Grande remains at about its present level. If any significant amount of water is transferred to the area to supplement the flow of the river, the price must be in the neighborhood of $18.65 which is the price at which 1,363,300 acre feet would be demanded. At this price, there could be an annual import of only 373,180 acre feet above the 990,120 level which can be expected to be supplied by normal river flow.

In Figure 2, the various quantities of water which can be profitably used for irrigation purposes in the Valley at various prices are depicted in a value-in-use curve. As such, it represents a "conditional demand curve" which differs from the usual demand function of economic theory in that it does not represent what producers might be <u>willing</u> to purchase at various prices but rather the quantities of water which <u>could</u> be profitably used at these prices. For example, at any water price lower than $17.48 per acre foot, water can be used to irrigate grain sorghum and will give a positive net return. As the price approaches this level, the difference between net returns for dryland and irrigated production narrows. As this occurs, some producers will shift to dryland production whereas the model shows that no shifts will occur until the difference in net returns equals zero. For this

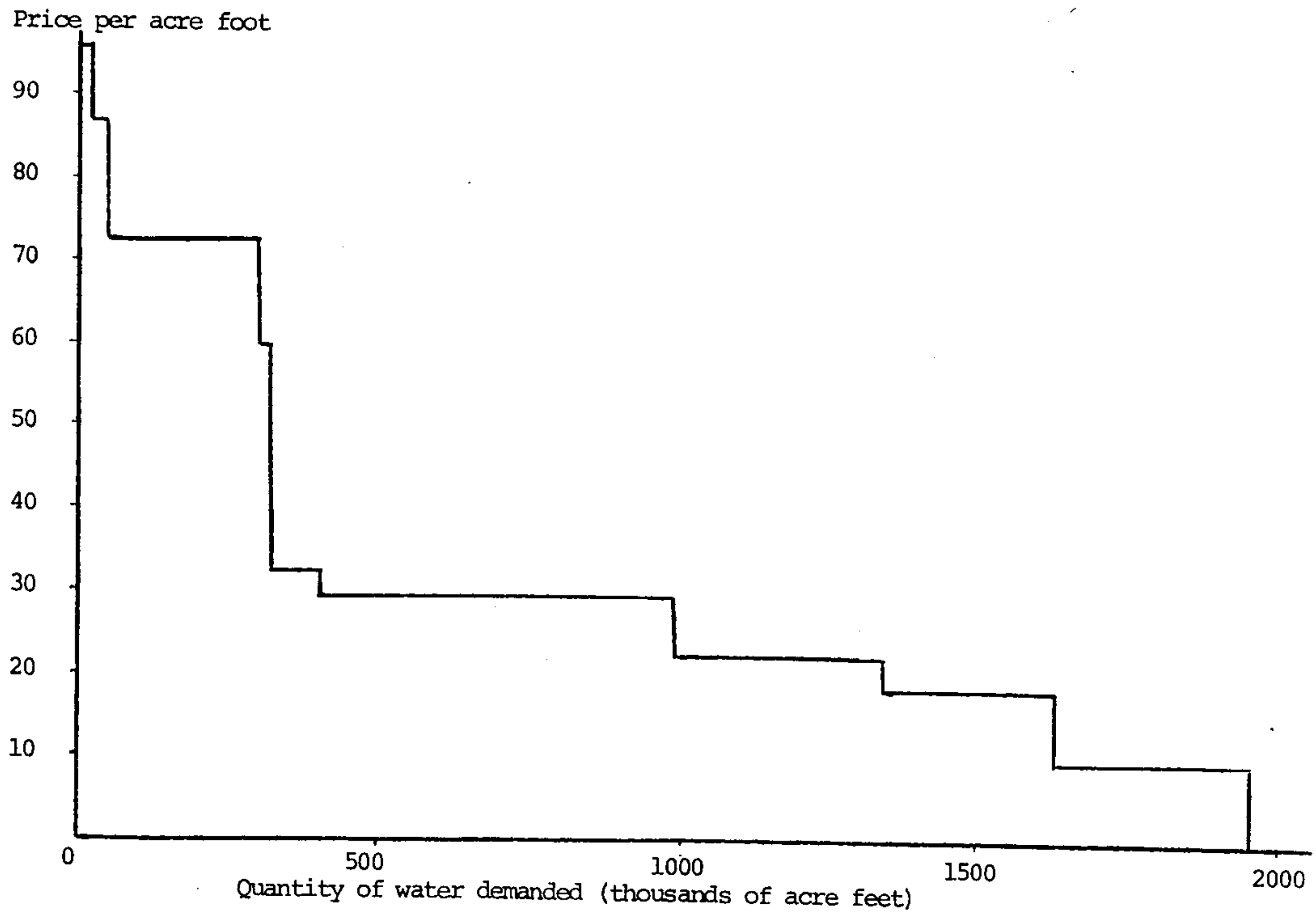

Figure 2. Demand for irrigation water, Rio Grande Basin, Texas

reason, the demand function probably overstates, for any particular price, the quantity of water which could be sold at that price. However, it should be a good approximation of the true demand for this resource.

Often when water transfer plans are formulated, the inverse price-quantity relationships of economic variables have not been considered; and it has been assumed that water use will proceed at a predetermined level so long as water is made available. The failure to consider the economic relationships could lead to serious miscalculations which would encourage construction of uneconomic water transport and distribution facilities. In this case, it is possible that such facilities could not be used and financially supported entirely by their intended primary beneficiaries. In such a case, if the facilities were constructed and utilized, their use would have to be supported by all users of water within the area, possibly through a modified price discrimination system of water pricing.

SECTION V

ANALYSIS OF DISTRICT OPERATIONS

The Water Control and Improvement Districts and Water Improvement Districts which pump and distribute irrigation water to the farmland of the Valley are among the more important institutions affecting water use in the region. Many of the districts have been in operation, in some organizational form or other, since before 1920 and approximately thirty-four are in active operation at the present time.

There are two primary reasons why a study of the operations of these districts seems particularly appropriate at this time. First, it is hypothesized that considerable differences in operational efficiency exist among districts because of variability in size, financial positions, management, physical facilities and services offered to members. With the ever increasing costs of operations, both of the districts themselves and of the farms which the districts serve, it is important to have a better understanding of district structure and organization as these things influence operational efficiencies in water distribution. While much has been written about special purpose districts, their organization and structure, little work has been done in analyzing the operations of these institutions or of their impact on water use and development in the area. Second, with the prospect of the importation of additional water supplies from other basins of origin, it is imperative that there be some political entity representing users in the Valley with the authority to accept and with the ability to pay for such imported waters. It is generally recognized that the State or Federal agency which might import the additional water supply could not deal with thirty-four separate legal entities, nor could it efficiently arrange to deliver this water to thirty-four separate delivery points within the Basin.

The districts in the Valley range in size from 1025 acres to over 72,000 acres. District size averaged 18,410 irrigated acres for the districts analyzed in this study.[3] For purposes of the study, data collected on district characteristics and operations included: (1) number of acres irrigated, (2) acre feet of water pumped, (3) total value of district assets, (4) annual revenue derived from flat rate assessments, (5) annual revenues derived from water deliveries, (6) net district debts, and (7) operations, maintenance, and administrative costs.

Relationships Among District Variables

The data were transformed for X_4, X_6 and X_8 to put them on a per acre basis, and simple correlation coefficients were calculated for each pair of variables. The variables were: (1) Acres irrigated per district, (2) Acre feet of water pumped annually by each district, (3) Total value of district assets, (4) Acre feet pumped per acre irrigated, (5) Percent of operating revenue derived from water deliveries, (6) Per acre value of district assets, (7) a trend variable representing time, and (8) Annual operations,

[3] Data on district operations was available on only twenty-five of the thirty-four districts. Nine of the districts have not been filing annual audits with state agencies.

maintenance, and administrative costs per acre. Table No. 17 is a matrix of the simple correlation values.

While it is realized that simple correlation coefficients reflect the degree of interrelationship only between the two variables involved, with the influence of all other variables being ignored, there were several enlightening relationships revealed by this analysis. In the case of the correlation between cost per acre and all other variables, the variable showing the greatest degree of relationship with this average cost was size of district. There was, as would be expected, a very high degree of correlation between district size, acre feet pumped, and total asset value of the district. However, when the correlations between size and asset value per acre, and quantity of water pumped and asset value per acre were computed, they did not vary significantly from zero. This would indicate, assuming that value of district assets per acre can be taken as a measure of the physical conditions of the district facilities, that there is very little difference in the physical condition of facilities among districts of various sizes. The simple correlation value of .09 between value of assets per acre and cost per acre would indicate also that there is very little relation between district physical condition and annual average costs. The positive correlation between acres irrigated and percent revenue derived from water sales indicates that the larger districts depend to a higher degree than do small districts upon deliveries of water than on flat rate assessments to finance district maintenance, operation and administrative costs. It is also interesting to note that there was a significant positive correlation between acre feet per acre

Table 17. Simple correlations (r) among variables associated with water control and improvement districts in the valley

		Acres irrig. X_1	Ac.ft. pumped X_2	Total assets X_3	Ac.ft/ acre X_4	% revenue derived from water del. X_5	Assets/ acre X_6	Years X_7	Per acre/ cost Y
Acres irrigated	X_1	-1.00	.96**	.62**	- .15	.38*	.08	- .08	- .50**
Acre feet pumped	X_2		1.00	.55**	.07	.44**	.02	- .07	- .44**
Total assets	X_3			1.00	- .19	.22*	.71**	.02	- .28**
Acre feet/acre	X_4				1.00	.27*	- .18	.05	.33**
% revenue derived from water del.	X_5					1.00	- .06	.08	- .13
Assets/acre	X_6						1.00	.03	.09
Years	X_7							1.00	.15
Cost/acre	Y								1.00

*Significant at $\alpha = .01$ level

**Significant at $\alpha = .05$ level

pumped and percent revenue derived from water sales. This would indicate that the districts which supply farms producing a higher proportion of crops which require large amounts of water annually (usually vegetables and citrus) are able to depend more on water sales for revenues.

The "years" variable which was included in an attempt to discover any trends in district operating policies or costs of operation yielded a non-significant correlation with every variable. It was interesting to note the negative signs on the correlations between acre irrigated, acre feet pumped and years even though these correlation coefficient values were not significant. The years included in the study were 1966 through 1969. The negative correlations between the above variables shows the influence of Hurricane Beulah in the 1968 crop year which substantially lowered the demand for irrigation water in that crop year.

Economies of Size in District Operations

In order to further study the effect of district size on operation costs, a multiple regression model was used to test the hypothesis that there are economies of size in district operations. The model was of the form

$$(3.1) \qquad Y = \alpha + B_1X_1 + B_2X_1^2 + B_3X_2 + B_4X_3$$

where

Y = Annual operations, maintenance, and administrative costs per acre

X_1 = Size of district in acres

X_2 = Acre feet pumped per acre irrigated

X_3 = Percent operating revenue derived from water deliveries.

When the model was fitted to the data, it yielded the equation:[4]

$$\hat{Y} = 11.7090 - .0003535\, X_1 + .000000004173\, X_1^2$$
$$(4.452)^{**} \qquad (3.209)^{**}$$

(3.2)

$$+ 1.8018\, X_2 - 1.4848\, X_3$$
$$(1.077)^{*} \qquad (0.489)$$

The F value for the equation was 13.085 which was significant at the α = .01 level. The correlation coefficient (R^2) was .395. This would indicate acceptance of the hypothesis that there are economies within certain size ranges associated with district size. The t values, of the regression coefficients for X_1 and X_1^2 reveals that both variables are significant at the α = .01 level and the signs of these coefficients would indicate, for the range of the data, the U shaped average cost curve from economic theory. The fact that the coefficient for acre feet per acre was both positive and significant (at α = .05) while the cost per acre was decreasing with district size up to about 40,000 acres would indicate that the smaller districts were supplying a greater quantity of water per acre irrigated. This analysis tends to substantiate the interpretation of the simple correlation value of -.15 in Table 6 which relates size of district and quantity of water pumped per acre.

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[4]For this and other regression equations in this study, the figures in parentheses are values of the t statistic for the respective coefficients. Two astericks indicate significance at the α = .01 level while one asterick indicates significance at the α = .05 level.

This could explain why farmers whose holdings are located in the smaller districts might be reluctant to see district consolidation or reorganization.

In order to determine the lowest point on the derived average cost curve, the regression equation can be differentiated with respect to size (X_1). This yields the equation,

$$(3.3) \qquad \frac{\sigma \hat{Y}}{\sigma X_1} = .000000008346 \; X_1 - .0003535$$

which, when set equal to 0 shows (given the district average cost curve as derived from the regression equation) that the most economical size of district is 42,355 acres, this being the low point on the district average cost curve.

Acceptance of the hypothesis that there are economies of size present in district operations makes one wonder why these economies have not been recognized and taken advantage of by consolidation and reorganization of the Valley districts. A look at the absolute magnitude of the change in district operating costs when district size varies helps in understanding why these possible economies have not generated enthusiasm for district reorganization. For example, a 10,000 acre district has a projected operating cost of \$10.73 per irrigated acre. The annual operating cost would be \$8.45 for a 20,000 acre district, \$6.64 for a 30,000 acre district, \$6.38 for a 40,000 acre district, and would climb back up to \$7.76 for a district with 50,000 acres. These calculations assume that all districts supply the same quantity of water per acre each year (1.61 acre feet), and that there is no difference in the district pricing policies, i.e., all districts derive 51 percent of their operating revenues from water deliveries.

This reveals that there is only $4.35 per acre difference in average annual cost between a district of 10,000 acres and one of 40,000 acres in size. Therefore, it would seem that the economies associated with reorganization or consolidation of existing water supply districts, while statistically significant, are relatively small when compared with all other farm operating costs. This is probably another reason for lack of interest in any plan for district reorganization or consolidation on the part of farm owners and operators.

Another major question concerning district reorganization and the increase in district size which is not analyzed in this study but which is important, is centered around the question of centralized versus decentralized control of district operations. With the present number of districts operating in the area, approximately 170 farm operators participate, as district directors, in the policy decisions of the Valley districts. Any consolidation or reorganization plan which would reduce the number of districts would also reduce the number of people on district governing boards and thus lead to a centralization of power in operation of the districts. There would probably be considerable opposition within the area to such a reorganization scheme for this reason.

A technical problem associated with reorganization of districts centers around the topography of the region and the physical layout of present districts. Since the irrigated lands of the Valley generally slope away from the river, the majority of the Valley districts have main canals running from the south to the north, at right angles to the river. These main canals have been sized and constructed with the express purpose of serving the lands in the present districts. In some cases, consolidation of districts could mean that an entire reorganization of district water distribution facilities would be necessary. However, if rehabilitation of existing facilities is being considered, this problem could be overcome at the time rehabilitation was carried out in the districts involved.

A study of the averages of the district operating data yields several interesting facts. For the years covered by this study, these averages are shown in Table 18. One of the statistics is particularly interesting in light of the recent water rights adjudication case in the Valley. This decision set a limit of 2.5 feet of irrigation water annually per irrigated acre. The average quantity of water actually pumped per irrigated acre for the period of the study was 1.61 acre feet per acre irrigated, well below the 2.5 acre feet limit set by the Court. The average operation, maintenance and administrative cost per acre for pumping and distributing water to the Valley lands was $9.97 per acre annually. The cost per acre foot of water pumped was $6.47. These costs do not, of course, include system construction costs as these are financed by ad valorem taxes assessed and collected by the districts.

Feasibility of System Rehabilitation

In the study by Casbeer and Trock it was suggested that rehabilitation of districts in the three-county area will be necessary to improve the efficiency of distribution systems. This suggestion was studied by calculation of benefits and costs for rehabilitation. In order to determine the benefits which could be

Table 18. Averages of data of valley water control and improvement districts

1. Acres irrigated per district	18,410
2. Acre feet of water pumped	28,351
3. Total value of district assets	$3,443,326
4. Acre feet pumped per acre irrigated	1.61
5. Percent district revenue from water deliveries	51.4
6. Assets per acre	$176.96
7. Cost per acre irrigated per year*	$ 9.97
8. Cost per acre foot of water pumped*	$ 6.47

*Includes operation, maintenance, and administrative costs.

expected to accrue to rehabilitation of the existing delivery systems in the Valley, it was necessary to analyze the regional system both "with" and "without" rehabilitation. For this study, five separate levels of rehabilitation were analyzed. The acreage irrigated and the quantity of irrigation water used at various prices, as determined by the linear programming model, were selected for the "with" rehabilitation, or efficient system conditions. For the "without" rehabilitation conditions, the quantities of water were limited at the various prices. This limit was determined by multiplying a water loss coefficient of 0.507 acre feet per acre irrigated times the acreage irrigated in the "with" model and subtracting this quantity of water from the water used in the "with" model at various prices. The model was then re-run, with the limited water supply and the various water prices. The difference in the value of the objective function between the "with" and "without" rehabilitation models was taken as undiscounted annual benefits to system rehabilitation. These undiscounted benefits for the five levels of rehabilitation are shown in Table 19.

The actual average cost of system rehabilitation for the four districts in the Valley which have been rehabilitated with the assistance of the U. S. Bureau of Reclamation was $166.00 per acre. This figure was assumed to be representative of costs for the rest of the Valley districts and was used as rehabilitation costs for this study.

For this analysis, the expected life of the rehabilitated system was assumed to be forty years. The annual benefits were discounted, using rates of 5 and 7-1/2 percent. These two rates correspond roughly to the rate presently used by Federal Agencies

Table 19. Returns to land and management with and without rehabilitation of district distribution facilities

Level	Acres irrig.	Returns to land and management w/rehabilitation	Returns to land and management w/o rehabilitation	Annual undiscounted benefits
1	990,017	$72,642,620		$ 4,140,613
	665,316		$68,502,007	
2	771,850	$69,970,482		$14,374,333
	536,905		$55,596,149	
3	610,428	$67,745,689		$15,090,013
	463,588		$52,655,676	
4	435,100	$61,030,112		$19,123,531
	333,443		$41,906,581	
5	166,820	$47,723,531		$11,434,420
	130,410		$36,289,111	

in project evaluation and to the current prime rate of interest. It was interesting to note that although the use of the higher rate lowered the absolute magnitude of benefits, it would never, at any level of rehabilitation, have changed the decision as to whether or not rehabilitation would have been economically feasible.

The results of the analysis are summarized in Table 20. They are particularly interesting in several respects. First, as might be expected, rehabilitation of distribution facilities to provide water for the entire irrigable acreage of the area (Level 1) did not prove economically feasible, i.e., the present value of the benefits was exceeded by cost of rehabilitation. This resulted in benefit cost ratios of 0.43:1 and 0.32:1 for the two discount rates used. This would indicate that system rehabilitation, even at the lower discount rate, would cause a loss of $94.40 per irrigated acre during the 40 year life of the project. The reason for the low value of rehabilitation is that with these high quantities of water and acreage irrigated, the water saved by rehabilitation is used on a crop (grain sorghum) which shows a low return to the application of irrigation water.

Results of this study indicate that there is no one optimum level at which to carry out rehabilitation of water distribution facilities in the Valley. If the decision maker wishes to maximize the benefit-cost ratio or the net benefits per acre, these decision variables are maximized at level five where irrigated acreage involved is only 166,820 acres. If return to investment in rehabilitation is the variable to be maximized, the optimum level is at 435,100 acres or level 4. At this point the present value of net benefits is at a maximum. Another decision which could be made might be to

Table 20. Benefits and costs associated with rehabilitation of valley irrigation districts at 0.507 acre feet of water saved per irrigated acre for selected levels of water use

Acres irrig. (level)	Acre ft. of water used	Cost of rehabil. @ $166/ac.	Present value benefits[a] discounted 5%	Present value benefits[a] discounted 7 1-2%	Net benefits	
					5%	7 1/2%
990,017[b]	1,948,805[b]	$164,432,822	$ 70,877,544	$ 52,022,628	-$ 93,465,278	-$112,320,194
665,316[c]	1,446,866[c]					
771,850[b]	1,609,065[b]	128,127,100	246,650,420	181,036,223	118,523,320	52,909,123
536,905[c]	1,217,738[c]					
610,428[b]	1,363,300[b]	101,331,048	258,930,835	190,049,789	157,599,787	88,718,741
463,588[c]	1,053,813[c]					
435,100[b]	990,120[b]	72,226,600	328,142,318	240,849,563	255,915,718	168,622,963
333,443[c]	769,524[c]					
166,820[b]	407,953[b]	27,692,120	196,204,199	144,009,757	168,512,079	116,317,637
130,410[c]	323,376[c]					

Table 20. (Continued)

Net benefits per irrigated acre		Benefit/cost ratio		Returns to land and management with rehabil.	Water price ac.ft.
		5%	7 1/2%		
-$ 94.40	-$113.45	0.43:1	0.32:1	$72,642,620	$ 9.60
153.56	68.55	1.92:1	1.41:1	69,970,482	17.48
258.17	145.34	2.55:1	1.87:1	67,745,689	18.65
588.17	387.55	4.54:1	3.33:1	61,030,112	27.90
1,010.14	697.26	7.08:1	5.20:1	47,723,531	32.46
					59.48

[a]Present value of benefits based on estimated 40 year useful life of district facilities.

[b]With rehabilitation.

[c]Without rehabilitation.

maximize regional net returns to land and management, with the constraint that the present value of net benefits must be positive. The level of rehabilitation which would maximize this variable is level two at which 771,850 acres would be rehabilitated.

As is shown in this analysis, rehabilitation of the Valley water distribution system is projected to be economically feasible up to at least the presently irrigated acreage. The procedure utilized in this section will allow the decision maker to choose any one or a combination of variables to consider in reaching a decision on the level of rehabilitation would come nearer to achieving program objectives.

Effects of System Rehabilitation on Operating Costs

To determine the influence of system rehabilitation on district operating costs, the regression model was modified to include a "dummy" variable representing rehabilitated versus non-rehabilitated districts. The districts which had been rehabilitated were coded with a value of 1 while the non-rehabilitated districts were coded with a 0.

The model was of the form:

$$Y = \alpha + B_1X_1 + B_2X_1^2 + B_3X_2 + B_4X_3 + B_5X_4 \tag{3.4}$$

Where Y, X_1, X_2, and X_3 were defined as in equation 3.1 and X_4 the "dummy" variable representing rehabilitation.

This regression yielded the equation

$$\hat{Y} = 11.6762 - .0003615\ X_1 + .000000004252\ X_1^2$$
$$(-4.408)^{**} \qquad (3.22)^{**}$$
$$+ 1.7592\ X_2 - 1.2110\ X_3 + .5515\ X_4$$
$$(2.004)^{*} \qquad (0.388) \qquad (0.423)$$

The regression gave an F value of 10.39 and an R^2 of .396. The t value of 0.423 for the dummy variable representing rehabilitation of district facilities plus the fact that inclusion of this variable raised the R^2 for the equation by only .001 indicates that it is impossible to relate a lowering of operational costs to rehabilitation of district facilities from an analysis of the data available for this study. There may be several reasons for the lack of difference in costs as determined by this study: (1) the districts which have been recently rehabilitated and have more efficient facilities may be carrying out a continual maintenance program on their facilities. These costs would appear in their annual audits while the districts with older, less efficient facilities might be postponing maintenance programs until such time that a major overhaul of facilities might be necessary. In this case, the relatively short time period of this study might have meant that these costs were missed for these districts, and (2) it is possible that the rehabilitated districts are providing a higher degree of service to their water users than that provided by the non-rehabilitated districts. This, too, would tend to raise their per acre delivery costs to their water users.

SECTION VI

SUMMARY AND CONCLUSIONS

Summary

There are several problems which must be faced by water users in the Lower Rio Grande Valley if it is to continue to prosper and remain one of the economically important irrigated areas of the State. Among these are periodic water shortages, inefficient use of available water supplies and drainage problems associated with floodwater disposal and salinity of area soil. Institutional factors have contributed to these problems in some cases and in others have acted as obstacles to their solution. If these institutions are to be altered so as to facilitate problem solution, it becomes increasingly important that people have a better understanding of the ways in which these institutions affect water use.

A major feature of this study was the analysis of water use and cropping patterns with negotiable water rights and/or annual allocations of water. It was recognized that market exchanges would affect water prices and water use. It was found that up to a price of $17.48 per acre foot, water could be profitably used in all crops presently irrigated in the Region and that 1,609,065 acre feet of irrigation water could profitably be used by producers in the Valley. At a price higher than $18.65 the irrigation of grain sorghum becomes unprofitable and at this price, irrigation water use could drop to about 1,363,300 acre feet annually. At a

Districts) on the distribution and use of water; to determine whether the particular ways in which these districts are organized and functioned may cause them to act as facilitating or obstructing elements in the efficient development and management of water resources in the Lower Rio Grande Basin.

First, simple correlation coefficients were developed between cost per acre irrigated, size of district, acre feet of water pumped, total assets of districts, percent revenue derived from water deliveries, acre feet pumped per acre irrigated and years. The highest correlation between cost per acre irrigated and any other variable was with size of district, indicating possible economies of size in district operations. Another significant correlation was found between size of district and acre feet pumped per acre irrigated, in this case the correlation was negative, indicating that the smaller districts are pumping more water per irrigated acre than are the larger districts. The lowest correlation was between cost per acre irrigated and per acre asset value of the districts. This would indicate that this variable has little influence on operating costs of the districts;and if asset value is taken as a proxy for the physical condition of district facilities, one can conclude that benefits from system rehabilitation must be realized in some other way than in their role of influencing district operating costs.

To test the hypothesis of economies of size in district operations, a regression model was fitted to the data using cost per acre irrigated as the dependent variable, and size of district in acres, acres in district squared, acre feet pumped per acre irrigated, and percent revenue derived from water sales. The F value of this equation was highly significant and the t values on acres, acres squared, and acre feet per acre were significant. Therefore, it was concluded that there are economies of size associated with district operations and that the optimum district size from the standpoint of lowest operating cost is a district of about 43,000 acres. Acceptance of the hypothesis prompts a question about why these economies of size have not been recognized and then realized by district reorganization and consolidation. A look at the magnitudes of the cost savings involved seems to point out why this has not been done. When the regression equation was used to calculate operating costs for various size districts, it was found that the cost per acre irrigated for a district with 20,000 acres was $8.45 while the cost was $6.40 for a district of 40,000 acres. This is a saving of only $2.05 annually per acre irrigated. This difference in operating costs has apparently not been great enough to encourage district members to attempt changes in district organization and structure.

The economic feasibility of rehabilitation of physical facilities of water supply districts was studied because of the prospects for improvement of efficiency in water distribution. It was found that to carry rehabilitation to the level of 771,850 acres, which is approximately the presently irrigated acreage in the area, the benefit/cost ratio would be 1.92 to 1 at a five percent discount rate and 1.41 to 1 at 7.5 percent discount rate. At a level of 990,017 acres, however, the benefit/cost ratios decline to 0.43 to 1 and 0.32 to 1 respectively. This would indicate that it would not pay to rehabilitate distribution facilities to this level because of the low net returns to the crops irrigated with the water saved by rehabilitation. It was also found that if the decision is to maximize return to investment in rehabilitation, the optimum level of rehabilitation is at the 435,000 acre level, where the present value of discounted benefits is $328,142,318.00 at the 5 percent discount rate and $246,849,563.00 at the 7.5 percent discount rate.

Conclusions

Several conclusions with important implications for water use in the Rio Grande Basin can be drawn from this study:

1. Given the present and expected supply of irrigation water available from the Rio Grande, the efficiency of water use and hence net income to the area can be increased by making water rights or annual water allocation freely negotiable.

2. With market exchanges of rights and/or allocations and the presently expected water supply, there could be changes in cropping patterns and enterprise combinations that would virtually eliminate the use of irrigation water to produce grain sorghum. In this case it could be expected that the water released from use on grain sorghum would be used for the production of cotton and for more intensive irrigation of citrus, especially during years of low river flow.

3. If water is to be imported into the area from the East Texas Basins to supplement the flow of the Rio Grande, the price of imported water must be below $18.65 if it is to be profitably used by Valley producers.

4. There is very little likelihood that area producers will

be encouraged to radically change the organization or structure of existing water supply districts in the Valley for several reasons. First, the economies of size which could be realized by district consolidation and reorganization are not large enough to encourage changes in this institution. Second, the physical layout of the districts and the orientation of their facilities to the river would make consolidation very expensive in terms of initial investment for many districts. Third, there are tremendous differences in condition of facilities, size of debts, and level of taxes among districts, which would make arrangements for consolidation very difficult. Fourth, the present organizational structure of the water districts allows approximately 170 producers to be active as directors in the operation and policy of the water districts. Any reorganization or consolidation of districts would reduce the number of local producers who can serve as directors and would tend to centralize control of this Valley institution.

5. Rehabilitation of water distribution districts is economically feasible, at least for the irrigated acreage now within districts. A lower level of rehabilitation, 435,100 acres, would maximize the investment in rehabilitation while a still lower level, 166,000 acres, would maximize the benefit/cost ratio and the return per acre of land rehabilitated. Such a low level of rehabilitation, however, would not allow full use of the river flow, would not be compatible with the present water rights systems of the Valley, and would actually lower the net returns to the region. Therefore, one would not expect this to be a feasible alternative.

Limitations and Need for Further Study

This study, like most, is subject to several limitations. While the study of water supply districts sheds considerable light on district operations, an analysis of the data available from district audits and annual reports did not contribute very much to an understanding of several important facets of district operation. For instance, many services can be provided by a district with modern, efficient facilities and management which could not be provided by districts with less modern and efficient facilities. Such a district can provide more timely delivery of water than other districts,but this does not show up as added efficiency in any analysis of per acre or per acre foot delivery cost. Another problem lies in the way in which district audits are conducted. Some districts report certain costs as annual operating expenses while others report the same costs as capital investment. A third problem with this part of the study is associated with the short time period of the analysis. Some districts appear to carry out only enough annual maintenance to continue operation and depend on occasional heavier outlays to maintain their systems. In a short term study, these outlays may not be isolated as annual operating and maintenance costs. Some of these maintenance costs were probably not accounted for in this study because of the relatively short period for which data were available.

Because the Water Control and Improvement Districts which pump and distribute irrigation water in the Valley play an important role in water management and use in the area, it would be desirable to have additional information about them. The most practical way to get it, given the problem of securing meaningful data from thirty-four separate and independent entitities, would probably be through the use of a case study approach, whereby selected district operations could be studied in depth, appraised and compared.

The phases of the study associated with derivation of demand for irrigation water and the analysis of rehabilitation are subject to the usual problems associated with the assumptions underlying the use of linear programming.

It should be remembered that each enterprise combination for various water prices is an "optimum" combination as determined by the model and is not likely to be carried out exactly in that way by producers in the Valley.

Another limitation of this study results from the subjective method used to determine marketing limits on vegetable and citrus crops. There remains a great need for price analysis and marketing improvement studies for these area crops.

Finally, there is a need for continuing reseach and refinement of crop budgets to keep abreast of changes in technology, input and output prices and relative returns from alternative enterprises.

This study has been an attempt to conduct an in-depth analysis of two of the more important institutions which affect water use and management in the Rio Grande Valley. The study has led to recommendations for change that should improve the efficiency of use of the scarce resource, water. But institutions do not change easily. The likely impacts of change must be well known and the effects must be positive and significant if the change in institutions is to be seriously considered. The need for research to identify and evaluate the impact of institutional factors which influence water development and use will continue to be of critical importance if the Rio Grande Basin is to continue to prosper as an important agricultural area.

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