Economic Analysis

Interindustry Effects of a Declining Groundwater Supply

Southern High Plains of Texas

THE TEXAS AGRICULTURAL EXPERIMENT STATION / J. E. Miller, Director, College Station, Texas / Texas A&M University

Contents

Summary

The adjustments in the economy of a 56-county area in the Texas High Plains resulting from the depletion of groundwater used for irrigation in the Southern High Plains were determined.

The evaluation of economic adjustments was based on the results of an earlier linear programing study which estimated effects on producers for each year from 1966 through 2015 and on an interindustry study for the study area. The years 1967, 1970, 1980, 1990, 2000, 2010 and 2015 were selected for the study. The expenditures for inputs from the linear programing study were delineated to be comparable to the economic sectors for the interindustry model. The interindustry model had 14 processing sectors, four final payments sectors and seven final demand sectors.

Agricultural production was maintained at the 1967 level for 35 of the 56 counties in the study area. The effects of the depleting groundwater in the remaining 21 counties in the study area were determined. The study area contained 9.6 million acres of crops. The number of irrigated acres declined from 5.7 million acres in 1967 to 2.4 million acres in 2015. The value of all crop production was estimated to decrease by 39.9 percent from 1967 to 2015.

Direct benefits associated with irrigation were $433.5 million in 1967, which were 68 percent of the total output of the Irrigated Crops Sector and 55.7 percent of total output of all crops. Indirect benefits decreased from $776.7 million in 1967 to $301.5 million in 2015. Stemming-from benefits were $536.5 million in 1967 and decreased by 35.8 percent from 1967 to 2015. The ratio of direct benefits to total benefits from irrigation was 4.03 in 1967. This means that an increase of $1 in direct benefits (net output associated with irrigation) would generate $4.03 in economic activity for all processing.

Economic Analysis

Interindustry Effects of a Declining Groundwater Supply

Southern High Plains of Texas

J. E. Osborn and T. R. Harris*

Economic growth and development in the Texas High Plains have been primarily based on natural resources such as fossil fuel and groundwater. These resources are exhaustible and nonrenewable. If the region cannot conceive and implement proposals to reverse the economic consequences of the declining resources, the area will face diminishing economic growth.

Groundwater is the major source of water for irrigation in the Texas High Plains. The groundwater aquifer is isolated from major sources of recharge. Gross pumpage for production of food and fiber has exceeded recharge to the aquifer in recent years. The effects of the imbalance between withdrawal and recharge to the aquifer are resulting in the depletion and ultimate exhaustion of the aquifer in the foreseeable future.

Irrigated production, in contrast to dryland production on similar acreages, results in greater per acre yields. Irrigated cotton yields in the Texas High Plains are approximately twice as high as yields of dryland cotton on similar acres. Irrigation and complementary resources have resulted in approximately six times more output than production under dryland conditions for grain sorghum, and irrigated wheat yields are usually three times the level of production under dryland in the Texas High Plains (5). In addition to increasing yields, irrigation, as opposed to dryland production, tends to stabilize production from year to year.

*Respectively, professor, Department of Agricultural Economics, Texas Tech University and Texas A&M University—Texas Tech University Cooperative Research Unit, Lubbock; and research assistant, Texas A&M University—Texas Tech University Cooperative Research Unit, Lubbock.

The benefits from irrigation are dispersed throughout the economic activity in the region. With increased incomes, producers will purchase additional resources that are complementary to irrigation in the production of food and fiber. Irrigated production has been a basis for increased aggregate demand and supply of the region and has provided an incentive for regional economic growth.

Returning to dryland production of food and fiber will result in significant declines in production and increased variation in production from year to year. As dryland production becomes the major technique for producing food and fiber, the demand for agricultural inputs complementary to irrigated production will diminish, and total sales by agricultural input suppliers will decrease. Reduced sales by agricultural input suppliers will lower their realized net revenues. Declining net incomes for agricultural producers and agricultural input suppliers will result in reduced purchases by these sectors of nonagricultural goods and services. This will create lower trade activity in the region between public and/or industrial consumers and industrial suppliers and adversely affect regional economic growth. In short, the ultimate economic effects on the Texas High Plains economy of a shift from irrigated to dryland production will affect a number of sectors directly and indirectly related to agriculture.

Interindustry relationships between different industrial sectors and agriculture can be depicted through interindustry analysis. The relationships that are estimated through an interindustry analysis can be used to

evaluate the impact on the regional economy of the declining groundwater resource in the Southern High Plains of Texas.

Objectives

The overall objective of this study was to determine the adjustments in the economy of the Texas High Plains resulting from the depletion of groundwater used for irrigation in the Southern High Plains. The specific objectives were

A. To assemble information concerning the rate of groundwater depletion of the Ogallala formation in the Southern High Plains of Texas.

B. To determine the economic adjustments required to cope with the declining groundwater resource in the Southern High Plains in the agricultural producing, processing and input supply sectors of the Texas High Plains economy.

C. To determine economic adjustments in nonagricultural sectors in the Texas High Plains economy necessitated by the declining groundwater resource in the Southern High Plains.

Study Area

The study area included 56 counties in West and Northwest Texas (Region 2 in Figure 1) containing 59,768 square miles and a population of 960,479 in 1970 (17). The four Standard Metropolitan Statistical Areas (Amarillo, Lubbock, Midland and Odessa) in the study area had a total population of 408,929 (50.1 per-

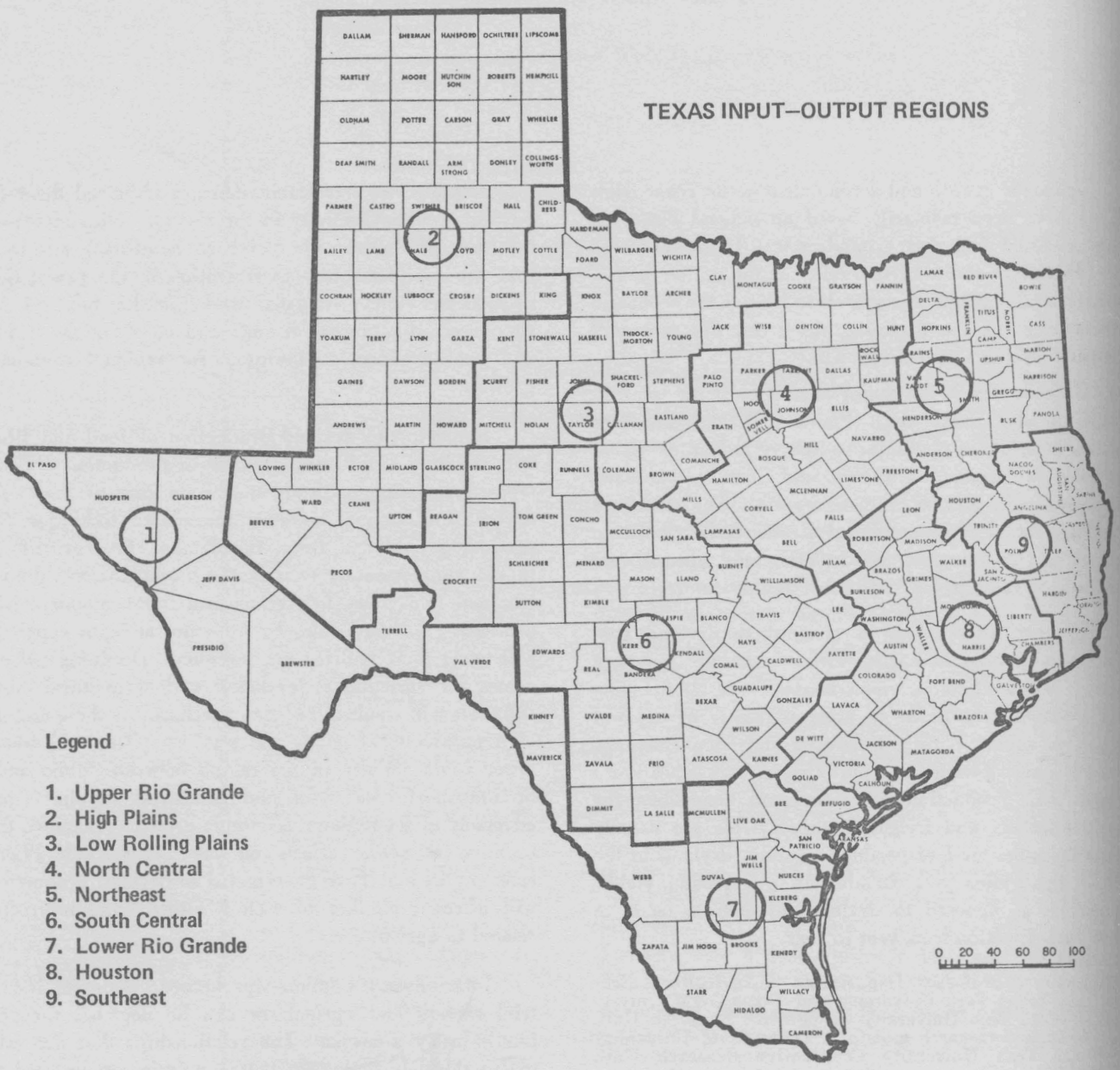

Figure 1. Texas input-output regions; study area includes the 56 counties of region 2.

TABLE 1. IRRIGATED AND DRYLAND CROP ACREAGE IN SUBAREA A COMPARED TO TOTAL STUDY AREA, TEXAS HIGH PLAINS, 1970

Item	Irrigated acres harvested			Dryland acres harvested		
	Study area	Subarea A	Percent in subarea A	Study area	Subarea A	Percent in subarea A
Cotton	1,485,280	1,172,830	79.0	880,050	376,600	42.8
Wheat	532,750	245,750	46.1	734,850	248,680	33.8
Grain sorghum	1,640,800	1,157,800	70.6	1,237,400	665,800	53.8
Total	3,658,830	2,576,380	70.4	7,852,300	1,291,080	45.2

Source: (16).

cent of the area population) in 1970 residing in five counties (17).

The topography of the area is nearly level with occasional "breaks." Elevation ranges from 2,500 feet in the southern counties to 4,000 feet in the northern counties (3). The length of the growing season ranges from 178 days in Dallam County to 226 days in Reeves County. Soil types range from coarse-textured soils in the southern area to fine-textured soils in the northern area. Average annual rainfall is less than 21 inches and as low as 8 inches in the southern counties (3).

The major industries are agriculture, manufacturing, petroleum and trade. Extensive petroleum production is in the southern portion of the area. Manufacturing and trade industries are centered in Amarillo, Lubbock, Midland and Odessa. Agricultural activity is located principally in the northern two-thirds of the area.

The total value of all agricultural products sold in the study area in 1970 was $1.0 billion (16). Crops accounted for 48.2 percent of the agricultural items; cotton and grain sorghum were grown extensively in the southern regions. Further north the growing season is shorter, and the soil type changes from coarse-textured soils in the south to fine-textured soils in the north. The conditions in the extreme northern part of the region restrict cotton production—major crops are grain sorghum and wheat.

Livestock ranches are located throughout the study area. Cattle feeding operations have developed in recent years. In 1970, 2.3 million cattle were marketed from feedlots (16). A 21-county area (Subarea A)[1] within the study area includes approximately 6.9 million acres and accounts for a large portion of the agricultural production in the region (Figure 2). However, agricultural production in Subarea A is highly dependent upon groundwater from a declining aquifer.

The majority of irrigated acres in the study area are in Subarea A, and a majority of receipts from the farm marketing and government payments are received from activity in Subarea A (Tables 1 and 2). Total cash receipts from marketing and government payments in the study area were $1.3 billion of which 64.6 percent or $867.2 million were received in Subarea A (16). Also, Subarea A accounted for 79 percent of irrigated cotton acres, 46.1 percent of irrigated wheat acres and 70.6 percent of irrigated grain sorghum acres harvested.

Hughes and Harman (8) estimated the aggregate adjustments by agricultural producers to the declining groundwater resource in Subarea A.[2] To estimate the impact of declining groundwater supplies on the agricultural producers, Subarea A was delineated into 80 hydrological subareas to reflect groundwater conditions. Linear programing was used to determine the annual withdrawal of groundwater from 1966 to 2015. As areas were dewatered, the irrigated land was returned to dryland conditions.

Hughes and Harman (8) provided estimates of the effects of declining groundwater supplies on the agricultural industry. However, nonagricultural sectors also receive benefits from irrigated agriculture.

Since interindustry analysis (input-output) is an appropriate technique for use in evaluating the nonagricultural effects of the declining resource, the results of the linear programing study were delineated into economic sectors which were comparable to the sectors for the interindustry model. The interindustry effects were estimated for the declining groundwater resource for 1967, 1970, 1980, 1990, 2000, 2010 and 2015 by use of the interindustry model.

[1]The 21-county area will be denoted as Subarea A; the remaining counties of the study will be referred to as Subarea B.

[2]A linear programing analysis of the 21-county area was not part of this study; however, results and procedures of the linear programing study were sufficiently important to warrant discussion.

TABLE 2. CASH RECEIPTS IN STUDY AREA AND SUBAREA A, TEXAS HIGH PLAINS, 1970

Item	Study area	Subarea A	Percent in subarea A
	— ($1,000,000) —		
All crops	502.8	341.7	68.0
Livestock and livestock products	540.0	326.2	60.4
Total crops and livestock	1,042.8	667.9	60.5
Government payments	303.6	199.2	65.6
Total farm marketing and government payments	1,346.4	867.2	64.4

Source: (16).

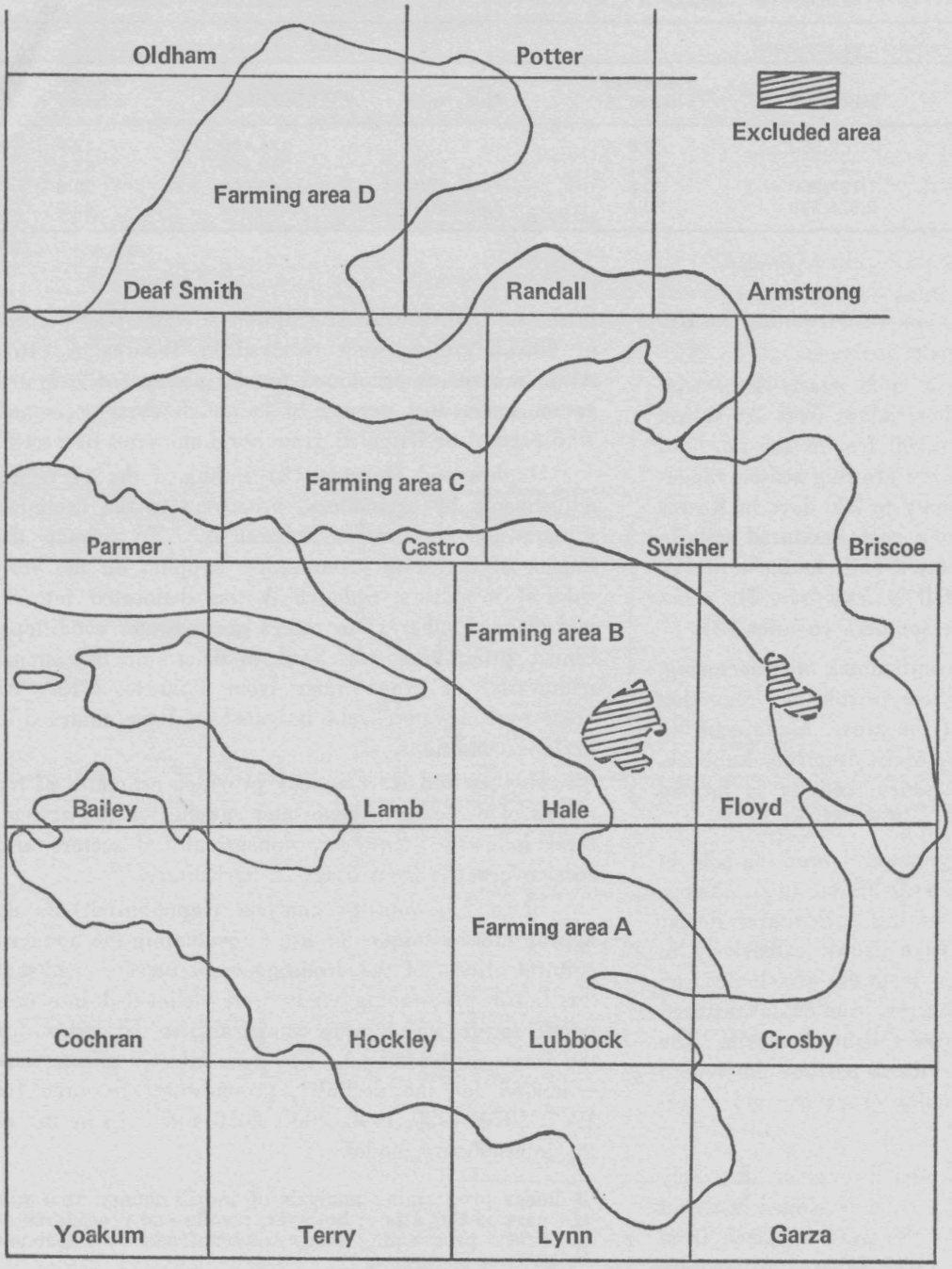

Figure 2. Subarea A with farming areas delineated.

Historical Perspective

Interindustry analysis was developed in the early thirties by Wassily W. Leontief. Leontief determined a national model of the United States which determined national input patterns (10). Models of regional economies in the United States were developed from Leontief's national model. However, regional input patterns may be different than national patterns. Moore and Peterson (13) and Hirsch (6) developed procedures for deriving coefficients to reflect regional input patterns.

In an interindustry study for the Texas High Plains area completed in 1972, Osborn and McCray (14) estimated direct, indirect and "stemming-from" effects from irrigation for the Texas High Plains economy. Nearly one-half of the total indirect benefits to the regional economy from irrigated production were associated with the Irrigated Feed Grains Sector (15).

Interindustry Analysis

An interindustry study is based on the transactions for economic sectors in an economy; that is, purchases of inputs and sales of outputs (Figure 3). Transactions can be delineated into four major classifications: (a) Quadrant I is the processing section which produces

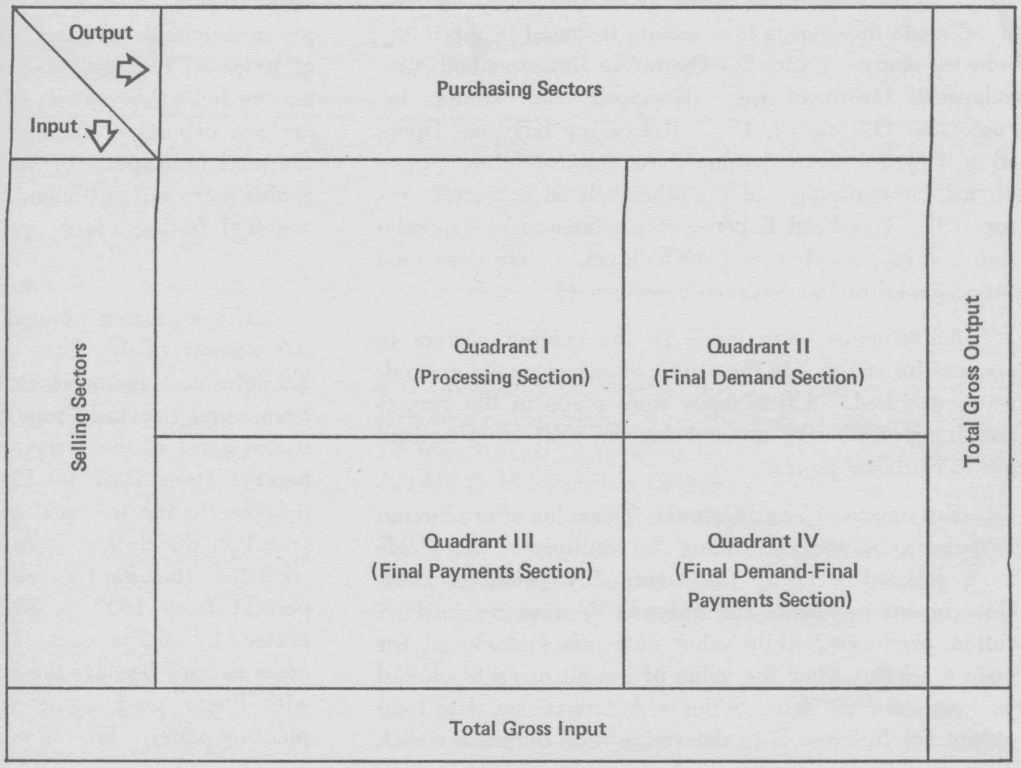

Figure 3. A classification of transactions.

goods and services; (b) Quadrant II includes sales of goods and services to final demand sectors—final demand sectors may be net inventory change, exports, government purchases, capital formulation and purchases by households; (c) Quadrant III includes purchases from final payments sectors which may contain imports, government, depreciations and households; (d) Quadrant IV represents direct inputs of goods and services to final demand which are not produced by industries in the processing section. Recent publications present more detailed discussions (10, 12, 14).

The transactions include the costs and revenues for an economic sector. First, transactions show the inputs (costs) that will be required by a purchasing sector (sector j) from the other sectors to produce its output. Second, transactions will give the distribution for sales of total output by a sector (sector i) to all other sectors.

A "closed" interindustry model was used for this study which included 15 processing sectors, four final payments sectors and seven final demand sectors (Appendix A, Table 1). A "closed" model includes a nonprocessing sector in the model. The Households Sector was included in the processing section to determine the interdependence of economic sectors.

Interindustry coefficients were computed from the matrix for the processing section. The inversion of the Leontief matrix was used to determine the interindustry coefficients. Interindustry coefficients measure the extent of interrelationships between different processing sectors.

General Procedures

Total cropland acres for the Irrigated Crops Sector and the Dryland Crops Sector for Subarea A of the study area were determined from results of the linear programming study by Hughes and Harman (7). The cropland acres for Subarea B were estimated by subtracting the cropland acres for Subarea A for 1967 from the cropland acres in the study area. Cropland acres for the Irrigated Crops Sector and the Dryland Crops Sector for 1967, 1970, 1980, 1990, 2000, 2010 and 2015 were determined by aggregating the respective irrigated and dryland acres for Subarea A and Subarea B. Output for the Irrigated Crops Sector and Dryland Crops Sector for Subarea B was constant at the level in 1967.

Purchases by the Agricultural Sectors of Subarea A

Purchase of inputs by the Irrigated Crops Sector and Dryland Crops Sector in Subarea A for each of the selected years was determined from the linear programming tableau and the acres for each crop sector in the study by Hughes and Harman (8). The per acre costs (8) were multiplied by the respective acres to derive specific purchases.

Types of Purchases by Major Crop Sectors: Purchase by agricultural producers in Subarea A were classified as Operating Expenses, Miscellaneous Overhead, Irrigated Machinery Overhead, Dryland Machinery Overhead, Irrigated Operating Expense, Irrigated Overhead Expense and Labor in the linear programing

study. Ratios were developed from secondary sources to delineate these costs into sectors included in the interindustry study. Ratios for Operating Expenses and Miscellaneous Overhead were developed from studies by Foote and Osborn (2, 15). Ratios for Irrigated Operating Expense were developed to delineate the sources of fuel for pumping and for other related economic sectors (9). Overhead Expense was composed of depreciation and interest charges for which ratios were developed for delineation into economic sectors (15).

Adjustments were made in the column vectors to account for changes in the source of energy as the groundwater declined. Adjustments were made in the respective input vectors to account for the shift from natural gas to electrical power.

Estimation of Total Output: The value of production in Subarea A was determined by multiplying the yields in a selected year by the commodity price in 1967. Government payments for Subarea A were received by cotton producers, while other enterprises produced for open market. After the value of output in each selected year was estimated for Subarea A, it was added to total output for Subarea B to determine total output for each agricultural sector in the selected year for the study area.

Taxes and the Educational Sectors

Final payments to government sectors and purchases from educational sectors were based on the 1967 per acre expenditure for the Irrigated Crops Sector and the Dryland Crops Sector. The per acre amounts were estimated from the 1967 interindustry study (14). Total purchases from the educational sectors as well as payments to the government sectors were determined by multiplying the appropriate acres of the respective sector in Subarea A by the per acre amount for each selected year.

Sources of Feed Grains for the Feedlot Livestock Sector

The purchase of feed grains by feedlots was maintained at the 1967 level for each of the selected years. With decreases in production of irrigated feed grains, other sources of feed grains were needed to fulfill the requirements of feedlots. The decreases in irrigated production were satisfied initially by decreasing exports of irrigated feed grains. If this nonexported grain was not sufficient to satisfy the requirements of feedlots, dryland exports of feed grains were used. However, if the total nonexports of both irrigated and dryland feed grains were not sufficient to satisfy the requirements of regional feedlots, feed grains were imported.

Results

The estimated planted acres of crops in 1967 was 9.6 million (Table 3). An estimated 5.7 million and 3.9 million acres were included in the Irrigated Crops Sector and Dryland Crops Sector, respectively. The estimated acres of the Irrigated Crops Sector decreased 4.4 percent from 1967 to 1970. The greatest percentage decrease in the irrigated acreage, 22.7 percent, was projected in the decade from 1970 to 1980. Although the irrigated acreage was estimated to decrease by 57.5 percent from 1967 to 2015, dryland crop acreage increased by 86.3 percent. It was possible for total planted acres to vary because the acres were determined partially with linear programing and because various skip-row planting patterns for cotton were included.

Total Output

Total output was estimated to be $778.1 million in 1967 (Table 4). The Irrigated Crops Sector accounted for $637.2 million, while the Dryland Crops Sector had an output of $140.9 million in 1967. Total output for the Irrigated Crop Sector decreased by 61.6 percent from 1967 to 2015 to $244.6 million. The output of the Dryland Crops Sector increased by 63.8 percent from 1967 to 2015. Although the output for the Irrigated Crops Sector would decrease by 61.6 percent from 1967 to 2015, total output for both sectors would decrease by only 39.1 percent. That is, increased output from the Dryland Crops Sector compensated for 22.5 percent of the decrease in output of the Irrigated Crops Sector.

Interindustry Effects

Selected Interindustry effects are discussed for 1970, 1990 and 2010. The interindustry coefficients for 1967, 1980, 2000 and 2015 are presented in Appendix B

TABLE 3. PLANTED ACRES FOR EACH CROP PRODUCING SECTOR FOR SELECTED YEARS, TEXAS HIGH PLAINS[1]

Year	Irrigated Crops Sector		Dryland Crops Sector		Total of Crops Sector	
	Acres (1,000)	Percent of 1967	Acres (1,000)	Percent of 1967	Acres (1,000)	Percent of 1967
1967	5,682.9	100.0	3,930.2	100.0	9,613.1	100.0
1970	5,430.3	95.6	4,193.1	106.7	9,623.4	100.1
1980	4,195.2	73.8	5,476.7	139.3	9,671.9	100.6
1990	3,331.3	58.6	6,327.6	161.0	9,658.9	100.5
2000	2,743.0	48.3	6,966.6	177.2	9,709.6	101.0
2010	2,537.5	44.6	7,196.7	183.1	9,734.2	101.2
2015	2,413.7	42.5	7,323.6	186.3	9,737.3	101.3

[1]Does not include nonplanted acres for skip-row planting pattern for cotton.

TABLE 4. TOTAL OUTPUT FOR EACH CROP PRODUCING SECTOR FOR SELECTED YEARS, TEXAS HIGH PLAINS[1]

Year	Irrigated Crops Sector		Dryland Crops Sector		Total Crops Sector	
	Total output ($1,000,000)	Percent of 1967	Total output ($1,000,000)	Percent of 1967	Total output ($1,000,000)	Percent of 1967
1967	637.2	100.0	140.9	100.0	778.1	100.0
1970	606.0	95.1	151.2	107.8	752.2	97.3
1980	462.8	72.6	181.8	129.7	644.6	82.8
1990	351.8	55.2	203.2	144.9	555.0	71.3
2000	288.2	45.3	218.9	156.1	507.1	65.2
2010	260.0	40.8	224.5	160.1	484.5	62.2
2015	244.6	39.4	229.6	163.8	474.2	60.9

[1]Excluding government payments.

Table 3.[3] The interindustry coefficients were adjusted for intrasectoral purchases; that is, purchases by a sector from itself.

Interindustry coefficients were relatively stable for each of the selected years for the crops sectors for many of the processing sectors. The interindustry coefficient of the Irrigated Crops Sector for the Utilities Sector increased from $0.072 per dollar of output in 1970 to $0.083 in 2010; this reflects the increased costs of producing water for irrigation (Table 5). The interindustry coefficients of the Irrigated Crops Sector for the Services Sector increased from $0.119 per dollar of output in 1970 to $0.127 in 2010.

Although the output interindustry coefficients indicate the relative effects per dollar of output from groundwater for irrigation, the total interindustry effect was determined by multiplying the output of the appropriate crop sector by its output interindustry coefficient (Table 6). The estimated decline in the requirements by the Irrigated Crops Sector from the Trade Sector was $87.8 million from 1970 to 2010, that is from $153.3 million in 1970 to $65.5 million in 2010. However, the increased interindustry effects of the Dryland Crops Sector from the Trade Sector was $18.2 million from 1970 to 2010 which resulted in an estimated net decline in total interindustry transactions of $69.6 million from 1970 to 2010.

Multipliers

The sum of the interindustry coefficients for a processing sector is called the final demand multiplier. This multiplier is an estimate of the economic activity that would be generated with an increase in sales of $1 to final demand by the appropriate sector. For example, it was estimated that an increase in sales of $1 to final demand by the Irrigated Crops Sector in 1980 would generate $2.85 of economic activity in the processing sectors in the regional economy (Table 7 and Appendix B Table 3[4]). The multipliers are relatively stable for the Irrigated Crops Sector and the Dryland Crops Sector.

[3]Appendix B consists of computer printouts, Tables 1, 2 and 3. These are available from the senior author, Office of the Dean, College of Agricultural Sciences, Texas Tech University, P.O. Box 4169, Lubbock, Texas 79409.

[4]See footnote 3.

TABLE 5. INTERINDUSTRY COEFFICIENTS ADJUSTED BY INTRASECTORAL PURCHASES FOR THE CROP SECTORS FOR 1970, 1990 AND 2010, TEXAS HIGH PLAINS[1]

Sector number and name	Year					
	1970		1990		2010	
	Irrigated Crops Sector	Dryland Crops Sector	Irrigated Crops Sector	Dryland Crops Sector	Irrigated Crops Sector	Dryland Crops Sector
1 Irrigated crops	1.000	0.021	1.000	0.021	1.000	0.020
2 Dryland crops	0.002	1.000	0.002	1.000	0.003	1.000
3 Livestock and livestock products	0.004	0.004	0.004	0.004	0.004	0.004
4 Ginning, compressing and agricultural services	0.048	0.065	0.050	0.069	0.051	0.070
5 Mining	0.089	0.057	0.090	0.058	0.090	0.058
6 Construction	0.028	0.028	0.028	0.028	0.029	0.028
7 Meat products	0.007	0.008	0.007	0.008	0.007	0.008
8 Crop products	0.006	0.007	0.006	0.007	0.006	0.007
9 Other manufacturing	0.154	0.093	0.142	0.098	0.131	0.100
10 Transportation and communication	0.042	0.045	0.042	0.044	0.042	0.044
11 Utilities	0.072	0.048	0.079	0.047	0.083	0.047
12 Trade	0.253	0.264	0.251	0.260	0.252	0.259
13 Fire, insurance and real estate	0.090	0.064	0.097	0.070	0.098	0.072
14 Services	0.119	0.121	0.122	0.120	0.127	0.120
15 Households	0.880	1.000	0.858	0.977	0.863	0.970
Total	2.795	2.825	2.780	2.814	2.787	2.806

[1]Source: Each element in a column was divided by the respective intraindustry coefficients to obtain "output" interindustry coefficients.

TABLE 6. INTERINDUSTRY EFFECTS FOR SELECTED SECTORS FOR 1970, 1990 AND 2010, TEXAS HIGH PLAINS

Sector number and name	Year								
	1970			1990			2010		
	Irrigated Crops Sector	Dryland Crops Sector	Total	Irrigated Crops Sector	Dryland Crops Sector	Total	Irrigated Crops Sector	Dryland Crops Sector	Total
	$1,000,000								
1 Irrigated crops	606.0	3.2	609.2	351.8	4.3	356.1	260.0	4.5	264.5
2 Dryland crops	1.2	151.2	152.4	0.7	203.2	203.9	0.8	224.5	225.3
9 Other manufacturing	93.3	14.1	107.4	50.0	19.9	69.9	34.1	22.2	56.3
11 Utilities	43.6	7.2	50.8	27.8	9.6	37.4	21.6	10.6	32.2
12 Trade	153.3	39.9	193.2	88.3	52.8	141.1	65.5	58.1	123.6
14 Services	72.1	18.3	90.4	42.9	24.4	67.3	33.0	26.9	59.9
15 Households	532.7	151.2	683.9	301.8	198.5	500.3	224.4	217.8	442.2

This was expected for the Dryland Crops Sector. However, the input vector for the Irrigated Crops Sector was changed each decade to account for projected changes in sources of fuel to pump irrigation water. The changes in the configuration of the input vector for the Irrigated Crops Sector were expected to affect significantly the final demand multiplier which decreased from 2.88 in 1967 to 2.85 in 2015 (not monotonically), 0.01 percent.

The output multipliers for the sectors were more stable for the Irrigated Crops Sector than for the Dryland Crops Sector (Table 7). The output multiplier is an estimate of the economic activity that would be generated with an increase in output of $1 by the appropriate sector. It is determined by dividing the final demand multiplier for a sector by its intrasectoral coefficient. For the Irrigated Crops Sector in 1967, it was estimated that $2.80 of economic activity would be generated in the processing sectors in the regional economy by increasing its output by $1.

TABLE 7. FINAL DEMAND AND OUTPUT MULTIPLIERS FOR SELECTED YEARS FOR EACH CROP PRODUCING SECTOR, TEXAS HIGH PLAINS[1]

Year	Irrigated Crop Sector		Dryland Crops Sector	
	Final demand multiplier	Output multiplier	Final demand multiplier	Input multiplier
1967	2.88	2.80	2.86	2.83
1970	2.87	2.79	2.86	2.82
1980	2.85	2.77	2.86	2.82
1990	2.86	2.78	2.86	2.81
2000	2.88	2.79	2.85	2.80
2010	2.87	2.79	2.85	2.81
2015	2.85	2.79	2.85	2.81

[1]Rounded to two decimals. The multipliers are estimated from the closed model.

Economic Activity Associated With Crop Producing Sectors

The economic activity associated with each crop producing sector was estimated by multiplying the projected output of the respective crop sector in each selected year (Table 4) by its output multiplier (Table 7). For example, the economic activity associated with the output of $606 million of the Irrigated Crops Sector in 1970 was estimated to be $1.69 billion (Table 8).

Economic activity associated with the Irrigated Crops Sector declined from $1.78 billion in 1967 to $0.68 billion in 2015 or 61.8 percent (Table 8). The greatest decline for one decade was $0.41 billion from 1970 to 1980 or 24.3 percent. The decrease in this period (1970 to 1980) was 37.3 percent of the total amount from 1967 to 2015.

The Dryland Crops Sector had an increase in economic activity from $0.4 billion in 1967 to $0.64 billion in 2015 or 60 percent. The greatest increase occurred from 1970 to 1980 as the irrigated acreage reverted to dryland production. The increase in economic activity associated with the Dryland Crops Sector from 1970 to 1980 was $80 million or 18.6 percent. In 2015, the

TABLE 8. ECONOMIC ACTIVITY ASSOCIATED WITH EACH CROP PRODUCING SECTOR FOR SELECTED YEARS, TEXAS HIGH PLAINS

Year	Irrigated Crops Sector		Drylands Crops Sector		Total for all crops	
	Economic activity (billion dollars)	Percent of 1967	Economic activity (billion dollars)	Percent of 1967	Economic activity (billion dollars)	Percent of 1967
1967	1.78	100.0	0.40	100.0	2.18	100.0
1970	1.69	94.9	0.43	101.8	2.12	97.2
1980	1.28	71.9	0.51	127.5	1.79	82.1
1990	0.98	55.0	0.57	127.5	1.55	71.1
2000	0.80	44.9	0.61	152.5	1.41	64.7
2010	0.72	40.4	0.63	157.5	1.35	61.9
2015	0.68	38.2	0.64	160.0	1.32	60.6

difference in economic activity associated with the Irrigated Crops Sector ($680 million) and the Dryland Crops Sector ($640 million) was only $40 million, while the total output of the respective sectors differed by $15.0 million.

Total economic activity associated with the crop sectors decreased from $2.18 billion in 1967 to $1.32 billion in 2015. The decline in economic activity associated with the output of the Irrigated Crops Sector of $1.1 billion was partially offset with a $0.24 billion increase in economic activity associated with the Dryland Crops Sector. The net overall decrease was $0.86 billion.

Economic Benefits

Three specific types of benefits were delineated to evaluate changes in economic activity associated with irrigation—direct, indirect and "stemming-from."

Direct Benefits: Direct benefits are defined as the increases in crop production derived from irrigation; that is, the additional output in the Irrigated Crops Sector over dryland crop production on similar acres. Direct benefits were $433.5 million in 1967 which was 68 percent of the total output of the Irrigated Crops Sector and 55.7 percent of total output of all crops (Table 9). Direct benefits declined to $169.0 million in 2015 —a decrease of 61 percent from 1967. The greatest percentage decline in direct benefits was estimated to occur from 1980 to 1990 although the greatest decline was $86.6 million from 1970 to 1980.

Indirect Benefits: Indirect benefits are defined as the summation of increased economic activity associated with the direct benefits from irrigated crop production. The direct benefits include cumulative effects of employment of agricultural inputs and purchases of nonagricultural goods and services to provide inputs for the irrigated crop producers.

Indirect benefits were greater than direct benefits. In addition, indirect benefits were greater than total output of the Irrigated Crops Sector for each selected year (Table 9). The indirect benefits declined by 61 percent from 1967 to 2015. In 1967, the benefits were 18 percent greater than the total output of the Irrigated Crops Sector. The benefits were 99.8 percent of the total value of crop production in 1967 but decreased to 63.6 percent in 2015.

TABLE 9. BENEFITS FROM THE NET INCREASE IN CROP PRODUCTION FROM IRRIGATION, TEXAS HIGH PLAINS

Type of benefit	Year						
	1967	1970	1980	1990	2000	2010	2015
	($1,000,000)						
Direct	433.5	410.1	323.5	244.8	202.0	180.8	169.0
Indirect	776.7	730.1	566.7	432.8	360.8	321.6	301.5
Stemming-from	536.5	521.8	484.7	426.5	384.7	360.6	344.2
Total	1,746.7	1,662.0	1,374.9	1,103.5	947.5	863.0	814.7

TABLE 10. BENEFIT MULTIPLIERS PER DOLLAR OF NET INCREASE IN CROP PRODUCTION FROM IRRIGATION, TEXAS HIGH PLAINS

Type of benefit	Year						
	1967	1970	1980	1990	2000	2010	2015
Indirect	1.79	1.78	1.75	1.77	1.79	1.78	1.78
Stemming-from	1.24	1.27	1.50	1.74	1.90	1.99	2.04
Total	4.03	4.05	4.25	4.51	4.69	4.77	4.82

Stemming-From Benefits: These benefits are defined as the increases in output of sectors through processing of the net increase in crop production from irrigation. The benefits were based on sales to final demand by the Livestock and Livestock Products Sector, the Meat Products Sector and the Crop Products Sector.

Stemming-from benefits were less than indirect benefits prior to the year 2000. However, the stemming-from benefits were greater than indirect benefits from 2000 to 2015. The stemming-from benefits were greater than direct benefits for all selected years.

Stemming-from benefits decreased by 35.8 percent from 1967 to 2015. This decrease was less than for the other types of benefits (Table 9). The benefits were less than total output of the Irrigated Crops Sector prior to 1980. After 1970, the benefits were greater than total output of the Irrigated Crops Sector, although the benefits declined monotonically.

Total Benefits: The summation of direct benefits, indirect benefits and stemming-from benefits were called total benefits. Total benefits decreased from $1.7 billion in 1967 to $0.8 billion in 2015, or 53.4 percent (Table 9). In 1967, total benefits were 63.5 percent greater than total output of the Irrigated Crops Sector.

Benefit Multipliers: The indirect benefits, stemming-from benefits and total benefits were divided by direct benefits to estimate benefit multipliers. The multipliers show the ratio of total benefits generated with the net increase (direct benefits) in production from irrigation. The indirect benefits multiplier ranged from 1.75 in 1980 to 1.79 in 1967 and 2000 (Table 10). That is, with a $1 increase in direct benefits, $1.78 of indirect benefits would be generated in the processing sectors in 1970. The ratio for stemming-from benefits increased from 1.24 in 1967 to 2.04 in 2015. With a $1 increase in direct benefits, stemming-from benefits would increase by $1.74 in 1990 to the processing sectors. The total benefits multiplier (includes the direct benefit of one dollar) ranged from 4.03 in 1967 to 4.82 in 2015. If the direct benefits would increase by $1 in 1970, total benefits generated in the processing sectors in the regional economy would increase by $4.05.

The total of the multipliers tended to increase as the groundwater declined for irrigation crops from 1967 to 2015. The total benefits, however, declined from $1.7 billion in 1967 to $0.8 billion in 2015. This type of result is expected as resources become relatively more restricting in an economy. That is, the efficiency of resource use generally increases as the absolute supply is relatively more limiting.

References

1. Bodkin, A. W. *Temporal Allocation for Maximum Value of Underground Water in Agricultural Uses: Texas High Plains.* Unpublished Master's Thesis, Department of Agricultural Economics, Texas Tech University, Lubbock, Texas, May 1964.
2. Foote, Richard J. A Series of Releases on Calculations of Agricultural Coefficients from June 26, 1969, through June, 1971. Division of Planning Coordination, Office of the Governor, Texas.
3. Godfrey, Curtis L., Clarence R. Carter and Gordon S. McGee. *Resource Areas of Texas.* Texas Agricultural Experiment Station Bulletin 1070.
4. Grubb, Herbert W. *Importance of Irrigation Water to the Economy of the Texas High Plains.* Texas Development Board Report 11, January, 1966.
5. Grubb, Herbert W., and Ronald D. Lacewell. *Economic Evaluation of Alternative Temporal Water Use Plans on Cotton-Grain Sorghum Farms in the Fine-Textured Soils of the Texas High Plains.* Texas Agricultural Experiment Station Technical Report Number 70-3, May 1970.
6. Hirsch, Werner Z. "Interindustry Relations of a Metropolitan Area." *The Review of Economics and Statistics,* Vol. 41, No. 4, November 1959, pp. 360-369.
7. Hughes, William F., and Wyatte L. Harman. *Net Returns Maximizing Irrigation Programs.* Texas Agricultural Experiment Station. Unpublished Data.
8. Hughes, William F., and Wyatte L. Hartman. *Projected Economic Life of Water Resources, Subdivision Number 1 High Plains Underground Water Resource.* Texas Agricultural Experiment Station Monograph 6, December 1969.
9. Jones, Lonnie L. "Budgets for Irrigated and Dryland Cotton, Feed Grains, and Wheat." *Regional and State Input-Output Models,* Division of Planning Coordination, Governor's Office, Texas, July 1970.
10. Leontief, Wassily W. "The Structure of the U.S. Economy." *Scientific American,* Vol. 212, No. 4, April 1965, pp. 25-35.
11. Martin, William E., and Harold O. Carter. *A California Interindustry Analysis Emphasizing Agriculture, Part I: The Input-Output Models and Results.* California Agricultural Experiment Station, Giannini Foundation of Agricultural Economics, Giannini Foundation Research Report Number 250, February 1962.
12. Miernyk, William H. *The Elements of Input-Output Analysis.* New York: Random House Company, 1965.
13. Moore, Frederick T., and James W. Petersen. "Regional Analysis: An Interindustry Model of Utah." *The Review of Economics and Statistics,* Vol. 41, No. 4, November 1959, pp. 360-369.
14. Osborn, James E., and William C. McCray. *An Interindustry Analysis of the Texas High Plains, Part I.* Texas Tech University College of Agricultural Sciences, Technical Publication T-1-102, April 1972.
15. Osborn, James E., Donald S. Moore and Don E. Ethridge. *Expected Production Requirements, Costs and Returns for Major Crops; Medium-Textured Soils—Texas High Plains.* Texas Agricultural Experiment Station MP-922, August 1969.
16. Texas Department of Agriculture, *Texas County Statistics.* Texas Crop and Livestock Reporting Service, 1970.
17. U. S. Department of Commerce, *Census of Population.* Bureau of Census. Washington, D. C., 1970.

Appendix A: Interindustry Model

Sector code number	Sector name	Standard industrial classification components
	Processing	
1	Irrigated Crops	Irrigated part of 0112, 0113, 0119, 0122 and 0123
2	Dryland Crops	Dryland part of 0112, 0113, 0119, 0122 and 0123
3	Livestock and Livestock Products	0132, 0134 through 0136 and 0139
4	Ginning, Compressing and Agricultural Services	0712, 0713 and 0731
5	Mining	1011 through 1099, 1311, 1321, 1381 through 1389 and 1411 through 1499
6	Construction	1511, 1611 and 1621 as well as special trade contractors
7	Meat Products	2011 through 2026
8	Crop Products	2031 through 2099 and 2211 through 2399
9	Other Manufacturing	2411 through 3231 and 3251 through 3999
10	Transportation and Communication	4011 through 4172, 4213, 4231, 4511 through 4712, 4742 through 4789, 4811 through 4899
11	Utilities	4911 through 4925 and part of 4931 through 4953
12	Trade	4221, 4731, 5012 through 5013, 5022 through 5089, 5092 through 5099, 5211 through 5311, 5331, 5399 through 5999 and 7531 through 7539.
13	Fire, Insurance and Real Estate	6011 through 6799
14	Services	7011 through 7319, 7331 through 7525, 7622 through 8911 and 8931 through 8999
	Final Payments	
15	Households	
16	Government	
17	Imports	
18	Depreciation	
	Final Demand	
19	Households	
20	Net Change in Inventory	
21	Federal Government	
22	State Government	
23	Local Government	
24	Exports	
25	Capital Formation	