WATER RESOURCE ECONOMICS

The Economic Effects of Weather Modification Activities

Part I
Crop Production

TEXAS DEPARTMENT OF WATER RESOURCES

LP-21

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THE ECONOMIC EFFECTS OF WEATHER MODIFICATION ACTIVITIES

PART I

CROP PRODUCTION IN THE BIG SPRING-SNYDER AREA

by

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ABSTRACT

The purpose of this study was to quantify the relationships between yield, technology, and weather for three crops in a fourteen-county region of Texas in order to estimate the economic effects of weather modification activities. Multiple regression analysis was used to estimate the crop yield response to assumed increases in average precipitation. The estimates of increased crop production were converted to monetary values and an input-output model was used to give a preliminary estimate of the economic activity generated in the region by increased crop revenues.

Results of the study indicate that there could be substantial direct increases in agricultural incomes resulting from assumed increases in average precipitation. The late winter months, January through March, and the summer months, June through August, were shown to have the greatest effects on crop production. Each dollar of direct income gain would lead to between 50 and 64 cents additional activity as a result of multiplier effects. The total regional effects of a 10 percent increase in average March rain were shown to be approximately $500,000.

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1. INTRODUCTION

1.1 Background

The Division of Atmospheric Water Resources Management, Bureau of Reclamation, United States Department of the Interior, has been given the task of "establishing a verified, working technology and operational management framework by 1980 capable of producing additional rain from cumulus clouds in the sub-humid High Plains Region." The five-year program is titled "The High Plains Cooperative Program (HIPLEX)."

To carry out this cloud seeding endeavor, three field research sites were selected along the High Plains. These sites are near Miles City, Montana, Goodland, Kansas, and Big Spring, Texas.

The Bureau of Reclamation, working through the Texas Water Development Board (TWDB) under a cooperative agreement, made available to the Board certain funds for carrying out specific tasks in the Southern portion (Big Spring area) of HIPLEX for the Federal Fiscal Year 1975.

A portion of these funds was awarded by the Board (under contract) to the Colorado River Municipal Water District, Big Spring, Texas, to collect and document rainfall data from a network of 50 recording rain gauges and approximately 94 wedge-type fencepost rain gauges. The District is also to operate an RD-65 rawinsonde unit to measure atmospheric temperature and humidity profiles during operational days. The District's seeding aircraft pilot is recording cloud base height, temperature and various updraft characteristics on those clouds seeded.

Since 1971, the District has sponsored a rainfall stimulation project. The District at first awarded a contract to a private firm to conduct an operational cloud seeding program for the purpose of inducing rainfall (TWDB, 1974). The primary goal of the project was to increase runoff into the storage lakes in the area, primarily Lake J.B. Thomas and E.V. Spence Reservoir. The District is now seeding clouds with its own aircraft and equipment.

Another part of the funds made available to the Board by the Bureau was assigned by the Board (under contract) to Meteorology Research, Incorporated, Altadena, California to upgrade and maintain the Snyder-based, Bureau-owned M-33 radar system used to measure certain cloud parameters for post analyses of cloud characteristics and seeding effectiveness.

A portion of the FY 75 funds made available by the Bureau was earmarked for in-house use by the Texas Water Development Board to begin a study of the economic effects of weather modification. The first phase of this study is described in this report.

1.2 Approach

The immediate goal of the HIPLEX program is to reduce scientific and management uncertainties in cloud seeding technology for the High Plains region. One of the uncertainties identified by the Bureau is determining the circumstances under which precipitation increases would be desirable from economic and social viewpoints. Specifically, how much economic value can be expected from a controlled increase in rainfall, and who will realize the benefits. It might well be expected that increased rainfall during certain times of a crop's growing season would be beneficial, and at other times detrimental. Increased rainfall in the middle of harvest time, for instance, may destroy part of the crop, but increased rainfall in the early stages of its growth may give it the boost it needs to establish itself.

For this reason the Bureau allotted $5,000 to the Board and the Board matched that amount to begin a study of agricultural production in the Big Spring-Snyder area during Federal Fiscal Year 1975. A detailed work plan was prepared by the Board covering a full 3½-year research effort. The initial emphasis of the study (FY 75) was to estimate the value of additional crop yields resulting from hypothetically-induced rainfall. These direct effects were realized as increases in income to the agricultural producers of food and fiber. The results of this preliminary demonstration study are described in this report.

With the completion of this portion of the study, further investigations into the economic effects of hypothetically-induced precipitation by cloud seeding can be made, should additional funds be made available to the Board. For example, with data on grass response to additional rainfall, the effects on livestock production may be determined.

Effects other than agricultural may also be examined. These include the effect of increased rainfall on the level of municipal and industrial water supplies and water-use patterns, and the effects on recreational use of study area reservoirs. Indirect effects of additional rainfall by cloud seeding may be estimated through interindustry analysis. Interindustry analysis can be used to estimate changes in regional income, employment, and output in different sectors of the economy.

The effects of induced rainfall on municipal and industrial water supplies can be examined using a forecasting model developed by the Board. This information could be quite useful to new industry which might want to develop in this region. Recreational effects can also be examined through the relationship between induced rainfall and the condition of study area reservoirs. Using methods already refined by the Board, the economic impact of increased recreational activity resulting from more stable water levels in the reservoirs could be determined.

1.3 Objectives

The specific objectives of the present phase of the study are:

1. Determine response of cotton, grain sorghum, and wheat to changes in the average amount of precipitation during various times of the year;

2. Determine direct income effects resulting from changes in crop response;

3. Determine effects on regional output, income, and employment of changes in crop response.

2. THE STUDY AREA

The area selected for this study consists of a 14-county region of the Texas Permian Basin lying generally between the Cities of Abilene, Lubbock, Midland, and San Angelo (see Figure 1). The counties included in the study are Borden, Coke, Dawson, Fisher, Garza, Glasscock, Howard, Kent, Lynn, Martin, Mitchell, Nolan, Scurry, and Sterling.

The terrain is characterized by plains in the West sloping downward to rolling hills in the East. The Caprock Escarpment divides the two types of terrain. Soils in the area are generally red or brown sandy loam several feet thick. This type of soil easily supports extensive crop production.

Precipitation in the study area varies from an annual normal of about 14 inches in the Southwest to about 22 inches in the East. Mean monthly temperatures range from 40F in January to 82F in July.

The study area encompasses 12,678 square miles, or 8,113,920 acres. Of this total area, 7,911,443 acres or approximately 97 percent are used in farming and ranching. This farmland is divided between cropland, both dry and irrigated, and rangeland. Of the 2,559,894 acres used in cropland, 230,409 acres are irrigated (Census of Agriculture, 1969) leaving 2,329,485 acres dependent on rainfall to supply its water needs.

Five surface water storage facilities constructed on the Colorado River or on its tributaries are located in or near the study area. These facilities are Lake J.B. Thomas, Lake Colorado City, and E.V. Spence Reservoir on the Colorado River, and Champion Creek Reservoir and Oak Creek Reservoir on the tributaries. These facilities provide water to the major cities and industries encompassed by the District.

Population in the study area is generally declining. It dropped from a level of 149,056 in 1960 to 128,587 in 1970. Of this 1970 population, 49.4 percent lived in the Cities of Big Spring, Snyder, Lamesa, and Sweetwater (Census of Population, 1970). Except for Howard County, in which Big Spring lies, all the counties in the study area are expected to experience continuing declines in population. It has been projected by the Economics Division of the TWDB that by 1980, population in the study area will be 116,100, eventually reaching a level of 101,600 by the year 2020.

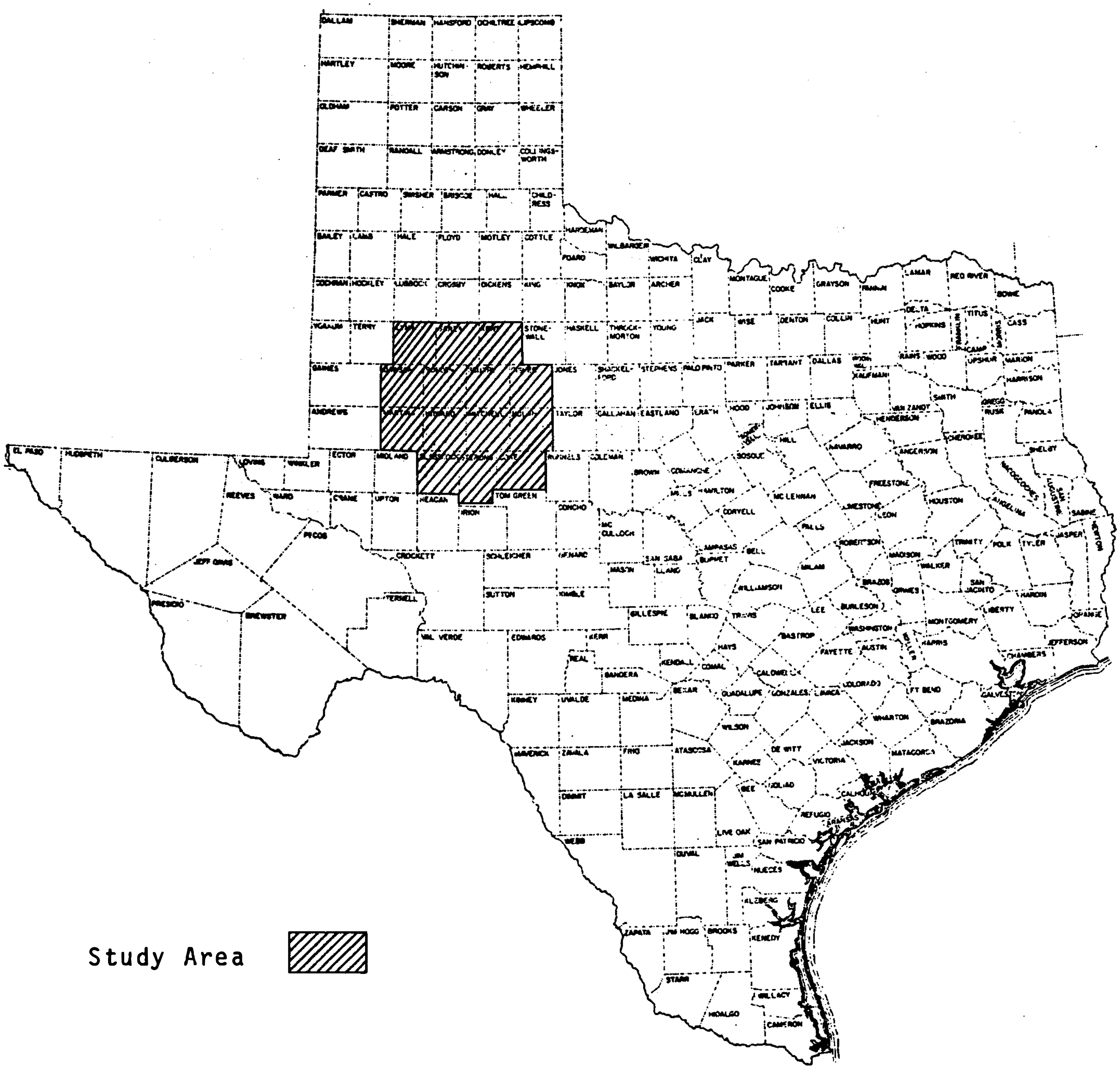


Figure 1

Big Spring - Snyder Study Area

The work force participation rate of the population rose slightly from 35.1 percent in 1960 to 38.7 in 1970. Of the 52,310 members of the work force in 1960, 2,140 or 4.1 percent, were unemployed. This unemployment figure was reduced in 1970 when 1,290 (2.6 percent) of the 49,740 member work force were unemployed.

Total and relative agricultural employment increased from 1960 to 1970. Agricultural employment rose from 10,330 (20.6 percent of the work force) to 12,085 (24.9 percent of the work force).

The economy of the area is centered basically around agriculture and oil. Farming, primarily cotton, grain sorghum, and wheat, accounted for 27.9 percent of all earnings in the region in 1970. Although the mining industry contributed only 6.1 percent to the total earnings of the region, spinoff industries such as production of oil field machinery, petrochemicals, textiles, and fertilizers gave the oil industry quite an impact on the economy (Bureau of Economic Analysis, 1972).

Another factor which emphasizes the importance of agriculture in the study area is that of proprietor's income. Proprietor's income is defined by the Bureau of Economic Analysis as the value of income earned by unincorporated businesses, less expenses. Farmers, doctors, lawyers, entrepreneurs in nonfarm businesses and others in self-employment status are included as proprietors. In 1970, total proprietor's income for the region was $125.4 million of which farm proprietors earned $87.0 million, 69.4 percent of the total.

3. CROP YIELD RESPONSE

The purpose of the Crop Yield Response portion of the study is to estimate the possible effects of hypothetically-induced precipitation on the production of agricultural crops in the Big Spring-Snyder Study Area. The general nature of the relationship between crop yields and precipitation is well known. At certain times of the year, additional precipitation will increase yields while decreasing them at other times. Yields are a function of more than just rain, however. Soil characteristics, farming skills, temperature, fertilizer use, and crop varieties are also influential in determining yields. For the purpose of this study, the above factors are described by the relation:

Yield = f (Precipitation, Temperature, Technology)

Before this relationship can be used to provide estimates of the effects of specific amounts and timings of additional precipitation, it must be given quantitative content.

The technique used to provide this content was multiple regression analysis. As it is used in this, and many similar studies, multiple regression provides a means of statistically estimating the functional relationships between variables. The general form of the regression equation is:

$$Y = b_0 + b_1 X_1 + b_2 X_2 \ldots + b_n X_n + e$$

where:

Y = the dependent, or predicted variable - crop yield.

$X_1, \ldots, X_n$ = the independent, or predictor variables - precipitation, temperature, technology.

$b_0, \ldots, b_n$ = empirically derived constants.

e = a residual error term.

In this form, the coefficients can be used to estimate the effects on a predicted variable of a change in one of the predictor variables if all the other variables are "held constant at their means." With appropriate theoretical justification, as in the case of rain during the harvest season, it is possible to attribute causal significance to the changes measured in this way. During this first phase of the study, a functional relationship of this type was specified for each of the major crops produced in the region and was used to estimate the effects of weather modification at different times of the year.

Specifications of a regression function of the type used here requires the collection of repeated observations of variables which are presumed to reflect the relationship. The variables in this study consisted of average crop yields, monthly precipitation, monthly minimum and maximum temperatures, and the level of technology. An observation consisted of the values for each of these variables for a particular crop year.

3.1 Data Acquisition

3.1.1 Yields

Total crop production and harvested acreage in each county in the region were obtained from reports of the Texas Crop and Livestock Reporting Service (Unpublished, 1975). These data were available on an annual basis for the three principal crops grown on the area. Production data on cotton and wheat cover the time span from 1940 to 1973, while data on grain sorghum were not available before 1959.

Production and acreage data were aggregated to the regional level and for each of four Crop Reporting Districts (see Figure 2). Gross crop production was converted to yield per acre for each district and the region in order to "average out" some of the technological influences on yields which are not related to time. By using the production and acreage harvested of all producers in the region, an average yield is produced which reflects the distribution of such factors as farming practices, management skills, and soil characteristics. While this yield per acre may be inappropriate for estimating the production from a specific tract, it does provide an estimate of what could be expected in the region as a whole, weighted by the existing mix of attributes in the region.

Since the procedure used to determine values for the weather variables requires a specific geographic control point, the "crop activity center" of each area was determined. The crop-activity, or production center for a crop is defined as the geographic point through which a north-south axis divides the harvested acreage equally between east and west, and an east-west axis divides it equally between north and south. Figure 3 shows the location of the production centers for each crop. The centers shown in Figure 3 were developed using the average number of acres harvested in the ten years from 1964 to 1973 (see Table 1). This crop activity center served as the location of the average yield per acre and was the point for which weather observations were developed.

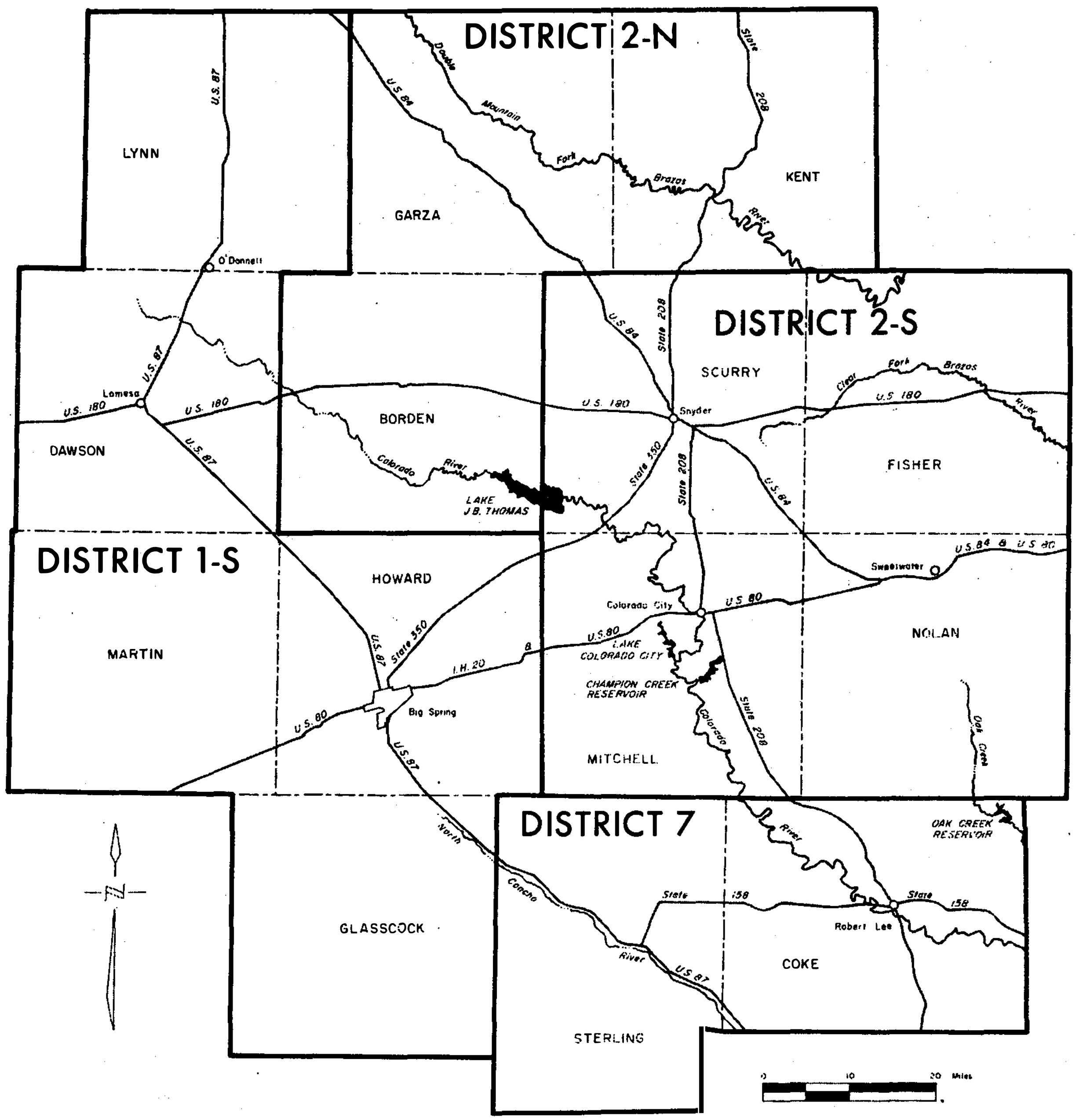
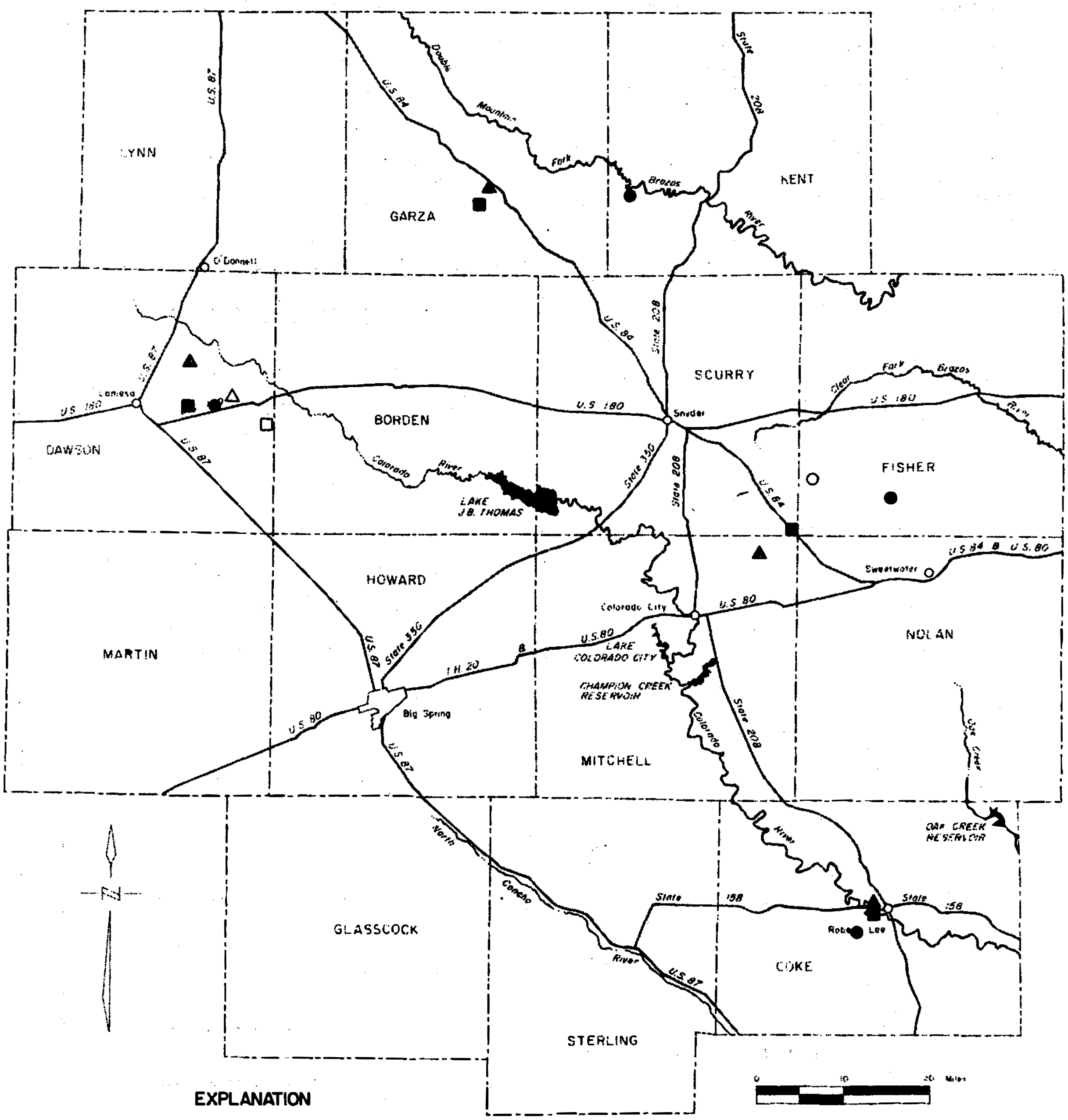


Figure 2

Big Spring-Snyder Study Area

Crop Reporting Districts



EXPLANATION

- ■ District Crop Activity Center–Cotton
- □ Regional Crop Activity Center–Cotton
- ▲ District Crop Activity Center–Grain Sorghum
- △ Regional Crop Activity Center–Grain Sorghum
- ● District Crop Activity Center–Wheat
- ○ Regional Crop Activity Center–Wheat

Figure 3

Big Spring-Snyder Study Area
Crop Activity Centers

TABLE 1

Average Acres Harvested by Crop-Reporting District From 1964 to 1973

Crop Reporting District	Cotton	%	Grain Sorghum	%	Wheat	%
1-S	501,915	66.5	227,090	76.1	6,537	21.4
2-N	63,165	8.4	17,795	6.0	2,705	8.8
2-S	188,020	24.9	50,780	17.0	20,540	67.2
7	1,957	0.2	2,585	0.9	808	2.6
TOTAL	755,057	100.0	298,250	100.0	30,590	100.0

3.1.2 Precipitation

The frequent variation in the amount of precipitation experienced by different locations within small areas is well known. This variability makes the selection of proper observations of rainfall for use in regression analysis very difficult. This difficulty is extenuated in this study by the fact that the dependent variable represents the weighted average yield per acre at the production center of a fairly large region.

Previous studies have dealt with this problem in several different ways and with varying degrees of success. The most common, and least successful, technique is the selection of a "representative" weather station. "Representative" is sometimes defined as "closest" and sometimes as "most typical." In either case, this method suffers from geographic vagueness in addition to the local variation mentioned above. An improvement over the "representative station approach" is the use of several stations to develop an average value for a region. This average can be computed in several ways, notably the simple arithmetic averaging of values, and through the use of Thiessen polygons. The first method is crude, while the second is time consuming and laborious.

The approach used in this study draws upon the techniques of computer graphics to determine weights for the weather stations used in computing an observation for the production center of a region. The procedure was to define a least-squares plane above a region based on weighted observations from within the region and to evaluate the plane at a point above the production center.

The precipitation records of 37 National Weather Service Stations were used in these calculations. The stations are among those listed in Table 2. The longitude and latitude of each station were converted to rectangular measures of the X and Y distance from an arbitrary origin. To minimize the error caused by the conversion from polar to rectangular coordinates, an origin in the approximate center of the study area was chosen. After the conversion, however, a constant was added to all coordinates to shift the entire region to Quadrant I for computational convenience.

For each month of the 34-year period of record, a weight was determined for all weather stations within 32.5 miles of the production center which recorded an observation for the month. Traces were treated as observations of zero precipitation. The weights were recomputed each month so that the data used in the regressions were based on the maximum amount of information available.

TABLE 2. Weather Stations Used in Big Spring-Snyder Weather Modification Study

Map #	Station #	Station Name
1	16	Abilene WB AP
2	34	Ackerly 3SE
3	248	Andrews
4	268	Anson
5	394	Aspermont 2S
6	493	Ballinger 1SW
7	779	Big Lake No. 2
8	786	Big Spring
9	1128	Brownfield No. 2
10	1511	Case Range 3S
11	1875	Coleman
12	1903	Colorado City
13	1974	Cope Range
14	2082	Crane
15	2448	Dickens
16	3214	Floydada
17	3253	Farsan
18	3401	Funk Ranch
19	3411	Gail
20	3445	Garden City 1E
21	3828	Guthrie
22	3890	Hamlin
23	3992	Haskell
24	4278	Hords Creek Dam
25	4570	Jayton
26	4841	Knapp 6SW
27	4960	Lake Abilene
28	5013	Lamesa 1SSE
29	5158	Lenorah
30	5183	Levelland
31	5351	Loop
32	5411	Lubbock WB Airport
33	5859	Mertzon
34	5890	Midland WB AP
35	5891	Midland 4ENE
36	6495	Oak Creek Lake
37	6747	Paint Rock
38	6932	Penwell 1SSE
39	7074	Plains
40	7146	Polar
41	7206	Post
42	7431	Rankin
43	7669	Robt. Lee
44	7678	Roby 1ESE
45	7743	Roscoe
46	7782	Rotan
47	7940	San Angelo Dam
48	7943	San Angelo WB AP
49	8201	Seminole
50	8373	Slaton 5SE
51	8433	Snyder
52	8630	Sterling City
53	8818	Tahoka
54	8939	Tesco
55	9122	Trent 2ENE
56	9154	Truby 3ESE
57	9501	Water Valley 1NNE
58	9847	Winters 1NNE

The weighting function is based on the distance between a station and the production center in relation to all of the distances to all of the other stations (Unitech, 1973). Weights for each observation were determined by the following formula:

$$w_i = (1 - r_i/R)^2 / (r_i/R)^2 / S$$

where:

w_i = the weight for weather station (i).

r_i = the Cartesian distance between weather (i) and the production center; $r_i \leq 32.5$ miles.

$$R = \sum_{i=1}^{n} r_i$$

$$S = \sum_{i=1}^{n} (1 - r_i/R)^2 / (r_i/R)^2$$

$$\sum_{i=1}^{n} w_i = 1.0$$

These weights were applied to each observation of rainfall and a set of simultaneous equations were solved to determine the value of a least-squares plane above the production center. The value at this point was interpreted as the weighted average precipitation for that location.

3.1.3 Temperature

Temperature data used in this study were developed in exactly the same way as the precipitation data. Since temperature is subject to far less local variation than rainfall, stations up to 60 miles from the production center were included in the averages.

National Weather Service records of minimum and maximum monthly temperature for 58 stations (see Table 2) were extracted from the Texas Water Oriented Data Bank for use in these computations. Average temperature is the simple average of the reported minimum and maximum.

3.1.4 Technology

The productivity of American agriculture has risen throughout the past forty years. This increase in productivity is the result of a wide variety of factors. The introduction of drought resistant hybrids, improved planting and harvesting machinery, and improved levels of management by the region's producers contribute to the increasing average yields. The general level of technology can be assumed to increase over time as a result of the additive nature of the type of changes described above. The basic measure of technology used in this study, therefore, was time. Technology was assigned a value of 1 in 1940 and was increased annually to a value of 34 in 1973.

A plot of regional yields over time is shown in Figure 4. From this plot it is apparent that yields of cotton and wheat have increased at a faster rate since 1956 than they did before. This observation led to the development of a second measure of technology similar to that used in a study by Thompson to account for the increased use of nitrogen in the United States in the years 1944 to 1946 (Thompson, 1969).

This second measure of technology consisted of two variables. One variable started with a value of one in 1940, increased by one each year until 1956, after which it remained constant at 17. This variable was considered a measure of pre-1956 technology. The level of technology since 1956 was represented by a variable which had a value of 1 from 1940 to 1956, when it began to increase by one each year.

It appears in Figure 4 that a technology factor for cotton which increases with time prior to 1956 would not be applicable. The trend line shows that cotton yield actually decreased with time from 1940 to 1956. The reason for the downward slope of the line, however, is not due to a decrease in technology; it is a result of the general drought period during the first half of the 1950's. If the technological trend is computed for two separate segments of this time period, it can be shown that the trend increased from 1940 to 1950. It then dropped to a new level in 1951 and increased again from that lower level through 1956.

3.2 Regression Models

Regression functions, or models, were specified for each crop at the regional and crop reporting district level. The equations were determined using the step-wise regression routine of the UCLA BIOMED statistical package on the TWDB's Univac 1106 (Dixon, 1971).

Although a total of 15 equations were developed, this discussion will be limited to the regional models for cotton, grain sorghum and wheat. Complete results for all of the models are given in Appendix A. In all cases, the regression equations are significant at the 0.5 percent level. All of the coefficients are significant at the 5 percent level. With one exception, the coefficient of determination, R^2, is above .80.

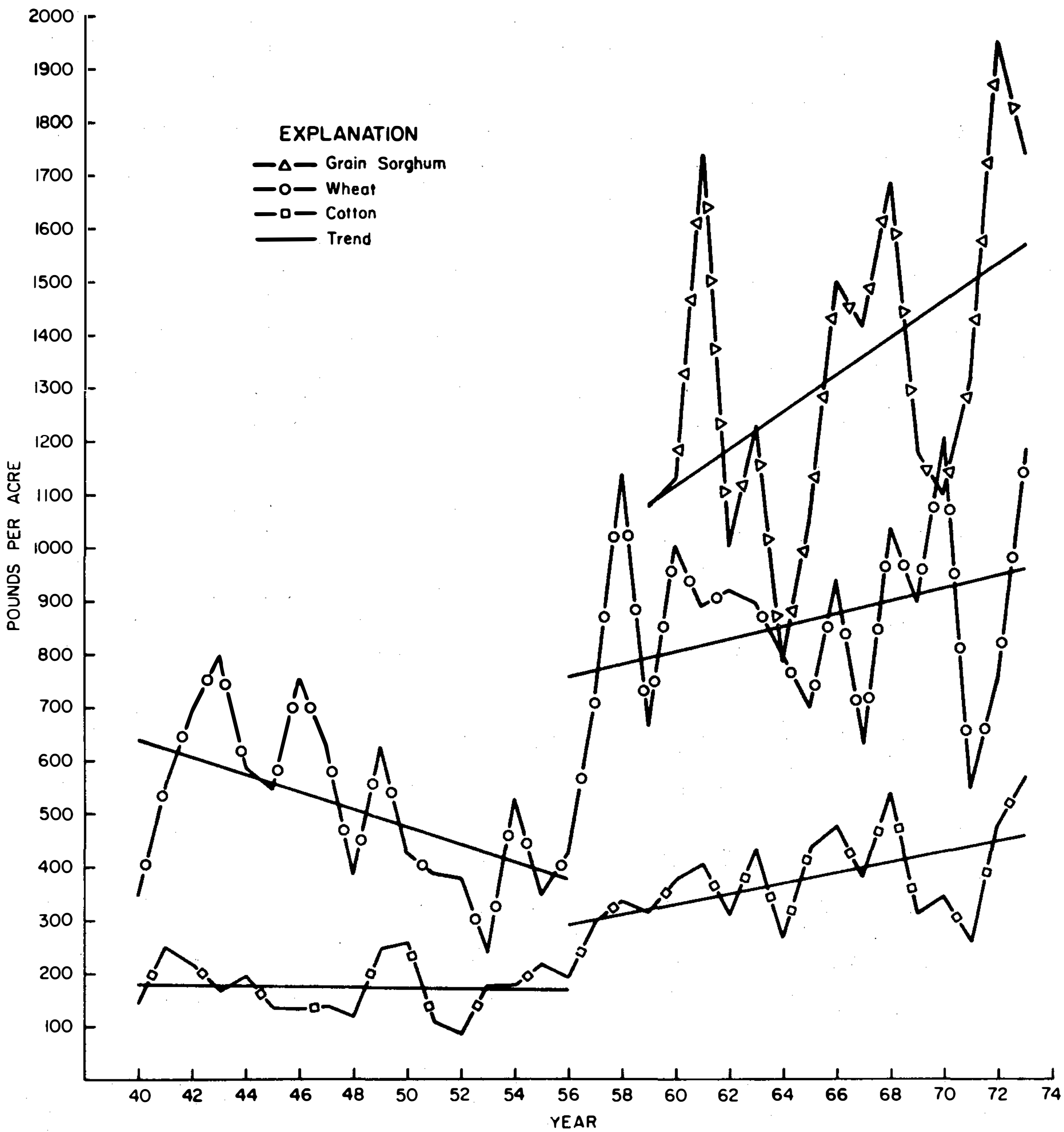


Figure 4
Big Spring-Snyder Study Area
Crop Yield Trends

As might be expected, the crop reporting district models are generally more detailed than the regional models, i.e., they typically contain a larger number of variables. On the regional level, some of the fluctuations in crop yields which are felt in the different sub-regions are cancelled out. At the average level of the region only a few factors are necessary to explain a very large part of the variation in yields from year-to-year.

3.2.1 Cotton

The regional model for cotton contains only one variable from each of the three main categories of data: the sum of January through March precipitation, the average temperature in August, and the level of technology since 1956.

The specific model is:

$$\hat{Y} = 649.84 + 41.81X_1 - 1.86X_1^2 + 5.20X_2 - 0.08X_3^2$$

where:

$\hat{Y}$ = estimate of cotton yield per acre (lbs).

X_1 = technology level since 1956.

X_2 = sum of January through March rainfall (inches).

X_3 = average August temperature (degrees F).

This model is successful in accounting for approximately 81 percent of the variation in annual yields in the region at the 99.5 percent confidence level.

Preseason rainfall has a strong positive effect on crop yield. With each inch of rainfall in the January to March time period, yield will increase 5.20 pounds per acre. One inch of rain, however, would be more than half the mean rainfall in this period. In terms of weather modification, measuring the effects of a 10 percent increase in rainfall would be more realistic. A 10 percent increase in January rainfall would increase yield by 1.13 pounds per acre. Expanded by the 755,057 acres harvested in the region, the increased production of cotton would be 853,214 pounds, or 1,706 bales, plus 727 tons of cottonseed. Production increases from a 10 percent increase in February and March rainfall are 1,465 bales of cotton, 624 tons of cottonseed and 2,477 bales of cotton and 1,055 tons of cottonseed, respectively.

It can be observed that temperatures in August have a negative effect on cotton yield. An increase in August average temperature from its mean value of 80.22F to 81.22F would cause cotton yield to decline by 12.92 pounds per acre. Cotton would seem to be quite sensitive to high August temperatures in this region.

The technology variable in this equation is expressed in a quadratic form. The negative coefficient for the squared term reflects the fact that technology tends to move ahead in bursts. After each burst, its effect on crop yield becomes less and less until the point at which increased applications of the same technology become counter-productive. It would appear from the solution to the quadratic that the region may be in a period of decreasing influence for technology with respect to cotton.

3.2.2 Grain Sorghum

The regional model for grain sorghum is very simple in terms of the variables; they are few in number and all in linear forms. The model, however, is successful in accounting for 83 percent of the year-to-year variation in yields at the 99.5 percent confidence level. Specifically, the grain sorghum model is:

$$\hat{Y} = 394.47 + 103.72X_1 + 107.58X_2$$

where:

$\hat{Y}$ = estimate of grain sorghum yield per acre (lbs).

X_1 = sum of January through March rainfall (inches).

X_2 = sum of June through August rainfall (inches).

As in the cotton model, preseason rainfall is an important determinant of grain sorghum yields. Each inch of January to March rainfall in the region increases yields by nearly 104 pounds per acre, about 8 percent of the average yield over the period of record. Ten percent increases in the mean rainfall at the center of grain sorghum production in the months of January, February, and March would increase production in the region by 6.2, 5.0, and 10.4 pounds per acre, respectively. Applied to the 298,250 acres harvested in the region, a 10 percent increase in mean rainfall from January through March would increase regional sorghum production by over 6.4 million pounds, or 114,623 bushels.

A similar increase in rain during the summer months from June through August would result in even larger gains. Mean rainfall at the production center during the summer months was 6.64 inches during the period of this study. Two-thirds of an inch of additional precipitation, therefore, would increase regional sorghum production by over 21 million pounds.

The absence of a temperature variable from this model does not mean that temperature does not have an effect on crop yield. In fact, the crop reporting district models listed in Appendix A indicate that temperature is related to yield in three of the four cases. The meaning of the regional model is that the two rainfall terms, taken alone, account for 83 percent of the variation in annual yields. The remaining 17 percent of the variation is the result of other factors, such as temperature, technology, and wind. The absence of a technology term in the equation probably results from the relatively short period of record for grain sorghum.

3.2.3 Wheat

The characteristics of wheat production are such that the yield and weather data had to be treated differently from that for cotton and grain sorghum. Where cotton and grain sorghum are normally produced on a calendar year cycle, wheat is produced on a July to June cycle. For wheat, July to September could be considered to be pre-planting season, October and November the planting season, December to April to be grazing and growing season, and May and June to be the harvest season. For this portion of the study, the benefits arising from grazing wheat during the winter were not considered; only grain wheat yields were regressed against weather variables.

The regional model for wheat contains a technology term, three rainfall terms, and a temperature term.

$$\hat{Y} = 844.90 - 79.49X_1 + 486.61\sqrt{X_1} + 44.70X_2 + 92.98\sqrt{X_3} + 157.68\sqrt{X_4} - 195.79\sqrt{X_5}$$

where:

$\hat{Y}$ = estimate of wheat yield/acre (lbs).

X_1 = level of technology since 1956.

X_2 = sum of October and November rainfall.

X_3 = sum of July through September rainfall.

X_4 = sum of December through April rainfall.

X_5 = average March temperature.

As in the cotton model, the technological level reaches a point where additional application of the same forms of technology will actually decrease production. This can be interpreted to mean that one cannot simply continue to increase applications of technological innovations and expect to receive increased returns.

As might be expected, any rainfall received from July to April will positively affect crop yield. The small number of acres harvested within the region, however, makes wheat a rather insignificant crop. The acreage harvested for wheat grain is only 4 percent of that harvested for cotton, so any economic effects from increased rainfall are also small. For example, a 10 percent increase in rainfall during the December through April growing season would only increase regional production by 9,050 bushels. In the July to September pre-planting period, a 10 percent increase would only raise production by 6,057 bushels. However, wheat has a value in terms of grazing during the winter months which will be considered in the next phase of the project.

4. ECONOMIC EFFECTS OF INCREASED YIELDS DUE TO WEATHER MODIFICATION

The Crop Response functions described in the previous section provide some of the information necessary to estimate the economic effects of additional rainfall caused by weather modification. In conjunction with data on crop prices and harvested acreage, the crop yield regression models can be used to make a preliminary estimate of the direct economic effect on agricultural incomes in the region of increasing crop yields. The effects of weather modification on other sectors of the regional economy will be addressed in later stages of this study.

Average harvested acreage for each of the three major crops was determined from Texas Crop and Livestock Reporting Service data for the years 1964 through 1973. Table 1 shows these average acreages for each of the four crop reporting districts and for the region as a whole. Two districts, 1-South and 2-South, contain approximately 90 percent of all the harvested acreage in the region.

Table 3 gives the average prices received by farmers for the three crops in 1967. The year 1967 was chosen because it is the base year for the input-output model which will be used later to estimate the economic activity in the region which would be induced by additional income received by the farming sectors.

Two major assumptions have been made with respect to costs in the determination of the economic effects of increased yields in this study. First, it is assumed that the agricultural producers in the region are not paying the cost of weather modification activities. While this may not necessarily be true in future projects, the assumption seems reasonable in this case because the project was formulated to stabilize the municipal water supplies in the region and the agricultural benefits are external to this primary goal. The second necessary assumption is that the effect of increased rainfall would be to improve the results a farmer would get from whatever level of technology and skill he applied to crop production. It is assumed that the farmer would not increase the amount of fertilizer, seed, or machine time he used, but rather, for each given amount of these things, his return would be better. The only costs which would increase with the higher yields would be the costs of transporting and storing the extra production. Since the changes in yield per acre which result from the amounts of additional rainfall assumed in this study are small, no attempt was made to net the transportation and storage costs out of the gross change in farm receipts which were computed.

TABLE 3

Prices Received by Farmers in 1967

Crop	Price	Unit
Cotton	$94.33	500 lb. bale
Cottonseed*	52.55	ton
Grain Sorghum	1.03	56 lb. bushel
Wheat	1.45	60 lb. bushel

* Cottonseed is estimated at .426 tons of cottonseed per bale of cotton produced.

SOURCE: Foote, 1970.

Two assumptions were made with respect to receipts also. First, it was assumed that all of the increased crop production could be sold. Second, it was assumed that the quantity of increased production would not be sufficiently large as to lower the price received for it. Both of these assumptions seemed reasonable since the largest production increase resulting from a 10 percent increase in yield was less than 1 percent of the region's 1973 production.

Table 4 provides a summary of the increases in revenue received by farmers which could be expected as a result of an assumed 10 percent increase in the mean monthly rainfall for the region. This table was developed by applying the increased yields per acre derived in the previous section to the average harvested acreage in the region. The 1967 commodity prices were used to value the change in regional production. Dashes in the table indicate that precipitation for that month was not used in the regression model for a particular crop. This is not an indication that additional rainfall is valueless in those months; it is a result of the regression approach used in this study. For this reason, care should be taken in comparing the total regional effects on income between different months.

Totals for different months should be compared only when the same crops were used to estimate the economic effects in each month. It should also be noted that it is not always possible to sum the monthly values, even for the same crop, to arrive at the total change which would be expected in response to a 10 percent increase in the average rainfall for a group of months. This problem results from the non-linear relationship between crop yields and some of the precipitation variables.

The first three months of the year, however, are present in the regression models for all three crops and are linear for two of them. Table 4 indicates that substantial benefits could result from increased precipitation in the late winter months. For the two major crops grown in the study area, cotton and grain sorghum, the months of January, February, and March comprise the "pre-planting" period. Much of the precipitation during this period is stored in the soil and provides the moisutre that is required to get young plants off to a strong start. The regression models for cotton and grain sorghum reflect the fact that this strong start plays a very important role in determining the ultimate yield of the crop. This is the growing season for wheat and yields presumably respond to greater than average rainfall.

The value of increased production in the region resulting from an assumed rainfall which is 10 percent higher than normal during each of the late winter months ranges from \$205,000 to \$323,600. Differences in the increased production result from the differences in normal monthly rainfall between months. The importance of rainfall to the cotton industry in the study area is reflected by the fact that it comprises less than 70 percent of the acreage harvested in the region, but accounts for over 80 percent of the estimated increase in income.

Increased precipitation in the three summer months would also seem to promise substantial benefits. Increased production of grain sorghum alone could increase income by well over $100,000 in each month where precipitation was raised 10 percent above normal. Since the summer precipitation term in the grain sorghum model is linear, it is possible to sum the monthly effects to arrive at a total of $389,000 additional income which could result from an increase in the average rainfall in the area.

While the regression model for cotton does not include a summer precipitation variable, the correlation between rainfall and yield is positive. It seems entirely reasonable to assume that a moderate (10 percent) increase in precipitation during the growing season would have a beneficial effect on cotton yields. For this reason, it is possible that the monthly totals for the summer months substantially underestimate the additional income which would be generated in the region if it were possible to increase average rainfall by 10 percent. The total regional effects of additional rainfall in spring and fall months also may be underestimates, but the planting and harvesting patterns of cotton and grain sorghum make it almost as likely that they are overestimates.

Table 4 indicates only the direct income effects for the three regional models. The values which were computed for each of the crop reporting district models are shown in Appendix B.

As previously pointed out, Table 4 indicates those direct effects on agricultural income in the region which might be expected to result from an assumed 10 percent increase in precipitation during certain specified months of the year. The total economic effect, however, does not end when that extra income reaches the farmer's pocket. The farmer who received the extra income will spend a certain portion, save a certain portion, and pay taxes. When he spends more money, he is buying goods and services produced by other sectors of the economy. This, in turn, causes other sectors of the economy to increase their output. To produce the increased output these sectors must increase their purchases of raw products and labor. This cycle of business activity continues until virtually every sector of the economy is affected.

One widely-accepted method of estimating the effects of spending in a region and for tracing those effects through the various sectors of a regional economy is the Leontief-type input-output model. This model is essentially a mathematical

TABLE 4

Direct Income Effect by Month and Crop Due
to 10% Increase in Rainfall (Regional Models)*

(Thousands of Dollars)

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cotton	176.3	176.3	264.4	-	-	-	-	-	-	-	-	-
Grain Sorghum	34.1	27.0	56.8	-	-	135.5	135.5	118.0	-	-	-	-
Wheat	2.0	1.7	2.4	4.7	-	-	2.6	2.8	3.5	7.3	3.1	2.2
TOTAL	212.4	205.0	323.6	4.7	-	135.5	138.1	120.8	3.5	7.3	3.1	2.2

* Values based on average acres harvested 1964 - 1973 and on 1967 prices received.

NOTE: Dashes indicate that these variables did not appear in the model.

framework in which the inputs required to produce an industry's output are balanced against the transactions which distribute it among other industries and final consumers. Final consumers include such groups as households, governments, exports, and inventories. Through appropriate manipulation, this model can be used to examine the regional consequences of changes which take place in a single sector.

The relationships between regional output, income, and employment and changes in a specific sector can be shown as numerical multipliers. These multipliers reflect the way in which economic activities are interrelated. For example, an output multiplier for a sector would indicate the total effect on regional output given a unit change in final demand (consumption) for the product of that sector. An income multiplier indicates the total regional change in payments to households resulting from an increase in the output of a sector which would require it to increase its payments to households by one dollar. The mathematics involved in determining these effects are well-established, but are beyond the scope of this report. The reader who is interested in a good introduction to input-output analysis is directed to the list of references following this report.

In the input-output framework, the total change in regional activity which results from a given change in a specific sector can be considered to have three parts. The direct effect consists of the original change in a sector. This direct change brings about an indirect effect as other industries expand their outputs to provide inputs to the original sector. The output expansions in both the original and the indirect industries produce additional income to households whose spending induces a further expansion of output.

It is this induced effect which is most applicable to the case of change resulting from increased rainfall. Since it was assumed that the increased production resulting from any increase in precipitation could be achieved without direct cost to the farmer, the increased revenue would be realized as additional profits in the household sector. Further effects of this added profit come about when the farm household spends it on consumer goods, pays additional taxes, or saves for future investment or consumption. This assumption means that only that output expansion resulting from increased household consumption would result from the increased output of the crop sectors.

It also means that it is not possible to use the input-output multipliers for the three crop sectors to estimate the indirect and induced effects of increased output without first adjusting the model. One of the basic assumptions of the input-output model is that an industry's "production recipe" is fixed. When we assume that all of the additional revenue would go to households, we are implicitly changing the recipe. Determination of precise output, income, and employment effects would require a time-consuming process of adjustment and manipulation. Since the input-output model being used in this first phase of the study will be replaced in later phases by one which was developed solely for this region, it was decided to only approximate the consumption effects of increased crop revenues at this time.

An estimate of the regional effects of increased crop production can be made by referring to the household column of the input-output tables and asking the questions "What is the effect of an increase in household spending?" It is assumed that farm households have approximately the same consumption patterns as all other households in the region and that household consumption patterns do not change over the relevant range of incomes. Under these conditions, a multiplier can be calculated which reflects the output expansion generated in the region in response to a change in the household sector.*

Tables included in an existing model of the Texas High Plains were used to estimate the total regional effects of increased crop production and revenue associated with assumed increases in average precipitation (Osborn, 1972). The household-output multiplier described above is 1.497 in this model. This means that each dollar of household spending generates an additional fifty cents of activity in the region. This multiplier appears reasonable in light of the induced effects shown in Table 5.

A range within which the "true" regional effect of increased crop production probably lies is estimated by the direct plus induced effects on the upper end and the direct plus consumption effects on the lower side. The induced effect includes activity generated by indirect effects we have assumed did not increase, while the consumption effect neglects the adjustments in other components of final demand which result from increased household taxes and savings.

The range of total output effects in the region resulting from an assumed 10 percent increase in precipitation can be determined by applying the household output and induced effect multipliers to the values found in Table 4 and Appendix B. For example, Table 4 shows that if rainfall in March could be increased by 10 percent, revenue from cotton would increase by $264,400, revenue from grain sorghum would increase $56,800 and revenue from wheat by $2,400. This produces a total direct effect of $323,600 in the region. This direct increase in

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* This multiplier is given by dividing the sum of the household column in the closed model interdependence matrix by the element in the household row.

TABLE 5. Output Multiplier Effects

Sector	Direct Effect	Induced Effect
Cotton	1.00	1.640
Grain Sorghum	1.00	1.496
Wheat	1.00	1.183

Source: Osborn, 1972

output would generate activity of at least \$484,400 (\$323,600 x 1.497). Multiplying the induced effect multipliers from Table 5 by the change in each respective crop gives an upper estimate of the total regional effect. In this case, the cotton output effect is \$433,600 (\$264,400 x 1.640), the grain sorghum effect is \$85,200 (\$56,800 x 1.496), and the wheat effect is \$2,800 (\$2,400 x 1.183). This gives a total output effect of \$521,600 for the region.

Further examples of this procedure could be given but would serve little purpose. The purpose of this procedure is to provide a rough estimate of the regional effects of weather modification which will be refined later by making the required adjustments to a model developed for this area in order to make the estimates in a "strict" input-output framework. The development of a model for this specific area will also facilitate the computation of income and employment effects of increased production in the region. No attempt was made to estimate these effects during this phase of the study.

5. SUMMARY AND FUTURE PLANS

5.1 Summary

The purpose of this phase of the study was to determine yield-weather-technology relationships for three major crops which could be used to estimate the economic effects of weather modification activities. Multiple regression analysis was used to quantify the functional relations which were used to estimate the crop yield response to assumed increases in precipitation. The estimates of increased crop production were converted to monetary values in order to determine their regional economic effects. An input-output model was used to give an preliminary estimate of the additional activity generated in the region by increased crop revenues.

Some of the major findings of this study were:

1. The greatest crop response to increases in rainfall occurs when the precipitation is received before the crop is planted or during its growing season. For the two major crops, cotton and grain sorghum, these two periods include the months of January, February, and March, and June, July and August, respectively. During these periods, significant increases in crop production could result from increased average precipitation.

2. The effects of technology on the production of cotton and wheat appear to adhere to the ecnomic principle of diminishing marginal returns. That is, the influence of a particular technology decreases over time. For each additional increment of the technological factor, a smaller return is realized.

3. Substantial increases in regional crop revenue could result from an increase in mean monthly precipitation of 10 percent in the late winter and summer months. The greatest economic benefit in terms of direct revenue resulting from increased rainfall in a single month would occur in March. Based on 1967 prices, crop revenue in the study area could increase by approximately $323,600 if normal March precipitation could be increased by 10 percent.

4. There are significant regional effects on output, income, and employment associated with the spending

of increased receipts from crop production. Because of the nature of the assumed increases in production, it was not possible to directly estimate the regional effects through the input-output model. However, an existing input-output model was used to estimate a range within which the total regional effect should be contained. This range indicates that the total effect of a 10 percent increase in normal March precipitation would be in the order of $500,000.

5.2 Future Plans

During the next phase of this study further effects of increased precipitation are to be examined. Of primary concern will be determination of rangeland response to increases in rainfall. Some preliminary work has already been done to provide the basis for this task. However, since this is a relatively new field of research, new methods of determining this response may have to be developed.

Once this rangeland response is determined, indirect relationships between increased rainfall and livestock production will be estimated. Although it is expected that the quantity of rainfall will have no effect on the numbers of livestock raised, it is felt that it will have a very strong effect on the cost of bringing the livestock to market weight.

As the data on livestock response becomes available, it will be combined with the data on crop response already determined, and production functions for each enterprise will be computed. The use of these production functions in a linear programming framework will determine the optimum mix of crops and livestock in order to maximize returns to the agricultural sectors of the regional economy for different assumed increases in precipitation.

An input-output model will be constructed for this region. This model will be used to perform the estimation of regional output, income, and employment effects of increased crop production. Adjustments to the model will be made in order to estimate the indirect and induced effects and to compute precise multipliers for each agricultural sector.

Estimates of the economic effects of weather modification on non-agricultural sectors of the economy will be made. These estimates will be related to the agricultural effects to arrive at an overall economic impact model for the Big Spring-Snyder Study Area.

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APPENDIX A

Crop Response Regression Models

Regional Cotton

$$\hat{Y} = 649.84 + 41.81X_1 - 1.86X_1^2 + 5.20X_2 - 0.08X_3^2$$
$$(7.84400)^* \quad (0.47863) \quad (1.25588) \quad (0.03567)$$

$\bar{Y}$ = 292.74 lbs/acre

X_1 = Technology Level 2 (6.28)**

X_2 = Sum of January thru March Rain (1.88 inches)

X_3 = Average August Temperature (80.22F)

S.E. = 60.6358

$F_{4,24}$ = 25.430

R^2 = .8091

* Indicates Standard Error of the Regression Coefficient

** Indicates Mean Value of the Variable

District 1-S Cotton

$$\hat{Y} = 1734.49 + \underset{(9.94424)}{59.70\sqrt{X_1}} + \underset{(22.00092)}{135.30X_2} + \underset{(12.19148)}{34.98X_3} - \underset{(1.24375)}{3.28X_3^2}$$

$$+ \underset{(15.10206)}{52.74X_4} - \underset{(207.48672)}{568.77\sqrt{X_5}}$$

$\bar{Y}$ = 331.12 lbs/acre

X_1 = Technology Level 2 (6.88)

X_2 = January Rainfall (0.50 inches)

X_3 = October Rainfall (2.11 inches)

X_4 = June Minimum Temperature (64.14°)

X_5 = Average June Temperature (78.37°)

S.E. = 52.4308

$F_{6,19}$ = 20.341

R^2 = 0.8653

District 2-S Cotton

$$\hat{Y} = 735.7 + 35.41X_1 - 1.59X_1^2 + 2.07X_2^2 + 40.46X_3 - 2.78X_3^2 - .11X_4^2$$
$$\qquad (8.49707) \quad (0.51986) \quad (0.72217) \quad (13.65876) \quad (0.76803) \quad (0.03697)$$

$\bar{Y}$ = 246.32 lbs/acre

X_1 = Technology Level 2 (6.46)

X_2 = Sum of January thru March Rain (2.61 inches)

X_3 = Sum of June thru August Rain (6.69 inches)

X_4 = Average August Temperature (81.62F)

S.E. = 59.9543

$F_{6,21}$ = 18.807

R^2 = .8431

District 7 Cotton

$$\hat{Y} = -838.83 + 22.29X_1 - 1.42X_2^2 + 80.18\sqrt{X_2} - 4.32X_3 + 4.93X_4$$
$$\quad (6.00070) \quad (0.36777) \quad (19.26168) \quad (1.79254) \quad (2.18906)$$

$$- 40.94X_5 - 0.10X_6^2 + 473.13\sqrt{X_7}$$
$$(12.40246) \quad (0.02511) \quad (193.99545)$$

$\bar{Y}$ = 131.75 lbs/acre

X_1 = March Rainfall (0.87 inches)

X_2 = Sum of June thru August Rainfall (5.31 inches)

X_3 = March Minimum Temperature (39.93F)

X_4 = April Minimum Temperature (51.46F)

X_5 = July Minimum Temperature (70.90F)

X_6 = Average August Temperature (82.11F)

X_7 = Average July Temperature (83.58F)

S.E. = 22.8199

$F_{8,11}$ = 11.615

R^2 = 0.8942

Regional Grain Sorghum

$$\hat{Y} = 394.47 + 103.72X_1 + 107.58X_2$$
$$(20.39296) \quad (15.78954)$$

$\bar{Y}$ = 1323.87 lbs/acre

X_1 = Sum of January thru March Rainfall (2.08 inches)

X_2 = Sum of June thru August Rainfall (6.64 inches)

S.E. = 146.7702

$F_{2\ 12}$ = 29.543

R^2 = 0.8312

District 1-S Grain Sorghum

$$\hat{Y} = 205.22 + \underset{(53.00731)}{283.15\sqrt{X_1}} + \underset{(13.92439)}{107.80X_2}$$

$\bar{Y}$ = 1280.47 lbs/acre

X_1 = Sum of January thru March Rainfall (2.02 inches)

X_2 = Sum of June thru August Rainfall (6.69 inches)

S.E. = 132.0531

$F_{2,12}$ = 34.890

R^2 = 0.8533

District 2-N Grain Sorghum

$$\hat{Y} = 549.87 + \underset{(1.78716)}{17.73\,X_1^2} - \underset{(50.30510)}{206.50\,X_2} + \underset{(19.38885)}{90.63X_3} - \underset{(16.26463)}{98.05X_4}$$

$$- \underset{(8.75810)}{56.03X_5} + \underset{(27.28056)}{166.07X_6}$$

$\bar{Y}$ = 1434.67 lbs/acre

X_1 = Sum of January thru March Rainfall (2.43 inches)

X_2 = November Rainfall (0.77 inches)

X_3 = May Minimum Temperature (56.39F)

X_4 = July Maximum Temperature (93.48F)

X_5 = August Maximum Temperature (92.63F)

X_6 = September Minimum Temperature (60.73F)

S.E. = 111.5301

$F_{6,8}$ = 26.930

R^2 = 0.9528

District 2-S Grain Sorghum

$$\hat{Y} = 27{,}745.33 + 3.34X_1^2 + 34.77X_2^2 - 867.45\sqrt{X_2} + 12.76X_3^2$$
$$\qquad (0.44046) \quad (6.05526) \quad (233.21810) \quad (2.09549)$$
$$- 941.96\sqrt{X_3} - 2628.80\sqrt{X_4}$$
$$(136.71226) \quad (275.62834)$$

$\bar{Y}$ = 1484.73

X_1 = Technology Level 3 (8.00)

X_2 = Sum of April and May Rainfall (4.31 inches)

X_3 = Sum of September and October Rainfall (5.75 inches)

X_4 = Average July Temperature (82.61F)

S.E. = 98.7518

$F_{6,8}$ = 34.489

R^2 = 0.9628

District 7 Grain Sorghum

$$\hat{Y} = 10{,}175.54 + 143.17X_1 - 137.38X_2 + 88.07X_3 - 34.87X_4 - 72.76X_5$$

Standard errors: X_1 (60.81408), X_2 (40,77976), X_3 (27.28590), X_4 (15.18061), X_5 (21.91383)

$\bar{Y}$ = 1285.07 lbs/acre

X_1 = March Rainfall (0.95 inches)

X_2 = August Rainfall (1.76 inches)

X_3 =September Rainfall (3.50 inches)

X_4 = April Maximum Temperature (80.34F)

X_5 = May Maximum Temperature (86.47F)

S.E. = 190.7422

$F_{5,9}$ = 12.941

R^2 = 0.8779

Regional Wheat

$$\hat{Y} = 844.90 - \underset{(18.73825)}{79.49X_1} + \underset{(94.83071)}{486.61\sqrt{X_1}} + \underset{(16.27723)}{44.70X_2} + \underset{(28.33143)}{92.98\sqrt{X_3}}$$

$$+ \underset{(37.59735)}{157.68\sqrt{X_4}} - \underset{(61.67843)}{195.79\sqrt{X_5}}$$

$\bar{Y}$ = 711.54 lbs/acre

X_1 = Technology Level 2 (6.69)

X_2 = Sum of October and November Rainfall (3.15 inches)

X_3 = Sum of July thru September Rainfall (6.85 inches)

X_4 = Sum of December thru April Rainfall (5.32 inches)

X_5 = Average March Temperature (53.85F)

S.E. = 88.2800

$F_{6,19}$ = 34.320

R^2 = 0.9155

District 1-S Wheat

$$\hat{Y} = -2553.39 + \underset{(9.47279)}{31.74X_1} - \underset{(1.60833)}{4.76X_2^2} + \underset{(120.40596)}{384.81\sqrt{X_2}} + \underset{(50.64331)}{225.14\sqrt{X_3}}$$

$$+ \underset{(16.02179)}{65.52X_4} - \underset{(376.58002)}{1156.12X_5} + \underset{(16.01481)}{50.61X_5^2} + \underset{(886.33449)}{2646.87\sqrt{X_5}}$$

$\overline{Y}$ = 728.96 lbs/acre

X_1 = Technology Level 1 (15.58)

X_2 = Sum of July thru September Rainfall (6.33 inches)

X_3 = Sum of October and November Rainfall (2.84 inches)

X_4 = Sum of December thru April Rainfall (3.26 inches)

X_5 = Sum of May and June Rainfall (4.04 inches)

S.E. = 130.8437

$F_{8,15}$ = 13.054

R^2 = 0.8744

District 2-N Wheat

$$\hat{Y} = 1554.00 + 1.89X_1^2 - 37.28X_2 - 77.43X_3 + 166.45\sqrt{X_4}$$
$$(0.30514) \quad (11.47123) \quad (22.63114) \quad (62.19641)$$

$$+ 31.11X_5 + 27.27X_6 - 18.78X_7 - 36.56X_8 - 25.22X_9$$
$$(11.82351) \quad (9.49562) \quad (5.29623) \quad (8.91861) \quad (4.34630)$$

$\bar{Y}$ = 791.86 lbs/acre

X_1 = Technology Level 2 (7.10)

X_2 = August Rainfall (2.39 inches)

X_3 = June Rainfall (2.27 inches)

X_4 = Sum of May and June Rainfall (5.27 inches)

X_5 = August Minimum Temperature (65.65F)

X_6 = November Minimum Temperature (36.49F)

X_7 = January Minimum Temperature (24.68F)

X_8 = June Minimum Temperature (63.33F)

X_9 = November Maximum Temperature (64.54F)

S.E. = 93.6244

$F_{9,11}$ = 17.308

R^2 = 0.9340

District 2-S Wheat

$$\hat{Y} = -1836.68 - \underset{(18.83640)}{91.02X_1} + \underset{(95.39020)}{530.49\sqrt{X_1}} + \underset{(27.81308)}{178.36\sqrt{X_2}} + \underset{(0.58954)}{4.56X_3^2}$$

$$-\underset{(0.60540)}{2.19X_4^2} - \underset{(0.03282)}{0.17X_5^2} + \underset{(97.97012)}{240.96\sqrt{X_6}}$$

$\bar{Y}$ = 813.37 lbs/acre

X_1 = Technology Level 2 (8.16)

X_2 = Sum of July thru September Rainfall (7.43 inches)

X_3 = Sum of December thru April Rainfall (5.93 inches)

X_4 = Sum of May and June Rainfall (6.01 inches)

X_5 = Average March temperature (53.57F)

X_6 = Average April Temperature (64.60F)

S.E. = 69.5204

$F_{7,11}$ = 28.814

R^2 = 0.9483

District 7 Wheat

$$\hat{Y} = -20{,}127.20 + \underset{(103.21078)}{588.45X_1} - \underset{(63.05197)}{260.85\sqrt{X_2}} + \underset{(1.11760)}{5.16X_3^{\,2}} + \underset{(1.90882)}{7.75X_4^{\,2}}$$

$$\underset{(6.94615)}{-31.83X_5^{\,2}} + \underset{(331.17780)}{1656.60\sqrt{X_5}} - \underset{(0.08594)}{0.23X_6^{\,2}} + \underset{(293.97966)}{1070.12\sqrt{X_7}}$$

$\bar{Y}$ = 693.00 lbs/acre

X_1 = Technology Level 1 (16.82)

X_2 = Technology Level 2 (8.24)

X_3 = Sum of July thru September Rainfall (5.52 inches)

X_4 = Sum of December thru April Rainfall (5.19 inches)

X_5 = Sum of May and June Rainfall (5.13 inches)

X_6 = Average March Temperature (55.04F)

X_7 = Average May Temperature (73.24F)

S.E. = 123.7949

$F_{8,8}$ = 8.116

R^2 = 0.8903

APPENDIX B

Estimated Direct Economic Effects Using Crop Reporting District Models

APPENDIX B

Direct Income Effect by Month and Crop Due to 10% Increase in Rainfall (District Models)*

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
District 1-S												
Cotton	792.6	-	-	-	-	-	-	-	-	505.5	-	-
Grain Sorghum	24.4	18.6	40.2	-	-	109.0	104.9	87.4	-	-	-	-
Wheat	.6	.5	.9	1.7	(-3.0)	(-2.6)	.5	.4	.5	2.4	.6	.4
District 2-N												
Cotton	16.7	16.7	16.7	-	-	45.3	45.3	45 3	-	-	-	-
Grain Sorghum	2.1	1.7	3.1	-	-	-	-	-	-	-	(-5.2)	-
Wheat	-	-	-	-	.7	(-.6)	-	(-.6)	-	-	-	-
District 2-S												
Cotton	21.9	21.9	43.9	-	-	22.2	16.4	16.4	-	-	-	-
Grain Sorghum	-	-	-	16.8	24.6	-	-	-	13.7	9.3	-	-
Wheat	2.1	2.4	2.9	5.7	4.3	3.7	3.2	3.8	5.0	-	-	3.0
District 7												
Cotton	-	-	-	-	-	.2	.2	.2	-	-	-	-
Grain Sorghum	-	-	.6	-	-	-	-	(-1.1)	1.5	-	-	-
Wheat	.2	.2	.2	.3	.1	.1	.1	.4	.3	-	-	.1
TOTAL	860.6	62.0	108.5	29.2	26.7	177.3	170.6	152.2	21.0	517.2	(-4.6)	3.5

* Values based on average acres harvested 1964 - 1973 and on 1967 prices received.

NOTE: Dashes indicate that these variables did not appear in the model.