IRRIGATION WATER REQUIREMENTS FOR CROP PRODUCTION IN THE ROSWELL ARTESIAN BASIN

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In 1956 the State Engineer and Pecos Valley Artesian Conservancy District jointly filed a suit to obtain a judicial determination of water rights, both artesian and shallow aquifers, in the Roswell Artesian Basin. The court on January 10, 1966 filed a partial final judgment and decree which further defined water rights in the Roswell Artesian Basin. The duty of water for irrigated agriculture was established at three acre-feet per acre per annum, only to be exceeded in any one year provided that the total amount diverted during any period of five consecutive years shall not exceed five times the annual duty of water.

A study was initiated in the Spring of 1966 at the request of the Pecos Valley Artesian Conservancy District through the New Mexico Water Resources Research Institute to assemble and analyze existing cropping patterns, water use, water quality, soil quality, crop yields, and income effects from the above-mentioned factors for the Roswell Artesian Basin in Southeastern New Mexico. This paper is concerned with the economic or income aspects of the problem.

The data for the economic analysis was derived from information obtained on 12 case study farms for the calendar years 1966, 1967 and 1968.

Linear programming was chosen as an analytical tool for the economic analysis. For the purpose of this study linear programming was used as a budgeting tool (it is a fast method for budgeting many alternative crop combinations). The primary purpose of the economic analysis was to determine the effect of different quantities of irrigation water on net farm returns.

Three linear programming models were developed from data derived from the 12 case study farms (models A, B, and C) and three for an analysis of the entire Roswell Artesian Basin (Models D, E, and F).

Case Farms

Model A

Designed to provide short-term optimal solutions with present crop enterprises based on 12 case farms, using less than three acre-feet of irrigation water. This was achieved by including only the necessary constraints which were: 1) land (size of farm)--a maximum of 209.88 acres; 2) irrigation water--a maximum depending on specified diversion level; 3) cotton allotment--a maximum of 84.34 acres.

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Model B

Designed to analyze the effect of a 5 percent increase in farm irrigation efficiency, using the same case farm data and constraints as in Model A.

Model C

Designed to meet the requirements of the government upland cotton program for the 12 case farms with about one-third of the water-right acres devoted to a soil conserving crop such as alfalfa. The constaints for Model C were the same as for Model A except for an additional constraint on a minimum alfalfa acreage of 67.64 acres. This was necessary to ensure an adequate alfalfa acreage at low diversion levels of irrigation water.

Roswell Artesian Basin

Model D

Designed to provide a short-term optimal solution with present farm enterprises, using less than three acre-feet of irrigation water per acre. Similar to Model A, but based on the entire Roswell Artesian Basin. The constrains were: 1) land--a maximum of 133,840 acres (water-right acres for the basin); 2) cotton allotment--a maximum of 37,800 acres; 3) irrigation water--a maximum depending on specified diversion level.

Model E

Designed to meet the requirements of the government upland cotton program for the basin with 52,940 acres or more of alfalfa, or about 40 percent of the total water-right acres in the basin. (Similar to Model C but applied to the entire basin).

Model F

Designed to analyze the effect of changing amounts of water diverted to a cropping pattern that closely represents the cropping pattern found in the basin in 1967. The model contained the same provisions as Model E but restricted the production of grain sorghum, forage crops, pecans, and castor beans, and required the production of small grains on a minimum of 7,000 acres. Acreages of alfalfa and small grains, approximately those of the present acreage in the basin, were used as the minimum.

The quantities of irrigation water considered in Models A, B, and C were 2.50 through 4.00 acre-feet per water-right acre, on one-quarter acre-foot intervals. The quantities considered in Models D, E, and F were 2.25 through 4.50 acre-feet per water-right acre, on one-quarter acre-foot intervals.

Cotton

Three cotton diversion plans were included in the linear programming models. These plans were designated as cotton 65, cotton 80, and cotton 95. Each acre of cotton 65 included 65 percent of the acre planted to cotton and 35 percent diverted under the government cotton program; cotton 80 included 80 percent of the acre planted to cotton and 20 percent diverted; and cotton 95 included 95 percent of each acre planted to cotton and 5 percent diverted. The water diversion and net return coefficients varied with each of the three cotton enterprises because of the different percentages of each acre planted to cotton in the three enterprises. The average irrigation water coefficients for the three cotton enterprises are presented in table 2.

Alfalfa

Four variations of alfalfa enterprises were included in the linear programming models as follows:

Alfalfa A was developed from data derived from the case farms for the production of alfalfa hay, with 4.67 acre-feet diverted, basically applied in one irrigation per cutting plus one winter irrigation and an average yield of 5.5 tons per acre.

Alfalfa B was developed from data derived from the case farms for the production of alfalfa seed and/or pasture.

Alfalfa C had a more intensive application of water than alfalfa A, using 5.33 acre-feet or irrigation water application in two 4-inch irrigations between cuttings plus two winter irrigations, with an average yield of 7.3 tons per acre.

Alfalfa D enterprise had a more intensive application of water than either alfalfa A or C, using 6.00 acre-feet of irrigation water applied in two 5-inch irrigations between cuttings plus two winter irrigations, with an average yield of 8.5 tons per acre.

The yields for crops used in the models were derived from yield data on the 12 case study farms. Prices received for commodities are reported in table 1.

The average irrigation water coefficients for the crop enterprises included in the linear programming models are presented in table 2.

Table 1. Product prices and yields, linear programming models A, B, C, D, E, and F, Roswell Artesian Basin, New Mexico.

Crop	Units	Average Yield per Acre	Average Price (dollars)
Cotton [1]			
Lint	lb	730	0.30
Seed	ton	0.6	72.00
Price support [2]	lb	750	0.1106
Diversion [2]	lb	750	0.1070
Alfalfa hay [1]	ton	5.5	25.00
Grain sorghum [1]	cwt	55.0	1.80
Forage crops [1]	ton	19.0	7.20
Small grains [1]			
Hay	ton	3.5	20.00
Grain	bu	50.0	1.00
Pasture [3]	a.u.m.	9.0	2.70
Fruits and vegetables [3]		--[4]	--[5]
Miscellaneous			
Castor beans [3]	lb	2,800.0	0.06

[1] Average of 12 case farms.
[2] Projected yield.
[3] From secondary data.
[4] Lettuce, 450 cartons; onions, 500 bags.
[5] Lettuce, $1.70 per carton; onions, $1.75 per bag.

Table 2. Coefficients for crop enterprises, linear programming models, Roswell Artesian Basin, New Mexico.

Crop Enterprise	Average Irrigation Water Diversion per Acre: Models A, C, D, E, F (acre-feet)	Model B (acre-feet)
Cotton (65) [1]	1.81	1.72
Cotton (80) [2]	2.23	2.12
Cotton (95) [3]	2.65	2.52
Alfalfa (A) [4]	4.67	4.44
Alfalfa (B) [5]	3.53	3.35
Alfalfa (C) [6]	5.33	5.06
Alfalfa (D) [7]	6.00	5.70
Grain sorghum	2.25	2.14
Forage crops:		
Forage sorghum	1.47	1.40
Corn silage	1.79	1.70
Small grains:		
Oats	2.17	2.06
Barley	1.50	1.42
Rye	0.45	0.43
Pasture [8]	4.00	3.80
Pecans [8]	6.01	5.71
Fruits and vegetables [8]	3.25	0.00
Miscellaneous:		
Castor beans	2.33	2.21

[1] 65 percent cotton, 35 percent diverted.
[2] 80 percent cotton, 20 percent diverted.
[3] 95 percent cotton, 5 percent diverted.
[4] One irrigation between cuttings.
[5] Alfalfa for seed or pasture.
[6] Two 4-inch irrigations between cuttings.
[7] Two 5-inch irrigations between cuttings.
[8] Not included in models A, B, and C.

RESULTS

Linear Programming Solutions -- Case Farms

Following are results of linear programming solutions for models A, B, and C. A typical farm budget was developed to compare with results of linear programming to determine the economic effect of restricting the diversion of irrigation water at seven different levels. The composition of the average net farm return was 91.35 per water-right acre.

Cotton

In models A and B cotton would be produced on 38.2 percent of the cropland at all levels of irrigation water diversions. In model C cotton would be produced on 32.2 percent of the cropland at 2.50 acre-feet diversion level and then on 38.2 at the 3.00 acre-feet level and above (figure 1)

Alfalfa

In models A and B, Alfalfa D would be produced on about 10 percent of the cropland at 2.50 acre-feet per acre diversion level and increase in almost a linear relationship to over 40% at 4.00 acre-feet per acre. In model C, by forcing in approximately 30% of the farm in alfalfa at the lower diversion levels, a mixture of alfalfa A, B, C, and D would be produced but at higher diversion levels all alfalfa D would be produced.

Other Crops

In models A and B over 45 percent of the cropland would be planted in grain sorghum, forage sorghum and castor beans at the lower irrigation water diversion levels but would decrease in almost a linear relationship to about 15 percent of the cropland at the 4.00 acre-feet per acre diversion level. This was a result of alfalfa substituting for other crops and fallow land as more irrigation water becomes available.

In model C the opposite relationship exists. Other crops comprise about 6 percent of the cropland at the 2.50 acre-feet per acre diversion level but increase to over 20 percent at the 3.5 acre-feet diversion level and then decreases to about 15 percent of the cropland at the 4.0 acre-feet diversion level.

Fallow Land

In models A and B fallow land constitutes about three percent of the cropland at the 2.5 acre-feet diversion level and decreases to about one percent beyond the 2.50 acre-feet diversion level. In model C, however, fallow land comprises about 22 percent of the cropland at the 2.50 acre-feet diversion level and decreases to about one percent at the 4.0 acre-feet diversion level. The primary reason for the high fallow acreage at the lower irrigation water diversion levels was the requirement of about 30% of the cropland be in the production of alfalfa. As the irrigation water diversion level was increased this requirement became

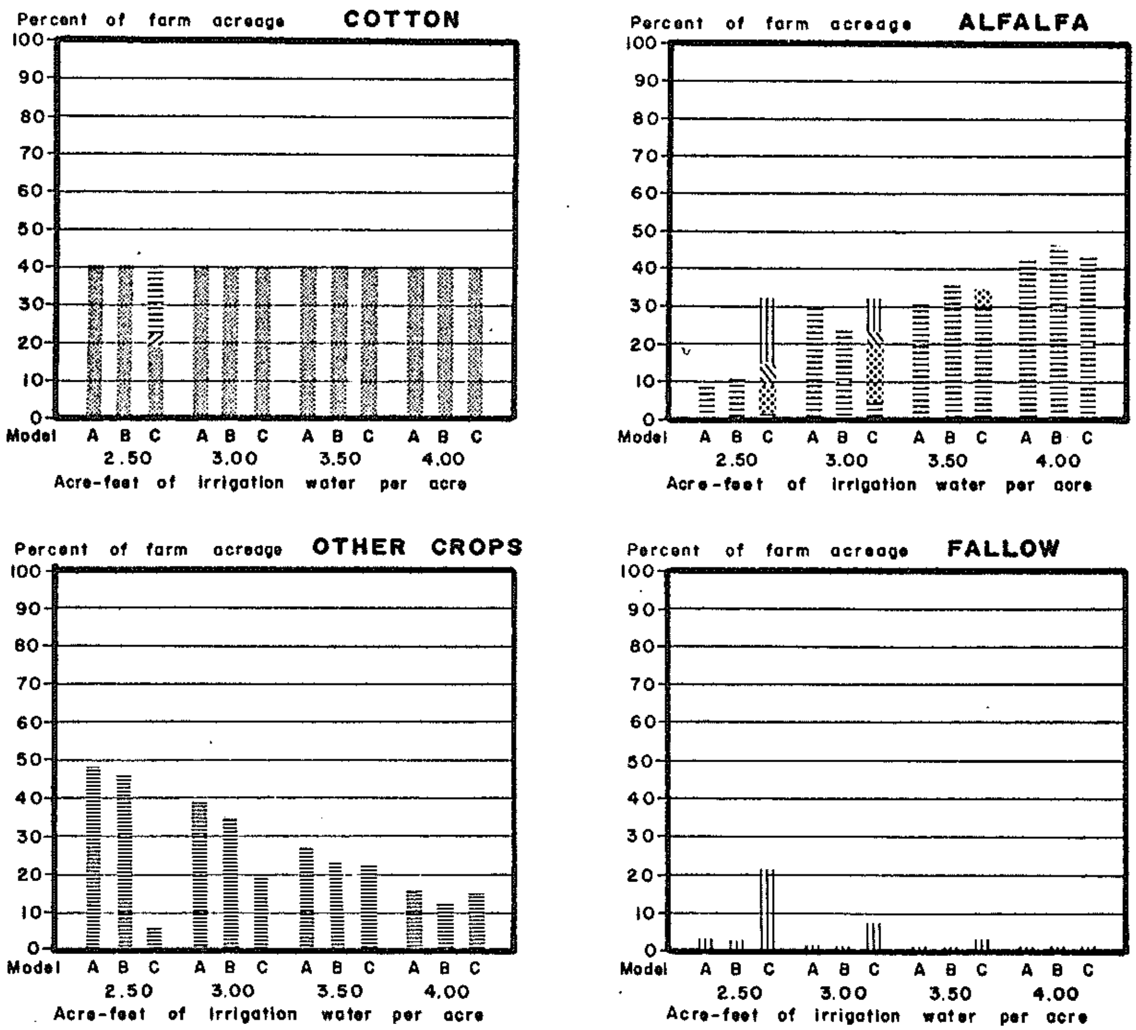

Figure 1. Percent of farm acreage devoted to cotton, alfalfa, other crops and fallow for models A, B, and C, at different irrigation water diversions, Roswell Artesian Basin, New Mexico.

easier to be satisfied. At 4.0 acre-feet per water acre Models A and C had the same cropping pattern.

The results obtained from linear programming Models A, B, and C are graphically summarized in figure 2 which shows the effect of seven quantities of irrigation water on net farm returns. In Models A and B, as irrigation water is increased from 524.70 to 629.64 acre-feet (2.50 to 3.00 acre-feet per water-right acre), net farm return increases at almost a constant rate. From 629.64 to 839.52 acre-feet (3.00 to 4.00 acre-feet per water-right acre) the rate of increase is at a lower constant rate for Models A and B.

In Model C, as irrigation water is increased from 524.70 to 629.64 acre-feet (2.50 to 3.00 acre-feet per water-right acre), the net farm return increases at almost a constant rate. From 629.64 to 734.58 acre-feet (3.00 to 3.50 acre-feet per water-right acre) the net farm return increases at a lower rate, and from 723.58 to 839.52 acre-feet (3.50 to 4.00 acre-feet per water-right acre) the net farm return increases at a still lower rate.

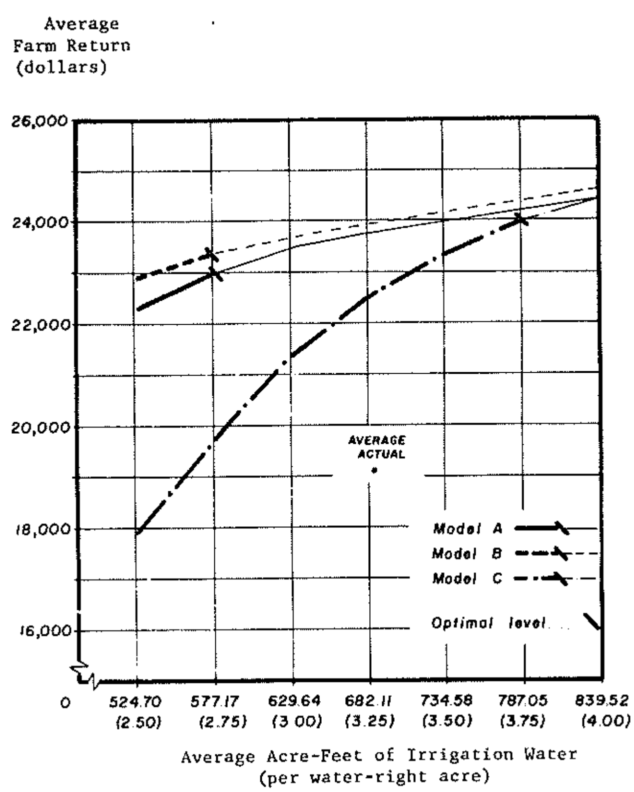

Figure 2. Average farm return and optimal point for operation for seven quantities of irrigation water of 12 case farms, models A, B, and C, Roswell Artesian Basin, New Mexico, 1967.

A comparison of the whole farm budget (3.27 acre-feet per water-right acre) with the optimal cropping programs at the 3.00 acre-feet level in each of models A, B, and C. reflects increased net returns per water-right acre under the optimal cropping programs as follows: Model A, 22.7 percent ($20.78); Model B, 23.8 percent ($21.74); and Model C, 12.0 percent ($10.95). These increased net returns were generated with larger percentages of the water-right acres planted to cotton, increased acreage of such crops as grain sorghum, castor beans, or forage sorghum and decreased acreages of alfalfa, corn silage and small grains.

Optimal Quantity of Irrigation Water - Case Farms

The optimal level of irrigation water diversion for each model can be determined by equating the shadow price with the cost of pumping an acre-foot of irrigation water, which was $7.68. These optimal levels are shown for Models A, B, and C in Figure 2.

The average shadow prices for Model A at the 577.17 and 629.64 acre-feet diversion levels (2.75 acre-feet and 3.00 acre-feet per water-right acre) were $8.58 and $4.80, respectively. Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole farm is equal to $7.68, which is the profit-maximizing point with respect to irrigation water, and likewise for Model B, at the 577.17 and 629.64 acre-feet diversion levels the average shadow prices were $9.02 and $5.06, respectively. Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole farm is equal to $7.68 which is the profit-maximizing point with respect to irrigation water.

In Model C the average optimal quantity of irrigation water was between 787.05 and 839.52 acre-feet (3.75 and 4.00 acre-feet per water-right acre). The average shadow prices for Model C at the 787.05 and 839.52 acre-feet diversion level were $11.54 and $4.13, respectively. Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole farm is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

The primary reason for the higher optimal irrigation water diversion level for Model C was the requirement that about one-third of the water-right acres be in alfalfa. This forced cropland to be left fallow at the lower levels of diversion. Fallow acreage accounted for about 22 percent of the water-right acres at the 2.50 acre-feet diversion level, 13 percent at the 2.75 acre-feet level, 8 percent at the 3.00 acre-feet level, 6 percent at the 3.25 acre-feet level, and 3 percent at the 3.50 acre-feet level.

Linear Programming Solutions -- Roswell Artesian Basin

Following are results of linear programming solutions for Models D, E, and F. A typical basin budget was developed to compare with results of linear programming solutions to determine the economic effect of restricting the diversion of irrigation water at 10 different levels. The composition of the average net basin return of $73.90 per water-right acre is shown in figure 4. The 1967 estimated net farm return to land and management for Roswell Artesian Basin was approximately $9.9 million.

Cotton

In all three models D, E, and F cotton would be produced on the maximum acreage allowed under government cotton program or about 28 percent of the cropland (figure 3).

Alfalfa

In model D alfalfa would be produced on about 2 percent of the cropland at 2.5 acre-feet per acre and would increase in almost linear relationship to 43 percent at 4.0 acre-feet per acre, then increase slightly to about 56 percent at the 4.5 diversion level (figure 3).

In models E and F at the 2.50 acre-feet acre diversion level seed alfalfa would be produced on 39.5 percent of the cropland. As more irrigation becomes available Alfalfa D was substituted for seed alfalfa. At the 4.0 acre-feet per acre diversion level model E has the same cropping program as model D but alfalfa in model F is produced on a slightly higher percentage of the cropland.

Other Crops

In Model D almost 70 percent of the cropland would be in the production of grain sorghum, forage sorghum, or castor beans at the 2.50 acre-feet per acre irrigation water diversion level but would decrease in almost a linear relationship to 15 percent of the cropland at the 4.5 acre-feet diversion level (figure 3). The decrease in acreage was a result of alfalfa substituting for these other crops. In model E other crops varied from 15 percent at the 4.5 acre-feet diversion level to 32 percent at the 3.0 and 3.5 acre-feet diversion levels. In model F other crops varied from 13 percent at the 4.5 acre-feet diversion level to 22 percent at the 3.0 and 3.5 acre-feet diversion levels.

Fallow Land

In model D there would be no fallow land at any of the 10 diversion levels. However, in models E and F by forcing 40 percent of the cropland into the production of alfalfa about 10 percent of the cropland below the 4.0 acre-feet diversion level would be fallowed.

The results obtained from linear programming models D, E, and F are graphically summarized in figure 4 which indicates the effect of 10 quantities of irrigation water on the per-acre net farm returns to the Roswell Artesian Basin.

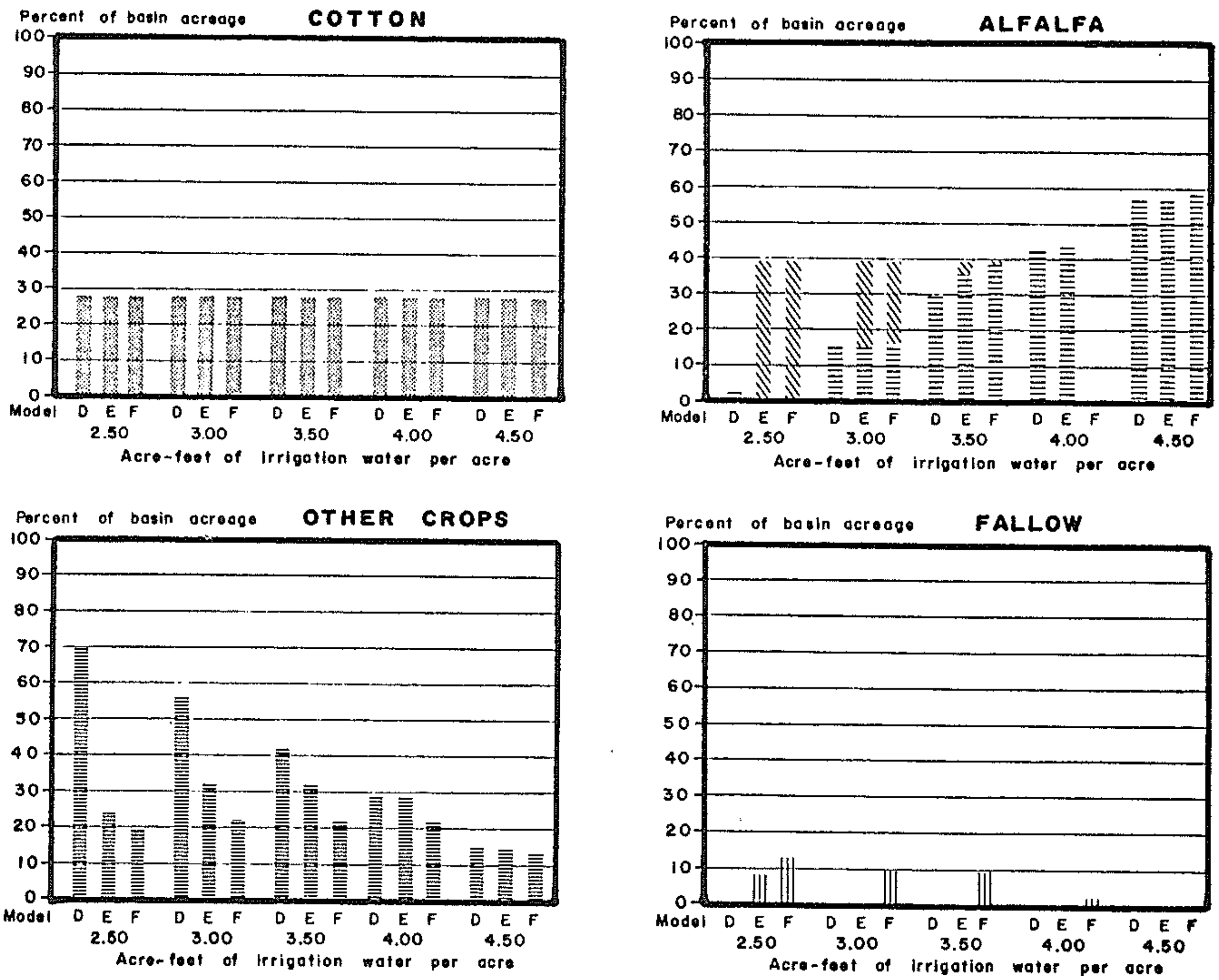

Figure 3. Percent of basin acreage devoted to cotton, alfalfa, other crops, and fallow for models D, E, and F, at different irrigation water diversions, Roswell Artesian Basin, New Mexico.

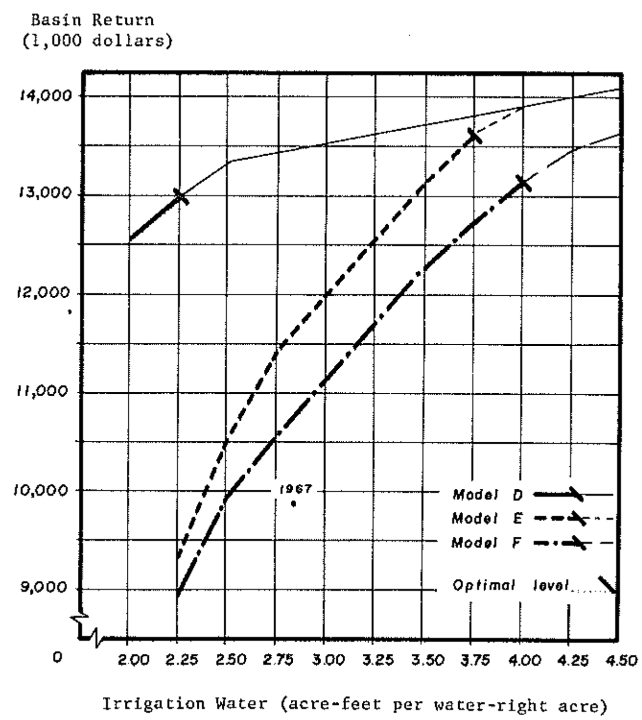

Figure 4. Basin return and optimal point for operation for eleven quantities of irrigation water, models D, E, and F, Roswell Artesian Basin, New Mexico, 1967.

In Model D as irrigation water is increased from 2.25 acre-feet to 2.50 acre-feet per water-right acre, net farm return per acre increases at a constant rate. From 2.50 acre-feet to 4.50 acre-feet per water-right acre net farm return per acre increases at a lower constant rate.

In model E as irrigation water is increased from 2.25 to 2.75 acre-feet per water-right acre, net farm return per acre increases at a decreasing rate, between 2.75 and 3.75 acre-feet it increases at a constant rate, and from 3.75 to 4.50 acre-feet per water-right acre it increases at a decreasing rate.

In model F as irrigation water is increased from 2.25 to 2.50 acre-feet per water-right acre the net return per acre increases at a constant rate, from 2.50 to 3.50 acre-feet it increases at a lower constant rate, and from 3.50 to 4.50 acre-feet it increases at a decreasing rate.

Solutions for linear programming models D, E, and F were also computed at 2.85 acre-feet per water-right acre in order to have a direct comparison with the estimated cropping patterns and net returns for the basin in 1967.

A comparison of the basin budget (2.85 acre-feet per water-right acre) with optimal cropping programs at the 2.85 acre-feet level in each of models D, E and F reflects increased net returns per water-right acre as follows: Model D, 36.3 percent ($26.79); Model E, 17.8 percent ($13.14); and Model F, 15.4 percent ($6.81). These increased net returns were generated primarily by an increase in planted cotton acreage and decreases in fallow land.

Optimal Quantity of Irrigation Water -- Roswell Artesian Basin

The optimal level of irrigation water diversion for each model can be determined by equating the shadow price with the cost of pumping an acre-foot of irrigation water, which was $7.68. These optimal levels are shown for models D, E, and F in figure 4.

Average shadow prices for Model D at diversion levels of 301,140 and 334,600 acre-feet (2.25 acre-feet and 2.50 acre-feet per water-right acre) were $13.60 and $2.80, respectively. Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole basin is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

The average shadow prices for model E at the 501,900 and 535,360 acre-feet diversion levels (3.75 acre-feet and 4.00 acre-feet per water-right acre) were $13.60 and $2.80 respectively. Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole basin is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

In Model F the average optimal quantity of irrigation water was between 535,360 and 568,820 acre-feet (4.00 and 4.25 acre-feet per water-right acre). The average shadow prices for model F at the 535,360 and 568,820 acre-feet diversion levels were $12.66 and $7.13, respectively. Somewhere between these two diversion levels the shadow price for an additional acre-foot of irrigation water for the whole basin is equal to $7.68, which is the profit-maximizing point with respect to irrigation water.

The primary reason for the higher optimal irrigation water diversion level for model E was the constraint that about 40 percent of the water-right acres be in alfalfa. This forced cropland to be left fallow at the lower levels of diversion. Fallow acreage accounted for about 25 percent of the water-right acres at the 2.25 acre-feet diversion level and about 8 percent at the 2.50 acre-feet level.

In model F the optimal irrigation water diversion level was higher mainly because of the constraint that about 40 percent of the water-right acres be in alfalfa, about 5 percent in small grains, and only about 4 percent in grain sorghum, 9 percent in forage crops and about 4 percent in miscellaneous (castor beans) crops. This forced cropland to be left fallow at all except the 4.25 and 4.50 acre-feet diversion levels. Fallow acreage accounted for about 25 percent of the water-right acres at the 2.25 acre-feet diversion level, 13 percent at the 2.50 acre-feet level, 10 percent at the 2.75, 3.00, 3.25, and 3.50 acre-feet levels, 6 percent at the 3.75 acre-feet level, and 2 percent at the 4.00 acre-feet level.

The primary differences between the calculated net farm returns for both the case study farms and Roswell Artesian Basin and the optimal solutions generated by the linear programming models were the result of differences in the cropping programs.