5-1973

Economic (Linear Programming) Model of the Farming Region Served by the D.M.D.A. Irrigation Company, Delta, Utah

Francisco Zarzalejo
Utah State University

ECONOMIC (LINEAR PROGRAMMING) MODEL OF THE FARMING REGION SERVED BY THE D.M.D.A. IRRIGATION COMPANY, DELTA, UTAH

by

Francisco Zarzalejo

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Agricultural Economics

ACKNOWLEDGMENTS

I wish to express my appreciation to Dr. Allen LeBaron, whose guidance contributed in the completion of this study. I am also very grateful to Dr. Darwin Nielsen and Dr. Herbert Fullerton, who were on my Graduate Committee and helped me in this thesis.

Thanks are also given to Dr. Reed Willis, whose aid was very important and to Ministerio Obras Publicas for financial support.

I would like to express my love to my parents, who always encouraged me during my school years and in other aspects of my life.

To my children, Patricia and Francisco Jose Jr., thanks for the many happy times they gave us during those two long years.

Last, but not least, I especially wish to give my sincere thanks to my lovely wife, Diana, whose constant encouragement and sacrifice were my major source of inspiration during my studies in this country.

Francisco Zarzalejo Soto

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Economic (Linear Programming) Model of the
Farming Region Served by the D.M.D.A.
Irrigation Company, Delta, Utah

by

Francisco Zarzalejo, Master of Science

Utah State University, 1973

Major Professor: Dr. Allen LeBaron

Department: Agricultural Economics

The main objectives of the study are to create a linear programming model of the study area in order to estimate changes in benefits when water delivery system losses are assumed to be affected by shifting between rotation, demand and continuous flow management systems.

Approximately 7,000 acres are included in the program model and the estimated potential "gains" or benefits from distribution system loss "savings" due to more efficient delivery range from $6,000 to $12,000 per season. This result is influenced by the facts that the loss estimates are hypothetical and the system studied is in an area where the cropping pattern is not heavily effected by total amounts of seasonal water available. (The model is not designed to handle weekly or monthly irrigations.)

Twenty or 30 percent reductions in normal expected seasonal water supplies are required to create a 15 percent drop in expected farm income.

The model is adaptable to planning situations, especially where new lands or new water engineering works are contemplated.

(87 pages)

INTRODUCTION

This thesis considers the problem of creating a linear program for an irrigation unit of 7,000 acres which will be responsive to expected variations in water supplies where the distribution management scheme can be shifted between demand, rotation, and continuous flow.

Justification

It is frequently noted that scarcity of water or water control places an upper bound on rural income levels. Even where irrigation systems are developed inefficient management may create unnecessary water losses of such magnitude as to have significant, measurable, negative impacts on realizable rural income(9).

Physical augmentation of irrigation water supplies is expensive, but in some situations the additional water can be obtained by alternative means such as changing distribution practices and improving efficiency. Gardner and Fullerton (5) have shown that positive income increases in rural farm incomes often can be obtained with small changes in institutions and traditional water management practices.

To expand on this notion, a research project has been undertaken by the Agricultural Economics Department of Utah State University. The overall objective is to develop a technique suitable for selecting loss minimizing alternative water delivery (continuous flow, rotation, demand, or any combination of these) schemes in existing and planned systems.

As part of this work, it is necessary to create an economic (linear programming) model of the farming region served by the physical system selected. The results will be used to obtain partial benefits that may be combined with the loss differences of the different management schemes and thereby obtain alternative estimates of total benefits.

The farming area chosen for this analysis covers 66 water users served by the D.M.D.A. Irrigation Company in Delta, Utah.

Since the study area is characterized by an active water market, an interesting possibility exists for corroborating the benefits estimation procedure of the economic model (L.P.) with real world data. Shadow prices obtained from the linear programming solution can be compared directly with observed market prices. This possibility is a unique feature of the proposed research.

Objectives of the Study

The specific objectives of the study are as follows:

1. To create an optimum enterprise combination by means of linear programming.

2. To estimate the change in benefits (using hypothetic reductions in system loss estimations) with the shift from one delivery method to another one, and observe the change in the optimum enterprise combination whenever the expected water supply at the beginning of the season differs from "normal."

In addition there are other secondary objectives that will be emphasized.

1. Compare shadow prices obtained from the linear programming method, with observed market prices of the area.

2. Measure the change in benefits and in the optimum enterprise combination whenever a change in water supply occurs early in the irrigation season.

3. Consider the possibility of adapting this work to areas where factors of production are used less intensely (virgin areas).

Uses of the Study Results

The output of the linear program procedure may be used by policy makers in several ways. With this procedure it is possible to examine the effect on farm incomes of varying water supply restrictions, water delivery rules, and crop production. It is also possible to derive from the model the benefits of prospective investments in facilities intended to provide additional water from any available source.

In less developed areas where the possibility of building new irrigation structures exists, the information obtained from a linear programming solution can be used as a planning tool to help measure the possible success of water investment.

The normative characteristics of the linear program procedure will be a powerful tool in planning new irrigation systems. With this system it is possible to establish the irrigation method that matches the area conditions at a given site and time. In addition the crop pattern and specialization of activities may be determined in the same process.

Study Area Treatment and Actual Production Units

The study area will be treated as a single unit although at present there exists 66 farmers with holdings varying from 20 to 600 acres. This assumption is made because according to available information differences do not exist in yield due to soil (12) or in farm enterprise organization such as would impose the necessity of breaking down the area into various categories.

The alternative is to stratify the area according to type of farming or similar enterprise alternatives facing similar yield potentials, prices and costs. This alternative would require sampling each strata to provide a basis for sorting farms into homogeneous groups based upon size, soil, or other relevant factors. After that, combine data from secondary sources with the information obtained from the sample, to construct representative farm linear programming models.

Either treatment alternative poses several potential sources of bias. Aggregation errors grow out of the practical necessity to group farms to represent fairly common situations rather than to obtain linear programming solutions for each individual farm and sum the results(2). Representative farms are usually developed by classifying farms and averaging those in a class. Then, those representative farms will be multiplied by a weighted factor defined as the subset it characterizes. If, however, the individual farms in the subset do not respond alike to changes in economic stimuli, the estimates of the aggregate output for the subset will be biased.

Since this likelihood is even greater in the "treatment as a whole" method, the aggregation errors will be even greater under the alternative chosen for this study.

Given this conclusion it is necessary to review some of the problems that are going to be present in the economic interpretation of the linear programming results. The L.P. output will be in terms of percentages of the total area required for each crop in order to achieve the optimum economic enterprise combination. These results have to be used cautiously when they are related to the original number of farms.

According to Unbewust (13) the rotation method is supposed to have less water losses than the other schemes and better allocation of water among crops. The allocation is closely related to the kind of crops and with the distribution of the crops in the area. Thus, when the "optimum" enterprise combination is related back to the original number of farms, it will not be possible to establish the same method of water rotation for each farm as if each farm were the whole unit.

Ordinarily this type of problem can be solved by means of specialization of areas. But this is not possible in the Delta area, because each farm already has infrastructures according to their situations and it would not be economic to change. However, in new irrigation systems this problem can be easily avoided by the specialization of production areas.

Another related problem has to do with farm size. In the Delta area, there is a great range of farm size. Thus the smallest size farms will not be able to use the percentage indications of the linear program output due to scale diseconomies. In new areas the output will provide a basis for the establishment of farm sizes while the irrigation system is in the planning stage.

Under the demand irrigation method, the intrepretation of the L.P. output will present similar problems as for the rotation method. There will be a big number of simultaneous "water calls" from scattered areas due to the fact that the same crop has to be watered at a very similar date. Therefore, the irrigation system manager will have problems related to water delivery dates. This can be avoided in planning new irrigation systems by means of specialization of areas. Again, some farms will not be able to use the same crop percentages or proportions as the L.P. solution suggests for the whole area. Another related problem that is going to be present under the demand irrigation method is an increase in water loss due to percolation, evaporation, etc.

The continuous flow management scheme does not present the "percentages problem" when the L.P. solution is related back to the original farms, because the water is available to the farm any time it is required for use. But as stated by Unbewust (13), the ditch losses from continuous flow of small heads is likely to be high. The same diseconomy problem of the "small farms" will be present when the L.P. output is related back to the actual acreage of each farm. Again, this is not on issue when planning new systems.

Description of Study Area

Location

The Delta area is located in Millard County, in the central-west part of the State of Utah, approximately 140 rail miles south and west of Salt Lake City. The total land area comprises 180 square miles, of which the irrigated and tilled area varies from 40,000 to 80,000 acres (35 to 60 percent of the total). The shortage of water in the area explains the difference between total land acreage and the irrigated and tilled area. Surface elevation ranges from about 4,565 to 4,650 feet(5). The Delta area is at the lower end of the Sevier River Basin.

Climate

The climate of the Delta area can be classified as arid, due to lack of precipitation, which is on average almost equal to 7 inches. Thus, most of the water for crops must come from irrigation with snow melt water that originates in higher elevations (Table 1).

Table 1. Mean monthly precipitation on irrigated lands. SRB (Sevier River Basin, 1931-1960 in inches)

Annual	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
7.18	0.59	0.55	0.84	0.79	0.82	0.49	0.27	0.45	0.42	0.83	0.47	0.66

Source: (15)

The temperature varies from over 100 degrees Farenheit during the summer months to -15 degrees in the winter. Killing frosts usually occur in early September, and the last killing frost in spring usually comes in late May (Table 2). Thus the growing season is 105-115 days.

Table 2. Mean monthly temperatures.

(Sevier River Basin, 1931-1960 in Farenheit)

Annual	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
49.4	26.0	31.9	39.8	48.8	57.1	65.5	74.1	69.3	63.1	51.2	36.7	29.3

Source: (15)

Soil and topography

Soils consist of alluvial materials deposited in main part by the Sevier River as its waters entered ancient Lake Bonneville. Texture of the soils range from slick clays to dune sand, the clay types being most prevalent. Soluable salts are present in varying degrees throughout the area. Meticulous irrigation and drainage practices are necessary to prevent serious alkali problems. In Table 3 the acreage of different soil types is shown.

The topography is generally smooth with slopes ranging from .09 to .37 percent.

Table 3. Acreage of different soils in all the Delta area.

Soil	Number of acres	Percent
Oasis clay	28,480	24.7
Gordon clay	12,922	
Friable phase	1,856	13.2
Slick phase	384	
Oasis silty clay		
Loam	14,400	
Light-textured bench phase	448	12.9
Oasis fine sandy loam	13,440	
Bench phase	128	11.8
Abbot clay	8,960	
Silty phase	3,136	10.5
Cache silty loam	11,392	9.9
Woodrow clay loam	9,024	7.8
Woodrow clay	5,376	4.7
Lynndyl gravelly sandy loam	1,856	1.6
Cache loam	1,408	1.2
Lahontan clay loam	1,344	1.2
Dune sand	512	.4
Rough stony land	64	.1
Total	115,200	100.00

Source: (5)

Water

This is the most important single resource affecting the development and economy of the area. With few exceptions availability of water is the limiting factor in the expansion of agriculture enterprises. Irrigation waters are derived from mountains and desert water sheds to the east and south. These enter the area via the natural course of the Sevier River.

In order to increase and stabilize the water supply, extensive storage and diversion facilities have been constructed along the course of this river. These have a combined storage capacity of approximately 250,000 acre feet. Except in periods of prolonged drought, these facilities serve admirably for their intended purpose.

Crops

The main crops under irrigation include alfalfa seed and hay, corn for silage and other small grains. In 1969 alfalfa covered 61 percent of the total area, small grains 35 percent and corn for silage 4 percent.

Livestock

The two most important feeding programs being followed in the research area consist of feeding purchased calves for about 133 days (October to March), and for 210 days (November to May). Also, in the area, there are a small number of dairy farms, as well as cow-calf enterprises. Both of these activities are of growing importance.

REVIEW OF LITERATURE

Linear Programming

Linear programming is a powerful self optimizing mathematical procedure which is widely used in planning efforts. Its power lies in computer applications which allow solution of problems with many decision variables and in the applications to linear programming solutions of parametric analysis(8).

A linear programming problem consists of three parts. First, there is a linear objective function which is either maximized or minimized. Second, there is a set of linear constraints which contain the technical specifications of the problem in relation to given resources or requirements. Third, there is a set of non-negative constraints since negative production has no physical counterpart.

Objective function

The linear program problem consists of an objective function which is to be optimized subject to applicable constraints. It is simply the summation of the various costs (or benefits) involved. It includes all the production costs. The objective function is expressed as $z = \Sigma Cj\ xj$, where cj is the cost of product xj. Z will be maximized if the problem is structured to determine profit, or it will be minimized if the intent is to minimize costs. The optimum objective function corresponds to defining the level of each xj such that marginal revenue equals marginal cost (if this is the intent of the economic problem analog). The objective function can be shown to be identical to the isocost or budget line of production theory.

Constraints

Any production operation is constrained in the short run by limited resources (capital, labor, physical inputs, plant size, etc.). In linear program format these are expressed in straightforward mathematical form as inequalities.

Non-negative constraints

The quantity of each activity level cannot be less than zero, or any value assigned to activities must not be negative. It is this restriction which limits the maximum level of an activity to that defined by the most limiting resource. The constraints define the boundary of the production possibility function and therefore serve the purpose of the isoquant in the production theory.

Summarizing we have:

$$\text{Maximize } Z = \left[C_1,\ C_2, \ldots\ldots, C_n\right] \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix}$$

Subject to:

$$\begin{bmatrix} a_{11}x_1 + a_{12}x_2 + \ldots\ldots\ldots + a_{1n}x_n \leq b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots\ldots\ldots + a_{2n}x_n \leq b_2 \\ \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \ldots\ldots\ldots + a_{mn}x_n \geq b_n \end{bmatrix}$$

Notice that the last constraint is of the $\geq$ bi type rather than $\leq$ bi type described above. This demonstrates a demand constraint which requires production to equal or exceed demand. Obviously costs would be minimized by no production at all if certain demand did not have to be met. If, on the other hand, the problem is to determine output in order to maximize profit the inqualities may be all $\leq$ type. In this case output is limited only by limitations on the resources (7) and this formulation is more closely related to the production theory problem.

Marginal value products (shadow prices) for each limiting factor of production are determined simultaneously as the systems of equations are solved. They appear in the solution as shadow prices and represent the reduction that would occur in the total returns if the availability of a resource is reduced by one unit and all other conditions are constant.

Parametric linear programming

Varying the values of one or more coefficients in a row or column, or some combination of row and column, it is called parametric linear programming. Parametric programming is a technique designed to permit estimates of change in the optimal plan for given changes in a Cj or bi.

Parametric linear programming is efficient and particularly useful in planning resource use for problems where programming is applicable.

Assumptions

There are some assumptions that apply to linear programming that may cause erroneous answers to certain problems. They are:

Linearity. Straight line relationships, as necessarily used by linear programming, are a source of criticism. This is a concept that, in effect, says that the input factors are combined in fixed proportions at all levels of output, and that the amount of resource use to produce a unit of a particular output is the same regardless the size of the output. A linear programming model which is properly developed allows for this. By parametrically changing the amount of one of the inputs a non-linear output function can be approximated.

Additivity. Activities must be additive in the sense that, when two or more are used, their total product must be the sum of their individual products. The best example of this would be two crops in rotation interacting and affecting the production of the other. In this case the entire rotation would have to be handled as one activity in order for the additivity assumption to apply.

Single value expectations. It is assumed that the quantity of resources, prices, and input output coefficients are all known with certainty. Of course, this is not so in the majority of cases and, as result, errors occur.

Divisibility. This is a characteristic of linear programming that states resources used and outputs produced can be divided into fractional units.

Finiteness. This is an assumption that merely states there is a limit to the number of alternative activities from which to choose for any particular problem as well as a limited number of resources to use. Stated in another way, the number is not infinity in either case, which is fairly obvious.

Normative characteristics. Linear programming is mainly a procedure for providing normative answers to problems which are so formulated. By normative Heady and Candler (7) refer to the course of action which ought to be taken by an individual, business unit, area, or other economic sector, when the objective takes a particular form, and the conditions and restraints surrounding the action or choice are of particular form (7). Thus, the linear programming procedure will produce normative results (what ought to be) rather than positive results (what is happening).

The simplex algorithm

If any feasible solution to the problem exists, the simplex procedure will procede in a finite number of steps to the feasible solution which is also the optimum solution.

Every optimal solution can have no more xj at non-zero level than the rank of the A matrix (which is the number of constraints unless some constraints are redundant). This means in the production problem framework the number of products (or processes) which will be produced in the optimum solution will be no greater than in the number of scarce resources.

The dual problem

Corresponding to each primal procedure, there is a dual procedure which is really the same problem in that it gives the same optimum value of the objective function but in an opposite way. If the primal problem is structured to maximize profit then the dual of that problem is to minimize costs and still produce the same output. If, in the primal, the cost coefficients are profit per unit of product (xj) the decision variables in the dual will be the inputed value (shadow prices) of the firm's production facilities.

Given the primal problem: Maximize $Z = cx$ subject to $Ax \leq b$, there is a dual problem minimize $Z = b'w$ subject to $A'w \geq c'$. The primal symbols are as previously defined, and A' is the transpose of matrix A; b' and c' are the transpose of b and c vectors, and w is a 1 x m vector of new variables which we have previously referred to as shadow prices.

Other Studies

Delta or similar areas

The Delta area was studied by Sumsion (12) in 1963. He employed the simplex method of linear programming to ascertain the most profitable enterprise combinations on farm organizations assuming various levels of resource supplies. The data used to construct crop and livestock budgets, were obtained by personal interviews with farm operators. Profitable crops were: silage, corn, alfalfa seed and barley. Yield differences due to soil were not detected. One hundred and sixty acres was selected as the representative farm size, although this was not the "optimum size" or the average size. Four basic yield levels were evaluated in connection with one, two, and three acre feet of water per acre. Each level was also evaluated assuming three, four, five and six thousand dollars of available spring and fall capital.

When water was the major production restriction, alfalfa seed was most profitable to raise. Corn for silage required more water and capital per unit of production and, therefore, only entered optimum plans at high yield levels when greater capital and water resources were available. Alfalfa hay and alfalfa seed combination crop was the most profitable through the greatest variety of water conditions and yield levels. A cattle fattening operation was the only livestock enterprise which entered in optimum plans. It is limited by fall capital and can be increased in number at a rate of approximately five head per $1,000 of fall capital.

Mitts (11) in 1963 made a study for Sevier County using the linear program method in order to find profitable enterprise combinations for that area. Special consideration was given to water and capital, because those are the most limiting resources according to the farmers.

Surveys were made to construct the budgets, and it was discovered that alfalfa, barley, sugarbeets, corn, silage, beef fattening and beef wintering were the enterprises considered feasible by this study.

When water is limiting, sugarbeet production should be emphasized, otherwise alfalfa and barley should be increased in acreage. A cattle wintering enterprise appears in the optimum plan for each farm covered by the study, and the size of this enterprise is determined directly by the supply of fall capital.

There are no methodological differences in the two studies cited. The only difference is in the profitable crops used in the linear programs, due to the fact that they describe operations in different counties.

Fullerton (5) in 1966 conducted a study of the Delta area in an effort to determine the relative efficiency of different allocative schemes for irrigation water. He considered two alternatives: (a) only intracompany transfers were permitted; and (b) intercompany transfers were allowed.

Efficiency of water allocation was determined by comparing indicators of the value of the marginal product associated with the two allocative arrangements. Due to the existence of market activity for more than 30 years in the study area it was possible to use the annual rental price of water as an indicator of the value of marginal product. During latter part of the 30 year period intercompany transfers were possible.

Because water price data covered a considerable period of time, other variables besides the changes in transfer policy which could be expected to influence the rental price of water were also considered. Those variables were: annual water available, product prices, other inputs, and technology.

Fullerton found statistically significant differences between the mean values and also the predicted values of the rental price under different allocative policies. He argued that this provides strong evidence that transfer policies influence allocation. The marginal value product of water was higher under the transfer policy, which was most flexible and permitted intercompany transfers.

Mijares (10) conducted a study in the Delta area of Utah in which the principal objectives were : (a) to develop a computer model capable of simulating estimates of water loss under various water delivery methods (demand, rotation, and continuous flow); and (b) to calculate potential streams of benefits and costs which result from each one of the three water delivery methods.

A model, designed to be tested on a digital computer, was formulated. Its purpose was to establish the amount of potential water losses attributable to canal seepage and administration of an irrigation system under three water delivery methods. This was done by linking water losses to physical attributes which are affected by the predominant delivery scheme.

An analysis of all water and labor saved or expended by changing from one method to another provides an estimate of the benefits and costs associated with water delivery methods. To make those benefits and costs comparable, they had to be expressed in monetary units, made equivalent on a time basis through discounting and adjusting for anticipated price level changes.

The main problem encountered in this study was that no recent investigations on canal seepage were available for the study area. For this reason a distribution of losses was made in the real system by using the wetted perimeter and the length of each canal segment to determine proportionate share of system losses. This permitted the calculation of a loss coefficient which in turn facilitated the simulation of losses associated with each of three alternative water delivery methods.

To determine the amount of monthly losses occurring when using any one of the three simulated water delivery methods, crop requirements were calculated based in consumptive use, physical properties of the soil, amount of land under irrigation and climatic data from the study area. Adding those requirements beginning from the last headgate of each canal, the net volume of water that would have to flow through each canal segment was determined. These volumes were multiplied by each canal segment loss function (during water flow periods) to estimate water losses.

The results showed that from the water management point of view demand delivery is the most costly system (operation and maintenance). Changing from demand to any other delivery method resulted in increased benefits through water saved, and decreased costs at the same time.

Irrigation water management

Anderson and Maass (1) have described and illustrated the use of a digital computer model of irrigation systems. The model has been designed to permit examination of the effects of varying water supply restrictions, water delivery rules and crop pattern on crop production and farm income in an irrigated area. The simulation does not examine design characteristics of the system directly because it is assumed that irrigators have made adjustments to engineering features of the system for water delivery. However one can derive from the model the benefits of prospective investments in facilities intended to provide additional water from any available source.

The main objective of this systems analysis study was to develop and test procedures by which operators and builders of irrigation systems can evaluate and compare alternative methods of distributing water among farmers. Such procedures will aid irrigation enterprises in selecting water supply sources and developing operating procedures. They will also aid in economic evaluations of irrigation practices and area cropping patterns.

During the growing season, the farmers' estimation of the water supply for the remainder of the season may change significantly from the estimate used to plan crop patterns at the beginning of the season. In that case the farmers might profitably replan their farms, abandoning certain crops and fields with the hope of bringing others through.

The possible alteration in the availability of water, and its correlated changed in benefits, if a shift from one delivery method to another occurs, is not considered in the Anderson and Mass study. The authors examine the existing availability of water with one delivery method at one time, and obtain the optimum enterprise combination for that quantity of water for that year, and then continue into the next year.

Hall and Butcher (6) state that the maximum yield of a crop which can be obtained under given conditions of climate, soil, variety, fertility, etc. will be only achieved under the best possible soil moisture conditions. They further postulate that if soil moisture falls to a value less than field capacity during a period of time, but remains at optimum during all other growth periods, the resulting yield can be expressed as:

$$y = ai\ Y\ max, \qquad (1)$$

Where ai depends on the soil moisture content (wi), that is,

$$ai = ai\ (wi). \qquad (2)$$

The first equation can be experimentally determined for a deficiency of xi during each growth period in succession, thus giving a1, a2, a3,...ai,......an. By letting wi vary over a range of soil moisture values as well, each time allowing a period to be deficient, there can be obtained a1(w1), a2 (w2), a3 (w3),......ai (wi),...an (wn). Then for the range of soil moisture deficiencies, crops, fertility levels, climates, etc., of interest, the yield to be expected when two or more of these time periods have deficiencies can be calculated by

$$Y = a1\ (w1)\ a2\ (w2)\ a3\ (w3) \ldots\ldots an\ (wn)\ Ymax \ldots\ldots (3)$$

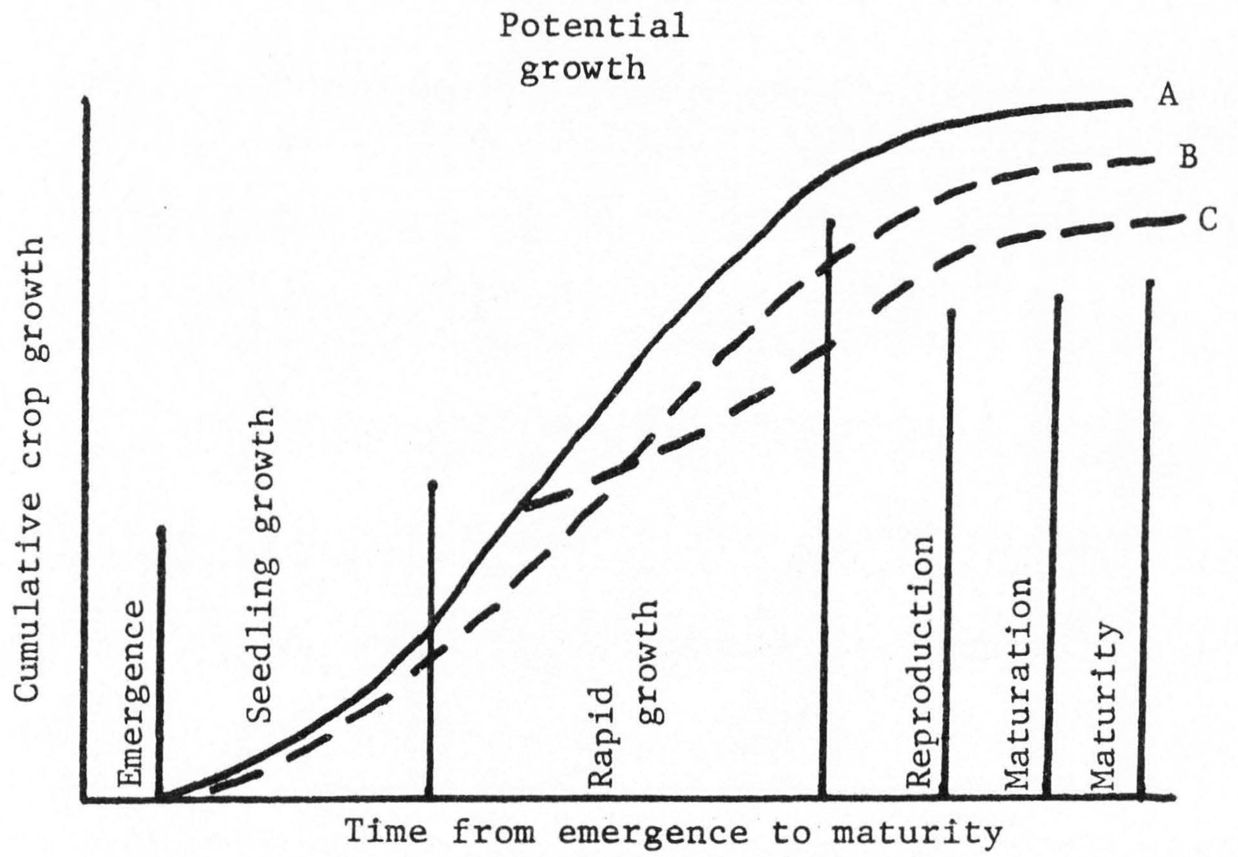
Thus this work also permits a farm manager to determine the time and quantity of irrigation which will maximize his total net returns from an array of crops.

The Hall and Butcher results can be linked to the present work in the following way: include in the linear program model different yields due to different missed irrigation periods, in order to establish which crops have to be planted under different conditions of water supply.

CONCEPTUAL FRAMEWORK

Intertemporal Availability of Water

Anderson and Maass (1) illustrate a group of theoretical growth curves of an annual crop considering adequate supply and inadequate water. See Figure 1.



Source: (1)

Figure 1. Theoretical growth curves of an annual crop.

Curve A illustrates the potential growth and yield of a crop when soil moisture is adequate throughout the growing season. Whenever soil moisture stress occurs potential growth is reduced as suggested by curves B and C. Since potential growth and potential yield are directly associated, it follows that harvestable yield will be reduced as a result of soil moisture stress. The amount of reduction in growth and yield will depend on the duration and severity of the stress period and time of occurrence during the growth cycle. If the stress period occurs when plant growth would normally be most rapid and water demands high, or when reproductive processes are critical, the reduction will be greater then (during periods of similar length) when growth and development are slow, such as near maturity(1).

Weather effects vary during a period when a crop goes without a needed irrigation(1).

Therefore, the irrigator has to make decisions or alterations, when water shortages are present, in order to achieve the highest possible benefits. This means, that the irrigator knowing the quantity of water he has at present time, must irrigate first those crops which would lose most value if they were not watered immediately.

Link Between Water Availability and Linear Programming

Suppose water rental or market prices are available, then a direct estimate of management system benefits is readily obtained as the product of water price times the quantity of water saved.

But in cases where an active water market does not exist, as in the case of less developed and developing areas, the benefits have to be found by means of the water shadow prices obtained from the linear program solution.

It is possible to develop an optimum enterprise combination by means of linear programming for the irrigation management systems given the original availability of resources. The result is the maximum possible benefits for that particular management method given the existing physical distribution system.

Using the model developed by Mijares (10) it is possible to find the quantity of water saved by a shift from one irrigation distribution method to another. As the quantity of water saved by the shift represents the increase in the amount of one of the available resources (water), it is also possible to develop a new optimum enterprise combination (holding constant the size of other factors of production) by the linear programming method.

Each new optimum enterprise combination should result in an increase of the benefits as measured in form of the objective function. Therefore the benefits genuated by a shift from one delivery method to another can be found from the difference in the amount of the benefits of the before and after optimum enterprise combinations, less the difference in costs associated with each delivery system. This process can be repeated as desired or as necessary.

Example of the Problem

An illustration of the approach employed is shown in Figure 2. This is a simplified hypothetical situation with two crop possibilities, crop 1 and crop 2, and with three limiting resources: land, labor and water. Input requirements, variable costs, and prices are implied in the level of crop activities and in the slope of the iso-revenue line.

Production possibilities, given the initial water supply, are delineated by the initial water and labor restraints. Any combination of crop 1 and crop 2 could be realized along or below these lines. If all crop 1 were grown, the production could be as high as the point A. At this point water is the only limiting factor and there is a surplus of land and labor.

The optimum, with prices as reflected in the slope of the iso-revenue line is at its highest point within the boundary of the restraints. This occurs at point P for the initial water supply. At point P the optimum crop combination is x_2' output for crop 2 and x_1' output for crop 1. Water and labor restrict these crops to this level. Net revenue is $C1x_1' + C2\ x_2'$, where Cj is defined as unit net revenue above variable costs for the jth activity.

If the initial water supply restriction is lifted to the second level, as illustrated, then production of crop 2 is reduced and crop 1 production is increased. The new optimum is at P2 with corresponding output levels. The change in revenue is $(C1\ x_1'' + C_2x_2'') - (C1x_1' + C_2x_2')$ which, under appropriate conditions, is attributable to the change in water supply from the initial to the second level.

In inputing this change in revenue to water it is assumed that adequate resources of land and labor are available to utilize the second level of water supply.

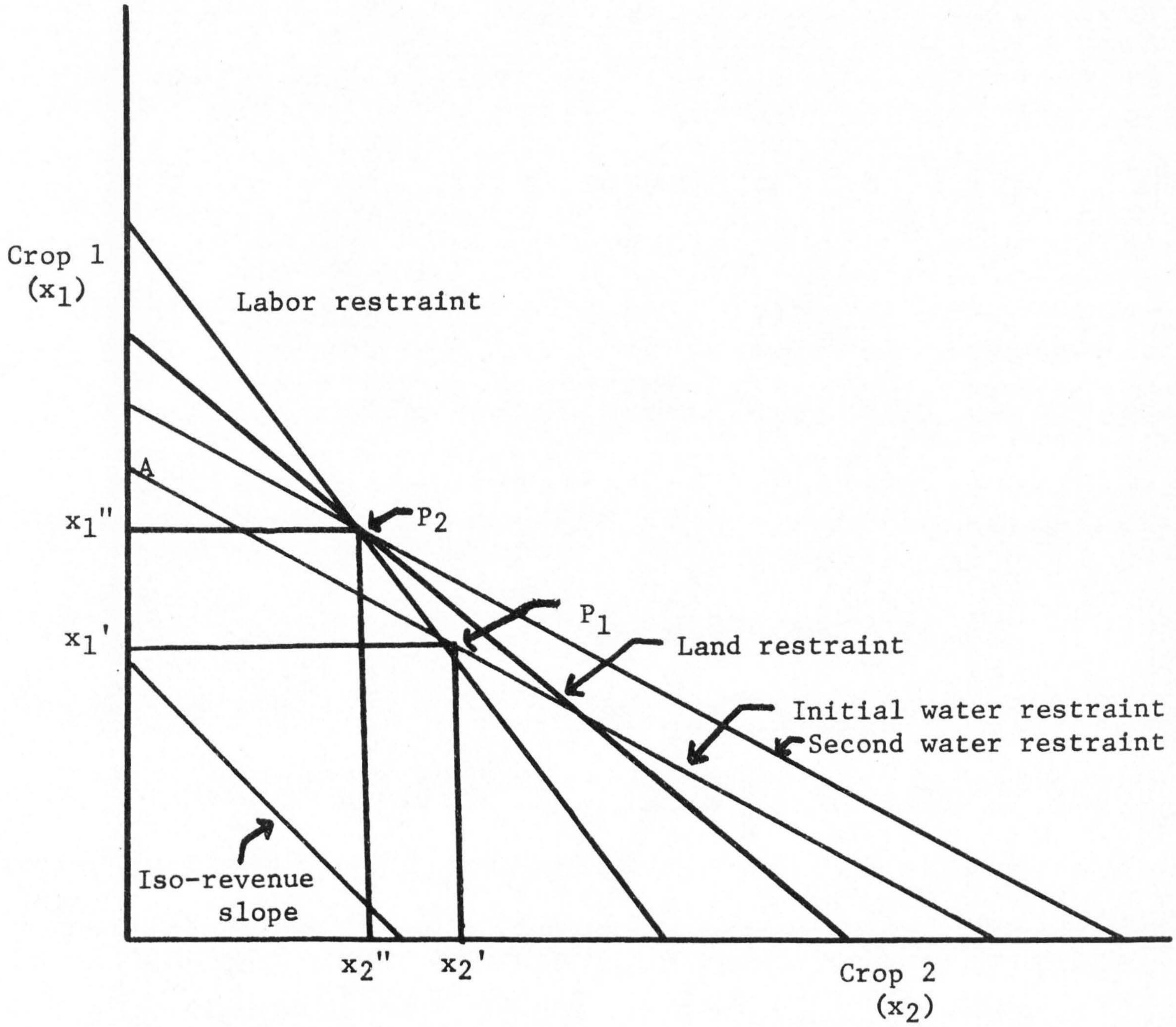


Figure 2. A two crop model showing the optimum crop averages for two water supply levels - land and labor supply constant.

METHODOLOGY

Data Sources

The basic data needed to satisfy the requirements of the study were three fold.

Personal interviews were conducted with some representative farmers of the Delta area. It was considered necessary to have up-to-date input-output coefficients from the area. The information obtained from this source included amounts of required and available labor, machinery and material requirements and costs, yields, cultivation and fertilization, practices, and water necessary to irrigate the crops, general livestock information, and other miscellaneous information.

Irrigation company records were searched for water deliveries, and share owned by the farmers from whom the enterprise data were obtained. It was necessary to have this information because the problem to be confronted in this work is mainly related to the water availability in the Delta region.

Other data (especially on system management) were already available from earlier studies of the area.

Estimate of the Constraints

The constraints used in the linear programming procedure were: water, alfalfa hay produced in the "total area" farm, barley produced in the "farm," corn silage produced in the "farm," maximum number of livestock, acreage of alfalfa seed and available labor.

Water

The normal or average supply of water found by Fullerton (5) in 1966, was used as the total availability of water for the whole area. This annual average may vary from 6,447 to 21,689 acre feet of water. The latter quantity occurred in 1969, the year on which Mijares (10) based his study. The water requirements of the different crops in the area were obtained directly from the farmers.

Maximum availabilities for a given crop are listed in Table 4.

Alfalfa hay, barley and corn for silage

Income from alfalfa hay, barley and corn for silage is obtained indirectly through the livestock enterprises. Therefore, maximum quantity available to these enterprises equals production of those crops. Each livestock enterprise is restrained by the amount of food implied by these crops.

Table 4. Water constraints, in acre feet, by crop.

Crop	Index #	Acre feet
Alfalfa hay	1	3.50
Alfalfa hay	2	2.00
Alfalfa hay	3	1.00
Alfalfa hay	4	3.15
Alfalfa hay	5	2.80
Alfalfa hay	6	2.45
Alfalfa hay	7	2.10
Alfalfa hay	8	1.75
Corn silage	1	4.00
Corn silage	2	2.00
Corn silage	3	3.60
Corn silage	4	3.20
Corn silage	5	2.80
Corn silage	6	2.40
Corn silage	7	2.00
Barley	1	2.00
Barley	2	1.00
Barley	3	1.80
Barley	4	1.60
Barley	5	1.40
Barley	6	1.20
Barley	7	1.00
Alfalfa seed	1	4.50
Alfalfa seed	2	2.50
Alfalfa seed	3	1.50
Alfalfa seed	4	3.60
Alfalfa seed	5	3.20
Alfalfa seed	6	2.80
Alfalfa seed	7	2.40

Livestock

According to other studies and information provided by livestock technicians of the area, the maximum number of calves that could be absorbed by the market would be 10,630. This corresponds to an average of 1.36 calves per acre. It was assumed that a maximum of 3,908 units of beef cows could be absorbed by the market (this cow activity is not included in any optimum enterprise combination).

Alfalfa seed

The maximum number of acres devoted to this crop was restricted to 4,738.93 which corresponds to the 56 percent of the total area.

Labor

It was assumed that the available labor is restricted farmers and their families. The maximum amount of monthly hours of work per individual was considered 300 throughout the year, because according to available information, the farmers of the area generally do not engage in non-farm work at anytime during the year.

Conventional Constraints

The alfalfa seed-hay combination and the alfalfa hay budgets were divided in the following way:

(a) the alfalfa seed-hay combination budget was sub-divided into seed and hay production, and treated as different enterprises;

(b) the alfalfa hay budget was divided in three different enterprises, called alfalfa hay one, two and three. This reflects the usual three cuttings per year.

To insure that the acreage of the seed part of the alfalfa seed-hay combination, and the alfalfa hay part of the same crop were equal, a constraint was developed which forced the solution to have the same acreage of "both enterprises." A similar criterion was applied to the alfalfa hay crop.

Factors Not Considered as Constraints

Capital

Generally, the farmers of the area have the capacity to borrow over and above actual need. Because of this characteristic, capital was not considered as a limiting factor.

Entreprenurial ability

The farmers of the area are known as good farmers. Thus managerial ability was not considered as constraint.

Linear Program Format Utilized to Solve the Problem

The specific linear program developed in the present work, will be explained in the following paragraphs.

Maximize:

$$A1X1 + A2X2 + A3X3 + \ldots\ldots + AmXm$$

Where:

Am = return coefficient per acre for enterprise "m"

Xm = number of acres (units) devoted to enterprise "m"

Subject to the following:

1. Water

   $W1X1 + W2X2 + W3X3 + \dots\dots\dots + WmXm \leq$ Availability of water

   Where:

   Wm = quantity of water required per acre for enterprise "m"

   Xm = number of acres devoted to enterprise "m"

2. Alflafa hay

   $H1X1 + H2X2 + H3X3 + \dots\dots\dots + HmXm \leq$ Availability of alfalfa hay

   Where:

   Hm = quantity of hay required per unit of enterprise "m"

   Xm = number of units of enterprise "m"

3. Barley

   $B1X1 + B2X2 + B3X3 + \dots\dots\dots + BmXm \leq$ Availability of barley

   Where:

   Bm = quantity of barley required per unit of enterprise "m"

   Xm = number of units devoted to enterprise "m"

4. Corn silage

   $C1X1 + C2X2 + C3X3 + \dots\dots\dots + CnXn \leq$ Availability of corn silage

   Where:

   Cm = the amount of corn silage required per unit of enterprise "m"

   Xm = number of unit devoted to enterprise "m"

5. Calves

   $X1 + X2 + \dots\dots\dots + Xm \leq 10,630$ units

   Where

   Xm = units of calf enterprise "m"

6. Beef cows

$X1 + X2 + \ldots\ldots\ldots + Xn \leq 3{,}908$ units

Where

Xn = units of beef cow enterprise "n"

7. Acreage

$X1 + X2 + X3 + \ldots\ldots\ldots + Xn \leq 7{,}816$ acres

Where

Xn = number of acres devoted to enterprise "n"

8. Labor

$L1X1 + L2X2 + L3X3 + \ldots\ldots\ldots + LnXn \leq 19{,}800$ hours[1] 300 hrs/farmer

Where

Ln = required labor per unit of enterprise "n"

Xn = number of units devoted to enterprise "n"

9. Conventional constraint for alfalfa seed crop

$Xsn = Xhn$

Where

Xsn = number of acres devoted to enterprise alfalfa seed "n"

Xhn = number of acres devoted to enterprise alfalfa hay (seed) "n"

10. Conventional constraint for alfalfa hay crops (cuttings)

$Xh1n = Xh2n = Xh3n$

Where

$Xh1n$ = number of acres devoted to enterprise alfalfa hay n (first cutting)

$Xh2n$ = number of acres devoted to enterprise alfalfa hay n (second cutting)

$Xh3n$ = number of acres devoted to enterprise alfalfa hay n (third cutting)

---

[1] Corresponds to 66 farmers

Implementation of the Linear Program

Fullerton (5) found that the normal supply of water for Delta area is 1.392 acre feet per irrigated acre. When expanded to the actual area, the normal water supply is 10,879.87 acre feet.

Combining this availability of water with the other input-output coefficients, an optimum enterprise combination was obtained by means of the linear program method. Then the water constraint was varied parametrically up and down by increments and decrements of 1 percent. In each case this created new optimum enterprise combinations and their related shadow prices.

The actual reduction in losses (increments in water available) which may be expected to occur when a shift is made from one management scheme to a more efficient one, is not available at present time (Mijares work is not completed). Thus it was necessary to arbitrarily assume that 10 to 25 percent of the water loss could be saved through changes in management schemes. Those increments in water quantity were included in the water constraint (one at a time) in order to observe the shift in benefits when the water losses are reduced.

As previously discussed, a shortage of water has a negative effect on the potential growth of any crop and this in turn is directly related to the potential yield. Therefore it was necessary to study the changes that occur in the benefits, and in the crop enterprise combination due to lower yields whenever a shortage of water occurs at the beginning of the season.

Ellis (3) shows different yields associated with different amounts of water supplied to alfalfa hay and corn crops. His estimates, together with hypothetical water/yield assumptions for alfalfa seed and barley, were included in the model. Table 5 shows the yield of crops corresponding to various quantities of water supplied as included in the linear programming matrix.

Table 5. Crop yield levels associated with different supplies of water.

Crop	Water supply		Yield	
	acre feet	percent	tons	percent
Alfalfa hay	3.50	100	5.50	100
	3.15	90	5.20	94
	2.80	80	5.06	92
	2.45	70	4.84	88
	2.10	60	4.40	80
	1.75	50	4.13	75
Corn	4.00	100	20.00	100
	3.60	90	18.60	93
	3.20	80	16.60	83
	2.80	70	15.00	75
	2.40	60	12.00	60
	2.00	50	11.00	55
Barley	2.00	100	1.90	100
	1.80	90	1.71	90
	1.60	80	1.61	85
	1.40	70	1.52	80
	1.20	60	1.33	70
	1.00	50	1.23	65
Alfalfa seed (seed part)	2.50	100	.182	100
	2.25	90	.167	91
	2.00	80	.155	85
	1.75	70	.145	79
	1.50	60	.118	64
	1.25	50	.101	55
Alfalfa seed (hay part)	1.50	100	1.50	100
	1.35	90	1.43	94
	1.20	80	1.38	92
	1.05	70	1.32	88
	.90	60	1.20	80
	.75	50	1.12	75

Source: (3, p. 1439).

ANALYSIS AND PRESENTATION OF THE RESULTS

Optimum Enterprise Combination Associated With the Normal Supply of Water

The normal supply of water as computed Fullerton (5) in his work was combined with the rest at the input-output coefficients gathered from farmers and other sources, to obtain an optimum enterprise combination using the linear program procedure.

The general result is shown in Table 6. This table lists the labor force and water used, and net return to the overall land unit.

Table 6. Net return, labor force and water used by months, water supply normal.

Net return ($)	Labor force used (hours)					
	April	May	June	July	August	Sept.
518,925.11	19,702.88	19,800.00	2,831.68	6,055.52	13,441.34	426.50
	Water used (acre feet)					
518,925.11	3,002.88	298.06	1,566.68	3,640.44	2,241.29	130.52

The enterprises include two different types of alfalfa hay, alfalfa seed, two types of barley, corn for silage, selling corn silage and calf feeding.

With the "normal" water supply the land is not used completely. The result is a slack variable on the land activity of 204.72 acres. Available labor is only limiting in the month of May.

The "normal" water supply, 10,879.87 acre feet, is utilized or called for by the linear program by months as shown in Table 6.

Therefore, in a normal water year, given the "slack" 205 acres, water is a constrained input and additional water would have value. Under the situation postulated the marginal value product of water is $20.83.

The return to the land unit is $518,925.11 which represents an average return per acre of $66.39. The average farm size of the area is 118.42 acres. Thus, the average return to an average size farm is $7,861.90.

Sumsion (12) stated in his work that the average return per acre in the Delta area varies from $31.64 per acre to $156.83 per acre, using different combinations of water, yield levels and available capital. Thus it is assumed that the return obtained from the linear programming model may be considered as representative of the area.

On the basis of an average size farm the optimum enterprise, combination would be as shown in the acreage of Table 7.

There is a land surplus of 3.18 acres, because in this optimum enterprise combination with a "normal" water supply, all the land is

Table 7. Optimum crop acreages for an average size farm, Delta, Utah, 1971.

Crop	Index #	Acre feet
Alfalfa hay	6	.11
Alfalfa hay	8	7.66
Alfalfa seed	3	63.96
Barley	1	5.07
Barley	2	.00
Corn	2	38.44
Total		115.24

not fully utilized. Alfalfa hay 6 and barley 2 may be ruled out due to the very small areas involved on the "average farm."

With respect to the labor force used in this optimum enterprise combination, the month of May is the only tight period. In that month all the labor supplied by the farmers is fully used.

Changes in Benefits Associated With a Reduction in Water Losses

Mijares (10) in his work found an 18.33 percent of water losses for the whole irrigation system under a demand management scheme. However due to the fact that his model is not completed, the quantity of water which could be saved through a change in irrigation management schemes is not available. For this reason it is necessary to assume hypothetical reductions in losses that might be associated with management shifts. Therefore imposition of rotation or continuous flow system may be imagined to reduce loss between 10 and 25 percent of the factor computed by Mijares. Consequently the range of possible increases in water supply varies from 199.43 acre feet to 498.57 acre feet. These increases in water supply, permit computations of new optimum enterprise combinations. Table 8 shows the increase in benefits

Table 8. Net return to the total land unit with allowance for effects of additional water loss savings due to shifts in management system.

Concept	Water (acre feet)	Return ($)
Normal or average supply	10,879.87	518,925.11
Assumed increase due to shift in water management	11,079.30	523,079.68
	11,378.44	529,269.31

associated with a hypothetical reduction of water losses. Under these assumptions the total benefits from 7,816 acres might be increased as much as $10,344.20 above the value if the L.P. solution based on an average water year supply.

Under a demand system, operation and maintenance costs are expected to be higher than for rotation or continuous flow schemes. This difference must also be taken into account. The amount is estimated at $2,000 per growing season.

Thus, the total increase in benefits is increased by about $2,000 when a shift is made from the demand delivery method. Table 9 shows the total net increase in benefits for both of the assumed water loss reductions. The range of increased benefits (6,000 - 12,000) is

Table 9. Net change in benefits with a shift from demand delivery system.

Concept	Increasing net return to the area ($)	Decrease in cost with a shift from demand delivery ($)	Total increase in benefits ($)
Normal supply of water plus 10 percent reduction in water losses	4,154.57	2,000.00	6,154.57
Normal supply of water plus 25 percent reduction in water losses	10,344.20	2,000.00	12,344.20

therefore due to a combination of reduced O and M costs and the opportunity to alter enterprise patterns to include more profitable activities.

Changes that Occur in Optimum Enterprise Combinations Given Variations in Known Seasonal Water Supplies

Suppose that at the beginning of the irrigation season a change in water supply occurs. What kinds of changes in the enterprise pattern are necessary in order to achieve the maximum possible benefits?

The optimum enterprise combination obtained using the "normal supply" of water is the same as discussed in the first part of this section. The only difference is that the livestock and selling activities were not mentioned at that time. The total area and activities are divided as shown in Table 10.

Table 10. Optimum crop acreages with normal water supplies, Delta, Utah, 1971.

Crop	Index #	Acres
Alfalfa hay	6	11.73
Alfalfa hay	8	505.68
Alfalfa seed	3	4221.72
Barley	1	335.06
Barley	2	.03
Corn silage	2	2580.01
Calf		7958.43 (heads)
Selling corn silage		18,804.13 (tons)

In this section the shadow prices and optimum enterprise combinations are obtained for a range of water supplies between 50 and 120 percent of normal. Thus, it is necessary to vary parametrically the water supply by increments of 1 percent on each side of the supply in order to observe the change in the objective function and enterprise pattern.

Changing values are shown in Table 11. Discussion of the results are confined to substantial changes in the activities included and/or in the value of the objective function.

When water supply is reduced by 1 percent of the original availability, the first important change occurs. Alfalfa hay 6 is dropped out of the solution, and the acreage of the enterprise alfalfa hay 8 is increased by 15 acres. The other changes are a reduction in the acreages of alfalfa seed 3, and corn 2, while the rest of the enterprises are held at their original level. Those changes are due to the fact that the water requirements of alfalfa hay 6 are greater than alfalfa hay 8. Thus, when the "water supply" is reduced by 107.89 acre feet, it is more profitable to irrigate a less profitable crop (alfalfa hay 8) and reduce in some quantity other crops than irrigate alfalfa hay 6. The value of the objective function reaches $516,627.24.

Between 98 and 78 percent of the "normal supply" of water the observed changes are a decrease of corn 2 activity and a corresponding reduction in the selling corn enterprise. The rest of the activities

Table 11. Optimum enterprise combinations associated with different pre-season water supplies

Area water supply as a percent of normal	Water supply (acre feet)	Value of the objective function $	Shadow price $	Alfalfa hay 6 (acres)	Alfalfa hay 8 (acres)	Alfalfa seed 3 (acres)	Barley 1 (acres)	Barley 2 (acres)	Corn 2 (acres)	Calf 1 (heads)	Sell corn 1 (tons)	Alfalfa hay 4 (acres)	Alfalfa hay 1 (acres)	Corn 1 (acres)	Alfalfa hay 3 (acres)
120	13,056	544,287	7.63			4,377.19	335.09		2,112.75	7,958	24,380		361.74	629.23	
119	12,947	543,457	7.63			4,377.19	335.09		2,167.15	7,958	24,108		361.74	574.83	
118	12,838	542,627	7.63			4,377.19	335.09		2,221.55	7,958	23,836		361.74	520.43	
117	12,729	541,797	7.63			4,377.19	335.09		2,275.94	7,958	23,564		361.74	466.03	
116	12,621	540,966	7.63			4,377.19	335.09		2,330.35	7,958	23,292		361.74	411.63	
115	12,512	540,136	7.63			4,377.19	335.09		2,384.75	7,958	23,020		361.74	357.23	
114	12,403	539,306	7.63			4,377.19	335.09		2,439.15	7,958	22,748		361.74	302.83	
113	12,294	538,475	7.63			4,377.19	335.09		2,493.55	7,958	22,476		361.74	248.43	
112	12,985	537,645	7.63			4,377.19	335.09		2,547.95	7,958	22,204		361.74	194.03	
111	12,077	536,815	7.63			4,377.19	335.09		2,602.35	7,958	21,932		361.74	139.63	
110	11,968	535,986	7.63			4,377.19	335.09		2,656.75	7,958	21,660		361.74	85.23	
109	11,859	535,155	7.63			4,377.19	335.09		2,711.15	7,958	21,388		361.74	30.83	
108	11,750	534,237	9.50	40.77		4,364.20	335.09		2,741.98	7,958	21,234	105.15	228.81		
107	11,641	533,189	10.01	164.59		4,337.25	335.09		2,741.98	7,958	21,234	237.09			
106	11,533	532,100	10.01	375.56		4,319.16	335.09		2,741.98	7,958	21,234	44.20			
105	11,424	530,191	20.29	299.86	152.19	4,286.88	335.06	.03	2,732.92	7,958	21,098				
104	11,315	527,983	20.29	195.79	279.87	4,263.27	335.0	.03	2,706.09	7,958	20,695				
103	11,206	525,725	20.83	143.55	343.95	4,251.42	335.06	.03	2,665.53	7,958	20,087				
102	11,097	523,458	20.83	99.61	397.86	4,241.46	335.06	.03	2,622.77	7,958	19,446				
101	10,989	521,192	20.83	55.67	451.77	4,231.49	335.06	.03	2,580.01	7,958	18,804				
100	10,880	518,925	20.83	11.73	505.68	4,221.52	335.06	.03	2,537.25	7,958	18,163				
99	10,771	516,627	21.23		520.07	4,218.86	335.06	.03	2,485.96	7,958	17,393				
98	10,662	514,318	21.23		520.07	4,218.86	335.06	.03	2,431.56	7,958	16,577				
97	10,553	512,009	21.23		520.07	4,218.86	335.06	.03	2,377.16	7,958	15,761				
96	10,445	509,699	21.23		520.07	4,218.86	335.06	.03	2,322.76	7,958	14,945				
95	10,336	507,390	21.23		520.07	4,218.86	335.06	.03	2,268.36	7,958	14,129				
94	10,227	505,081	21.23		520.07	4,218.86	335.06	.03	2,213.96	7,958	13,313				
93	10,118	502,772	21.23		520.07	4,218.86	335.06	.03	2,159.43	7,958	12,497				
92	10,009	500,462	21.23		520.07	4,218.86	335.06	.03	2,105.16	7,958	11,681				
91	9,901	498,153	21.23		520.07	4,218.86	335.06	.03	2,050.76	7,958	10,865				
90	9,792	495,844	21.23		520.07	4,218.86	335.06	.03	1,996.36	7,958	10,049				
89	9,683	493,534	21.23		520.07	4,218.86	335.06	.03	1,941.96	7,958	9,233				
88	9,754	491,225	21.23		520.07	4,218.86	335.06	.03	1,887.56	7,958	8,417				
87	9,465	488,916	21.23		520.07	4,218.86	335.06	.03	1,833.16	7,958	7,601				
86	9,357	486,607	21.23		520.07	4,218.86	335.06	.03	1,778.76	7,958	6,785				
85	9,248	484,297	21.23		520.07	4,218.86	335.06	.03	1,724.36	7,958	5,969				
84	9,139	481,988	21.23		520.07	4,218.86	335.06	.03	1,669.96	7,958	5,153				
83	9,030	479,679	21.23		520.07	4,218.86	335.06	.03	1,615.56	7,958	4,337				
82	8,921	477,370	21.23		520.07	4,218.86	335.06	.03	1,561.16	7,958	3,521				
81	8,813	475,060	21.23		520.07	4,218.86	335.06	.03	1,506.76	7,958	2,705				
80	8,703	472,751	21.23		520.07	4,218.86	335.06	.03	1,452.36	7,958	1,889				
79	8,595	470,442	21.23		520.07	4,218.86	335.06	.03	1,397.96	7,958	1,073				
78	8,486	468,132	21.23		520.07	4,218.86	335.06	.03	1,343.56	7,958	257				
77	8,377	464,515	38.79		420.75	4,110.94	335.06	.03	1,326.41	7,958					207.24
76	8,268	460,296	38.79		275.68	3,953.30	335.06	.03	1,326.41	7,958					509.95
75	8,160	456,077	38.79		130.62	3,795.66	335.06	.03	1,326.41	7,958					812.65
74	8,051	451,459	46.12		64.96	3,625.05	335.06	.03	1,326.41	7,958					989.35
73	7,942	446,441	46.12		78.77	3,441.46	335.06	.03	1,326.41	7,958					1,039.98
72	7,833	441,423	46.12		92.57	3,257.87	335.06	.03	1,326.41	7,958					1,090.61
71	7,725	436,406	46.12		106.38	3,074.29	335.06	.03	1,326.41	7,958					1,141.24
70	7,616	431,489	46.12		120.19	2,890.70	335.06	.03	1,326.41	7,958					1,191.87
69	7,507	426,371	46.12		133.99	2,707.11	335.06	.03	1,326.41	7,958					1,242.50
68	7,398	421,353	46.12		147.80	2,523.52	335.06	.03	1,326.41	7,958					1,293.13
67	7,289	416,336	46.12		161.60	2,339.93	335.06	.03	1,326.41	7,958					1,343.76
66	7,181	411,318	46.12		175.41	2,156.35	335.06	.03	1,326.41	7,958					1,394.39
65	7,072	406,301	46.12		189.21	1,972.75	335.06	.03	1,326.41	7,958					1,445.06
64	6,963	401,283	46.12		203.02	1,789.17	335.06	.03	1,326.41	7,598					1,495.64
63	6,854	396,261	46.12		216.82	1,605.58	335.06	.03	1,326.41	7,598					1,546.27
62	6,745	391,248	46.12		230.63	1,422.00	335.06	.03	1,326.41	7,598					1,596.90
61	6,637	386,230	46.12		244.43	1,238.41	335.06	.03	1,326.41	7,958					1,647.53
60	6,528	381,212	46.12		258.24	1,054.81	335.06	.03	1,326.41	7,958					1,698.16
59	6,419	376,195	46.12		272.04	871.23	335.06	.03	1,326.41	7,958					1,748.79
58	6,310	371,177	46.12		285.85	687.64	335.06	.03	1,326.41	7,958					1,799.42
57	6,201	366,160	46.12		299.65	504.05	335.06	.03	1,326.41	7,958					1,850.05
56	6,093	361,142	46.12		313.46	320.46	335.06	.03	1,326.41	7,958					1,900.68
55	5,984	356,124	46.12		327.26	136.87	335.06	.03	1,326.41	7,958					1,951.31
54	5,875	351,064	47.65		303.13		330.04	5.06	1,321.49	7,929					2,036.48
53	5,766	345,880	47.65		167.84		310.29	24.81	1,302.15	7,813					2,222.65
52	5,657	340,695	47.65		32.55		290.55	44.55	1,282.81	7,697					2,409.22
51	5,549	334,898	55.07				268.72	66.38	1,261.44	7,569					2,421.97
50	5,440	328,907	55.07				246.23	88.87	1,239.42	7,437					2,379.69

remain at their original level. The total return to the land unit is reduced to $468,132.36.

The next reduction in water availability brings in 207.24 acres of enterprise, alfalfa hay 3. The corn selling activity is dropped out of the solution, because with water available at this level, it is more profitable to feed livestock than sell the product. The alfalfa hay 8, alfalfa seed 3 and corn 2 activities are reduced in size, while barley and calf activities do not change. The value of the objective function is reduced by almost $4,000.00.

Between 76 and 55 percent of the normal supply of water the observed changes are the decrease of activities alfalfa hay 8, alfalfa hay 6 and alfalfa seed 3, with a marked increment in the activity alfalfa hay 3. The calf enterprise and barley maintain their original levels. The net return is reduced to $356,124.47.

At 54 percent of water available, the alfalfa seed 3 is dropped out of the optimum solution, and the alfalfa hay 8, corn, barley 1 and calf activities decrease their size. Barley 2 increase its acreage by the number of units by which barley 1 was decreased. Alfalfa hay 3 continues its increase in size. Those changes can be explained in that at this level of water supply (5,983.87 acre feet) it is more profitable to irrigate crops with lower return per unit but even less water requirements.

The last change observed occurs when water supply is reduced to 51 percent. Here the alfalfa hay 8 activity is out of the solution, and the other activities continue their observed trend. The value of the objective function is reduced to $334,898.16.

It is now necessary to describe the changes that occur when water is above normal at the beginning of the season.

Between the normal supply of water and an increase of 5 percent, the observed changes are an increase in the size of enterprises alfalfa hay 6, alfalfa seed 3, corn 2 and selling corn, while the alfalfa hay 8 activity is reduced; the remainder are held constant. The net return to the land unit increased to $530,191.35.

When available water is increased by an additional 1 percent, the activities alfalfa hay 8 and barley 2 are dropped out of the solution, and a new enterprise comes in (alfalfa hay 4) with a size of 44.20 acres. This new activity is more profitable than alfalfa hay 8. Calf enterprises maintain their levels, while all the other activities increase their size. The value of the objective function is increased by almost $2,000.00.

The next change observed is when water available is increased by 8 percent of the "normal supply." At this point, a new enterprise enters (alfalfa hay 1) with an acreage of 228.81 acres. The barley 2, corn 2 and calf activities do not change in size, while the rest of the enterprises reduce their size. The net return to the land unit is $534,236.96.

At 9 percent increase of available water two enterprises are dropped out of the solution (alfalfa hay 4 and 6) with the inclusion of a new activity (corn 1). The activity corn 2 reduces its size. It can be observed that all other enterprises increase their sizes except barley 1. The value of the objective function increases to $535,155.37.

Between 10 and 20 percent increase in water supply, the alfalfa seed 3, barley 1, alfalfa hay 1 and calf activities hold their sizes stable. Corn 2 decreases, and selling corn and corn 1 increase their sizes. The net return is increased to $544,286.95.

The value of the objective function for each different availability of water is plotted in Figure 3. It is observed in Figure 3 that there is a direct relationship between water available and the return to the land unit. Whenever the farmers expect an increase in normal supply of water for the area, they are able to consider sizes and types of enterprises, which are going to maximize their net returns.

Shadow Prices and Observed Market Prices

To achieve the third objective, that is to compare computed or implied marginal value products (shadow prices) with the observed market prices of the area, the water availability (constraint) was varied by increments of 10 percent above and below the normal supply.

Table 12 contains the different shadow prices associated with each assumed water supply. From the linear programming model standpoint each assumed supply is given at the start of the crop year.

The value of the marginal product of water in the study area was found to be a declining function with respect to increased water deliveries. These values (shadow prices) for water indicate the marginal contribution to net income from the last acre foot employed in crop production.

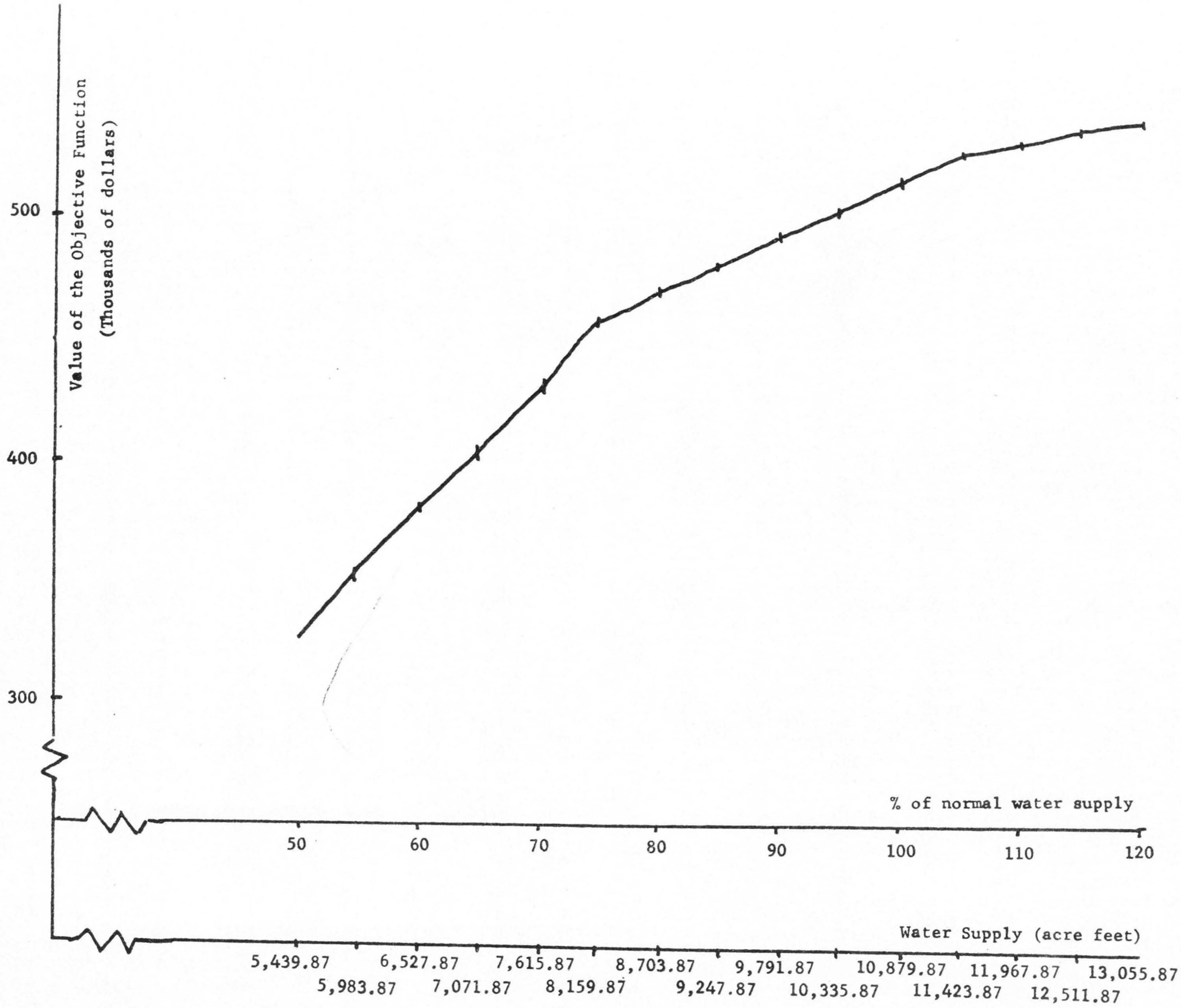


Figure No. 3. Value of the objective function at different water supply levels, Delta area

Table 12. Marginal value product of water corresponding to different availabilities of water.

Availability of water (% of the normal)	Shadow price (MVP) ($)
120	7.63
109	7.63
108	9.50
107	10.01
106	10.01
105	20.29
104	20.29
103	20.83
100	20.83
99	21.23
78	21.23
77	38.79
75	38.79
74	46.12
55	46.12
54	47.65
52	47.65
51	55.07
50	55.07

The derived value of the marginal product function is shown as Figure 4. A quadratic equation with an r^2 of .90 was calculated using the least squares method:

$$Y = 103.29 - .0099X + .00000018\ X^2,$$

Where:

Y = MVP of water

X = annual area water supply in acre feet.

Figure 4 illustrates the movement in shadow prices as various amounts of water were assumed to enter into the L.P. model solutions.

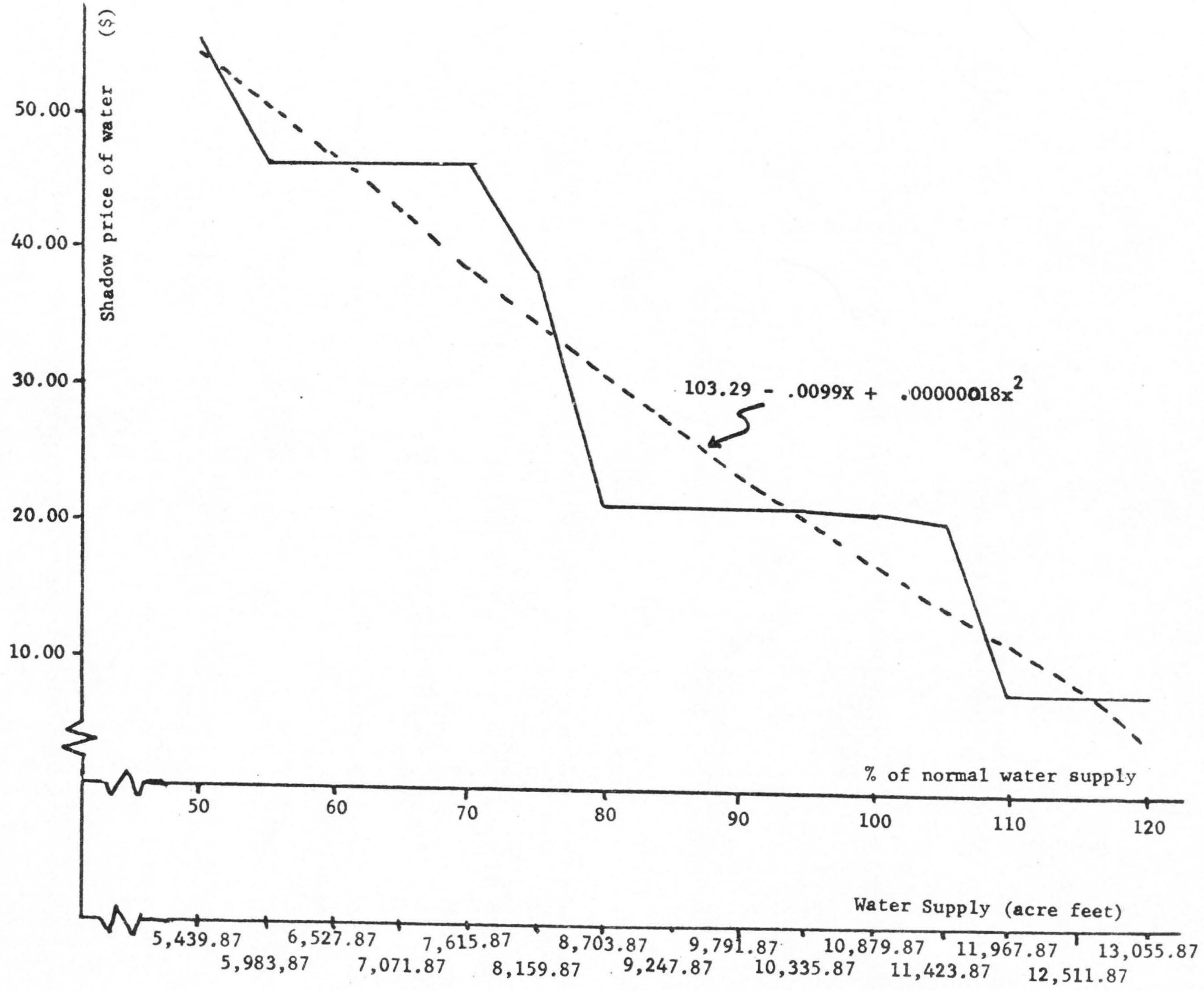


Figure No. 4. Estimated demand for irrigation water, Delta area

Figure 4 may be interpreted as an approximation of a possible demand curve for water in the Delta area during the period when this study was made.

The arc elasticity of the demand curve between the normal supply of water (10,879.87 acre feet) and 6,527.87 (60 percent of the "normal" supply of water) is -.662.

The inelastic demand can be explained on the basis that if farmers could not obtain the minimum water required for crops, the reduction in the benefits will be greater than the prices paid for water.

In order to make the shadow and market price comparisons, it is necessary to develop intervals of water availability due to fact that the percentage and ranges of observed water supplies and prices do not correspond exactly to the water supply percentages associated with the calculated shadow prices. To calculate the "in between" shadow price a weighted average of the prices bracketing the extra water availability is employed. The weighting factor is the observed frequency of each of the "bracketed" shadow prices. In some selected water availability intervals, three shadow prices are known; only one weighted average price is computed.

Table 13 shows the observed average market prices for water at different levels of water supply in various years for the Delta area.[1]

---

[1]The values are averages of prices observed within one irrigation season.

Table 13. Observed market prices for water at different levels of water supply for Delta Area, Utah.

Year	Water available per irrigated acre (acre-feet per acre)	Rental price per acre foot[a] $
1961	.8249	19.94
1963	.8809	16.95
1956	.9441	10.40
1957	.9715	15.15
1960	1.0327	15.89
1964	1.0454	15.00
1954	1.3772	6.46
1951	1.3938	5.66
1955	1.3951	6.44
1959	1.4131	6.96
1962	1.4644	9.94
1950	1.8168	3.55
1958	1.8475	4.98
1953	2.2250	2.70
1952	2.2417	3.95

(a)Rental price adjusted to real terms by using U.S. Wholesale Price Index, 1957-59 base.

Source: (5)

The calculated shadow prices of water imply that everybody associated with the irrigation system has equal "water rights." Thus, once the pre-season supply is known, the price is assumed to stabilize and remain fixed. In the "real world" water rental prices vary throughout the season among other things, to natural disasters and abrupt changes in the price of other inputs or products. Nevertheless, the known pre-season water supply has an important bearing on prices. Fullerton (5) found that 75 to 90 percent of the variability in rental prices was explained by changes in the water supply.

Table 14 and Figure 5 show the comparison between average weighted shadow prices of water obtained from the linear program and the observed average water prices for the area. Both series are adjusted to 1959 price levels.

Table 14. Comparison among average weighted shadow prices of water and the observed market prices for water in the Delta area.

Water supply (acre feet per irrigated acre)	M.V.P. of water[a] ($)	Observed market prices of water[b] ($)
.65 - .85	42.46	19.94
.85 - 1.05	40.35	14.10
1.05 - 1.25	20.85	14.77
1.25 - 1.45	18.63	6.38
1.45 - 1.65	7.88	9.94
1.65 - 1.85	6.75	3.55

[a] Weighted average. Adjusted to real terms by using U.S. Wholesale Price Index, 1957-59 base.

[b] Average prices obtained from a range of 15 years (1950-1965).

Source: (5)

The test of the reliability of the model by this comparison is not all that might be hoped. Certain refinements could be employed. For example, it would be more accurate to introduce into the linear programming the selling and input prices prevailing in the years

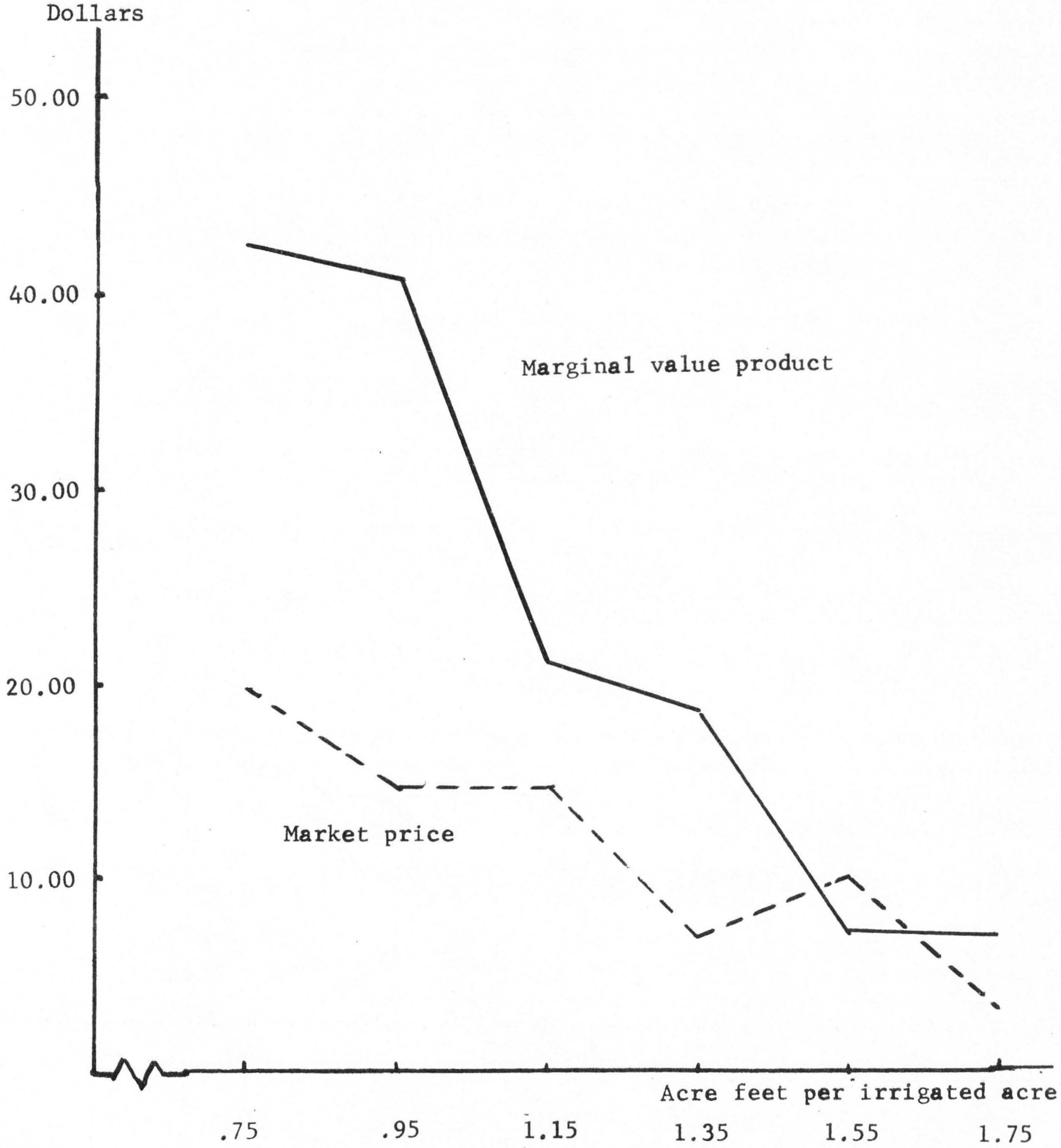


Figure No. 5. Marginal value product and market price of water functions (U.S. Wholesale Price Index 1957-59 = 100) observed by Fullerton.[1] The water prices observed by Fullerton (5) could also be corrected for long term trends due to technological advances, etc.

Possibility of Adapting This Work to Virgin Areas

For new irrigation systems, this methodology appropriately adapted to the given conditions of the area will be a powerful planning device.

A brief explanation of one possible way of adaptation of this

---

(1) As a rough check on whether the differentials between the observed (market) and shadow prices of water (Figure 4) might be reduced if contemporary crop prices were employed, 1950, 1961 and 1969 data are shown below for 3 of the selling activities. Based on Tables 13 and 14 the 1961 shadow prices would be above the observed prices, while the reverse is true in 1950. It is evident that on balance introduction of 1950 prices would probably widen the differential and the same is true for 1961.

	Adjusted prices [a]		
	1950	1961	1969
Enterprise	#	#	#
Alfalfa seed	46.52	38.75	30.42
Corn silage	7.05	8.33	5.53
Calf	25.19	25.00	28.76

[a] (14)

research to virgin areas follows. After the preliminary studies are completed in the area, the cost of the project has to be calculated under different irrigation layouts. A priori the less expensive irrigation alternative is taken as the best possibility. Employing synthetic crop budgets while introducing constraints associated with the given conditions of the area permits an optimum enterprise combination to be obtained by the use of linear programming.

According to the physical characteristics of soil, climate, etc., a water loss coefficient could be calculated for each irrigation delivery system. With that coefficient it is possible to measure the change in water availability due shifting from one management method to another one. Linear programming optimizations can be obtained for each new availability of water. The present value of construction plus operation and maintenance costs for the different management schemes could be compared with the present value of benefits for each availability of water. This would reveal the irrigation construction and management which is going to give the best use of the resources of the area.

There are also other interesting possibilities of the use of this methodology. The shadow prices of water obtained from the linear program procedure could be considered as an initial indication of the maximum possible price to be paid by farmers included in the project.

The problems encountered in this work when total area results are related back to the original number of farms will be avoided when developing new irrigation projects by means of specialization sub-areas within the projects.

SUMMARY AND CONCLUSIONS

The objectives of this study were: (1) to create an optimum enterprise combination by means of linear programming; (2) to measure the change in benefits associated with a reduction in water losses; (3) compare shadow prices obtained from the linear program method with observed market prices of the area; (4) measure the change in benefits and in optimum enterprise combination whenever a change in water supply occurs; and (5) observe the possibility of adaptation of this work to new irrigation projects.

The first objective was reached using the input-output coefficient obtained from the area, other sources of information, and assuming the normal supply of water to be 1.39 acre feet per irrigated acre.

To achieve the second objective it was necessary to assume a reduction in the quantity of losses when changing management between 10 and 25 percent. This means was employed because the exact figures are unknown. A reduction in losses of 25 percent would be worth about $12,000 per year in the Delta area.

In reaching the third objective, the shadow prices obtained by the increase and decrease of water supply by 1 percent, were adjusted using the U.S. Wholesale Price Index, in order to make them comparable with a time series of observed water market prices in the area. The model does not predict the market prices very accurately.

The fourth objective was achieved by comparing the value of the value of the objective function and changes in enterprise patterns when changes in the normal supply of water would be anticipated early in the season. A 50 percent cut in water availability has a great effect on area income. A 25-30 percent cut has a 15 percent effect.

The possible adaptation of this work to virgin areas was treated by explaining a possible way of planning irrigation systems using the methodology followed in this work.

According to the results obtained, the shift from demand delivery method to a more efficient one (whether this is rotation, continuous flow or any combination of those) might be adopted in the Delta area, because the reduction in losses associated with the change in the irrigation scheme represent an increase in the beneifts through an increase in the value of the objective function and a decrease in the costs of operation and maintenance. But this is an priori conclusion because it first is necessary to find the costs associated with the system alternations generated by the management change. If this value is subtracted from the loss benefits obtained previously, it could be possible to have a net increase in benefits with a shift to a non-demand system. However, a demand system has certain conveniences, the values of which are hard to measure.

The shadow prices obtained for water in the Delta area are observed as a declining function with respect to available water. The same characteristic is observed in the water market prices for the same area. The difference in water rights, changes in prices, and other factors, explain why the observed market prices are lower than the calculated marginal value product of water for the same availability of water for the whole area.

The necessary adjustments, that the farmer might be able to make when the predicted supply of water changes at the beginning of the irrigation season, were taken into account in this research. Farmers could know which crops they have to plant in order to achieve the maximum possible benefits.

Adaptation of this work to the planning of new irrigation systems, is possible to achieve, taking into account the existing conditions of the proposed project area.

To complete this work, estimation of the costs associated with the alternate management of the system is necessary.

NEED FOR FURTHER RESEARCH ON INTRATEMPORAL WATER ALLOCATION

Whenever a change in water availability occurs during an irrigation season, the farmers have to decide what will be the best irrigation practice adjustment to follow in order to maximize their income.

To work on this problem it is necessary to include in the linear programming model some method of changing the water supply within the irrigation season, in order to maximize the net returns to the land unit.

Suppose the farmers are faced with a normal supply of irrigation water and rainfall. With this pre-season expectation they establish the cropping pattern and enterprise combination to maximize their incomes. Later the expected rainfall is reduced by some quantity. This shortage could be viewed in two ways:

(a) The rainfall shortage is for only one month, after which the water fainfall remains as predicted;

(b) the rainfall shortage continues for the rest of the season according to the new predictions of meteorological reports.

What do the farmers have to decide? They need to know whether to reduce the amount of irrigation to some crops in a "short" month (a) while returning to the previous schedule later or to hold at a reduced level the remainder of the season (a)(b). When should they short an existing crop and begin new enterprises (b)? What is needed is technical information about what happens to growth, yield and quality when crops are put under short moisture stress at various stages of their growth cycles. If this were available it would be possible to introduce the necessary data and constraints into the L.P. model.

The other side of the temporal problem is increase in water supply during the irrigation season. In that case, the farmers must decide whether to save water for the next irrigation period or sell it.

LITERATURE CITED

Anderson, Raymond L. and Maass, Arthur. A simulation of irrigation systems: The effect of water supply and operating rules on production and income on irrigated farms. Technical Bulletin No. 1431, U. S. Department of Agriculture, Economic Research Service, January 1971.

Day, Lee H. The use of representative farms in Agricultural Economics. Journal of Farm Economics Vol. 45, December 1963, pp. 1438-1447.

Ellis, Frank. A correlation analysis of water supply and irrigated yields, Mirage Flats Project, 1952-1960. Journal of Farm Economics Vol. 44, December 1962, pp. 1439-1443.

Frick, George E. and Andrews, Richard A. Aggregation bias and four methods of summing farm supply functions. Journal of Farm Economics Vol. 47, August 1965, pp. 696-700.

Fullerton, Herbert H. Transfer restrictions and missallocation of irrigation water, M. S. Thesis. Utah State University Library, Logan, Utah 1966.

Hall, Warren A and Butcher, William S. Optimal timing of irrigation. Journal of Irrigation and Drainage Division. ASCE, June 1968, 00. 267-277.

Heady, Earl and Candler, Wilfred. Linear programming methods. Ames: Iowa State College Press, 1958.

Hughes, Trevor. The relation of linear programming to production theory. Unpublished mimeo, Ag. Econ. dep., Montana State University, 1971.

LeBaron, Allen; Israelsen, Eugene K. and Fullerton, Herbert H. Non-optimal irrigation delivery shcemes and the level of local rural income. Unpublished OWRR research proposal, Utah Center for Water Resources Research, U.S.U., November 1970.

Mijeres, Hugo. A model for estimation of economic benefits under alternative irrigation delivery schemes: an application to central Utah area. Unpublished notes, Ag. Econ. dep., Utah State University, 1971.

Nitts, Isaac O. Optimum enterprise combinations for representative farms in Sevier County Utah. Unpublished M. S. Thesis, Utah State University Library, Logan, Utah, 1963.

Sumsion, Neil D. An economic study of farm adjustment possibilities in Delta area of Utah. Unpublished M. S. Thesis, Utah State University Library, Logan, Utah, 1966.

Undewust, J. S. Modified demand system. East Low Field Branch Paper, Bureau of Reclamation; Othello, Washington, 1968.

U. S. Bureau of the Census. Statistical abstract of the United States: 1967 (Eighty-fifth edition) Washington, D. C., 1965.

U. S. Department of Agriculture. Soil Conservation Service. Water and related land resources, Sevier River Basin, Utah. Appendix x, 1969.

APPENDIX: STUDY DATA

Table 15 Selected crops, yields, costs, water, and labor requirements - Delta, Utah, 1971

Crop	Yield (ton)	Cost ($)	Net return ($)	Water requirement (hours)						Labor requirement (hours)					
				April	May	June	July	August	Sept.	April	May	June	July	August	Sept.
Alfalfa hay 1	5.50	65.20		.50	.50	.50	1.00	.50	.50	2.65	.77	1.50	2.00	.50	1.25
Alfalfa hay 2	4.00	47.67		.50		.50	.50	.50		2.65	.27	1.25	1.25	.50	.25
Alfalfa hay 3	2.50	32.87		.50			.50			2.65	.27	1.00	.50		.25
Alfalfa hay 4	5.20	61.58		.45	.45	.45	.90	.45	.45	2.55	.71	1.40		.45	1.15
Alfalfa hay 5	5.06	60.97		.40	.40	.40	.80	.40	.40	2.45	.66	1.31	1.71	.40	1.08
Alfalfa hay 6	4.84	60.25		.35	.35	.35	.70	.35	.35	2.35	.61	1.21	1.56	.35	1.01
Alfalfa hay 7	4.40	57.53		.30	.30	.30	.60	.30	.30	2.30	.56	1.11	1.40	.30	.90
Alfalfa hay 8	4.13	54.87		.25	.25	.25	.50	.25	.25	2.25	.50	1.00	1.25	.25	.82
Corn 1	20.00	62.29			1.00	1.00	1.00	1.00		.80	1.40	1.25	1.00	5.00	
Corn 2	12.00	47.55			1.00		1.00			.80	1.40		1.25	2.40	
Corn 3	18.60	58.63			.90	.90	.90	.90		.80	1.30	1.15	.90	4.62	
Corn 4	16.60	54.67			.80	.80	.80	.80		.80	1.20	1.05	.80	4.11	
Corn 5	15.00	50.91			.70	.70	.70	.70		.80	1.10	.95	.70	3.70	
Corn 6	12.00	46.45			.60	.60	.60	.60		.80	1.00	.85	.60	3.00	
Corn 7	11.00	42.99			.50	.50	.50	.50		.80	.90	.75	.50	2.70	
Barley 1	1.90	54.73		1.00	.50					2.30	.50	.60	1.00		
Barley 2	1.14	47.36		1.00						2.30		.10	.60		
Barley 3	1.71	51.51		.90	.45	.45				2.20	.45	.55	.90		
Barley 4	1.61	48.76		.80	.40	.40				2.10	.40	.50	.85		
Barley 5	1.52	46.07		.70	.35	.35				2.00	.35	.45	.80		
Barley 6	1.33	42.85		.60	.30	.30				1.90	.30	.40	.75		
Barley 7	1.23	40.10		.50	.25	.25				1.80	.25	.35	.70		
Alfalfa seed 1	.182	89.09	42.91				1.50	1.00		.37			1.93	2.10	
Alfalfa seed (hay) 1	1.50	43.11		.50	.50	.50				1.03	.77	1.25			
Alfalfa seed 2	.159	76.92	38.58				1.00	.50		.37			1.43	1.48	
Alfalfa seed (hay) 2	1.00	28.12		.50	.50					1.03	.77	.50			
Alfalfa seed 3	.136	70.43	38.57				.50	.50		.37			.60	1.35	
Alfalfa seed (hay) 3	1.00	24.43			.50					.53	.77	.50			
Alfalfa seed 4	.167	86.28	35.16				1.35	.90		.37			1.78	1.91	
Alfalfa seed (hay) 4	1.43	32.67		.45	.45	.45				.98	.71	1.10			
Alfalfa seed 5	.155	83.59	28.61				1.20	.80		.37			1.63	1.65	
Alfalfa seed (hay) 5	1.38	31.33		.40	.40	.40				.93	.65	1.08			
Alfalfa seed 6	.145	81.14	24.46				1.05	.70		.37			1.48	1.44	
Alfalfa seed (hay) 6	1.32	29.95		.35	.35	.35				.88	.59	1.00			
Alfalfa seed 7	.118	77.52	8.28				.90	.60		.37			1.33	1.23	
Alfalfa seed (hay) 7	1.20	28.28		.30	.30	.30				.83	.53	.90			
Alfalfa seed 8	.205	97.39	51.11				1.50	1.50		.37			1.93	2.73	
Alfalfa seed (hay) 8	1.50	34.11		.50	1.00	.50				1.03	1.27	1.25			
Alfalfa seed 9	.155	75.91	36.29				1.00	.50		.37			1.10	1.95	
Alfalfa seed (hay) 9	1.00	24.43			.50					.53	.77	.50			

Table 16. Cost[1] and returns per unit (1 calf) in the calf-yearling I enterprise, Delta, Utah, 1971.

Receipts		
1 yearling x \$212.00 x .988 = \$209.45[2]		
Expenses		
Calf purchase	\$135.00	
Veterinary expenses	1.00	
Rent of range	4.50[3]	
Supplements and minerals	2.50	
Various	1.40[4]	
Total		\$144.40
Returns		\$ 65.05
Requirements of food per unit		
Corn silage	2.5 tn during 7 months	
Alfalfa hay	.8 tn during 7 months	
Barley	.08 tn during 7 months	

[1] Does not include the cost of food produced in the farm.

[2] 2% of death losses per annum.

[3] Cost of renting range is \$3.00 per month per A.V. The calf is assumed to have an average of .5 A.V., and they are on the range for 5 months.

[4] Includes expenses for corral, etc.

Table 17. Cost and returns per unit (1 calf) in the calf-yearling II enterprise, Delta, Utah,* 1971.*

Receipts

1 yearling x $190.80 x .988 = $188.47.

Expenses

Calf purchase	$135.00	
Veterinary expenses	1.00	
Rent of range	4.50	
Supplements and minerals	2.50	
Various	1.40	
Total		$144.40
Returns		$ 44.01

Requirements of food per unit

Corn silage	2.25 tn during 7 months
Alfalfa hay	.72 tn during 7 months
Barley	.07 tn during 7 months

* See notes, Table 16.

Table 18. Cost and returns per unit (1 calf) in the calf-yearling III enterprise, Delta, Utah, 1971.*

Receipts		
1 yearling x $171.72 x .988 = $169.66		
Expenses		
Calf purchase	$135.00	
Veterinary expenses	1.00	
Rent of range	4.50	
Supplements and minerals	2.50	
Various	1.40	
Total		$141.40
Returns		$ 25.16
Requirements of food per unit		
Corn silage	2.00 tn during 7 months	
Alfalfa hay	.64 tn during 7 months	
Barley	.06 tn during 7 months	

*See notes for Table 16.

Table 19. Costs[1] and returns per unit (1 cow and 1 calf) of the beef cow-calf feed enterprise I, Delta, Utah, 1971.

Receipts

1 yearling x \$212.00 x .98 x .90 x .84 = \$157.06[2]
1 cull cow x \$170.00 x .16 = 27.20[3]
1 heifer replacement x 600 lbs. x \$.26 x .20 = \$31.20[5]

Total		\$215.46

Expenses

Veterinary expenses	\$ 4.20	
Breeding charge	3.15	
Supplements and minerals	14.00	
Various	1.40	
Range rent[4]	24.30	
Total		\$ 47.05

Returns	\$168.41

Requirements of food per unit[6]

Corn silage	17.34 tn (10.7 x 1.62)
Alfalfa hay	5.56 tn (3.43 x 1.62)
Barley	.56 tn (.343 x 1.62)

[1] Does not include the cost of the food produced in the farm.

[2] 2 percent of dead losses per annum
90 percent of calf crop
84 percent of calves are sold

[3] Average weight - 1,000 pounds
Price per unit - 17 cents
Percent of replacement - 16

[4] 1.62 AV x \$3/month/AV x 5 months = \$24.30

[5] 20 percent of replacement, \$26/100 pounds

[6]

Cows	1.00 av.
Calves	.34
Heifer	.16
Yearling	.12
	1.62

Table 20. Costs and returns per unit (1 cow and 1 calf) in the beef cow-calf enterprise II, Delta, Utah, 1971.*

Receipts		
1 yearling x \$190.80 x .98 x .90 x .8¢ =	\$141.36	
1 cull cow x \$153.00 x .16 =	24.48	
1 heifer replacement x 600 lbs. x \$.26 x .20 =	27.60	
Total		\$193.44
Expenses		
Veterinary expenses	\$ 4.20	
Breeding charge	3.15	
Supplements and minerals	14.00	
Various	1.40	
Range rent	24.30	
Total		\$ 47.05
Returns		\$146.39
Requirements of food per unit		
Corn silage	15.61	tn/yr
Alfalfa hay	5.00	tn/yr
Barley	.50	tn/yr

*See notes for Table 19.

Table 21. Costs and returns per unit (1 cow and 1 calf) of the beef cow-calf feed enterprise III, Delta, Utah.*

Receipts		
1 yearling x \$171.72 x .98 x .90 x .84 =	\$127.23	
1 cull cow x \$137.70 x .16 =	22.03	
1 heifer replacement x 600 lbs. x \$.21 x .20 =	25.20	
Total		\$174.46
Cost		\$ 47.05
Returns		\$127.41
Requirements of food per unit		
Corn silage	13.88 tn/yr	
Alfalfa hay	4.44 tn/yr	
Barley	.44 tn/yr	

*See notes for Table 19.

Table 22. Linear programming matrix

	Alfalfa Hay 11	Alfalfa Hay 12	Alfalfa Hay 13	Alfalfa Hay 21	Alfalfa Hay 22	Alfalfa Hay 23	Alfalfa Hay 31	Alfalfa Hay 32	Alfalfa Hay 33	Alfalfa Hay 41	Alfalfa Hay 42	Alfalfa Hay 43	Alfalfa Hay 51
Objective Function	-21.44	-25.13	-18.63	-15.43	-19.12	-13.12	-13.12	-13.12	- 6.63	-20.62	-23.54	-17.42	-19.96
April Labor	1.55	.55	.55	1.55	.55	.55	1.55	.55	.55	1.45	.55	.55	1.35
May Labor	.77			.27			.27			.71			.66
June Labor	1.00	.50		.75	.50		.50		.50	.95	.45		.91
July Labor		2.00			1.25				.50		1.85		
August Labor			.50			.50						.45	
September Labor			1.25		1.25							1.15	
October Labor													
November Labor													
December Labor													
January Labor													
February Labor													
March Labor													
Alfalfa Hay	- 2.00	- 2.00	- 1.50	- 1.50	- 1.50	- 1.00	- 1.00	- 1.00	- .50	- 1.90	- 1.90	- 1.40	- 1.84
Corn													
Barley													
Water, April	.50			.50			.50			.45			.40
Water, May	.50									.45			.40
Water, June		.50			.50						.45		
Water, July		1.00			.50			.50			.90		
Water, August			.50			.50						.45	
Water, September			.50									.45	
Land	1.00			1.00			1.00			1.00			1.00
Conventional 1	1.00	- 1.00											
Conventional 2	1.00		- 1.00										
Conventional 3				1.00	- 1.00								
Conventional 4				1.00		- 1.00							
Conventional 5							1.00	- 1.00					
Conventional 6							1.00		- 1.00				
Conventional 7										1.00	- 1.00		
Conventional 8										1.00		- 1.00	
Conventional 9													1.00
Conventional 10													1.00
Conventional 11													
Conventional 12													
Conventional 13													
Conventional 14													
Conventional 15													
Conventional 16													
Conventional 17													
Conventional 18													
Conventional 19													
Conventional 20													
Conventional 21													
Conventional 22													
Conventional 23													

Table 22. (Continued)

	Alfalfa Hay 52	Alfalfa Hay 53	Alfalfa Hay 61	Alfalfa Hay 62	Alfalfa Hay 63	Alfalfa Hay 71	Alfalfa Hay 72	Alfalfa Hay 73	Alfalfa Hay 81	Alfalfa Hay 82	Alfalfa Hay 83	Alfalfa Seed 11	Alfalfa Seed 12
Objective Function	-23.28	-17.73	-19.59	-22.91	-17.75	-18.86	-22.18	-16.49	-18.39	-20.31	-16.17	42.91	-34.11
April Labor	.55	.55	1.25	.55	.55	1.20	.55	.55	1.15	.55	.55	.37	1.03
May Labor			.61			.56			.50				.77
June Labor	.40		.86	.35		.81	.30		.75	.25			1.25
July Labor	1.71			1.56			1.40			1.25		1.93	
August Labor		.40			.35			.30			.25	2.10	
September Labor		1.08			1.01			.90			.82		
October Labor													
November Labor													
December Labor													
January Labor													
February Labor													
March Labor													
Alfalfa Hay	- 1.84	- 1.38	- 1.76	- 1.76	- 1.32	- 1.60	- 1.60	- 1.20	- 1.50	- 1.50	- 1.13		- 1.50
Corn													
Barley													
Water, April			.35			.30			.25				
Water, May			.35			.30			.25				.50
Water, June	.40			.35			.30			.25			.50
Water, July	.80			.70			.60			.50			.50
Water, August		.40			.35			.30			.25	1.50	
Water, September		.40			.35			.30			.25	1.00	
Land			1.00			1.00			1.00			1.00	
Conventional 1													
Conventional 2													
Conventional 3													
Conventional 4													
Conventional 5													
Conventional 6													
Conventional 7													
Conventional 8													
Conventional 9	- 1.00												
Conventional 10		- 1.00											
Conventional 11			1.00	- 1.00									
Conventional 12			1.00		- 1.00								
Conventional 13						1.00	- 1.00						
Conventional 14						1.00		- 1.00					
Conventional 15									1.00	- 1.00			
Conventional 16									1.00		1.00		
Conventional 17												1.00	- 1.00
Conventional 18													
Conventional 19													
Conventional 20													
Conventional 21													
Conventional 22													
Conventional 23													

Table 22. (Continued)

	Alfalfa Seed 21	Alfalfa Seed 22	Alfalfa Seed 31	Alfalfa Seed 32	Alfalfa Seed 41	Alfalfa Seed 42	Alfalfa Seed 51	Alfalfa Seed 52	Alfalfa Seed 61	Alfalfa Seed 62	Alfalfa Seed 71	Alfalfa Seed 72	Corn 1
Objective Function	38.58	-28.12	38.57	-24.43	35.16	-32.67	28.61	-31.33	24.46	-29.95	8.28	-28.28	-62.29
April Labor	.37	1.03	.37	.53	.37	.98	.37	.93	.37	.88	.37	.83	.80
May Labor		.77		.77		.77		.65		.59		.53	1.40
June Labor		.50		.50		1.10		1.08		1.00		.90	1.25
July Labor	1.43		.60		1.78		1.63		1.48		1.33		1.00
August Labor	1.48		1.35		1.91		1.65		1.44		1.23		5.00
September Labor													
October Labor													
November Labor													
December Labor													
January Labor													
February Labor													
March Labor													
Alfalfa Hay		- 1.00		- 1.00		- 1.43		- 1.38		- 1.32		- 1.20	
Corn													
Barley													
Water, April													
Water, May		.50				.45		.40		.35		.30	1.00
Water, June		.50		.50		.45		.40		.35		.30	1.00
Water, July						.45		.40		.35		.30	1.00
Water, August	1.00		.50		1.35		1.20		1.05		.90		1.00
Water, September	.50		.50		.90		.80		.70		.60		
Land	1.00		1.00		1.00		1.00		1.00		1.00		1.00
Conventional 1													
Conventional 2													
Conventional 3													
Conventional 4													
Conventional 5													
Conventional 6													
Conventional 7													
Conventional 8													
Conventional 9													
Conventional 10													
Conventional 11													
Conventional 12													
Conventional 13													
Conventional 14													
Conventional 15													
Conventional 16													
Conventional 17													
Conventional 18	1.00	- 1.00											
Conventional 19			1.00	- 1.00									
Conventional 20					1.00	- 1.00							
Conventional 21							1.00	- 1.00					
Conventional 22									1.00	- 1.00			
Conventional 23											1.00	- 1.00	

Table 22. (Continued)

	Corn 2	Corn 3	Corn 4	Corn 5	Corn 6	Corn 7	Barley 1	Barley 2	Barley 3	Barley 4	Barley 5	Barley 6	Barley 7
Objective Function	-47.55	-58.63	-54.67	-50.91	-46.45	-42.99	-54.73	-47.36	-51.51	-48.76	-46.07	-42.85	-40.10
April Labor	.80	.80	.80	.80	.80	.80	2.30	2.30	2.20	2.10	2.00	1.90	1.80
May Labor	1.40	1.30	1.20	1.10	1.00	.90	.50		.45	.40	.35	.30	.25
June Labor		1.15	1.05	.95	.85	.75	.60	.10	.55	.50	.45	.40	.35
July Labor	1.25	.90	.80	.70	.60	.50	1.00	.75	.90	.85	.80	.75	.70
August Labor	3.00	4.62	4.11	3.70	3.00	2.70							
September Labor													
October Labor													
November Labor													
December Labor													
January Labor													
February Labor													
March Labor													
Alfalfa Hay													
Corn	-15.00	-18.60	-16.60	-15.00	-12.00	-11.00							
Barley							- 1.90	- 1.43	- 1.17	- 1.61	- 1.52	- 1.33	- 1.23
Water, April							1.00	1.00	.90	.80	.70	.60	.50
Water, May	1.00	.90	.80	.70	.60	.50	.50		.45	.40	.35	.30	.25
Water, June		.90	.80	.70	.60	.50	.50		.45	.40	.35	.30	.25
Water, July	.50	.90	.80	.70	.60	.50							
Water, August	.50	.90	.80	.70	.60	.50							
Water, September													
Land	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 22. (Continued)

	Calf 1	Calf 2	Calf 3	Beef 1	Beef 2	Beef 3	Sell Alfalfa Hay 1	Sell Alfalfa Hay 2	Sell Alfalfa Hay 3	Sell Corn 1	Sell Corn 2	Sell Corn 3	Sell Barley 1
Objective Function	65.05	44.01	25.16	108.41	146.39	127.41	17.00	15.00	13.00	6.00	5.00	4.00	42.10
April Labor	1.50	1.00	.75	.80	.50	.50							
May Labor	1.50	1.00	.75	.80	.50	.50							
June Labor				.80	.50	.50							
July Labor				.80	.50	.50							
August Labor				.80	.50	.50							
September Labor				1.80	1.00	1.00							
October Labor				1.80	1.00	1.00							
November Labor	1.50	1.00	.75	1.80	1.00	1.00							
December Labor	1.50	1.00	.75	1.80	1.00	1.00							
January Labor	1.50	1.00	.75	1.80	1.00	1.00							
February Labor	1.50	1.00	.75	1.80	1.00	1.00							
March Labor	1.50	1.00	.75	1.80	1.00	1.00							
Alfalfa Hay	.80	.72	.64	5.56	5.00	4.44	1.00	1.00	1.00				
Corn	2.50	2.25	2.00	17.34	15.61	13.88				1.00	1.00	1.00	
Barley	.08	.07	.06	.36	.50	.44							1.00
Water, April													
Water, May													
Water, June													
Water, July													
Water, August													
Water, September													
Land													

Table 22. (Continued)

	Sell Barley 2	Sell Barley 3	Water Transfer 1	Water Transfer 2	Water Transfer 3	Water Transfer 4	Water Transfer 5	
Objective Function	33.68	25.20						
April Labor								19,800.00
May Labor								19,800.00
June Labor								19,800.00
July Labor								19,800.00
August Labor								19,800.00
September Labor								19,800.00
October Labor								19,800.00
November Labor								19,800.00
December Labor								19,800.00
January Labor								19,800.00
February Labor								19,800.00
March Labor								19,800.00
Alfalfa Hay								
Corn								
Barley	1.00	1.00						
Water, April			1.00					10,789.87
Water, May			- 1.00	1.00				
Water, June				- 1.00	1.00			
Water, July					- 1.00	1.00		
Water, August						- 1.00	1.00	
Water, September							- 1.00	
Land								7,816.00