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A Multi-Year Analysis of Irrigation Practices Affecting Salt Outflow: A Case Study in Uintah Basin

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A MULTI-YEAR ANALYSIS OF IRRIGATION PRACTICES AFFECTING SALT OUTFLOW: A CASE STUDY IN UINTAH BASIN

by

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ABSTRACT

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Salt Outflow: A Case Study in Uintah Basin

by

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Utah State University, 1977

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The Colorado River is subject to a salinity problem which affects the downstream user. It has been suggested that approximately 40% of the salinity in the Colorado River results from irrigation return flow. The evapotranspiration process extracts nearly pure water for plant use leaving behind soluable salts which may become part of the return flow. These salts adversely affect the crop yield for the downstream user.

Farmers' contributions to the irrigation return flow have been criticized. With the criticisms have been many suggestions on salinity control, including restriction of salt outflow at the farm level through either voluntary or mandatory means. An important element in the policy making procedure is a good information base showing the economic effect of salinity control on the individual farm to which the control affects. To date such a base has not been available. Such an information base is necessary to establish policies and implement programs to solve the salinity problem in the Colorado River.

INTRODUCTION

High salinity levels in the Colorado River constitute an interesting and challenging problem to water users and policy makers who must deal with the adverse effects of salinity and with the costs of reducing these effects.

The physical aspects of the problem include both natural processes and man controlled sources which cause a buildup of salts in the river water. Of the sources controlled by man, the most significant is the irrigation return flow. The high salt content of some irrigation return flows is due to the evapotranspiration process whereby water is lost from the soil to the atmosphere through the action of evaporation from wet surfaced combined with transpiration, the exhalation of water vapor by plants. This evapotranspiration leaves a higher concentration of salts in the irrigation water and soil profile. It has been suggested that approximately 40 percent of the salinity in the Colorado River results from this process (Hanks et al., 1970).

There are several economic aspects of the salinity problem because the well-being of the upstream user conflicts with the well-being of the downstream user. As the upstream farmer "uses" the water for irrigation, higher salinity levels result in the stream. The downstream water user is affected adversely by these high salt concentrations. Some of the detrimental effects of high salinity are decreased agricultural productivity, lower palatability of drinking water, possible reduced life of water pipes and fixtures, and even some adverse health effects (Young et al., 1973).

The farmer's contribution to the salinity problem has been criticized, and suggestions have been made to restrict the salt outflow from farm operations. However, there is currently little information available concerning what economic effects such restrictions would have on the individual farm enterprise. Without a suitable information base concerning the economic impact of salinity controls, the policy makers are hindered in their efforts to find an equitable solution to the salinity problem in the Colorado River.

The purpose of this study is to supply a base of information concerning an irrigation management approach to reducing salinity in the Colorado River. The study is based on physical data taken from the Hullinger Experimental Farm in Vernal, Utah, and from computer simulations of the salinity effects on crop yield. Both the short and long term physical and economic impacts of salt outflow controls are herein presented, but particular attention is given to the multi-year analysis, since this is obviously the most relevant to making sound policy decisions.

This study deals with the economic management and environmental situation of one farm in eastern Utah. The specific results of the analysis pertain exclusively to that farm; however, some important inferences of the analysis may be considered for other similar situations.

The objectives of this economic study of the Hullinger Farm were: (1) to develop farm cost and revenue information for management alternatives concerning cropping patterns, rates of water application, and irrigation methods, subject to three alternative initial soil salinity levels; (2) to develop a function relating the reduction of salt outflow to the net revenue; (3) to determine the shadow price (value) of salt outflow under incremental changes of the salt outflow; (4) to suggest irrigation management practices which will decrease the salt outflow to less harmful levels, and at the same time indicate the farm management alternatives which will yield maximum net revenues subject to constraints on salt outflow; (5) to analyze by linear and recursive programming the physical and economic effects of four levels of water application during a six year period.

BACKGROUND MATERIAL FOR STUDY

Economic Effects and Management Studies

Because of the great variety of literature concerning the economic effects of salinity, this section will review primarily the literature dealing with the topics most relevant to the Colorado River Basin problem.

The problem of salinity in the Colorado River has been discussed at length by Young et al. (1973).

> Rivers typically contain some dissolved salts acquired naturally by leaching from rocks and solids or from inflows of saline water from underground sources. The modification of river inflows in the course of development of a river basin's resources for human purposes can further contribute to dissolved salts in the water.
>
> The tail waters of the (Colorado) River flow into Mexico. The Mexican government has been quite critical of the quality of waters released from the United States.

In order to reduce salinity concentration in the downstream waters, costs must be incurred to desalinate the river water or to reduce the salt inflows from man-made sources such as irrigation systems. In the study quoted above, the authors discuss alternative irrigation and crop management practices for salinity adaptation. Among the various management practices discussed are the following:

1. Ditch Lining: Economically feasible when soil salinity levels are high, ditch lining reduces seepage losses and alleviates some of the salt pickup from the soil.

2. Soil Management:

   a. Land leveling is necessary for uniform distribution of water and prevention of salt buildup in the high spots of the field.

   b. Drainage is necessary for leaching to be effective. A good drainage system must be provided. Tile drains usually increase efficiency of drainage water removal.

   c. Subsoil tillage is done by moldboard plow to depths of four feet or more, sometimes disrupting stratification to improve drainage efficiency and uniform water penetration.

3. Salt Leaching: Salts accumulate in the soil surface during the period of crop maturation when water is not applied or in hills during conventional or special bedded furrow irrigation. Both sprinkler and flood irrigation may be applied for leaching purposes before planting the next crop.

4. Special Bedding: Double row crops were adopted to control salinity in the root zone in the Yuma area, Coachella Valley, and Imperial Valley. Flat topped double beds are used for crops such as lettuce and carrots, while sloping beds are used for melon crops.

Pincock (1969) used a budget approach to measure the effect of salinity on crop yields and provided a conceptual basis for the analysis used by the Environmental Protection Agency (1971).

In Lorenstein (1971) a dynamic model was constructed through the use of a differential equation relating the instantaneous rate of change in soil salt concentration to the salinity of applied water, existing salt concentration, consumptive use of water, and the water application rate.

Gisser (1970), d'Arge (1970), and Sun (1971) have utilized linear programming to treat problems dealing with salinity in irrigation water. The d'Arge and Gisser studies deal with the salinity problems in the Pecos River Basin of New Mexico. Sun applied the linear programming technique to a model which determines crop response to water quantity and salinity in the Imperial Valley of California.

The interfacing of economics and soil science is demonstrated in the study of Young, Franklin, and Nobe (1973) which has previously been quoted. The Young et al. (1973) study used physical data from experiments described in Bernstein (1964) which show the physical effects of salinity on crop yield. A mathematical model was derived from the physical data and combined with a mathematical economic expression showing the relationship between yield and income. The resulting equation was used to predict reduction in profits due to salinity.

Another interdisciplinary linking economics and agricultural science is that of Bresler and Yaron (1972). This work described an economic model which indicates the optimal combinations of water quality and quantity for an agricultural enterprise. Water quantities of varying salinity and cost were evaluated in simulations of irrigation management effects on the profitability of a grapefruit operation.

In a subsequent study Yaron (1973) developed a long run model to evaluate salt accumulation in the soil profile. In his model water quality is considered exogenous and is varied parametrically for a series of simulation runs. The decision variable is restricted to the quantity of water used for leaching.

In the Yaron study, net revenue losses are calculated at different initial soil salinity levels. The calculations take into account the income loss caused by yield reductions due to salt concentrations in the soil profile during one year. Summer and winter leaching were incorporated into the model through the use of Bresler's soil yield prediction equation. The results showed essentially the same loss of revenue due to salinity for all five initial soil salinity levels which were simulated in the model.

Review of Programming Methods

This second part of the review of literature is concerned with the programming methods used in this study to analyze the economic effects of salt outflow controls. For the one year static model the objective was to maximize net revenue given three possible crops, six alternative water application levels, three different soil salinity conditions, and two possible irrigation methods. Because of the number of different activities and constraints, and because the salt outflow would be incrementally increased, linear programming was the logical choice of methods for the one year model. Linear programming and other relevant programming procedures are discussed below.

Linear programming

Linear programming is a tool used to maximize or minimize a specific objective function subject to specific constraints. According to Ferguson and Sargent (1958), the roots of linear programming date back to 1874 with the work of the mathematical economist Leon Walras. In his work Elements d'Economie Politique, Walras (1874) showed that the price of any number of commodities at a given time can be determined by solving simultaneously the appropriate number of equations in terms of the numbers of unknowns for which a solution is sought. This was the first attempt to solve problems of scarcity by stating problem conditions in equation form. However, the method of solving the equations by linear programming is completely different from that used by Walras. Linear programming as it is known today descends from an input-output analysis developed by Wassily W. Leontief (1927) in the 1920's. A more recent development in linear programming is the Simplex Method of solving a set of simultaneous equations for an optimum solution. The Simplex Method was developed and announced in 1947 by George B. Dantzig (1947).

Simulation "dynamo" programming

Another programming alternative is the Burroughs simulation program called "Dynamo" (1972). This simulation operates on a continuous time series and changes state at irregular intervals whenever one of its defined events occurs. The Dynamo program advances discreetly by uniform intervals of any size desired, and the entire system is reevaluated at each interval. This periodic reevaluation in continuous time simulation resembles analog simulation which solves systems of differential equations in variables that are continuous functions of time.

The Dynamo system plots the different variables and constants over a time series according to the equations used in the program. This program is useful in showing the interaction of the variables over time. For instance, the path of net revenue, salt outflow, and final soil salinity could be plotted for a six month period. However, the plot would become too cluttered if more than one water application rate or initial salt level were introduced. This routine was not used in the present study because it was thought that the same results had already been calculated by a FORTRAN program and because it was easier to graph the results in the normal manner or use a standard plotting program.

Interactive programming

This program simulates the activities of variables over a time period, then maximizes the objective function and simulates for another time period, using the conditions which resulted from the first maximization process.

This procedure is repeated successively for a given number of time periods. The interactive programming alternative was not chosen for this study because of the high costs and computer programming expertise involved.

Recursive programming

Linear programming models can be used to express the hypothesis that farm producers try to maximize their net revenue with the given conditions of limited returns and uncertainty. This approach can be imbedded in a dynamic framework where current decisions and results are conditioned by past decisions and results and performance. The appropriate methodology for this dynamic setting is known as recursive programming.

Day (1964) establishes the basic mathematical reasoning behind recursive programming. He starts with the technical structure of the decision-making process and derives from it the relations that connect production to prices, costs, acreage controls, and technological changes. Many other dynamic models use stochastic processes to estimate supply relationships by the prices of commodities and their major competitors.

In the multi-years calculations of final soil salinity where the beginning salinity level of a given year depends on the final salinity of the previous year, a program was needed to calculate and maximize net revenue over a six year period. To accomplish this, a very simple recursive program was utilized. In this study, constant prices and a constant water application rate were assumed for the entire period. A program could be developed in which the water quality is changed over the six year period, but this was judged unnecessary for the present study.

PROCEDURES

This study applies directly to the Hullinger Farm, a Utah State University experimental farm in Vernal, Utah. Results of the study are therefore influenced by conditions on that farm. For example, results of the analysis showed a relatively high amount of upward moisture flow in the soil which was due to a high water table. It is assumed that there is one type of soil on the farm, and that all data are related to that particular soil type, even though there are some variations on the portion of the farm used for the tests related to this study.

Physical Data

Yield data for three crops were obtained from a model developed by Hants et al. (1974). This model predicts the ratio of actual transpiration to potential transpiration $(T/T)_p$ for different management practices. Since it is assumed that the ratio of actual crop yield to potential yield is exactly equivalent to the ratio of actual transpiration to potential transpiration, the T/T_p ratio can be used to represent relative yield for a given crop. When the T/T_p ratio predicted for a given management practice is multiplied by the top potential yield on the farm, it gives a predicted yield figure for that management practice. The yield predictions for each crop for each water application level and initial soil salt level were used in calculating the revenue figures, as will be explained with more detail in a subsequent section of the study.

The multi-year physical data from Childs (1975) were used to generate a series of tables for each crop and beginning soil salinity level. These tables trace the year to year changes in the initial salt level, final salt level, salt outflow and yield. In setting up the program, three physical variables were considered: initial soil salinity, crops, and water application levels and methods. The details concerning these variables are discussed below.

Initial soil salinity

In the model it was assumed that there were 10 acres of each of three initial soil salt levels: 20 meq/1, 50 meq/1, and 200 meq/l. The meq/1 is a standard abbreviation for the salinity measure of millequivalents per litre.

Crops

Corn, alfalfa and oats were the crops used in this study. Alfalfa was limited to a maximum of 6.7 acres per 10 acre unit to allow a nurse crop of oats to come in every third year. Corn was restricted to a maximum of half the acreage to provide for disease control and crop diversification strategies. These represent the actual crops grown on the farm except for oats, which was used in the simulations to represent a grain crop. Barley is another grain crop commonly grown in the area of the Hullinger Farm.

Water

On the Hullinger Farm water is pumped from ditches and distributed by a sprinkler system. The cost component of water use in the model includes energy and sprinkler system costs (Hanks et al., 1974, p. 33).

The water application levels include rainfall during the growing season. In the multi-year study the rates used were 20, 36, 52, and 66.7 centimeters per year. Some of the optimizing yearly runs showed that it would be profitable to apply more water to less than the 30 acres available. For this reason and others to be explained, the water application levels represent an average application rate for the entire acreage.

Flood irrigation was also run to represent a management alternative to sprinkling. A coefficient of uniformity is used to distinguish between sprinkler and flood irrigation. This coefficient of uniformity was developed to account for the fact that even with the best irrigation system, parts of the field receive more water than others. The uniformity coefficient Cu is formulated as follows:

$$Cu = \frac{D}{M}$$

Where Cu is the coefficient of uniformity, M is the average or ideal irrigation rate, and D is the average deviation from M disregarding the sign. When the coefficient is equal to zero, the average deviation is zero, meaning that irrigation is applied equally to all parts of the field.

For the sprinkler system alternative, the Cu used in the model was equal to 0.88, which can be approximated by a parabolic distribution. The

Cu for flood irrigation was 0.47 with a rectangular distribution. The Cu of 0.47 is one of the poorest uniformities possible and is representative of the system used on the Hullinger Farm prior to the installation of a sprinkler system. The value of Cu seems to affect salt outflow and yield, so the irrigation technique decision is important to environmental effects.

Linear Programming Procedures

The linear programming technique rests on several basic assumptions which are explained in detail by Leftwich (1970). In the first place, the decision-making process to which it applies involves certain constraints on the individual firm, in the present case a farm in the Colorado River Basin. Secondly, input and output prices are assumed to be constant. The third important assumption is that the firm's input-output, output-output, and input-input relationships are linear. These will be discussed in more detail as to their application to this study.

Constraints

In linear programming problems, the firm is viewed as facing various limitations on its activities. These limitations may be on the quantity of particular inputs or facilities used by the firm. In this study, water application rates and the quantity or portion of land allowed for the cultivation of certain crops are constraints on the production alternatives for the farm. There may also be constraints associated with the output of the firm. Salt output through irrigation return flows may be considered as this latter type of constraint because there is a higher salt outflow associated with the higher crop yields, according to the previously mentioned assumption that the T/T_p ratio is equivalent to the ratio of actual yield to potential yield.

Constant factor and output prices

Output and input prices are assumed to be unaffected by the actions of a ny one individual firm. This is a purely competitive approach to prices which dictates that firms are price takers rather than price makers. The Hullinger Farm and other similar enterprises fit well into this theoretical framework because their scale is not large enough to influence prices and because their output is relatively homogenous in quality.

Linear relationships of input and output

In many instances linear relations of input and output are found. When a firm pays a constant price per unit of a given input, it faces a linear resource cost curve for that input. The total revenue curve will be linear when the product sells for a constant price per unit.

In cases where relationships among the variables are not linear, they can be usefully represented by a series of different discreet linear relationships or by a single linear relationship. As an example, an isoquant curve which is ordinarily a nonlinear constant product curve for two inputs may be represented by a series of connected linear relations as shown in Figure 1. Linear programming techniques incorporate this type of linear simplification in cases where the relations are not actually linear. Production functions are taken as being homogenous to degree one.

The general model

The linear programming technique is used for both the one year and multi-year evaluations. The general linear programming model for profit maximization has the algebraic form:

$$\text{Maximize:} \qquad Z = CX$$

$$\text{Subject to:} \qquad AX \quad B$$

$$X \quad O$$

Where Z is net revenue, C is the row vector of net revenue per unit of activity, X is the set of activities or production processes, A is the matrix of technical coefficients or production relationships, and B represents the column vector of constraints on resource availability.

The model for the one-year study had 108 columns. The constraints involved in the model have been explained in previous sections of this study. Through the use of this model, net revenue was maximized and optimal input combinations were indicated for levels of salt outflow that were incrementally changed from zero to the level where the shadow price of salt outflow equalled zero. The specific results of the linear programming simulations are shown in the next section of the study.

RESULTS

In this section, the results of the economic study are presented for both the single year model and the multi-year model. The procedure for setting up a physical model to predict the T/T_p transpiration rates together with the procedures and results of the linear programming model in which salt outflow is incrementally changed, are given in Hanks et al. (1974) for both the single year and multi-year cases. The linear program was constructed to accommodate three crops, three initial soil salt levels, six water application levels, and two irrigation techniques. The multi-year study shows the changes that occur over time as practices are continued.

Results of the One-Year Study

The one year study utilized the data on initial soil salinity, crop alternatives, and irrigation techniques with water application at six possible levels. These options were developed into a linear programming model which incrementally increased allowable salt outflow from zero up to an unlimited amount.

Net revenue and the salt outflow shadow price are calculated for each level of salt outflow. The series of net revenue figures provide enough data to construct a curve with net revenue plotted on the vertical axis and salt outflow plotted on the horizontal axis. The net revenue curves which result are positively sloped curves which increase at a decreasing rate. The shadow price is derived from the relationship of net revenue and salt outflow. It represents the money value to the farm enterprise measured by each additional ton of salt outflow allowed in the drainage water or cost to farm enterprise of restricting salt outflow. The results of the one year study show a downward sloping shadow price curve signifying the fall in the shadow price for each increase in salt outflow as shown in the lower portion of Figures 2 and 4. Both the net revenue and shadow price were calculated for the optimal cropping patterns and irrigation strategies appropriate to the following situations:

1. Corn silage is restricted to half of the acreage for each soil class. Flood irrigation (Cu. - 0.42) is used. The three lowest water application levels are eliminated from the physical data in the model because those water levels are not sufficient for irrigation. The results are shown in Figures 1 and 2.
2. Corn silage is restricted to half of the acreage for each soil class. Sprinkler irrigation (Cu. - 0.88) is used. The results are shown in Figures 3 and 4.
3. Other situations were simulated in which combinations of flood and sprinkler irrigation were allowed on the 30 acre farm. Because these situations have little application to real situations and possibilities, their corresponding results are not presented in this study.

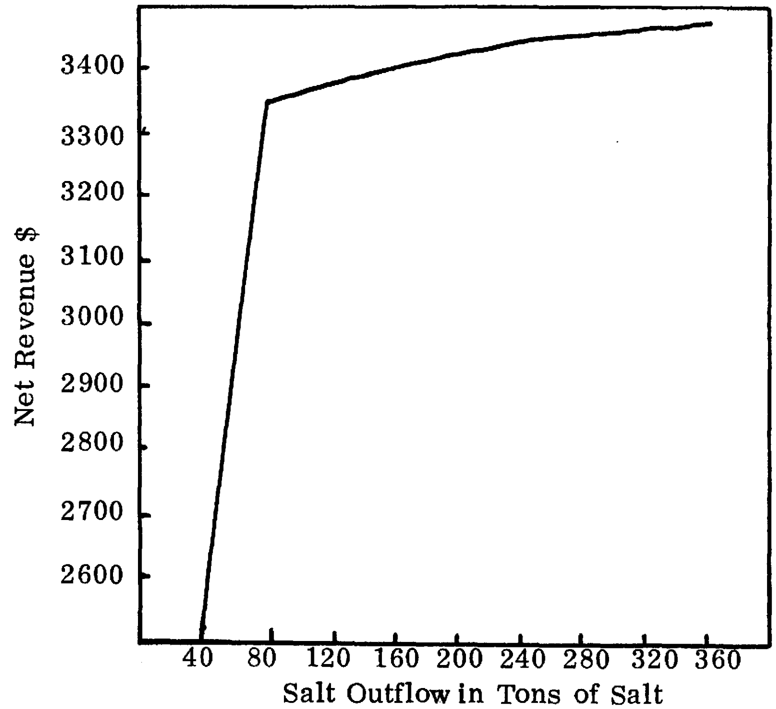

Figure 1. The relationship between net revenue and salt outflow assuming flood irrigation and a limit of 50 percent of acreage in corn silage.

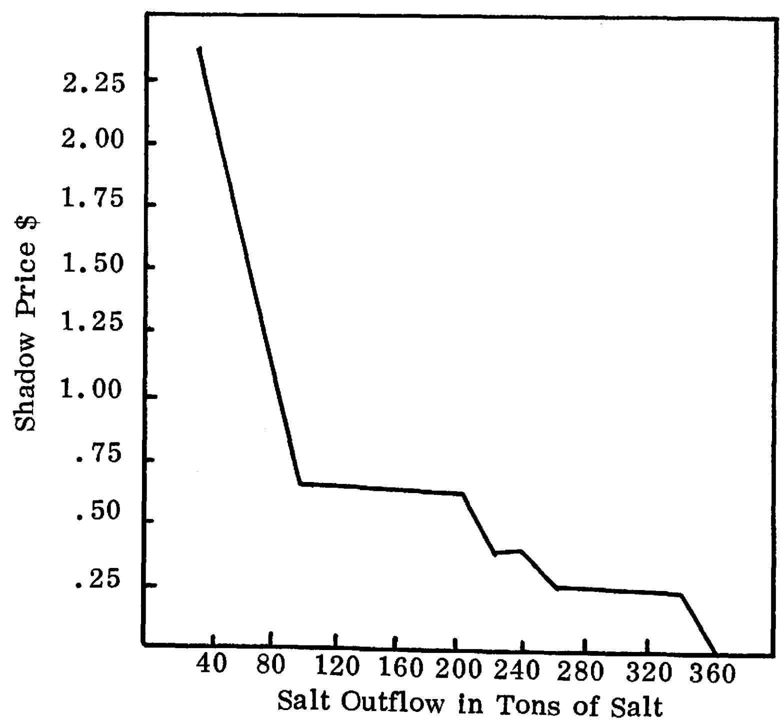

Figure 2. The relationship between shadow price and salt outflow assuming flood irrigation and a limit of 50 percent of acreage in corn silage.

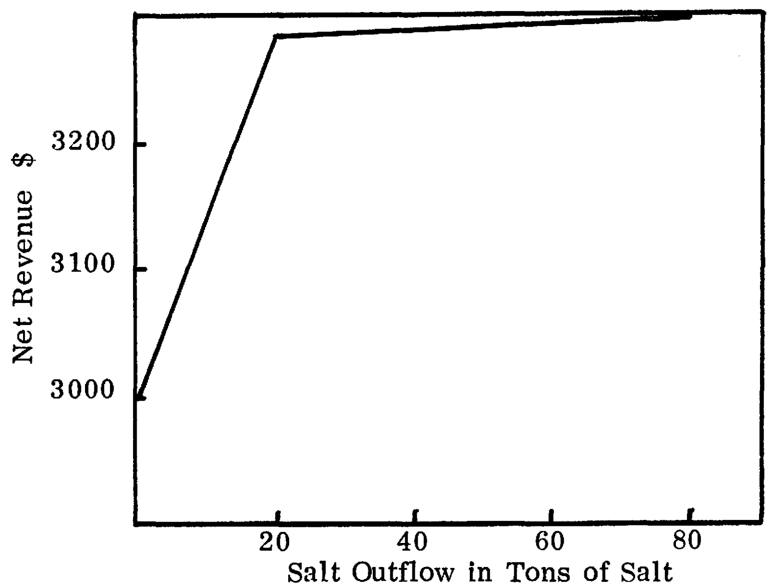

Figure 3. The relationship between net revenue and salt outflow assuming sprinkler irrigation and a limit of 50 percent of acreage in corn silage.

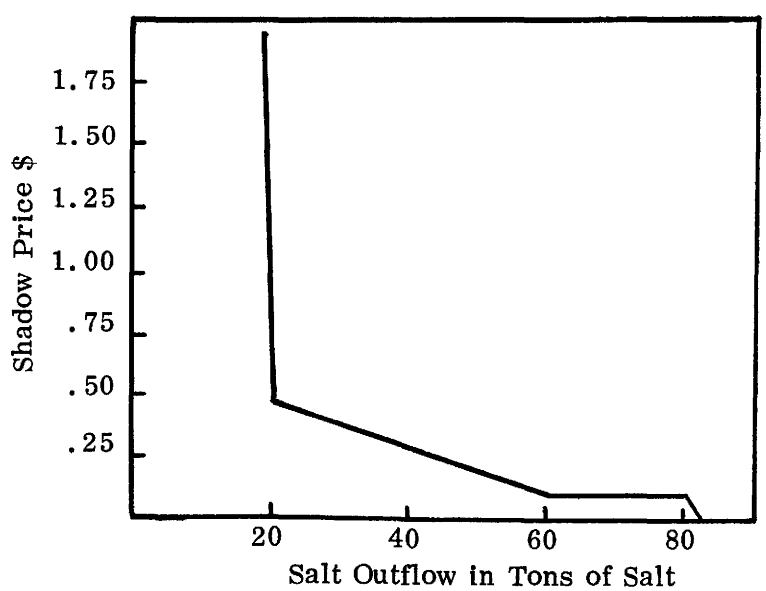

Figure 4. The relationship between shadow price and salt flow assuming sprinkler irrigation and a limit of 50 percent of acreage in corn silage.

The results of these model runs show that, in situations where salt outflow is not constrained, flood irrigation is at least $8 per acre more profitable than sprinkling. Flood irrigation remains more profitable when salt outflow is constrained down to a level of approximately one ton per acre, after which sprinkler irrigation is shown to be the most profitable technique by about $10 per acre. Under sprinkler irrigation, a decrease in the salt outflow level from 2.6 tons to less than one ton per acre results in a decrease of about $16 per acre in net revenue. Restricting the salt outflow to zero resulted in a dramatic drop in net revenue; therefore it can be seen that the first ton of salt outflow allowed is the most critical and valuable to the farm enterprise. The results of this one year study are discussed at length in Hanks et al. (1974). Although the conclusions reached by the one year analysis are important, the long run implications must be taken into consideration for proper evaluation of the economic and physical effects of salt outflow constraints.

Results of the Multi-Year Model

The multi-year model also utilized the data on initial soil salinity, crop alternatives, and irrigation techniques with decision options of water applications of 20.0, 36.0, 52.0 and 66.7 centimeters for each of the crops.

A multi-year evaluation of management practices was accomplished by using the final conditions of the previous year for the initial conditions of the following year subject to the assumptions of the physical model.

The linear program was subject to constraints on final salt, salt outflow, and incrementally increased water quantity. The acreage utilized was not always the total 30 acres available. In some instances, especially under low water application conditions, and/or minimal salt outflow, the total acreage was less than 30 acres.

The results of the multi-year linear programs are presented in the following pages according to initial salt and water application levels. Each initial soil salt condition and water application level is given with the figures on final salt, salt outflow, and net revenue. The net revenue is the total net revenue for the entire farm. A table, recording cropping patterns and irrigation techniques, is included for each initial soil salt level. The first initial soil salt evaluation is represented in Figures 5, 6, and 7. Figure 5 shows final salt for the four separate water levels. Figure 6 shows salt outflow for the four separate water levels. Figure 7 shows net revenue for the four separate water levels.

Salt outflow measurements are given in millequivalents (meq.) and not in tons of salt as in the one year model. The conversion ratio is 0.00367 millequivalents per ton of salt.

Initial soil salt 20 meq/.1

Water level 20 cm. In Figure 5 it will be noted that for the water level of 20 cm. the final salt increased rapidly through the fourth year, then tapered off in the fifth year and again in the sixth year. It would be well to note in Table 1 that the acreage was reduced in the fifth and sixth year by about 10%.

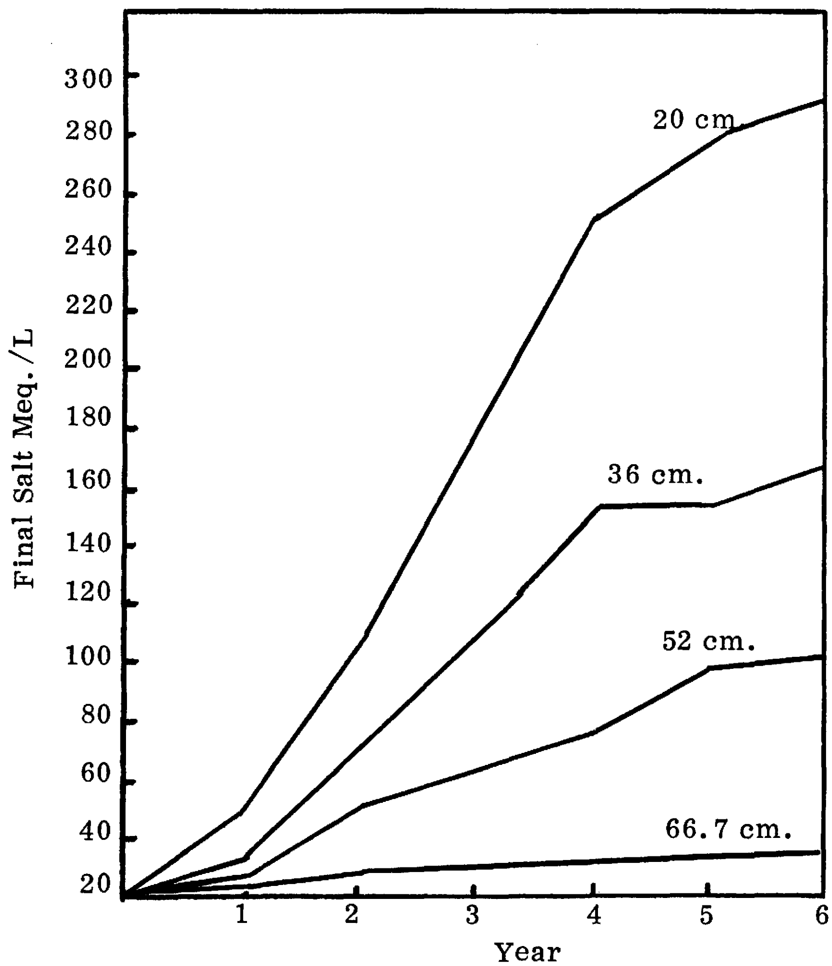

Figure 5. Estimated final salt or year end soil salinity comparisons over a six year period for four rates of water application at an initial soil salinity of 20 Meq./L.

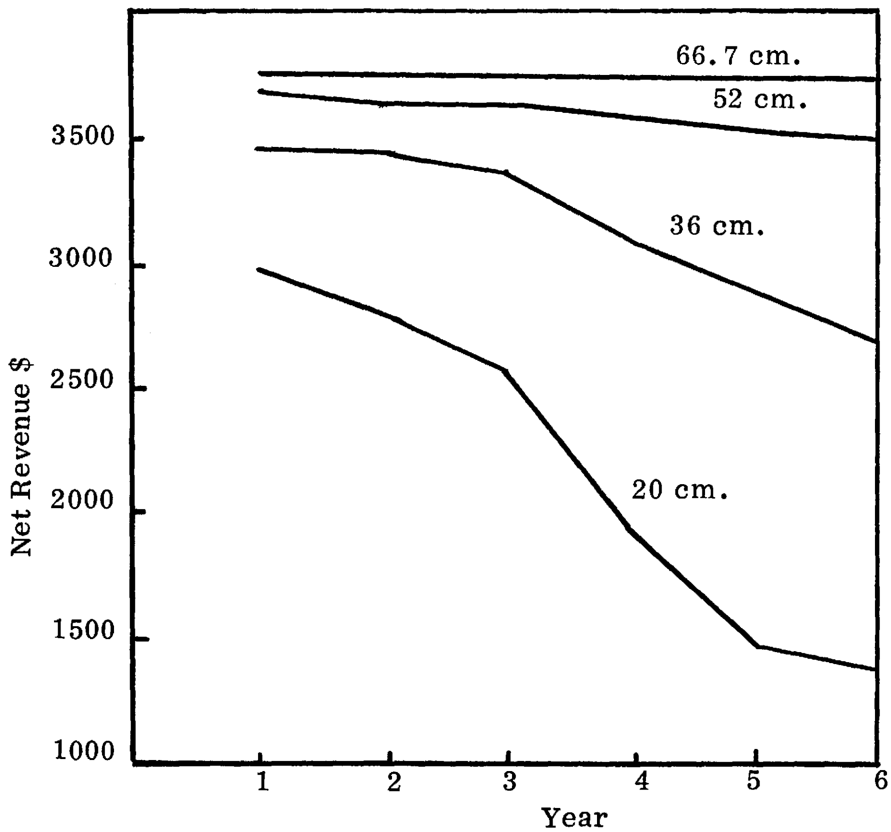

Figure 7. Estimated net revenue comparisons over a six year period for four rates of water application at an initial soil salinity of 20 Meq./L.

This reduction would result in greater application of water per acre during those two years. Also note that sprinkler irrigation was used for most of the acreage. In the fifth and sixth year the acreage under flood irrigation increased.

Figure 6 shows that at this same water level the salt outflow increased only slightly over the first four years. Most of the salt remained in the soil profile. In the fifth and sixth years it may well be possible that the salt outflow increased because of the greater application of water per acre mentioned above.

As shown in Figure 7, the net revenue for this water level declined quite rapidly in the first, second, and third year; declined more rapidly in the fourth and fifth year; then leveled off a little in the sixth year.

The cropping pattern as viewed in Table 1 shows a change from sprinkled alfalfa to a smaller acreage of alfalfa which is flooded and some idle land during the six year period. As mentioned previously, the lower water levels were not used in the flood irrigation part of the program because of the lack of ability to control flood irrigation with such a small quantity of water. However, flood irrigation does generally produce higher net revenue than sprinkler irrigation because of lower costs. In analyzing these results, another variable to keep in mind is that deep rooted plants draw water from a larger zone and yields tend to be higher at the low water levels for deep rooted plants (Childs 1974).

Table 1. Cropping pattern, irrigation methods, and acreage over a six year period for four rates of water application at an initial soil salinity of 20 Meq./L.

Water Application 20 cm.

Irrigation Method	Crop	1	2	3	4	5	6
Sprinkler	alfalfa	22.5	22.6	22.6	22.6	11.7	10.8
	corn						
	oats		2.2	7.4	6.6	6.7	6.6
Flood	alfalfa					8.6	9.1
	corn						
	oats	7.4	5.2		.9		

Acres; Year

Water Application 36 cm.

Irrigation Method	Crop	1	2	3	4	5	6
Sprinkler	alfalfa	7.7	7.7	7.7	22.6		
	corn						
	oats				7.4		
Flood	alfalfa	14.9	14.9	14.9		19.9	19.9
	corn						
	oats	7.4	7.4	7.4		6.6	6.6

Acres; Year

Water Application 52 cm.

Irrigation Method	Crop	1	2	3	4	5	6
Sprinkler	alfalfa						
	corn						
	oats						
Flood	alfalfa	17.0	17.0	17.0	22.6	22.6	22.6
	corn	7.4	7.4	7.4			
	oats	5.6	5.6	5.6	7.2	7.4	7.4

Acres; Year

Water Application 66.7 cm.

Irrigation Method	Crop	1	2	3	4	5	6
Sprinkler	alfalfa						
	corn						
	oats						
Flood	alfalfa						
	corn	30.0	30.0	30.0	30.0	30.0	30.0
	oats						

Acres; Year

In evaluating Figures 5, 6, and 7 at the 20 cm. water level, it appears that with so little water the soil salinity increased significantly, salt outflow was minimal, and the farm enterprise was extremely unprofitable.

Water level 36 cm. Referring again to Figure 5, note that at the water level of 36 cm., final salt increases significantly through the fourth year, then levels off, because of the reduction in acreage and increased water per acre noted above. The leveling off is more dramatic in the fifth year at 36 cm. than in the fifth year at 20 cm. This result may be due to the fact that, in the fifth year at 36 cm., not only was the acreage reduced, but the irrigation was changed to all flood irrigation. These facts may be noted in Table 1.

The salt outflow at 36 cm. as plotted in Figure 6 increases steadily through the fourth year, then takes the same type of jump in the fifth and sixth years as was seen at the 20 cm. water level. Table 1 records the acreage and irrigation changes which continue to account for this jump.

Figure 7 plots the net revenue decline at this water level. The decline is not as dramatic as shown for the 20 cm. water level, but still significant enough to reflect the lack of water and the soil salt accumulation.

Table 1 shows that alfalfa and oats continue to be the optimum crops at this water level. Sprinkler and flood are used for the first three years, just sprinkler in the third year, and just flood in the fifth and sixth years.

In evaluating Figures 5, 6, and 7 at the 36 cm. water level, the water constraint continues to result in high soil salinity, minimal salt outflow and decline net revenue, but all of these results are less dramatic than those noted at the 20 cm. water level.

Water level 52 cm. At the water level of 52 cm., final salt increased gradually through the fifth year, then leveled off to about 100 meq./l in the sixth year. It would be well to note that this increase is significantly less than that plotted for the water level of 36 cm.

The salt outflow for this water level was considerably more in total millequivalents than the amount measured at the 36 cm. water level, but the rate of increase was approximately the same. This salt outflow increase is particularly noticeable between the fourth and fifth year. At this point the salt concentration of the soil profile is high enough that some leaching occurs.

Net revenue for this water level shows a very gradual decline with a decrease of only about 5% in total net revenue for the entire farm. Such a gradual decrease in net revenue suggests that for this 30 acre farm, with the low initial soil salt level of 20 meq./l, 52 cm. of water approaches an adequate level for maintaining constant net revenue.

The cropping pattern for this water level shows corn being brought into production as a third crop in the first three years. One of the reasons for introducing corn at this point is that several variables are produced by using crops of different root levels. Flood irrigation is used throughout at this water level because flood irrigation costs less, resulting in higher profits.

An evaluation of the 52 cm. water level in Figures 5, 6, and 7 seems to indicate that, because of the leveling out of final salt in the sixth year, and the gradual but continuing rise of salt outflow in the same year, soil salinity has remained low enough not to adversely affect crop yields.

Water level 66.7 cm. By continuing to refer to Figures 5, 6, and 7 it can be seen that for the 66.7 cm. water level, final salt changes very slightly. It rises only 11 meq./l during the entire six year period. Salt outflow, on the other hand, is at its highest level, showing a significant increase during the six year period due to the leaching effect of the water.

The net revenue reflects these results. The decrease is net revenue during those six years is almost negligible. This can be partially explained by the fact that the water level is adequate to prevent the soil salinity from becoming too harmful to yields.

The cropping pattern at this water level is entirely corn and irrigated by flood. Shallow root crops such as corn have a higher yield at low salinity levels and higher water levels than crops such as alfalfa and oats which have deeper roots.

This water level is characterized by low end of year salinity, high salt outflow, and fairly constant total net revenue.

Initial soil salt 50 meq./l

Water level 20 cm. This water level can be evaluated by the use of Figures 8, 9, and 10 and by the use of Table 2. In Figure 8 it may be seen that the final salt rises dramatically through the third year, levels off until the fifth year, and then rises again in the sixth year. In comparing Figure 8 with Table 2 it may be noted that the crops were mainly sprinkler irrigated at this water level except in the fourth year.

Salt outflow is rather irregular at this water level. More acreage is flood irrigated in the fourth year, as was mentioned above, and this may account for the increase in salt outflow that year.

Figure 10 shows that net revenue for the 20 cm. water level declines steadily and at a rapid rate until the fifth year and then, though it continues to drop, it levels off somewhat. This is due to the fact that net revenue approaches zero and the acreage is cut back about 6% in the fifth year and about 9% in the sixth year.

The cropping pattern for this water level is alfalfa and oats. Corn does not appear at this low water application level.

Water level 36 cm. Final salt for 36 cm. as a water level increases steadily through the fifth year. In the sixth year, final salt is significantly less. Salt outflow during this same period shows a moderate increase and net revenue shows a marked decrease at a constant rate. The cropping pattern is again alfalfa and oats. Irrigation is mainly flood in the first two years, sprinkler in the third year, and all flood in the last three years. Acreage is up the first two years, down the third year, and up again the last three.

Water level 52 cm. The results for this water level, as noted in Figures 8, 9, and 10, are characterized by moderate changes. Final salt increases moderately with only slight variation in slope. Total salt outflow

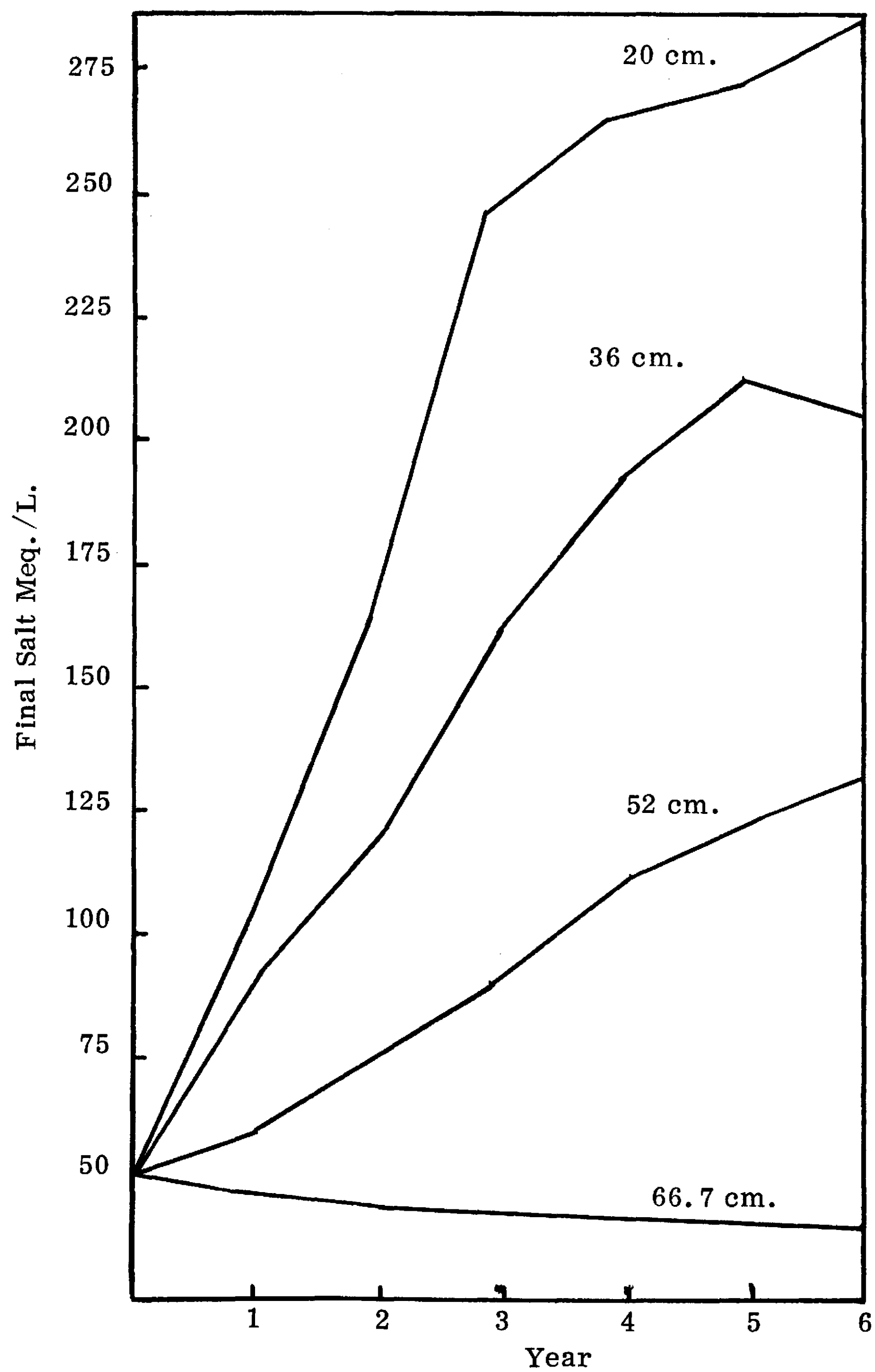

Figure 8. Estimated final salt or year end soil salinity comparisons over a sixty year period for four rates of water application at an initial soil salinity of 50 Meq./L.

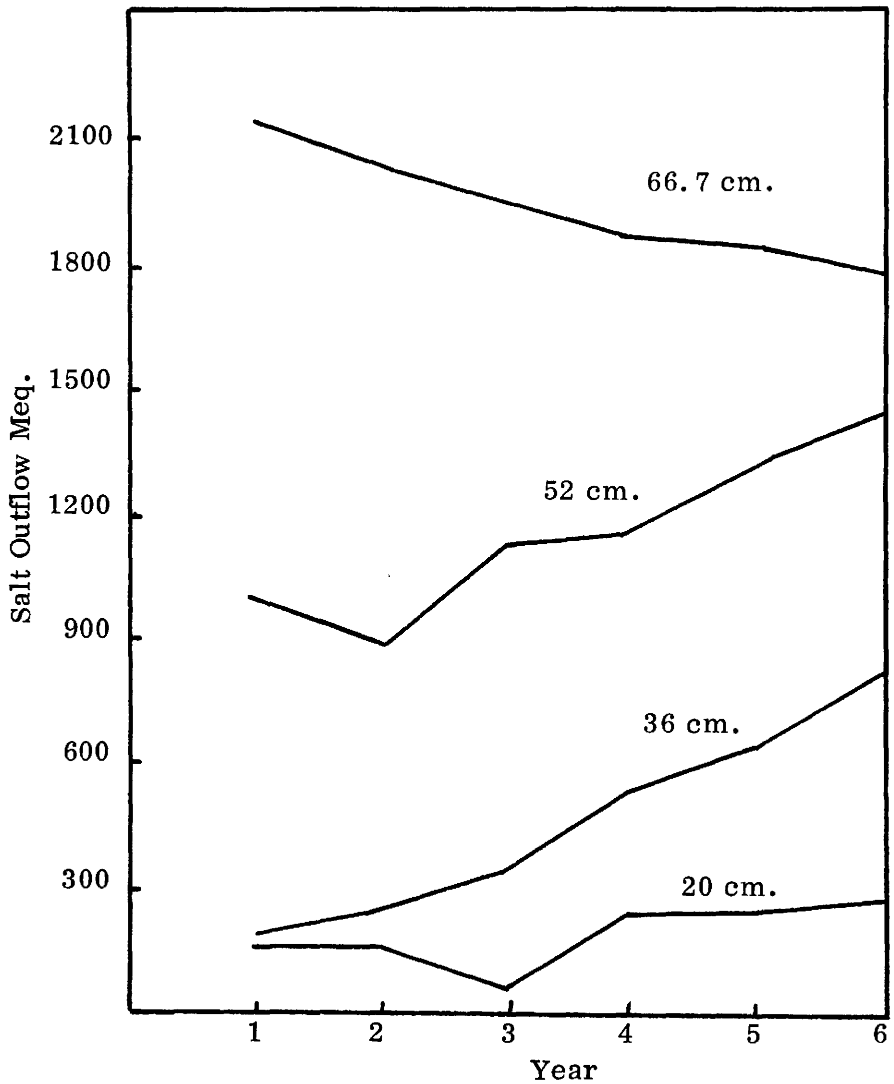

Figure 9. Estimated salt outflow comparisons over a six year period for four rates of water application at an initial soil salinity of 50 Meq./L.

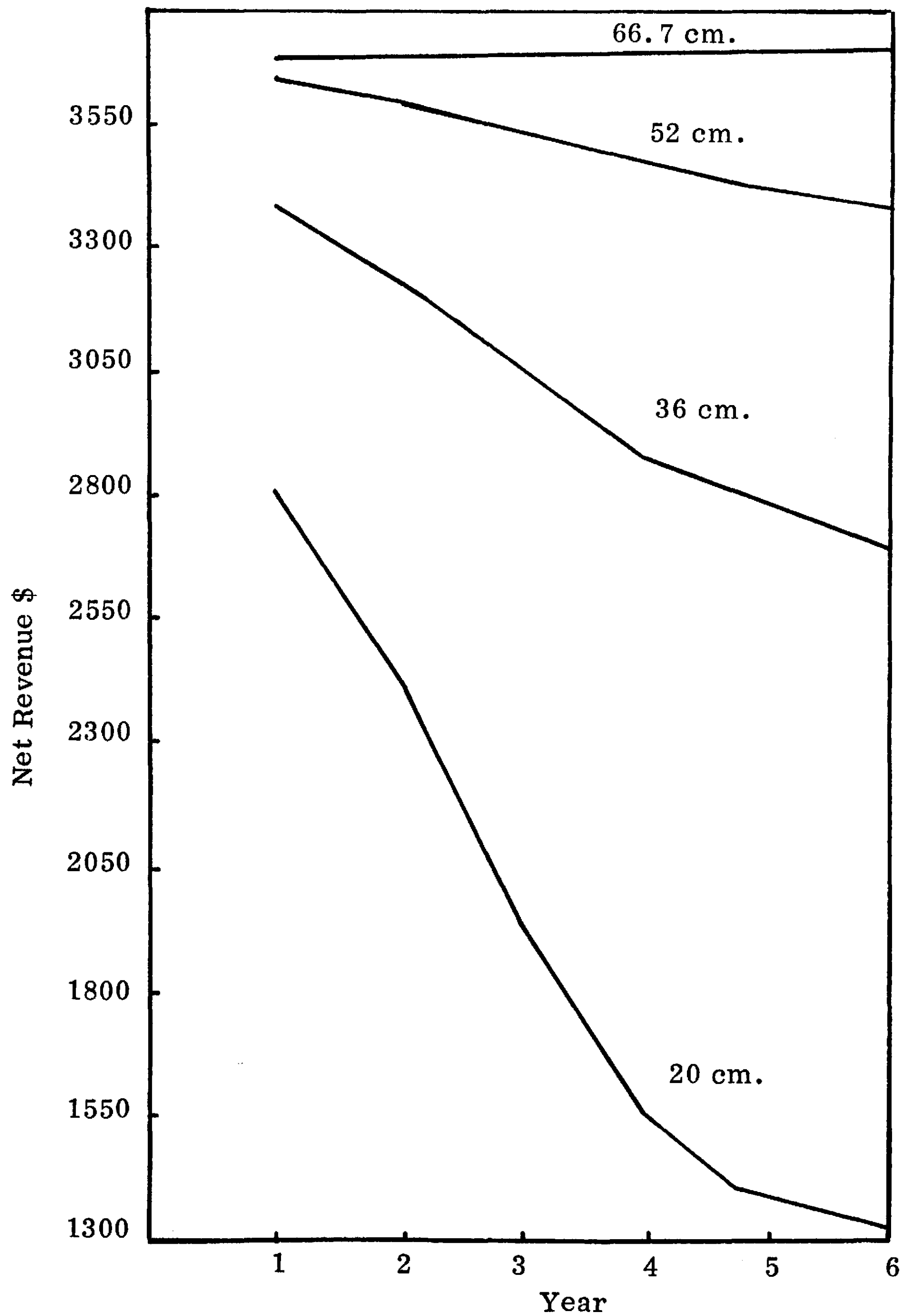

Figure 10. Estimated net revenue comparisons over a six year period for four rates of water application at an initial soil salinity of 50 Meq./L.

Table 2. Cropping pattern, irrigation methods, and acreage over a six year period for four rates of water application at an initial soil salinity of 50 Meq./L.

Water Application 20 cm.

Irrigation Method	Crop	1	2	3	4	5	6
Sprinkler	alfalfa	22.6	22.6	22.6	10.8	12.2	11.8
	corn						
	oats	2.2	6.6	.1		6.8	6.7
Flood	alfalfa			6.6	10.2	8.5	6.7
	corn						
	oats	5.2	.1		6.9		

Acres; Year

Water Application 36 cm.

Irrigation Method	Crop	1	2	3	4	5	6
Sprinkler	alfalfa	5.6	7.7	7.6			
	corn						
	oats			14.9			
Flood	alfalfa						
	corn						
	oats						

Acres; Year

Water Application 52 cm.

Irrigation Method	Crop	1	2	3	4	5	6
Sprinkler	alfalfa						
	corn						
	oats						
Flood	alfalfa	17.0	22.6	22.6	22.6	22.5	22.5
	corn	7.4					
	oats	5.6	7.4	7.4	7.4	7.4	7.4

Acres; Year

Water Application 66.7 cm.

Irrigation Method	Crop	1	2	3	4	5	6
Sprinkler	alfalfa						
	corn						
	oats						
Flood	alfalfa						
	corn	30.0	30.0	30.0	30.0	30.0	30.0
	oats						

Acres; Year

also increases moderately for the six year period, showing a decline only in the second year. Net revenue decreases moderately. The slope of this decrease is not as steep as the slope for the 20 cm. and the 36 cm. water levels.

The cropping pattern for this water application level includes corn in the first year. Yield for shallow root crops, such as corn in this case, is higher at lower salt levels with adequate water, than yield for deeper rooted crops. Yield drops back when salinity increases. The crop irrigation for this water level is all flood. The acreage is fairly constant. These facts are noted in Table 2.

Water level 66.7 cm. For this water application, the results show a leveling off. Final salt decreases slightly, going from 50 meq./l to 35 meq./l during the six year period. Salt outflow declines, although it might be expected to increase because of the decline in final salt. However, at this particular level, the salt goes into the water table. Net revenue increases very slightly, less than 1%. The cropping pattern is corn silage with flood irrigation. The full thirty acres was utilized each year.

Initial soil salt 200 meq./l

Because the final salt increased rapidly in the lower water application levels, the subsequent final salt levels were higher for initial salt 200 meq./l than the limits set in the physical model. For this reason, there was not an accurate computer run of the sixth year in the multi-year comparison for this initial salt level. However, estimates should be fairly accurate since the trend of yield, final salt, and salt outflow is known. The figures to refer to when analyzing this salt level are Figures 11, 12, and 13.

Water level 20 cm. Final salt and salt outflow (Figures 11 and 12) for this water level, increase in the second year, then tend to level off. Salt outflow also decreases in the fifth year. The net revenue for this salt level is fairly constant the first and second year. It shows a sharper drop in the third year, and then it is fairly constant again in the fourth and fifth year. The cropping pattern (Table 3) is alfalfa and oats as the optimum crops with a combination of sprinkler and flood irrigation methods. The acreage is decreased from one tenth of an acre to one acre each year.

Water level 36 cm. Final salt increases moderately with this water application. The water application is not sufficient to leach. Salt outflow increases gradually. It is interesting to note that the salt outflow of the 36 cm. water level for all six years exceeds the salt outflow of the 52 cm. water level. This irregularity does not occur at any of the other initial salt levels. This result is due to the fact that the irrigation method is mainly sprinkler for this initial salt level at the 52 cm. water application. The 36 cm. water application irrigation method is mainly flood. For the other initial salt levels the 52 cm. water level was irrigated by flood.

Water level 52 cm. Final salt shows a slight decrease due to leaching of the soil profile. This effect is more rapid in the third year. Salt outflow is almost constant in its slope, but below the salt outflow pattern of the 36 cm. water application level. Total net revenue for the farm increases

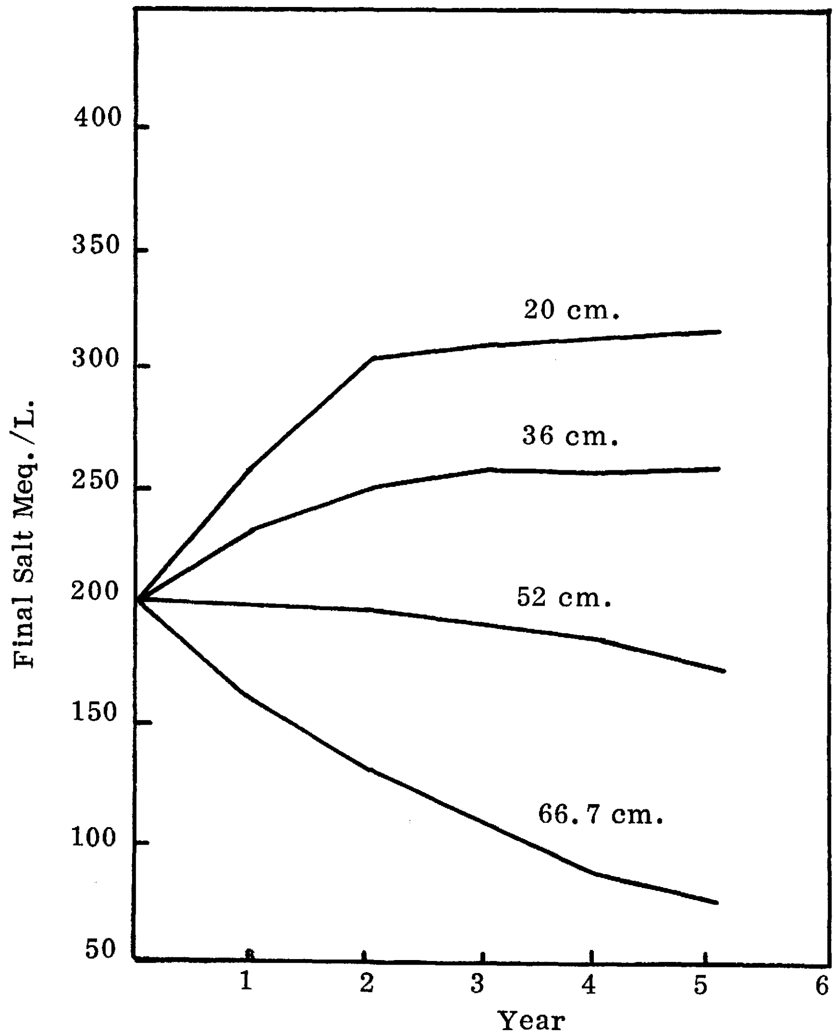

Figure 11. Estimated final salt or year end soil salinity comparisons over a six year period for four rates of water application at an initial soil salinity of 200 Meq./L.

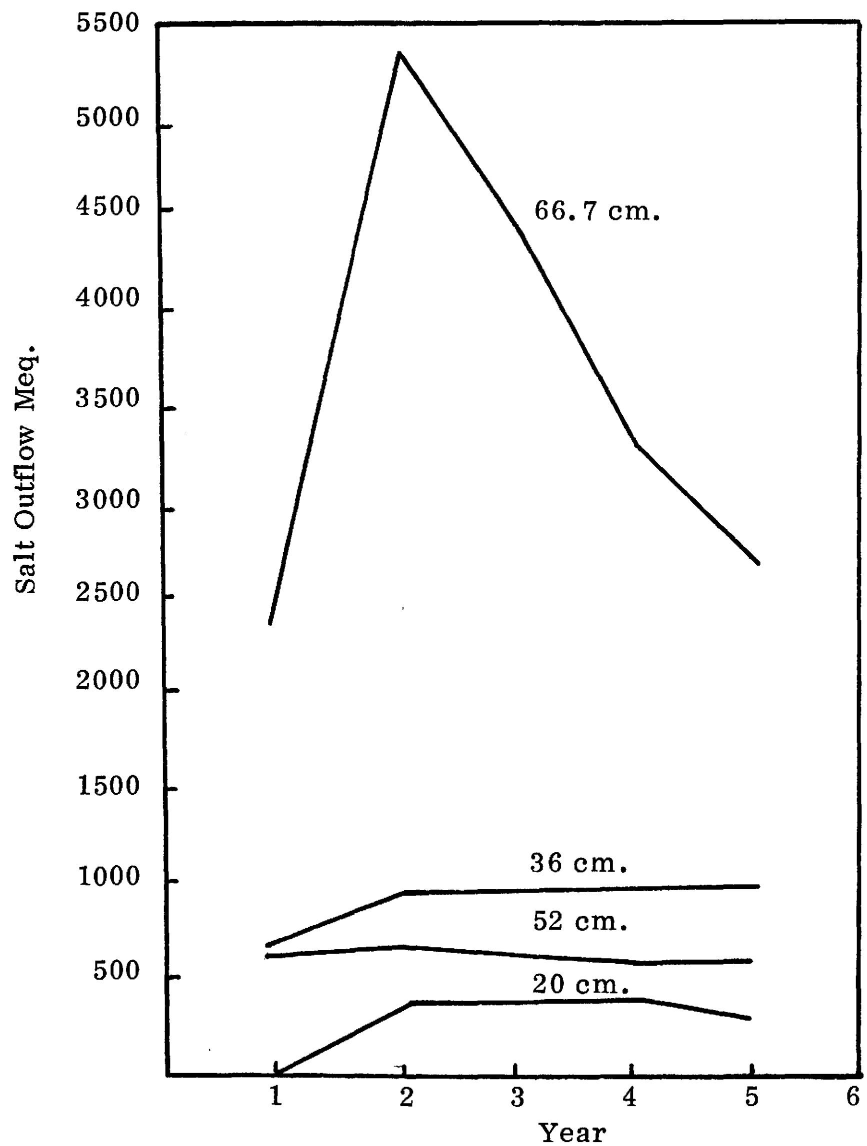

Figure 12. Estimated salt outflow comparisons over a six year period for four rates of water application at an initial soil salinity of 200 Meq./L.

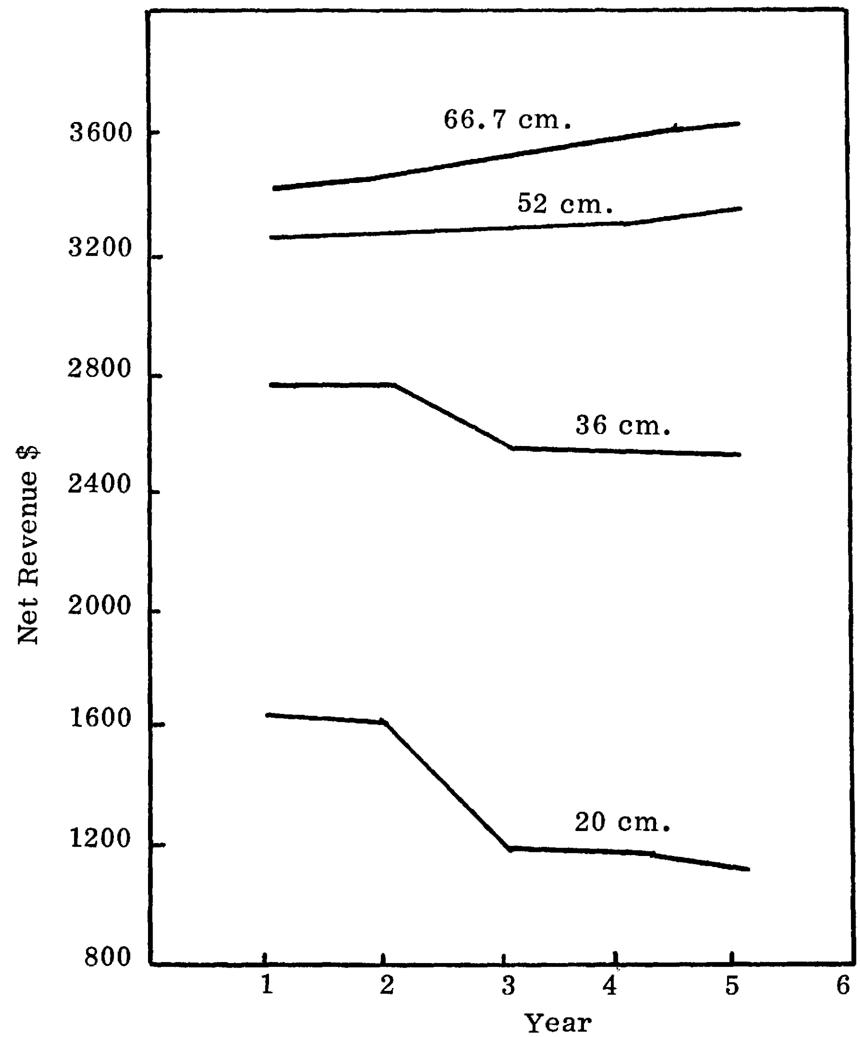

Figure 13. Estimated net revenue comparisons over a six year period for four rates of water application at an initial soil salinity of 200 Meq./L.

Table 3. Cropping pattern, irrigation methods, and acreage over a six year period for four rates of water application at an initial soil salinity of 200 Meq./L.

Water Application 20 cm. (Acres)

Irrigation Method	Crop	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Sprinkler	alfalfa	22.6	13.1	12.5	12.7	13.8	
	corn						
	oats	6.6	7.4		7.3	7.1	
Flood	alfalfa		9.5	9.7	9.8	7.8	
	corn						
	oats	.9		7.3			

Water Application 36 cm. (Acres)

Irrigation Method	Crop	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Sprinkler	alfalfa	7.7					
	corn						
	oats		4.7	3.7	3.6	3.3	
Flood	alfalfa	14.9	22.6	21.9	21.9	21.8	
	corn						
	oats	7.4	2.7	3.6	3.6	3.9	

Water Application 52 cm. (Acres)

Irrigation Method	Crop	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Sprinkler	alfalfa						
	corn	21.5	21.5	21.5	21.5	21.5	
	oats						
Flood	alfalfa	6.4	6.3	6.3	6.4	6.4	
	corn						
	oats	2.1	2.1	2.1	2.1	2.1	

Water Application 66.7 cm. (Acres)

Irrigation Method	Crop	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Sprinkler	alfalfa						
	corn	30.0					
	oats						
Flood	alfalfa		22.6	22.6	22.6	22.6	
	corn						
	oats		7.4	7.4	7.4	7.4	

slightly. The cropping pattern is mainly corn under sprinkler irrigation with the remainder of the crops grown being alfalfa and oats under flood irrigation.

Water level 66.7 cm. For this last water level, final salt decreases rapidly from the 200 meq./l to a much lower level of soil salinity over the 5 year period. This drop is mainly due to leaching. Salt outflow, on the other hand, shows an unusually large jump in the second year, and then declines through the fifth year. This unusual peak is due partly to a switch in the cropping pattern from corn under sprinkler irrigation in the first year to alfalfa and oats under flood irrigation in the second year. Sprinkler irrigation tends to restrict salt outflow in the first year. The switch to flood irrigation in the second year increases salt outflow. During the second and third year, much of the salt is leached out, and salt outflow decreases. In Figure 13 it will be noted that net revenue increases slightly through the fifth year.

SUMMARY AND CONCLUSION

In summary, the one year model compared the net revenue and the shadow price calculated for the optimal cropping patterns and irrigation strategies. The analysis shows that with no constraint on salt outflow, flood irrigation is the most profitable for the farm. However, according to this study, if the constraint on salt outflow is less than two tons per acre, sprinkler irrigation is more profitable. Flood irrigation is more profitable when salt is not controlled because the cost of flood irrigation is sufficiently less so that higher yield does not compensate for the higher water application cost. Sprinkler irrigation is more profitable when salt is controlled because a reduction in salt outflow when using irrigation is only accomplished by a major decrease in the quantity of water applied which limits yields and crop alternatives. Therefore, using a smaller quantity of water, some of the land must remain idle or all of the land must receive less water than is optimum for high crop yield in flood irrigation. Also, it must be considered that under sprinkler irrigation, the water application is much more controlled, more evenly distributed, and, therefore, results in a higher yield.

In summary of the one year model, an evaluation of the shadow prices of salt output (remembering that shadow price is the value to the farm of allowing an additional ton of salt output) shows that the first ton of salt outflow is the most critical. In other words, according to this study, controlling the first ton of salt output is considerably more expensive than controlling salt output after the first ton. This is true because according to analysis of the physical model, cutting salt outflow to less than one ton per acre means a sizable reduction in water application which results in a sizable reduction in yield. Studies thus far have not definitely determined how much salt is coming from farm land bordering the Colorado River but it appears that it is possible for the individual farmers to reduce salt outflow considerably by applying good management practices. These conclusions are limited, however, to the single year study and do not account for the soil salt build up over a period of time.

The multi-year analysis of management practices was developed to show the results of salt build up over a six year period. As previously explained, this analysis was achieved by using the final soil salinity of the previous year as the initial soil salinity for the current year; remembering that the results of the study are influenced by the conditions of the specific physical model.

In summary of the multi-year analysis, we see that a number of somewhat expected results occured in the estimated final salt or year end soil salinity comparisons over the six year period. First, the lowest level of water application resulted in a salt build up in the soil profile because the water application was not sufficient to result in leaching. Second, this build up tended to taper off near the end of the six years.

This tapering off was caused by the profit maximizing model eventually approaching a steady state, and also allowing a few acres to remain idle, thus resulting in heavier water application being available for leaching the remaining acreage. This heavier water application on part of the acreage reduced the salt in the profile on that part resulting in a lower average soil salinity for the entire farm. Third, the heaviest water application rates of the multi-year program resulted in no significant change in the soil salinity for the six year period. This result is due to leaching.

The salt outflow over the six year period is shown in Figure 6, 9, and 12. As might be expected, the heaviest water applications flush the salt through the soil resulting in increased soil outflow.

Comparisons in net revenue (gross income less variable costs) for the multi-year period are shown in Figures 7, 10, and 13. At heavier rates of water application, the net revenue remains fairly constant. At lower rates of water application net revenue declines because salt build up decreases yields.

The cropping pattern of the multi-year study is dominated by alfalfa with a nurse crop of oats. Corn becomes most profitable with flood irrigation in the heaviest water applications.

In analyzing all of these conclusions, a zero discharge of salt outflow seems impossible, but a large reduction in salt outflow with only limited loss of net revenue does seem possible using a set of management practices designed specifically for that purpose.

LITERATURE CITED

Bernstein, Leon. 1964. Salt Tolerance of Plants. USDA, Agr. Inf. Bul. No. 283.

Boulding, Kenneth. 1966. The Economics of Spaceship Earth, in Henry Jarrett, ed. Envirnomental Quality in a Growing Economy. John Hopkins, Baltimore, Maryland. pp. 4-5.

Bresler, E. and D. Yaron. 1972. Soil Water Regime in Economic Evaluation of Salinity in Irrigation. Water Resources Research. Vol. 8, No. 4.

Burroughs. 1972. Simulation Dynamo. Burroughs Corporation, Detroit, Michigan.

Burroughs. 1973. Tempo B6700. Burroughs Corporation, Detroi, Michigan.

Childs, Stuart. 1975. A Model to Predict the Effect of Salinity on Crop Browth. Masters Thesis. Utah State University, Logan, Utah.

d'Arge, Ralph. 1970. Quantitative Water Resource Basin Planning: An Analysis of the Pecos River Basin, New Mexico. Report No. 8, New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces.

Davis, Lynn, Rondo Christensen, and Stuart Richards. 1973. Agricultural Budgets and Costs for Utah.

Day, Richard H. 1963. Recursive Programming and Production Response. North Holland Publishing Company. Amsterdam, Holland.

Freeman, A. Myrick III, Robert H. Haveman, Allen V. Kneese. 1973. The Economics of Environmental Policy. John Wiley and Sons, Inc.

Friedman, Milton. 1962. Price Theory. Revised edition. Aldine Publishing Company, Chicago, Illinois. 175 pp.

Ferguson, Robert O. and Lauren F. Sargent. 1958. Programming: Fundamentals and Applications. McGraw-Hill Book Company, Inc., New York, New York. p. 6.

Gisser, M. 1970. Linear Programming Models for Estimating the Agricultural Demand Function for Import of Water in the Pecos River Basin. Water Resources Research. Vol. 6, No. 4, pp. 1025-32.

Hanks, R. J., Jay C. Andersen, L. G. King, S. W. Childs, J. R. Cannon. 1974. An Evaluation of Farm Irrigation Practices as a Means to Control the Water Quality of Return Flow. Research Report No. 19. Agricultural Experiment Station. Utah State University, Logan, Utah.

Handy, Earl O. and Wilfred Chandler. 1958. Linear Programming Methods. The Iowa State University Press. Ames, Iowa.

Hyatt, M. Leon, J. Paul Riley, M. Lynn McKee, Eurgene Israelsen. 1970. Computer Simulation of the Hydrologic Salinity Flow System Within the Upper Colorado River Basin. Utah Water Research Laboratory. Utah State University. 955 pp.

Lorentson, R. G. 1971. Temporal Production Interdenepdency in Agriculture Arising from Water Quality. Ph.D. Dissertation. University of Washington, Seattle, (University Microfilms No. 71-28, 442).

Liftwich, Richard H. 1973. The Price System and Resource Allocation. The Dryden Press. Hinsdale, Illinois.

Pincock, M.G. Assessing Impacts of Declining Water Quality on Gross Value Output of Agriculture: A Case Study. Water Resources Research, Vol. 5, No. 1. pp. 1-12.

Oster, J.D., L. S. Willardson, and G. J. Hoffman. Sprinkling and Ponding Techniques for Reclaiming Saline Soils. Trans. Amer. Soc. Agr. Eng. 15. pp. 1115-1117.

Robinson, F. E., O. D. McCoy, and G. F. Worker, Jr. An Evaluation of Sprinkler Irrigation for Imperial Valley, California. Agr. 21. pp. 6-8.

Robinson, F.E., O. D. McCoy, G. F. Worker, Jr., and W. F. Lehman. Sprinkler and Surface Irrigation of Vegetables and Field Crops in an Arid Environment. Agron. J. 60. pp. 696-700.

Stigler, George J. 1966. The Theory of Price. The MacMillan Company, New York, New York. pp. 110-117.

Sun, Po-Chuan. 1971. An Economic Analysis of the Effects of Quantity and Quality of Irrigation Water on Agricultural Production in Imperial Valley, California. Ph.D. Dissertation. University of California, Davis.

U.S. Environmental Protection Agency. 1971. The Mineral Water Quality Problem in the Colorado River Basin. Summary and Appendices, A, B, C, D.

U. W. Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. U.S.D.A. Handbook 60.

Young, R.A., W. T. Franklin, and K.C. Nobe. 1973. Assessing Economic Effects of Salinity on Irrigated Agriculture in the Colorado River Basin: Agronomic and Economic Considerations. Report to the Bureau of Reclamation. U.S. Dept. of Interior.

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