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Development of a methodology for analyzing irrigation investment with a case application

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Development of a methodology for analyzing irrigation investment with a case application

by

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CHAPTER I.

INTRODUCTION

Since 1956, the area of irrigated Iowa cropland has increased steadily. The number of irrigated crop acres increased nearly seven-fold from 27,000 acres in 1957 to 185,000 acres in 1977 (31, p. 1). This increasing trend represents large amounts of private investment. Whether or not such investment has been profitable is a moot question, whose answer affects two important Iowa resources, capital and water.

Although Iowa is endowed with ample average rainfall for crop production, the timing and amount of rainfall during crucial periods of crop growth impose serious constraints upon crop production (88, p. 1247). Inadequate rainfall during these crucial stages have led to supplemental irrigation which provides stand-by insurance when and if rainfall becomes insufficient for crop production.

Information is needed by farmers and various resource agencies permitting them to analyze the profitability of Iowa irrigation investment. This would enable them to better determine whether or not the increased funds and water have been placed into profitable uses in terms of water's value productivity.

Needs of Supplemental Irrigation Investment

The needs of supplemental irrigation investment in Iowa, an investment requiring considerable capital and water, is as uncertain as the timing and distribution of a season's rainfall.

Over 95 percent of Iowa irrigated cropland is planted to corn.[1] Of this irrigated area, 55 percent is equipped with a center-pivot system and a water pumping unit powered with diesel.[1]

Today's typical center-pivot system services around 160 acres (i.e., a quarter-section), of which approximately 133 acres are effectively irrigated (79, p. 93). The system is comprised of three major parts: a water source, a water pump with a power unit, and a sprinkler-studded water main supported by at least seven wheeled towers (79, p. 90). Each tower is powered with its own motor, typically an electric drive unit in Iowa.[2] According to Splinter (79, p. 93), "The center-pivot system is by far the predominant method of automatically irrigating crops available."

Initial investment costs[3] for a quarter section range from $50,000 to $60,000 (71, pp. 12-13). Given an average Iowa farm size of 320 acres, full irrigation thereof would vary from $100,000 to $120,000. Prior to making such a substantial investment, the farmer must have a good idea whether irrigation's increased yield revenues will sufficiently exceed its total costs to render the investment profitable.[4]

Substantial amounts of water are required to irrigate crops, often

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[1]Data were obtained from Professor of Agricultural Engineering, Dr. Stewart Melvin, Ames, Iowa. Private communication, April, 1978.

[2]Otherwise, the tower is propelled via a water drive unit.

[3]Investment is defined as the cost of purchasing and installing the system, drilling and powering a water source, as well as implementing any required land reshaping. Investment does not include added variable costs such as labor, fuel required of irrigation, or increased seed and fertilizer costs.

[4]It must be sufficiently profitable so as to exceed alternative rates of return.

during droughty periods when supplies are least available.

Splinter (79, p. 94) estimates the typical Iowa center-pivot system irrigating 133 acres for two months annually as using the same water volume as a town of 1,000 people. Since irrigation is a water use for which the Iowa Natural Resources Council (I.N.R.C.) must issue a water permit and since, according to Timmons (87, p. 148), the Iowa Code (37) may be reasonably interpreted as advocating water allocation according to the marginal value productivity[1] criterion, the I.N.R.C. needs information on water's value productivity in order to allocate efficiently Iowa's available water supplies.[2] If irrigation should have a higher marginal value productivity in another use, then some of Iowa's irrigation water allotments may be allocated to the non-irrigation use, so as to maximize the value products of outputs resulting from water use in production.

Problem of Iowa Irrigation[3]

Private investment funds should not be allocated to irrigation when a higher yielding return is obtainable from an alternative option, because the farmer's net returns would not be maximized since investment capital

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[1]The marginal value productivity of a resource is the market value of the added output increment resulting from the use of another resource unit in production.

[2]Efficient allocation is defined as use of inputs to the point where the last input's marginal value product equals its price. Therefore, determining the profitability of a firm enables conclusions as to whether or not an input such as water is being optimally allocated. If the marginal value product exceeds marginal input cost, more water should be allocated to a use. If the marginal value product is less than cost, less of the input should be used so that total returns are increased.

[3]Irrigation refers to the supplemental irrigation of corn in Iowa.

could be reallocated for a better return. Neither should water be allocated to irrigation when it would have a higher marginal value product in an alternative use, for then the total value product of water by all users would not be maximized (9, p. 509). In a perfectly competitive situation, a farmer maximizes profit by using inputs to the point where input cost equals its marginal value product (9, p. 68). If the same input price is common to all an area's producers, an input is optimally allocated when all marginal value productivities are equal (9, p. 23). It is not clear whether Iowa water, as an input, is so-allocated among various users.

Despite the apparent need for studies directed towards the analysis of Iowa irrigation, no research indicating whether or not irrigation has been profitable exists except the reports of Colbert (22) and Hallberg (31). Colbert's study deals only with the general profitability of Northwest Iowa irrigation for areas of "average" climate and soils, and lacks information regarding profitability on specific Iowa soils and under particular production scenarios (22, p. 56). That of Hallberg deals only with irrigation costs and ignores revenue.

Colbert (22, p. 65) found center-pivot irrigation profitable on only a limited number of Northwest Iowa sites, mainly on bottomlands whose areas are of coarse, permeable soils, and whose corn crops experience large yield variation resulting from climatic volatility. Colbert (22, pp. 95-96) deems studies investigating irrigation profitability upon specific sites and soil types of Iowa as being an important research need. Such studies would provide information reflecting irrigation's net returns to be compared to net returns of alternative options. These studies would also offer water value productivity information which would aid the I.N.R.C. in allocating water according to the marginal analysis criteria.

The question of Iowa irrigation profitability is complicated by five developments: (1) United States trade policy utilizing farm exports as a trading tool (31, p. 43), (2) the 1973 commitment of the United States to rebuild and maintain domestic grain reserves (97, p. 824), (3) the continued margin of increased world population over increased world food production (5, p. 16), (4) 1977-2000 weather patterns, which are expected to be more variable and less yield-favorable than those of the favorable 1956-1973 period (31, p. 3), and (5) the upward spiral in energy prices since 1974 (75, p. 8).

Factors Affecting Prospective Demands for Iowa Crops

Of the five factors listed above, the first four affect farm prices on the demand side, and the fifth, on the supply side. Therefore, these five factors also affect the future profitability of Iowa crop irrigation.

In the early 1970's, the United States began using farm exports as an economic tool to offset the nation's chronic trade deficit (31, p. 3). The added demands from the grain and soybean markets established in Eastern Europe and Japan place upward pressures on farm price trends,[1] thereby bolstering future farm revenues, and hence, Iowa irrigation profitability.

The United States is now committed to the rebuilding and long-run maintenance of domestic grain reserves, depleted during the 1972-1973 world food shortage (97, p. 824). The added storage demands from this commitment support farm prices at higher levels, thereby increasing Iowa farm revenues,

[1]Note that the term used here is "trends", which does not refer to the short-run price fluctuations. Such fluctuations occur around this long-run trend.

and rendering irrigation more profitable.

World population increases are expected to exceed those of world food production well into the twenty-first century (5, pp. 16-17). Provided that rapidly populating nations have effective food demand, i.e., demand backed with purchasing power, long-term world food demands are expected to continue exceeding supply. Therefore, higher farm price trends are expected to bolster irrigation profitability. World farm product price inflation is occurring, for despite the large 1976-1977 world grain harvests, average world grain prices are still more than double their pre-1972 levels (5, p. 16).

According to Thompson et al. (23, p. 1), the 1956-1973 yield levels were unusually high due to the period's "...remarkable run of near-normal weather - or even that unusual weather that produces even higher yields." These weather conditions are not expected to persist into the 1990's (23, p. 1). Given the expected weather variability with its unfavorable effect upon corn yields, irrigation could be an investment whose desirability is increased by the risk aversion motive of Iowa farmers (31, p. 1). Irrigators often avoid serious crop failure through the strategic application of a few acre inches of water during such water critical corn growth stages as July silking or the ear's kernel filling in August (17, pp. 23-24). The existence of such risk aversion was reflected by the backlog of over 1,100 water permit applications which accumulated at the I.N.R.C. office during the peak of the 1975-1977 drought.[1] According to Amos, roughly 75 percent of this backlog was filed by prospective Northwest Iowa irrigators. In addi-

[1]This information was obtained from former Deputy Iowa Water Commissioner Orley M. Omos of Ames, Iowa. Private communication, August, 1977.

tion with such risk-aversion, the probability of drought for Iowa corn is high, thereby motivating a farmer to irrigate. There is a 9.6% chance that any single year will be a droughty one, and a 26% chance that any three-year period will include at least one droughty season (23, p. 1).

The rising energy costs comprise a fifth development affecting the future profitability of Iowa irrigation. This development affects profitability in a negative way. The large post 1973 rise in fossil fuel costs may have more than offset any of the favorable effects upon Iowa irrigation profitability of the other four developments cited above. The main reason for the negative influence of rising fuel costs is the energy intensitivity of irrigation as a production practice (27, p. 1). According to Dvoskin and Heady (27, p. 1), "...energy for irrigation represents a major part of the total energy use in on-farm food production. On the average, irrigated crops require two to three times more fossil fuel energy per acre than dryland crops." Therefore, the profitability of Iowa irrigation becomes more uncertain in the light of the increasing cost of fossil fuel and the energy-intensive nature of irrigation.

The United States trade policy, the commitment to rebuild and maintain domestic grain reserves, increasing world population, and expected future weather patterns all help to bolster irrigation's profitability. Their favorable effects are at least partially offset by rising fossil fuel costs. Together, all five developments provide elements of uncertainty in answering the question of Iowa irrigation profitability. Uncertainties associated with irrigation's value productivity in Iowa make vague the indications of whether the increased allocation since 1956 of capital and water to Iowa irrigation has been warranted.

Objectives of the Study

This study aims to (1) develop a model for analyzing the economics of supplemental Iowa irrigation, (2) apply the model to a case study of a farm in the Moody Silty Clay Loam Association of Lyon County, Iowa, and draw conclusions of irrigation profitability and the optimality of capital and water allocations thereto, and (3) develop recommendations for further research needs.

Methods for Pursuing Objectives

Rather than comparing a farm's pre-irrigation and post-irrigation performances,[1] the model developed herein compares the "with irrigation" and "without irrigation" performances of a single farm over the 1957-1977 period. Bergmann and Boussard (12, p. 33) established the "with-without" approach superior to the "before-after" approach. The latter fails to account for such intertemporal dynamics as time preference of income and present value considerations (12, p. 33). Also ignored are increased yields from improved rain-fed agricultural development which would have occurred without irrigation. Such improvements are not unique to irrigated areas and should not be unduly credited to irrigation, lest the profitability study lose accuracy from a pro-irrigation bias. This bias would falsely justify resource allocation to irrigation when the resources should be elsewhere directed.

Developing the model (objective 1) is accomplished through multi-period linear programming incorporating the technique of irrigated corn

[1]This approach is known as the "before-after" approach.

yield estimation developed (19, 20, 24, 64, 65, 66, 67, 68, 69). Since no irrigated corn yield data were located in a review of Iowa irrigation literature, such yields are estimated from rain-fed data in order to estimate what the farm's irrigated income would have been. Shaw's method (69) is demonstrated superior to Parvin's technique (55) due to the latter's basis upon unrealistic climatic assumptions and the former's incorporation of Parvin's omitted variables into a soil moisture stress variable (68, pp. 1-9; 54, p. 85).

Objective 2, applying the model, is a case study[1] of irrigation investment in Lyon County, Iowa. Multi-period linear programming maximizes yearly profit to generate 1957-1977 income streams for the irrigated and rain-fed scenarios.[2] The gap between the two income streams represents the net returns to irrigation investment and is compared to the rates of return for four other options. If net irrigation returns are less than those of alternative investment options, then funds should be redirected from irrigation to the alternative options. Likewise, poor profitability may imply a low marginal value product for water, and hence the increased allocation since 1956 of scarce water should be directed elsewhere, insofar as society prefers more to less of the goods and services obtained through water use (88, p. 1248).

Recommendations for further research, as encompassed in the third objective, are made after the model application's results, strengths, and weaknesses have been examined.

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[1]According to Salter (60, p. 71), a case study is a study concerned with studying the performance of a single entity, perhaps a single farm.

[2]The yearly incomes are first adjusted to fixed costs.

Area and Nature of Study

This study deals with the shaded area of Figure 1, the Moody Soil Association of Lyon County. However, the study's results would appear also applicable to farms similar or identical to that simulated herein located in the Sioux County Moody Association outlined in Figure 1.

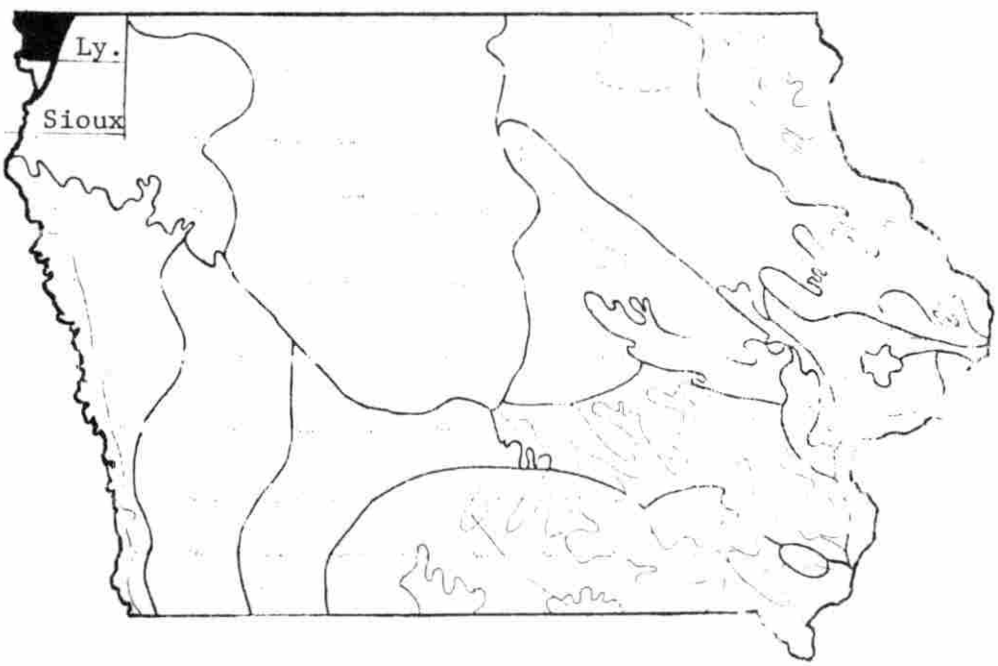

Figure 1. Iowa's principal soil associations

The Lyon County portion of the Moody Association is situated within Iowa's droughtiest region, where the average annual precipitation is 24-26 inches, as compared to the 30-32 inches of Central Iowa, and the 32-34 inches of Southeast Iowa (96, p. 5).

The simulated farm is comprised of 320 Moody acres of which 133 acres per quarter section or a total of 266 acres are effectively irrigated.

Because of a lack of reliable corn yield data in Northwest Iowa, the rain-fed yields for the Doon Experimental Farm's rate of planting experiment[1] comprise this study's data base. Shaw[2] indicates these yields to be representative of most corn rotations which are high-yielding and grown by the most capable management, where managerial capability is positively measured with financial success. Hence, this one data set serves as a representative performance of the more capable farm operators within the Lyon County Moody Association.

Organization of the Study

Chapter I deals with the problems of increased Iowa crop irrigation and the effects of increased irrigation upon capital and water use. Also stated are the objectives and methods for pursuing them.

Chapter II delves into the economic theory of water allocation, in order to establish criteria for allocating scarce water supplies to competing productive[3] uses. Marginal analysis criteria for allocating water to a use, among a use's competing enterprises, and between competing

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[1]According to former Doon Experimental Farm superintendent Kenneth Ross, these data are standardized for a continuous corn rotation planted at a planting population of 16,000. Such information and data were obtained from Mr. Ross by private communication, Ames, Iowa, March, 1978.

[2]This information was obtained from Iowa State University Professor of Agricultural Climatology, R. H. Shaw, Ames, Iowa. Private communication, March, 1978.

[3]In Chapter II, the difference between a consumptive water use and a productive one is laid out.

users are presented. The work of Timmons (85, 86, 87, 88) serves as a basis for the formulation of such criteria.

Chapter III contains the development of the model. Herein, the model's assumptions and the data needs are discussed.

Chapter IV deals with the model's application to the study area. In addition, the data for this study are derived.

Chapter V contains the interpretation of the application's results and states the conclusions derived concerning the profitability of Iowa irrigation and of the optimality of increased capital and water allocations to irrigation since 1956. The irrigated yield estimations of Parvin (55) and Shaw (69) are compared as bases for the annual irrigated profit functions.

Chapter VI summarizes the study and states its conclusions. Also included are recommendations for future research.

References, Acknowledgements, and the Appendices follow Chapter VI in that order.

CHAPTER II.

THEORY OF WATER ALLOCATION

In sub-humid areas such as Northwest Iowa, water has historically been considered a free good (88, p. 1245). According to Herfindahl and Kneese (34, p. 359), a free good is one "...so abundant that the marginal value to any user, or potential user, is zero." Figure 2 illustrates the conception of water as a free good. Supply allegedly exceeds demand throughout the entire price-quantity space by a sufficient margin to render water a zero price.

Geiseke (30, p. 76), however, refutes this free good concept:

> "The use of water in Iowa has been increasing each year and it is anticipated that it will continue to increase along with Iowa's population, industrial development, and economic growth. There has been and will be . . . local shortages of water."

Geiseke (30, p. 76) states water scarcity in Iowa to be localized in nature. According to Timmons (87, pp. 144-145), these localized shortages are a result of a differentiated water supply falling short of a differentiated water demand, where differentiation may be inherent in one or more of the following three differentiation sources: "...(1) qualities linked with demands by amounts and qualities linked with supplies by amounts, (2) spatial occurrences of quality-linked supplies and of quality linked demands, and (3) temporal occurrences of quality-linked supplies and quality-linked demands.

Differentiation source 1 may be exemplified by a drought-stricken Atlantic seaboard town suffering a drinking water shortage alongside the boundless water supplies of the Atlantic. The saline quality of water,

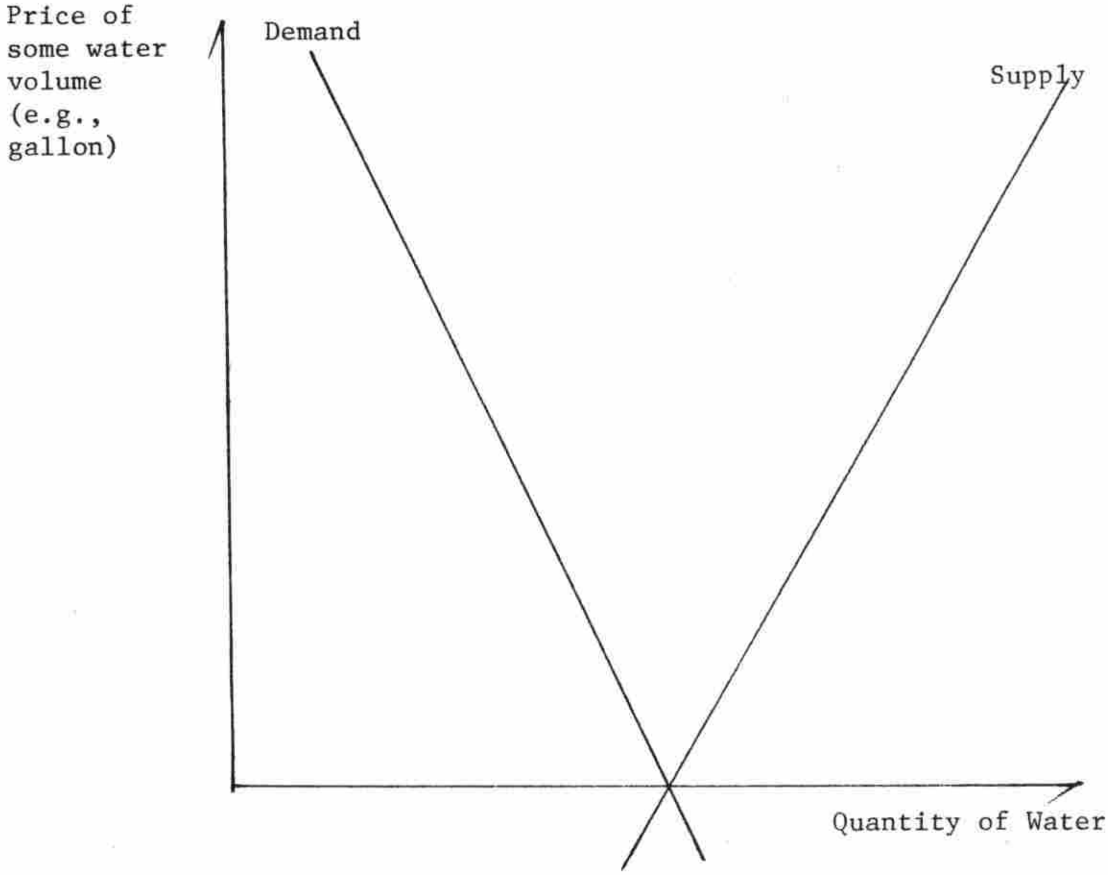

Figure 2. Water as a free good.

untreated, does not satiate the drinking water demand in the same way that one of an Iowa's plentiful, though mineralized, aquifer supplies may not suffice as Iowa irrigation water. Presently, the physical qualities of available water supplies are often inferior to those tolerated by quality-differentiated (or "quality-tolerating") water demands. Many Dakota sandstone wells yield water whose qualities may have detrimental effects upon soil characteristics and corn yields and hence, should not be considered available irrigation water (31, p. 27).

Spatial occurrence of water may cause another sort of water shortage. In Northwest Iowa, the low yields of Dakota sandstone wells may preclude irrigation in some areas (31, p. 27). Although water may exist, its spatial occurrence in an aquifer whose well yields are insufficient for center-pivot irrigation may preclude its use in irrigation, or the yields may be of insufficient yield to satisfy all competing irrigator demands.

Thirdly, water demands and supplies are linked by time. Improper timing of water availability may cause a water shortage. For instance, although heavy rains came at the end of July, 1977, they occurred too late after the July 23 silking date to have had much yield benefit. Thus, the plentiful rains, by their ill-timed temporal occurrence, did not relieve the drought damage which had already occurred.

Therefore, localized Iowa water shortages are caused by mismatched supplies and demands for water commodities differentiated by physical qualities, spatial occurrence, and/or temporal occurrence (87, pp. 144-145). Economics, which deals with allocating scarce means among alternative wants such that benefits are maximized, offers much in resolving localized water shortages caused by the water supply and demand mismatches mentioned above (87, p. 143).

However, beneficial Iowa water uses are broken down into consumptive (domestic) and productive (manufacturing) uses, where the former include such things as drinking, cooking and bathing, and where the latter include agriculture, manufacturing, car washing, etc. Consumptive uses cannot be allocated according to market prices (88, p. 1255). Consumptive uses have a higher ordinal ranking than productive, and according to Timmons (88, p. 1255):

> "Obviously people want a per-capita distribution of these uses. Some people should not die of thirst or even forgo bathing..., while other people use limited water to wash cars. The high ordinal importance of water for drinking purposes is sufficient for governmental units . . . to decree other uses be curtailed or banned in assuring a sufficient supply of water for domestic uses."

Therefore, marginal analysis should be used as a primary criterion in allocating water supplies among competing productive uses only after consumptive demands have been satiated. Fortunately, Iowa is, in the long run, generally endowed with plentiful water supplies, and hence, economic analysis offers much in allocating water to productive uses and in alleviation of many localized water shortages (87, p. 143).

For a flat $15 fee, the I.N.R.C. will presently allocate water to a productive use, requiring only that the use be "beneficial" to the user and not impose cost or hardship upon another user.[1] No parameters of relative "beneficialness" exist, and the I.N.R.C. will allocate, perhaps, ten acre inches per year to a use whether the water M.V.P. in the use is one or ten thousand dollars. Such does not lead to efficient water allocation according to marginal analysis criteria, for water is not necessarily allocated to the

[1] N. W. Hines (36, pp. 60-61).

use with the highest marginal value product, hence, precluding the maximization of the goods and services produced with a limited water input.

Water Allocation via Marginal Analysis

According to the Iowa Code (37):

> "It is hereby declared that the general welfare of the people of the state of Iowa requires that the water resources of the state of Iowa be put to beneficial use to the fullest extent of which they are capable, and that waste or unreasonable methods of the use of water be prevented, and that conservation of such water be exercised with the view fo the reasonable and beneficial use thereof in the interest of the people."

Referring to this statement, Timmons (87, p. 148) contends that "It seems reasonable to interpret the statute as meaning that any use is beneficial as long as the marginal value productivity of water is non-negative." Timmons (88, p. 1248) states elsewhere that marginal analysis offers much in better allocating scarce water supplies among competing demands, because "...from a public viewpoint, the maximization of longrun social benefit from the use of water resources may appropriately represent a public objective . . . insofar as people prefer more to less of the goods and services obtainable from the use of water." Therefore, the marginal value productivity criterion ought to be included by the I.N.R.C. in allocating a water supply to a water demand, which are both matched with respect to specific attributes of physical qualities, as well as spatial and temporal occurrence (87, pp. 143-145).

Three criteria must be met if water is to be allocated via marginal analysis. These three criteria are, according to Timmons, (88, p. 1249) "...how much water may be used economically in particular uses, allocation of a given amount of water among competing uses, and allocating a given amount of water among users engaged in a particular use."

Using water economically in a particular use

Assume a setting of pure competition,[1] where there exists an irrigated farm operation raising corn. The problem is to determine the optimal amount of irrigation water the farmer applies to his fields. Assume the corn yield response production function is $Qc = H(\bar{F},W)$ where Qc represents the per acre yield response of corn yields to applied irrigation water, and H, the functional relationship between the input quantities and Qc. $\bar{F}$ represents the annual per acre input use of fertilizer, a constant, and W is the amount of acre inches of irrigation water applied to the corn crop. It must be carefully noted that this function is an irrigation water production function which measures the per acre yield response of corn to irrigation over and above some expected rain-fed yield level.[2] Therefore, Qc is not the total acre yield.

Figure 3 is a modified version of that formulated by Timmons (88, p. 1250). The horizontal axis is double-tiered, where the first-tier measures the total per acre costs of applying W. Such outlays are primarily constituted of pumping costs incurred from extracting the water from an assumed underground aquifer. Along the second tier of the horizontal axis are the number of acre inches of irrigation water applied.

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[1]According to Baumol (9, pp. 394-395), the four necessary assumptions of perfect competition are (1) numerous price-taking firms, (2) homogeneous products, (3) freedom of entry and exist, and (4) independent decision-making.

[2]Therefore, to obtain the total farm irrigation water product, simply multiply Qc times the number of irrigated acres. All acres cultivated are considered identical except for the acre's location.

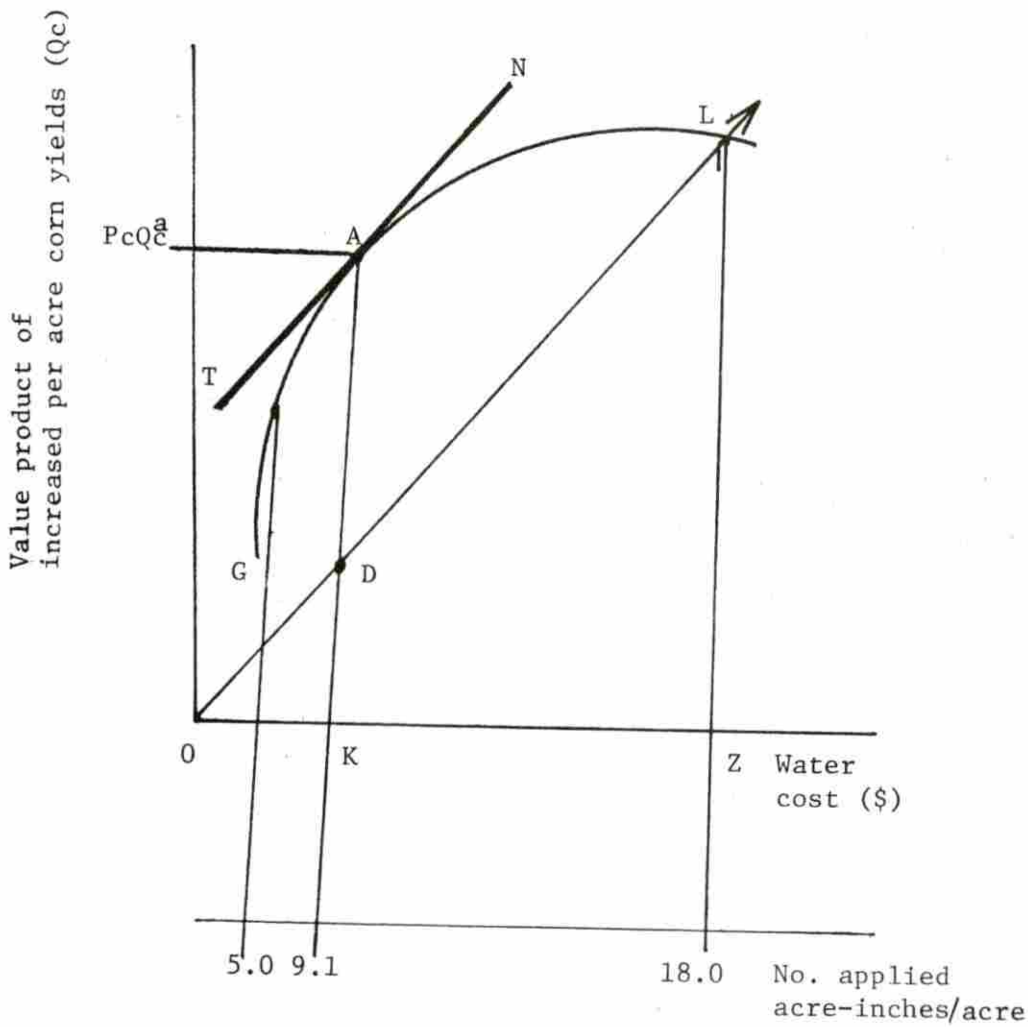

Figure 3. Optimal water use by a user.

OL, a water cost function, is represented by $C = C(W)$ and here happens to also equal the cost of Qc production, since W is assumed to be the sole variable input.[1]

The vertical axis measures the total value product of Qc production. GAL represents the total value product of Qc, $Pc \cdot H(\bar{F},W)$, where Pc equals the market price of corn, that is the per-acre increase in revenue from irrigating.

According to Baumol (9, p. 276), the competitive profit-maximizer produces to the point where his marginal revenue[2] equals the marginal cost[3] of production. This MC = MR condition is realized in Figure 3 by producing upon point A, such at Qc^a is produced and $PcQc^a$ generated per acre. Such a level uses 9.1 acre-inches at a cost of K. Here, the GAL slope at point A equals OL's slope. Since at point A the slope of GAL equals $Pc\ \partial H/\partial W$, the marginal revenue of production, and the slope of OL equals $\partial C/\partial W$, the marginal cost of production, then here is where MC = MR. The 9.1 acre-inches comprise the optimal amount of W the farmer uses per acre.

However, the I.N.R.C. allocates to any non-detrimental use with a positive marginal productivity for water (87, p. 148). Thus, the I.N.R.C. is willing to allocate, if needed by the farmer, 18 inches of water.[4]

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[1]C refers to cost.

[2]Marginal revenue is the added revenue resulting from the production of another unit of output. It is represented hence by M.R.

[3]Marginal cost is the change in cost from producing another unit of output. It is represented hence by M.C.

[4]This equals 18 x 266 acres or 4788 acre-inches in a case where two pivots collectively service 266 acres. Note also that since 1978, after this study's purview, this rule was changed to 12 inches.

According to Timmons (88, p. 1251), this is a cost-benefit analysis criterion too often used in water development projects. Hence using this cost-benefit analysis criterion caused the I.N.R.C. to violate the MC = MR criterion of marginal analysis, and in this example, would over-allocate 8.9 acre inches x 266 acres or a total of 2367.4 acre-inches to the farmer.

Therefore, water is economically used in a use to the point where MC = MR, although the I.N.R.C. presently allocates water if the use is beneficial, or as interpreted by Timmons (88, p. 1248), has a non-negative marginal value product. The I.N.R.C. would conserve more scarce water if allocations to a use were based on the MC = MR criterion rather than on the uneconomical cost-benefit analysis criterion of a non-negative M.V.P.

Allocation of scarce water supplies among a use's competing enterprises

Now assume a slightly different situation, where the farmer faces the task of optimally allocating a scarce water allotment among two competing demands in the farm's production scenario. In other words, a certain farm is considered a water use, whose internal workings contain two enterprises competing for the scarce water allotment: corn and soybeans. A fully-irrigated 320 acre[1] farm is assumed, where one quarter-section is cultivated with soybeans, and the other, with corn. The implicit production function for the farm is assumed as $H(Qc, Qs, \bar{F}, W) = 0$. H, $\bar{F}$, and W are terms defined exactly as in the previous section. Qs and Qc are added per acre yield responses over and above expected rain-fed yield levels caused by irrigation for soybeans and corn, respectively.[2] It must be noted that Qc

[1]Again, all acres are assumed identical in all aspects except location.

[2]Total Qs and Qc for the farm is obtained by multiplying Qs and Qc by the number of acres cultivated.

and Qs do not represent total per-acre yields, but rather the corn and soybean responses to irrigation water applications above rain-fed yield levels, given the season's weather patterns.

Therefore, the farmer has a fixed input vector $(W,\bar{F})$[1] which must be allocated among corn and soybeans. W is allocated to the farmer by the I.N.R.C., and $\bar{F}$ is assumed pre-determined at some constant per-acre rate. Different W-$\bar{F}$ combinations give rise to as many Qc-Qs combinations, given the farmers fixed input vector $(W,\bar{F})$, the farmer's "state-of-the-art," and fixed capital stock (61, p. 20).

Curve SS' in Figure 4 is the locus of all possible Qs-Qc combinations producible with $(\bar{F},W)$ subject to the farmer's state-of-the-art, capital stock, etc. Had the farmer's skill suddenly improved, or were additional inputs made available, he could produce upon a higher plane, such that SS' which would expand to perhaps QQ'.

The farmer may produce at any point on SS', assume at point A. Qc^a of added per-acre corn yields and Qs^a of added per-acre soybean yields would result. Likewise, less of the fixed input amounts may be allocated to corn and more to soybeans, so as to produce at point B in Figure 4. Therefore, given the farmer's state-of-the-art, capital, input vector, etc., the slope of the production possibilities curve (SS') represents the rate of sacrifice the farmer faces in production of one output for increased amounts of the other (88, p. 1253). The slope of a production possibilities curve at any point is the rate of product transformation, hence referred to as the R.P.T. (33, p. 90). In Figure 4, the slope at any SS' point is

[1]Again note that $\bar{F}$ is a constant per-acre fertilizer application and does not enter the analysis since $\partial H/\partial \bar{F} = 0$.

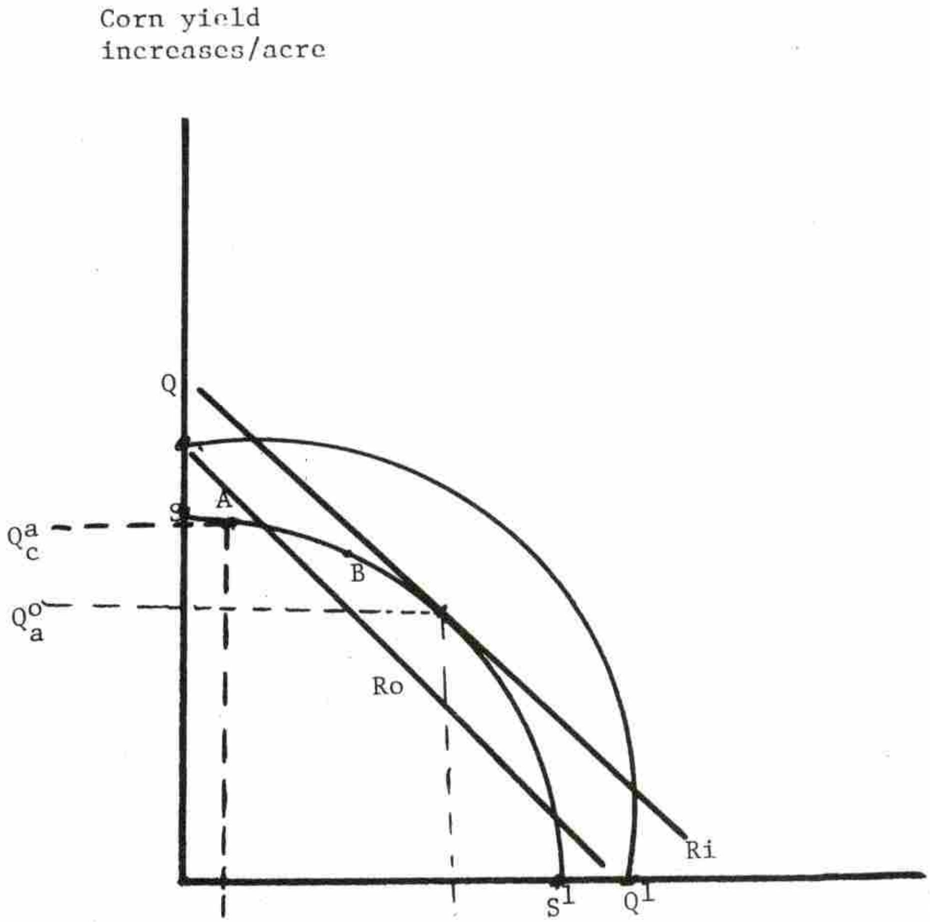

Figure 4. Product transformation curve with water products.

$\frac{\partial H}{\partial S} / \frac{\partial H}{\partial C} = \frac{\partial H}{\partial Qs} \cdot \frac{\partial Qc}{\partial H} = \frac{\partial Qc}{\partial Qs}$, that is, the amount of Qc that must be forgone if the producer reallocates ($\bar{F}$,W) so as to gain an additional Qs. Given the scarcities of inputs and limited productive capacity, more Qs is gained at the expense of Qc and visa-versa. Also note that if all inputs are allocated to Qs, then S' of Qs results, and if all inputs are allocated to the Qc activity, then S of Qc is produced. The shape of the production possibilities curve SS' reflects the assumption of diminishing returns to specializing in any one product (9, p. 277). By adding increasing input amounts to Qs, more Qs is obtained but at a decreasing rate.[1]

Ri is also plotted upon Figure 4. This represents one of an infinite number of iso-revenue lines, where each is defined for a unique revenue level which increases as the line expands from the origin. $Ri = PsQs^i + PcQc^i$, where Ri represents the revenue level. Qs^i and Qc^i are the Qc and Qs levels associated with Ri, and Ps and Pc are the market prices of soybeans and corn, respectively. Pc and Ps are exogenously determined in the market and are taken as constants. Therefore, Qs^i and Qc^i vary along Ri in such a way that a constant revenue level is maintained (9, p. 280). Ri is then a locus of all $Qs^i \cdot Ps$, $Qc^i \cdot Pc$ combinations, whose sum renders a constant revenue level. Therefore, along any Ri:

$$dRi = 0 = PsdQs^i + PcdQc^i$$

$$-PsdQs^i = PcdQc^i$$

$$-\frac{Ps}{Pc} = \frac{dQc^i}{dQs^i}$$

[1]The reverse is true when moving leftward along SS'. Here, as inputs are reallocated from Qs to Qc, more Qc is obtained at the expense of forgone Qs, but added Qc is obtained at a decreasing rate.

It is demonstrated that $\frac{dQc^i}{dQs^i}$ or Ri's slope at any point equals the negative of the output price ratios, that is the relative price of the two products (88, p. 1253). Assuming Pc and Ps to equal \$2/bushel and \$4/bushel, respectively, the relative price of corn equals .5 and that of soybeans, 2.0. That is, consumers reflect through dollar-voting in the market place a higher preference for soybeans than corn, such that a bushel of the former is worth two of the latter and a bushel of the latter is worth a half of the former. Timmons (88, p. 1253) contends that "Through the relative prices that consumers are willing to pay for products, consumers reflect the relative importance they attach to each."

The production possibilities curve SS' and the iso-revenue line Ri of Figure 4 are reproduced in Figure 5. With the given $(W,\bar{F})$ input vector, 30 bushels per acre of corn over an expected rain-fed level can be produced if all inputs are allocated to Qc. With all inputs allocated to Qs, 15 bushels per acre of added soybean yields can be added to expected rain-fed yield levels. According to Baumol (8, p. 277), "...profit maximization requires the firm to select the highest iso-revenue line on any production frontier . . . which is tangent to SS'."[1] The farmer produces along his production possibilities curve until his RPT (or the slope of SS') equals the output price ratio (or the slope of the iso-revenue line). Such occurs at a tengency between the production possibilities curve and the furthest iso-revenue line from the origin. At E in Figure 5, such a tengency occurs, where the rate at which the farmer's production function enables him to gain Qs in terms of forgone Qc equals the rate at which Qs

[1]In Baumol (9, p. 276), SS' refers to a production possibilities curve.

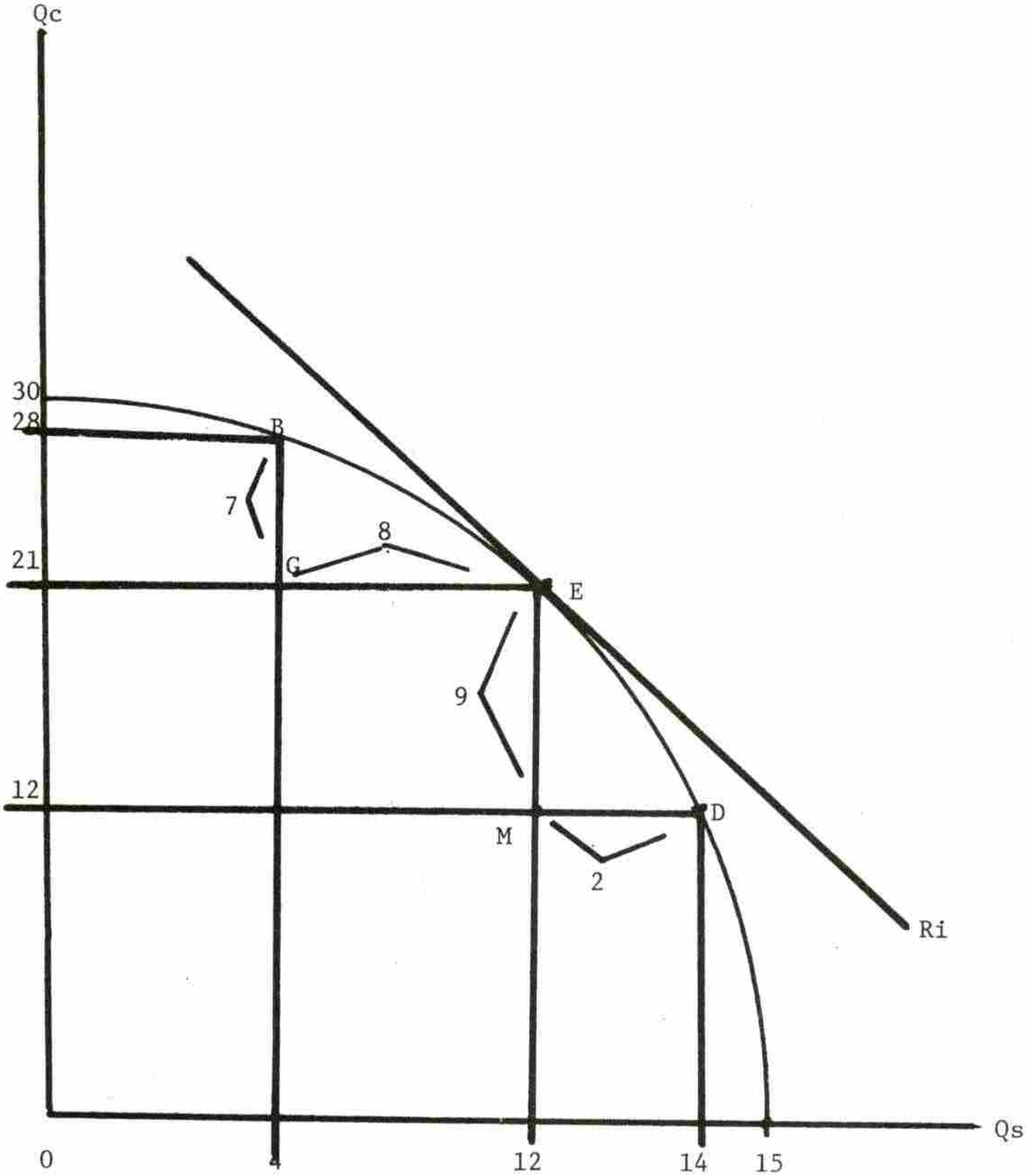

Figure 5. Qc-Qs production possibilities curve.

is exchanged for Qc in the market.

Again noting Figure 5, suppose the farmer is initially situated at point B upon SS', where his RPT is less than the ratio of output prices. That is, at B, Ri is steeper than SS'. This implies the farmer as being able to acquire another Qs unit in production at a less expensive cost of forgone Qc than he would exchange Qs for Qc in the market. Thus, Qs is "cheap" and hence the farmer reallocates inputs from Qc to Qs such that 7 units per acre of Qc are forgone for 8 additional Qs units per acre. The seven bushels/acre of forgone Qc, worth $14/acre, are exchanged in production for 8 bushels/acre of Qs, worth $32/acre, as the farmer moves from point B to E on SS'. Such a move entails a $18/acre gain in revenue.

Now suppose that the farmer, represented in Figure 5, is initially at point D on SS', where his RPT exceeds the ratio of output prices. Here, SS' is steeper than Ri. Thus, the farmer can acquire Qc in production at a cheaper rate in terms of forgone Qs than prevails in the market. Hence, MD or 2 units per acre of Qs are forgone to acquire ME or 9 units per acre of Qc. Since the 9 units/acre of Qc acquired are worth $18/acre and the 2 units of forgone Qs, $4/acre, then by re-allocating inputs, here water, from Qs to Qc, $14/acre is gained in moving from point D to E on SS'.

Therefore, the farmer allocates scarce amounts of water between two competing enterprises to the point where his RPT or the rate at which the farmer can sacrifice Qc for more Qs, equals the relative price ratio, or the rate at which Qs and Qc are exchanged in the market (9, p. 280).

Allocating water among competing users

Assume two water users, say farmers A and B, competing for a scarce water supply. Assume that A and B both operate irrigated farms, between which only the levels of managerial competence, the efficiencies of production, the type of outputs, and the acreage locations differ.[1] Qa and Qb are the output quantities of farms A and B respectively. Qa represents added per-acre corn yields above rain-fed levels due to the application of irrigation water. Qb is assumed to be added per-acre oats yields above rain-fed levels resulting from the application of irrigation water. Both farmers draw water from the same aquifer and under the same head, so as to incur identical water costs. The combined withdrawals of A and B are assumed to excessively deplete the aquifer faster than its rate of recharge. Seeing this, the I.N.R.C. decides to carefully regulate water withdrawals from the aquifer. The problem is to decide how much water the I.N.R.C. should permit each farmer to withdraw.

A's production function is $Qa = A(W, X_2, X_3, ..., X_n)$, where W is the amount of irrigation water allotted by the I.N.R.C., and the $X_2, X_3 ..., X_n$ variables represent other variable inputs required in producing Qa or additional per-acre corn yields above rain-fed levels resulting from irrigation.

B's production function is $Qb = B(W, Y_2, Y_3, ..., Y_n)$ where W again represents irrigation water and $Y_2, Y_3, ..., Y_n$ represents the other inputs required to produce added per-acre oats yields above rain-fed levels.

A's cost of production is $C_A = PwW + Px_2X_2 + Px_3X_3 + . . . + Px_nX_n$. Ca is A's level of production costs and Pw, Px_2, Px_3, Px_4 . . . Px_n are input prices faced by A.[2]

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[1]Therefore both farms are of the same size, of the same soil type, etc.

[2]The cost of the water input is assumed to be constituted by pumping costs. It is taken as being equal for both, A and B.

B's cost function is $C_B = PwW + Py_2Y_2 + P_{y_3}Y_3 + \ldots + P_{y_n}Y_n$, where C_B represents B's level of production costs and Pw, Py_2, Py_3, ..., Py_n, the input prices faced by him.

Below are π_a and π_b, the profit functions of A and B respectively, along with their maximizations.[1]

$$\pi_a = P_aA(W, X_2, X_3, \ldots, X_n) - P_wW - P_{x_2}X_2 - P_{x_3}X_3 - \ldots - P_{x_n}X_n$$

(1A) $\frac{\partial \pi a}{\partial W} = P_a \frac{\partial A}{\partial W} - P_w = 0$

(2A) $\frac{\partial \pi a}{\partial X_2} = P_a \frac{\partial A}{\partial X_2} - P_{x_2} = 0$

(3A) $\frac{\partial \pi a}{\partial X_3} = P_a \frac{\partial A}{\partial X_3} - P_{x_3} = 0$

. . .
. . .
. . .
. . .

(NA) $\frac{\partial \pi a}{\partial Xn} = P_a \frac{\partial A}{\partial X_n} - P_{x_n} = 0$

$$\pi_b = P_bB(W, Y_2, Y_3, \ldots, Y_n) - P_wW - P_{y_2}Y_2 - P_{y_3}Y_3 - \ldots - P_{y_n}Y_n$$

(1B) $\frac{\partial \pi b}{\partial W} = P_b \frac{\partial A}{\partial W} - P_w = 0$

(2B) $\frac{\partial \pi b}{\partial Y_2} = P_b \frac{\partial A}{\partial Y_2} = P_{y_2} = 0$

(3B) $\frac{\partial \pi b}{\partial Y_3} = P_b \frac{\partial A}{\partial Y_3} - P_{y_3} = 0$

. . .
. . .
. . .
. . .

(NB) $\frac{\partial \pi b}{\partial Y_n} = P_b \frac{\partial A}{\partial Y_n} - P_{y_n} = 0$

---

[1]Only the first-order conditions are shown. The second-order conditions are not shown, but are assumed to hold.

1A through NA are the first-order conditions of π_a's maximization and equations 1B through NB represent those of π_b's maximization. Note that the first equations in both sets of conditions refer to the water input. $P_a \frac{\partial A}{\partial W} - P_w = 0$ is rewritten as $P_a \frac{\partial A}{\partial W} = P_w$ and $P_b \frac{\partial B}{\partial W} - P_w = 0$ is rewritten as $P_b \frac{\partial B}{\partial W} = P_w$. Since P_w is assumed the same for A and B, then $P_b \frac{\partial B}{\partial W} = P_w = P_a \frac{\partial A}{\partial W}$. $P_a \frac{\partial A}{\partial W} = M.V.P._a$ and $P_b \frac{\partial B}{\partial W} = M.V.P._b$, where M.V.P. refers to marginal value product of water. Therefore, each producer so combines water with his other inputs so as to equate his M.V.P. for water with P_w. Since the same P_w is faced by both farmers, $MVP_a = MVP_b$ for water. Since a competitive profit-maximizer uses each input to the point where the input's MVP equals the input price, then the I.N.R.C. should allocate water to each producer such that water's MVP of each farmer equals P_w (33, p. 68).

This condition is demonstrated in Figures 6, 7 and 8. Figures 6 and 7 are total value product curves for W of A and B, respectively. Each is derived by taking each farmer's production function and varying W, ceteris paribus. In other words, for A, $\frac{\partial A}{\partial X_i} = 0$ for all i except W, where $\frac{\partial A}{\partial W} \neq 0$. Likewise for B, $\frac{\partial B}{\partial Y_i} = 0$ for all i except W, where $\frac{\partial B}{\partial W} \neq 0$. As W varies, so does Qa and Qb. Each output resulting from a W-variation as all other input quantities were held constant is then multiplied by its market price to render the two functions in Figures 6 and 7. Figure 8 is a combination of 0_aA from Figure 6 and 0_bB from Figure 7 into an Edgeworth box framework. The horizontal borders are defined for water-use, where water use increases along the Edgeworth Box's horizontal axes in the arrow directions. The vertical borders represent the value product of water as its quantities are repeatedly varied, ceteris paribus, for both producers.

Since it was shown that $P_a \frac{\partial A}{\partial W} = P_b \frac{\partial B}{\partial W}$, and since $P_b \frac{\partial B}{\partial W}$ and $P_a \frac{\partial A}{\partial W}$ are

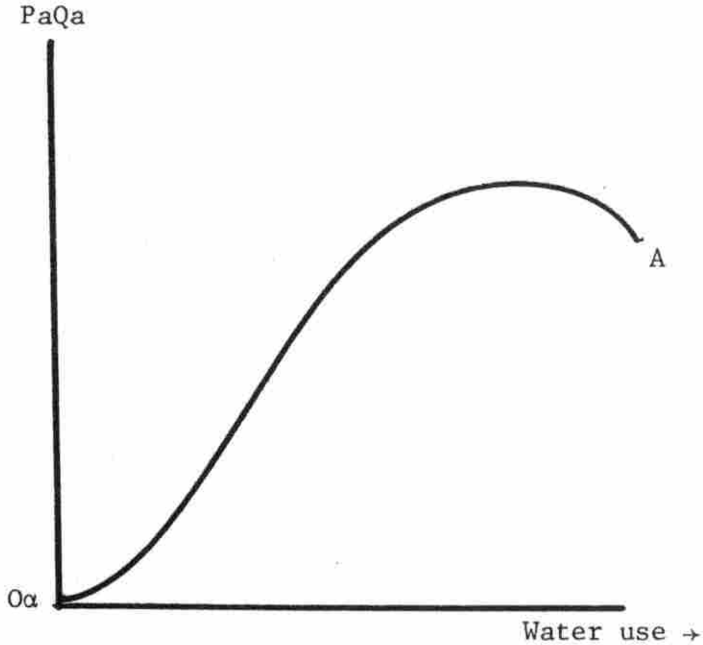

Figure 6. A's total value product for water.

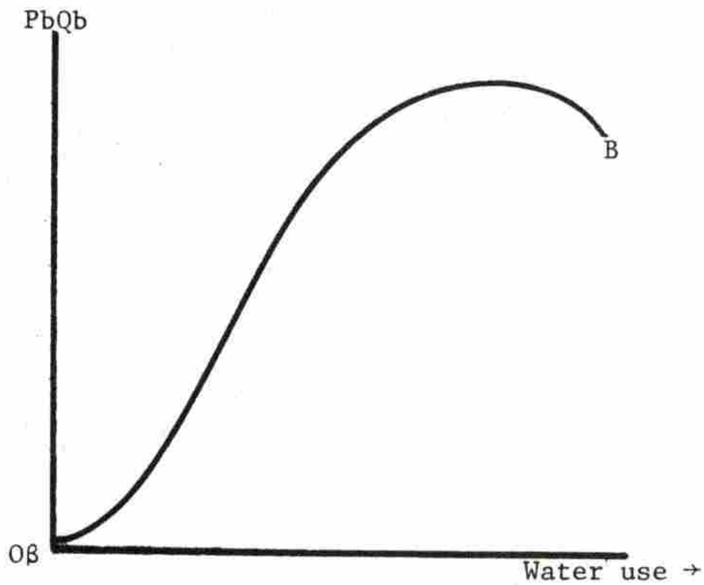

Figure 7. B's total value product for water.

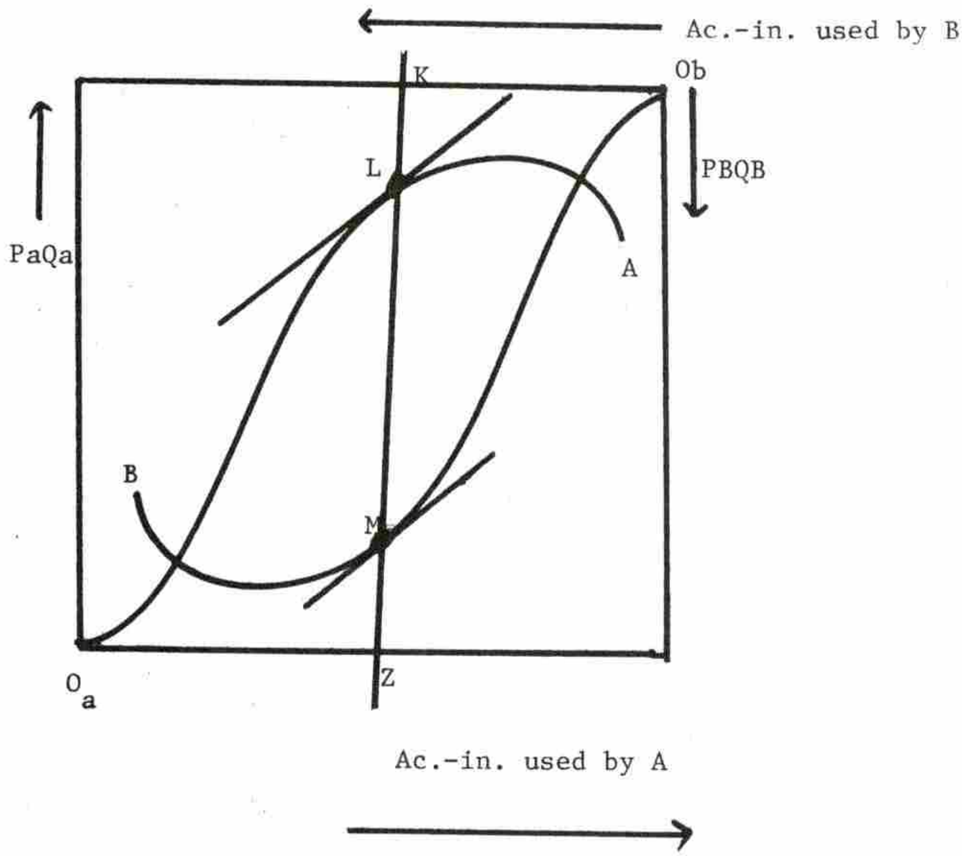

Figure 8. Edgeworth box framework for A and B.

the slopes of the water MVP functions of B and A, then the I.N.R.C. should so allocate scarce irrigation water to farmers A and B such that the amount used in production equates water's MVP_a with P_w. Such occurs in Figure 8 when 0_aZ and 0_bK are allocated to A and B, respectively. The slope at any point upon the total revenue curves in Figures 6 and 7 is the marginal value product of water for the respective producer. MVP_a and MVP_b for water are equal in Figure 8 at point L for A and at point M for B. Such is demonstrated by the parallel nature of the two tangent lines.

Therefore, the I.N.R.C. should allocate a scarce water supply to competing demands such that the water's M.V.P. for all competing uses are equal (9, p. 23).

Summary

Allocating water via marginal analysis requires that three conditions be fulfilled (88, p. 1244). First, water is allocated to a single use to the point where MC = MR. Assuming two enterprises competing for a use's scarce water supply, the producer so-allocates water such that his R.P.T. equals the relative product price ratio, Thirdly, water should be allocated to competing uses such that water's M.V.P. for all uses are equal.

CHAPTER III.

DEVELOPMENT OF THE MODEL

The model herein developed uses multi-period linear programming to generate two streams of 1957-1977 income for a farm under (1) a rain-fed production scenario and (2) an irrigated production scenario. Both scenarios are developed for a 320 acre farm located within the Moody Soil Association of Lyon County, Iowa. All acres are considered homogeneous in every aspect[1] except acre-location, and the land tract is assumed comprised of two perfectly square quarter-sections.

Annual profits as well as 1957-1977 period income are maximized for both scenarios. The gap between these two income streams is delimited, and represents the return to irrigation investment.

The model is predictive in that past irrigation performance, given the present (1978) technology levels, is examined for its indications of future profitability. Irrigation profitability during subhumid periods in such states as Iowa hinges crucially upon drought intensity and weather favorability, phenomena which are not predictable. Hence, the best indicator of future Iowa irrigation profitability is a study of past irrigation performances, given the latest technology.[2]

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[1] t is the descending numerical ranking of post-1956 years such that t = 1, 2, ..., 21 and 1957 = 21, 1958 = 20, ..., 1977 = 1. These superscripts are not exponents except in the $(1.09)^t$ term.

[2] Irrigation will not be as profitable in Iowa during periods of yield-favorable weather. If weather is good, yields will be high, and response of yields to irrigation, low. In arid or semi-arid areas such yield responses to irrigation are always high.

Given this, a farmer pondering future irrigation investment regards past irrigation performances in terms of 1978 dollars as a basis for future returns. Therefore, using the discount formula, $\sum_{t=1}^{21} \frac{\text{Revenue}}{(1+r)^t}$, where the 1957-1977 incomes are discounted into 1957 terms, has little relevance to a predictive model. What is important is whether irrigation was profitable and hence will continue to be sufficiently profitable to justify future capital commitments therein. Hence, the reverse of the above formula, $\sum_{t=1}^{21} (\text{Revenue})(1+r)^t$, is used which puts all incomes into 1978 terms, because farmers do not use 1957 profitability criteria for investment decisions concerning the 1978-1998 period. Thus, using 1978 dollars in estimating income is adequate to answer both questions: (1) was irrigation profitable? and (2) as best as can be predicted, will irrigation be profitable?

The Basic Multi-Period Linear Programming Model

Maximize:
$$[C_1^{\,1}X_1^{\,1} + C_2X_2^{\,1} + \ldots + C_n^{\,1}X_n^{\,1}]\ (1+r)^1 + [C_1^{\,2}X_1^{\,2} + C_2^{\,2}\ X_2^{\,2} + \ldots + C_n^{\,2}X_n^{\,2}]\ (1+r)^2 + \ldots + [C_1^{\,t}X_1^{\,t} + C_2^{\,t}X_2^{\,t} + \ldots + C_n^{\,t}X_n^{\,t}]\ (1+r)^t$$

$$= \sum_{t=1}^{21}[C_1^{\,t}X_1^{\,t} + C_2^{\,t}X_2^{\,t} + \ldots + C_n^{\,t}X_n^{\,t}]\ (1+r)^t$$

Subject to:

$$A_{11}^1\ X_1^1 + A_{12}^1X_2^1 + \ldots + A_{1n}^1X_n^1 \le b_1^1$$

$$A_{21}^1\ X_1^1 + A_{22}^1X_2^1 + \ldots + A_{2n}^1X_n^1 \le b_2^1$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$A_{m1}^{\,2}\ X_1^1 + A_{m2}^1X_2^1 + \ldots + A_{mn}^1X_n^1 \le b_m^1$$

$$A_{11}^{2}X_{1}^{2} + A_{12}^{2}X_{2}^{2} + . . . + A_{1n}^{2}X_{n}^{2} \leq b_{1}^{2}$$

$$A_{21}^{2}X_{1}^{2} + A_{22}^{2}X_{2}^{2} + . . . + A_{2n}^{2}X_{n}^{2} \leq b_{2}^{2}$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$A_{m1}^{2}X_{1}^{2} + A_{m2}^{2}X_{2}^{2} + . . . + A_{mn}^{2}X_{n}^{2} \leq b_{m}^{2}$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$A_{11}^{t}X_{1}^{t} + A_{22}^{t}X_{2}^{t} + . . . A_{1n}^{t}X_{n}^{t} \leq b_{1}^{t}$$

$$A_{21}^{t}X_{1}^{t} + A_{22}^{t}X_{2}^{t} + . . . A_{2n}^{t}X_{n}^{t} \leq b_{2}^{t}$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$A_{m1}^{t}X_{1}^{t} + A_{22}^{t}X_{2}^{t} + . . . A_{mn}^{t}X_{n}^{t} \leq b_{m}^{t}$$

$$X_{j}^{t} \geq 0 \text{ for all t and j}$$

Where

t superscripts refer to the year.[1]

X_{j}^{t} represents one unit of an activity during the t-th year.

C_{j}^{t} represents the net return of a particular activity's unit during the t-th year.

A_{ij}^{t} represents, in year t, the amount of resource i required by X_{j}^{t}.

b_{i}^{t} represents the resource i constraint in year t.

$j = 1, 2, ..., n$ and this subscript refers to a particular activity, that is a column.

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[1] t is the numerical ranking of post-1956 years such that t = 1, 2, ..., 21 and 1957 = 1, 1958 = 2, ..., 1977 = 21.

i = 1, 2, ..., m and this subscript refers to a resource constraint, that is a row.

r refers to the rate used to convert all previous annual program values into 1978 terms.

Each bracketed expression of the objective function, $\sum^{n} C_j^t X_j^t$, represents the annual profit function for year t. Likewise, each block of rows such as the following represents the block of constraints facing the farmer in year t:

$$\sum_{j}^{n} A_{1j}^{t} X_j^t \leq b_1^t$$

$$\sum_{j}^{n} A_{2j}^{t} X_j^t \leq b_2^t$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$\sum_{j}^{n} A_{mj}^{t} X_j^t \leq b_m^t; \; X_j^t \geq 0$$

Thus, the model is comprised of twenty-one yearly programs covering the 1957-1977 period.

The Cj coefficients are the objective function coefficients and represent the amount by which the value of the program changes as another unit of the coefficient's activity, Xj, is implemented (11, p. 40). If a Cj is defined for a selling activity, then the Cj represents the anticipated selling price, hence carrying a positive sign (8, p. 40). Should Cj be defined for a purchasing activity, then Cj carries a negative value equaling the prevailing cost, that is a value by which the purchase of such an activity's unit decreases the objective function value (11, p. 40).

A resource use coefficient, A_{ij}, reflects the amount of resource i required or demanded by Xj (11, p. 39). If the A_{ij} places a positive demand upon resource i, that is consumes part of the resource, then the resource-use coefficient is positively valued (11, p. 39). Likewise, if the A_{ij} places a negative demand upon resource i, that is by adding to the available amount of resource i, then the resource use coefficient is negatively valued (11, p. 39). For instance, assume X_j to be defined as an acre of corn. The activity requires scarce labor, and hence, the A_{ij} corresponding to labor is greater than zero. But an acre of corn adds bushels of corn to the farm's total product, thereby requiring a negative A_{ij} coefficient corresponding to this activity and the corn product accounting row.

Multi-Period Linear Program for the Rain-Fed Scenario

The following linear model represents that of a year, t, where t can be any year within the 1957-1977 period:

Maximize: $[C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 + C_6X_6]\ (1+r)^t$

Subject to:

$$A_{11}\ X_1 + A_{12}\ X_2 + A_{13}\ X_3 + A_{14}\ X_4 + A_{15}\ X_5 + A_{16}\ X_6 \leq b_1$$

$$A_{21}\ X_1 + A_{22}\ X_2 + A_{23}\ X_3 + A_{24}\ X_4 + A_{25}\ X_5 + A_{26}\ X_6 \leq b_2$$

$$\vdots$$

$$A_{13,1}X_1 + A_{13,2}X_2 + A_{13,3}X_3 + A_{13,4}X_4 + A_{13,5}X_5 + A_{13,6}X_6 \leq b_{13};$$

$X_j \geq 0$[1]

---

[1]For convenience, superscript t has been omitted. Keep in mind that this model refers to a certain year, t.

Throughout the remainder of the text, the following abbreviations are used to represent the activities of the rain-fed model:[1]

P01-K = the activity of producing one acre of corn in the study area defined below.

P02-K = the activity of hiring one hour of April labor during year K.

P03-K = the activity of hiring one hour of May labor during year K.

P04-K = the activity of hiring one hour of October labor during year K.

P05-K = the activity of borrowing one dollar from the bank for production capital at the market interest rate of year K.

P06-K = the activity of selling one bushel of corn during year K.

Therefore, there are six basic yearly activities for each of the twenty-one years, thereby rendering 6 x 21 or 126 activities in the rain-fed model.

The following abbreviations represent the constraints of the rain-fed model throughout the remainder of the text:

R01-K = the row of resource use of the farm's land.

R02-K = the row of resource use, by the farmer, of labor made available during November of year K.

R03-K = the row of resource use by the farmer of labor available in April of year K.

R04-K = the row of resource use by the farmer of labor available in May of year K.

---

[1]The activities and constraints, for instance P01-K and R01-K are defined for k, representing the last two digits of any year. So P01-57 represents P01 in 1957.

R05-K = the row of resource use by the farmer of labor available in June of year K.

R06-K = the row of resource use by the farmer of labor available in September of year K.

R07-K = the row of resource use by the farmer of labor available in October of year K.

R08-K = the row corresponding to the use of operating capital.[1]

R09-K = the amount of money the bank allows the farmer to borrow as operating capital during year K.

R10-K = the row representing the use of April labor hired from outside the farmer's family during year K.

R11-K = the row representing the use of May labor hired from outside the farmer's family during year K.

R12-K = the row representing the use of October labor hired from outside the farmer's family during year K.

R13-K = an accounting row for "bushels of corn" into which produced bushels are entered and out of which the product is sold.

INC-K = an accounting row for income. Herein, all income-producing C_jX_j amounts are entered as positive amounts and all income-expending C_jX_j amounts are entered as negative amounts.

For the rain-fed model, there are fourteen rows or constraints faced annually by the farmer. Given the twenty-one years covered by this study, the model has 294 rows.

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[1]The farmer's personal financial resources used to meet production expenses.

Multi-Period Linear Program for the Irrigated Scenario

For each year of the 1957-1977 models, aside from 1957, 1960, 1962, 1969, and 1972 when crops were not irrigated, the yearly profit model representing the rain-fed production scenario is as follows:[1]

Maximize: $C_1X_1+C_2X_2+C_3X_3+C_4X_4+C_5X_5+C_6X_6+C_7X_7+C_8X_8+C_9X_9$

Subject to:

$$A_{11}X_1+A_{12}X_2+A_{13}X_3+A_{14}X_4+A_{15}X_5+A_{16}X_6+A_{17}X_7+A_{18}X_8+A_{19}X_9 \le b_1$$

$$A_{21}X_1+A_{22}X_2+A_{23}X_3+A_{24}X_4+A_{25}X_5+A_{26}X_6+A_{27}X_7+A_{28}X_8+A_{29}X_9 \le b_2$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

$$A_{17,1}X_1+A_{17,2}X_2+A_{17,3}X_3+A_{17,4}X_4+A_{17,5}X_5+A_{17,6}X_6+A_{17,7}X_7$$

$$+A_{17,8}X_8+A_{17,9}X_9 \le b_{17}$$

$X_j \ge 0$ for all j.[2]

Throughout the remainder of the text the following abbreviations represent the activities of the irrigated model:[3]

Q01-K = the activity of producing corn under rain-fed conditions within the study area defined below. To this activity,

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[1]These years are hence referred to as non-irrigation years and the other study period years, as irrigation years.

[2]For simplicity, the superscript t is omitted. Keep in mind that this model can represent any of the 21 years of the study, aside from the years when crops were not irrigated.

[3]The activities and constraints are identified here with a K. The K, such as with P01-F or R01-K, refer to the last 2 digits of any year, 1957, 1958, .., 1977. Therefore, P01-K and R01-K, refer to any P01 activity and R01 activity in the model. P01-K may be P01-57, P01-58, ..., P01-77 and R01-K may be R01-57, R01-58, ..., R01-77.

Q07-K, Q08-K, and Q09-K, irrigation activities later defined, are added to form an irrigated production scenario.

Q02-K = the activity of hiring one hour of April labor during year K.

Q03-K = the activity of hiring one hour of May labor during year K.

Q04-K = the activity of hiring one hour of October labor during year K.

Q05-K = the activity of borrowing one dollar from the bank for production capital at the market interest rate of year K.

Q06-K = the activity of selling one bushel of corn during year K.

Q07-K = the activity of applying, in units of 66.5 acre-inches,[1] the first 50 percent of a year K's recommended total irrigation application. This application is assumed to produce 65 percent of a year K's yield response.[2]

Q08-K = the activity of applying the next 30 percent of a year K's recommended total irrigation application in 66.5 acre-inch units after Q07-K has entered at its upper limit. Q08-K is assumed to bring about 30 percent of the year's total irrigation response.

Q09-K = the activity of applying in units of 66.5 acre-inches, the final 20 percent of a year's recommended total application to bring about the final 5 percent of the year's K's estimated total irrigation response.

Given the twenty-one years comprising the 1957-1977 period, and given

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[1]According to Sheffield (70, p. 1), .25 acre-inches is the smallest amount applicable per irrigation application, and hence is used as an application unit in this study.

[2]These assumptions regarding the value productivity of water are discussed in subsequent portions of this Chapter.

the 5 non-irrigation years when the three irrigation activities are eliminated, the irrigated model is comprised of 189 less 15 or 174 activities.

The following abbreviations represent the irrigation model's yearly income constraints for some year, K,[1] throughout the remainder of the text:

S01-K = the row of resource use of the farm's land.

S02-K = the row of resource use, by the farmer, of labor made available during November of year K.

S03-K = the row of resource use, by the farmer, of labor made available during April of year K.

S04-K = the row of resource use, by the farmer, of labor available in May of year K.

S05-K = the row of resource use, by the farmer, of labor available in June of year K.

S06-K = the row of resource use by the farmer of labor available in September of year K.

S07-K = the row of resource use by the farmer of labor available in October of year K.

S08-K = the row corresponding to the use of operating capital.

S09-K = the amount of money the bank allows the farmer to borrow as operating capital during year K.

S10-K = the row representing the use of April labor hired from outside the farmer's family during year K.

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[1] Again, the constraint set for the non-irrigation years differ from years when irrigation water was applied to crops. During 1957, 1960, 1962, 1969, and 1972, the constraints S14-K, S15-K, and S16-K are eliminated.

S11-K = the row representing the use of May labor hired from outside the farmer's family during year K.

S12-K = the row representing the use of October labor hired from outside the farmer's family in year K.

S13-K = an accounting row for "bushels of corn" into which produced bushels are entered and out of which the product is sold.

S14-K = the limited amount of irrigation water comprising half of year K's total recommended seasonal irrigation application.

S15-K = the limited amount of irrigation water comprising 30 percent of year K's total recommended seasonal irrigation application.

S16-K = the limited amount of irrigation water comprising 20 percent of year K's total recommended seasonal irrigation application.

S17-K = a minimum acreage constraint requiring the farmer to plant at least the irrigated area each year.

irr-K = the income accounting row into which all positive and negative C_jX_j amounts are entered so as to calculate year K's profit.

Given the twenty-one years of this study, there are 17 x 21 = 357, less the three eliminated rows for each of the five non-irrigation years or 342 rows in the irrigated model.

Assumptions of the Model

General assumptions of linear programming

According to DeBenedictis (26, pp. 32-34), five assumptions are required by the linear programming procedure: linearity, divisibility, finiteness, and single-valued expectations.

The linearity assumption requires all functions to be linear, that is have constant input-output proportions. These proportions remain unchanged, despite the extent to which a function, or "process", is used (26, p. 33).

The divisibility assumption implies that any process may be used to any positive extent (26, p. 33). Therefore, 101.48 acres may be planted and 1.97 tractors purchased. Fortunately, the solution components may be rounded off to the nearest full integer without seriously hindering the accuracy and.or optimality of the solution (26, p. 33).

The third linear programming assumption, finiteness, simply means that a finite number of activities, products, and factor amounts (including water in this study) are assumed.

Fourth is the linear programming assumption of single-valued expectations. According to Beneke and Winterboer (11, p. 8), "...all enterprises are treated as though they were equally without risk." All prices, future technological trends, and price-cost relations are assumed known by the entrepreneur with certainty.

And finally, the assumption of addivity is assumed. Such implies the output of any two activities produced simultaneously to be equal to the sum of the outputs of the separate activities (26, p. 33).

The assumptions of perfect competition

The farm examined in this study is assumed to be a perfectly competitive, price-taking entity whose operator maximizes profits. These assumptions have been previously stated above. The assumptions of perfect competition are reasonable for this study, since according to Knight (44, p. 1), "Agriculture is an industry whose characteristics approach those of pure competition."

Assumptions of the farm

The farm is a simulated representative cash-grain entity comprising 320 acres within the Moody Soil Association of Lyon County, Iowa. The acreage is assumed comprised of two, square quarter-sections such that in the irrigation production scenario, two center-pivots may be installed with no irrigated area overlap and such that only the farm's land is irrigated. The irrigated scenario may, as suggested by Dougal,[1] be one half of a 640 acre farm whose 320 irrigated corn acres rotate each year with soybeans. Each year, the two irrigated quarter-sections alternate with the non-irrigated quarter-sections.

The yield-data base, derived in Chapter 4 of this study, reflects the high-yield rate of planting experiments undertaken at the Doon Experimental Farm, located near Doon in Lyon County, Iowa.

No other production activities besides corn planted under a continuous corn rotation are assumed for either the rain-fed or irrigated production scenarios for four reasons: (1) Melvin[2] states that of the 185,000 irrigated Iowa crop acres, 175,000 are cultivated with corn and 10,000 with non-corn crops, mostly soybeans. (2) The yield data used are good representatives of most high-yielding corn yields grown under most corn rotations found in Lyon County's Moody Association. Hence, results from an analysis of the continuous corn data are relevant to most high-yielding corn rotation situations upon Lyon County Moody soil. (3) An attempt is made to standardize

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[1] This opinion was expressed in a private communication with Iowa State University Professor of Civil Engineering, Dr. Merwin Dougal, Ames, Iowa, August, 1978.

[2] This information was obtained by private communication with Agricultural Engineer Stewart Melvin, Ames, Iowa, April, 1978.

the maximal number of production setting conditions to a uniform scenario (continuous-corn) in order to isolate the pure yield and income impacts of irrigation. (4) Such an assumption of one production activity, continuous corn, is realistic, given Baldwin's[1] information that several financially successful farmers grow continuous-corn upon Lyon County Moody soil.

1978 technology, the latest and most advanced available, is assumed to have prevailed throughout the study's period, 1957-1977. Hence, the latest 1978 models of machinery, center-pivot irrigation systems, 1978 levels of farmer managerial and productive capability, etc. are assumed. There are two reasons for this assumption: (1) It would be difficult, if not impossible, to adjust yields to separately compensate for the changing farm machinery qualities and capabilities, increased farmer productivity, genetic advances, advances of production technology, etc. which have undoubtedly caused the post 1956 increases of agricultural output (100, p. 292-295). Therefore, rain-fed yields are adjusted for technology with a method used by both, Shaw (67, p. 251) and Thompson (82, p. 83), which is explained in Chapter 4 of this study. (2) Such an assumption lends the model developed herein a predictive nature. Since irrigation profitability in non-arid regions such as Iowa greatly hinges upon the yield-favorability of annual weather patterns,[2] and since such weather patterns are too random a variable to predict, then an analysis of past irrigation performance with

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[1]The names of such farmers are obtainable from Lyon County Extension worker Roger Baldwin, Iowa State University Cooperative Extension Service, Rock Rapids, Iowa.

[2]That is, if weather is good, yields are high, yield response to irrigation is low, and hence, irrigation profitability is low. Given bad weather, rain-fed yields are low, irrigation yield responses high, and profitability of irrigation, high.

the latest technology provides the best indicator of the future profitability of Iowa irrigation.

Assumed discount rate, r, used in the reverse-discount formula

The multi-period linear programs for the rain-fed and irrigated scenarios operate on the assumption that r=9%. This is a composite rate developed by Harris and Nehring (32) in order to evaluate long-term capital investments in agriculture. This 9 percent is the rate at which an investment's returns are compounded over the investment's life span so as to adequately compensate a typical Iowa cash grain farmer of 254 to 360 acres for five time-related costs: (1) risk aversion, (2) time preference of income, (3) the uncertainty of time-related phenomena (e.g., weather variability) (4) interest costs of waiting for the investment's generated returns, and (5) decreased purchasing power from expected future inflation.

This rate is used in the following reverse-discount formula, incorporated in the multi-period linear programming model: $\sum_{t=1}^{21}$ (income year t) $(1+r)^t$. The $(1+r)^t$ term, where r equals 9 percent and t refers to the year,[1] converts all past incomes into 1978 dollars, based on the time preference, risk, etc. which now characterize the average Iowa cash grain farmer of 254 to 360 acres. Therefore, a compound rate of 9 percent would now be required upon the returns of a long-term investment if the investment is to be worthwhile to the farmer. Thus the past is analyzed in terms of present expectations (r=.09). As a basis for future investment, r=.09 is assumed a viable rate over the 1957-1977 and 1978-1998 periods.

[1] 1977 = 1, 1976 = 2, ..., 1957 = 21.

The incomes and costs adjusted with the reverse-discount term, $(1+.09)^t$, are hence called real constant 1978 dollar incomes and costs. However, incomes adjusted with this 9 percent reverse-discount rate term are actually more than just past nominal dollar incomes converted into a base year's past nominal dollar incomes such that they are adjusted for changes in inflation.

Herein, time is considered money. Waiting for an income until year k+1 rather than receiving and consuming it in year k incurs real inter-temporal costs such as (1) incurring time preference costs by having to wait until year k+1, (2) running the uncertainty of income loss from bad weather, (3) enduring purchasing power erosion from inflation, (4) not having the money to invest and hence forgo year k investment options, and (5) interest charges for having to wait for the generated returns. Thus, this 9 percent rate places inter-temporal income premiums upon past incomes because earning incomes in year k avoids the inter-temporal costs mentioned above and hence, increases the real value of past-earned income. Since these intemporal costs are avoided with incomes earned in the past, then the incomes earned further into the past, when converted into constant-dollars, are multiplied by a larger $(1+.09)^t$ term.

Therefore, in addition to adjusting for inflation, an average of 5 percent annually over the study period, the residual 4 percent of the nine percent reverse-discount rate was found by Harris and Nehring (32, p. 164) to compensate average Iowa cash grain farmers of 254 to 360 acres for inter-temporal costs.

Therefore, the constant dollar incomes and costs in this study are adjusted for the 1978 value of past inter-temporal income premiums earned as well as for changes in value of 1978 dollars.

Diminishing returns for water

Hundreds of weather variables interact each year to produce a season's weather patterns, and hence yield levels (68, pp. 1-9). Therefore, a different year may experience different bushels/acre yield responses per applied acre-inch of water, as was found in Iowa by Beer, Shrader, and Schwanke (10) and in Nebraska by Noffke (52, p. 47). While, for any season, reasonably accurate estimates of total recommended irrigation applications which maximize yields are available from the analysis of the crop's seasonal soil moisture stress conditions, and although good, accurate estimated total yield responses are obtainable from Shaw's yield equations based on the soil moisture stress variable, a diminishing return relationship between the total applications and yield responses is unavailable for Iowa (69, pp. 101-106). Unlike arid or semi-arid areas such as Arizona or Nevada, where climatic conditions are reasonably uniform over time, subhumid areas such as Iowa have volatile weather conditions, whose great annual variability preclude the formulation of an irrigation water production function over time.[1] At best, and only given the availability of more than the existing amount of agronomic research regarding the Iowa corn yield responses and amounts of applied irrigation, (10, 63) yearly water production functions could be developed.[1] Presently, the diminishing return

[1]Shaw stated this to be common knowledge among Agricultural Climatologists and Agronomists. Private communication, Agronomy Department, Iowa State University, Ames, Iowa, May, 1978.

relationships between a year's total yield response to a recommended total irrigation water application can be captured only by making reasonable assumptions based upon the small amounts of information regarding irrigation water's diminishing marginal product in terms of added yields.

From the findings of Miller (48, pp. 64-76) and of Beer et al. (10, p. 92), a near linear relationship exists between yield response and the amounts of water applied for up to 90-95 percent of a year's application, with a sharp leveling-off of productivity with a year's total application of irrigation water. Shrader[1] contends from his own observations that such a linear relationship, is very roughly captured by the "rule of thumb" of one inch bringing about 10 bushels per acre. In addition, he contends such a linear acre-inch-yield response relationship to prevail up to the first 10 acre-inches applied.[1]

However, these are only rules of thumb and empirical studies supporting or invalidating them do not exist. In an effort not to over estimate irrigation's water productivity during years with low recommended total applications, the following assumptions, formulated to capture irrigation water's diminishing yield returns, are made for all years, even during the years when the total recommended applications are less than 10 inches/acre: (1) The first 50 percent of each year's total application brings about 65 percent of the total yield response which would have occurred during the year. Such is represented by segment 1 of Figure 9. This segment

[1]This information was obtained from Iowa State University Agronomy Professor, Dr. William Shrader. Private communication, Ames, Iowa, May, 1978.

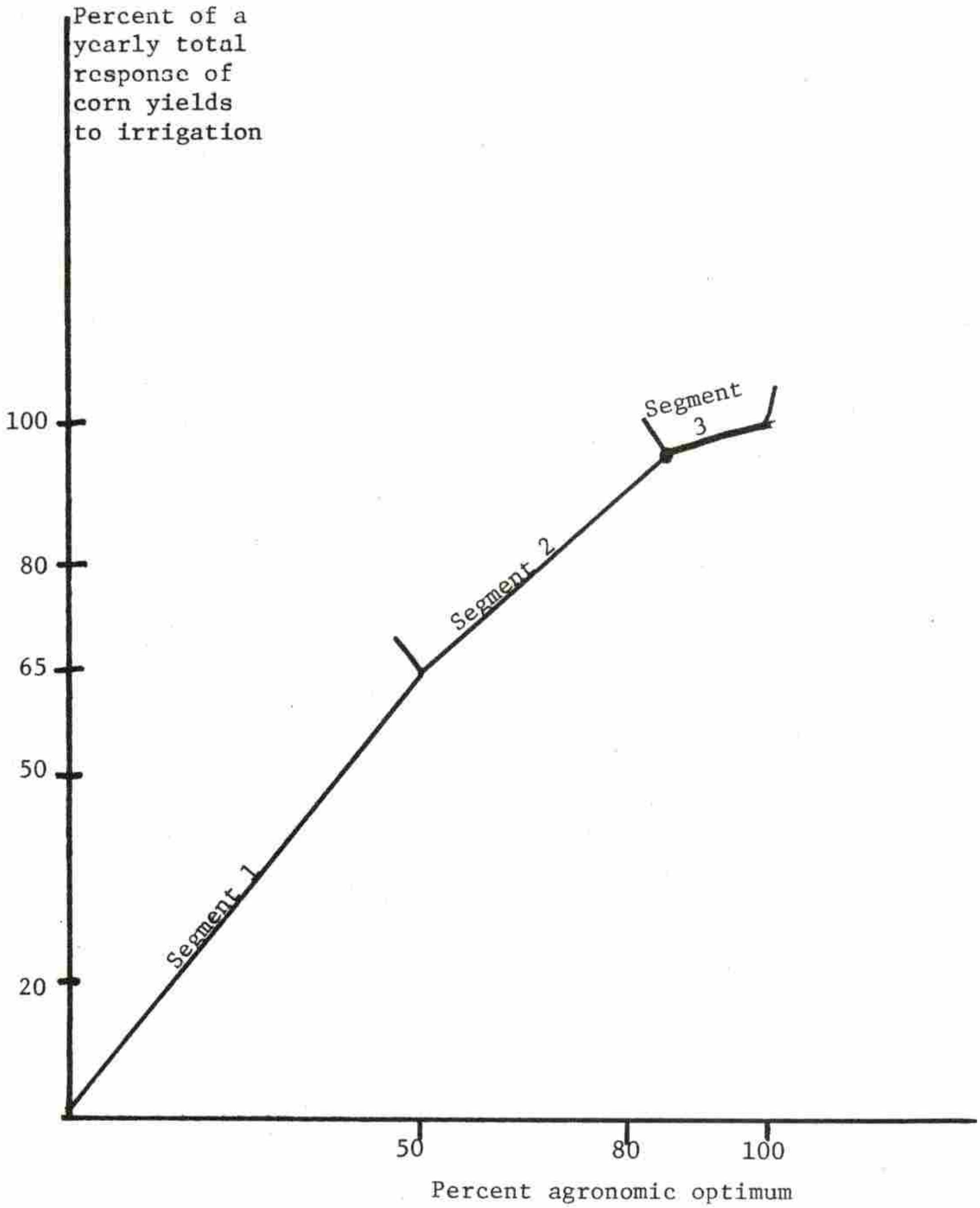

Figure 9. Linear approximation of irrigation's diminishing returns relationship.

corresponds to a constant marginal product for irrigation water, hence called MP_1. The exact value of MP_1 of any year depends upon the amounts of recommended total application and the total yield response thereto.

(2) After the application of the first half of a year's total amount of applied water, the next 30 percent of this total brings about the next 30 percent of the total response. This is represented by segment 2 in Figure 9, which has the second highest marginal product for irrigation water, MP_2, whose exact value depends upon the total recommended application and the total estimated corn yield response.

(3) The sharp leveling off of the marginal product of irrigation water occurs with the final 20 percent of the total recommended application, bringing about 5 percent of the total yield responses. Such occurs in segment 3 of Figure 9, and corresponds to MP_3, the lowest of a year's three marginal products. Therefore, $MP_1 > MP_2 > MP_3$ and after the latter, MP hits zero and shortly thereafter, begins to decline.

It is very obvious that these assumptions greatly simplify the complex relationship between applied irrigation water and yield responses. However, no agronomic research exists spelling out the exact diminishing return relationship between irrigation water and Northwest Iowa corn yields. Hence, one which seems reasonably coincidental with what little research which exists on this subject (10, 48, 63) must be assumed. Such is done above. Given the opinions of Shaw and Shrader, these assumptions appear very reasonable. Remember that the total recommended irrigation applications were calculated with accuracy using a technique developed by Ross and discussed in Chapter 4. Also, the accurate yields under irrigation have been calculated. The only doubt lies in the diminishing return relationship between the total applications and total yield responses.

Limitations of the model

The first and foremost limitation of the model is the dearth of yield, input, cost, and price data regarding irrigation feasibility in Iowa, from which the C_j, A_{ij}, and bi coefficients are formulated. These limitations are hence discussed in the data derivation section of Chapter 4.

Assuming linearity, a requisite of linear programming models, precludes the incorporation of diminishing return relationships, which characterize most production processes (61, p. 24). However, this is largely overcome by approximating a smooth production function, characterized by diminishing returns, with a series of linear segments, where each successive segment corresponds to a separate activity with a lower marginal product for the factor in question than that of the previous segment. The linear program will include the relevant segments which optimize the solution.

The divisibility assumption for all linear programming processes is very unrealistic. However, most solution values, say 201.98 acres of corn, can for all practical purposes be rounded off to the nearest integer, here 202 acres of corn, without seriously altering the accuracy or optimality of the solution (26, p. 33).

The finiteness assumption of linear programming causes problems with the incorporation of infinitely small substitutions along production isoquants. When a finite number of production processes are assumed, then there are as many input-output proportions. However, such can be overcome through activity-redefinition or reformulation into a larger set of production processes (26, pp. 33-34). Note Figure 10, where there exist

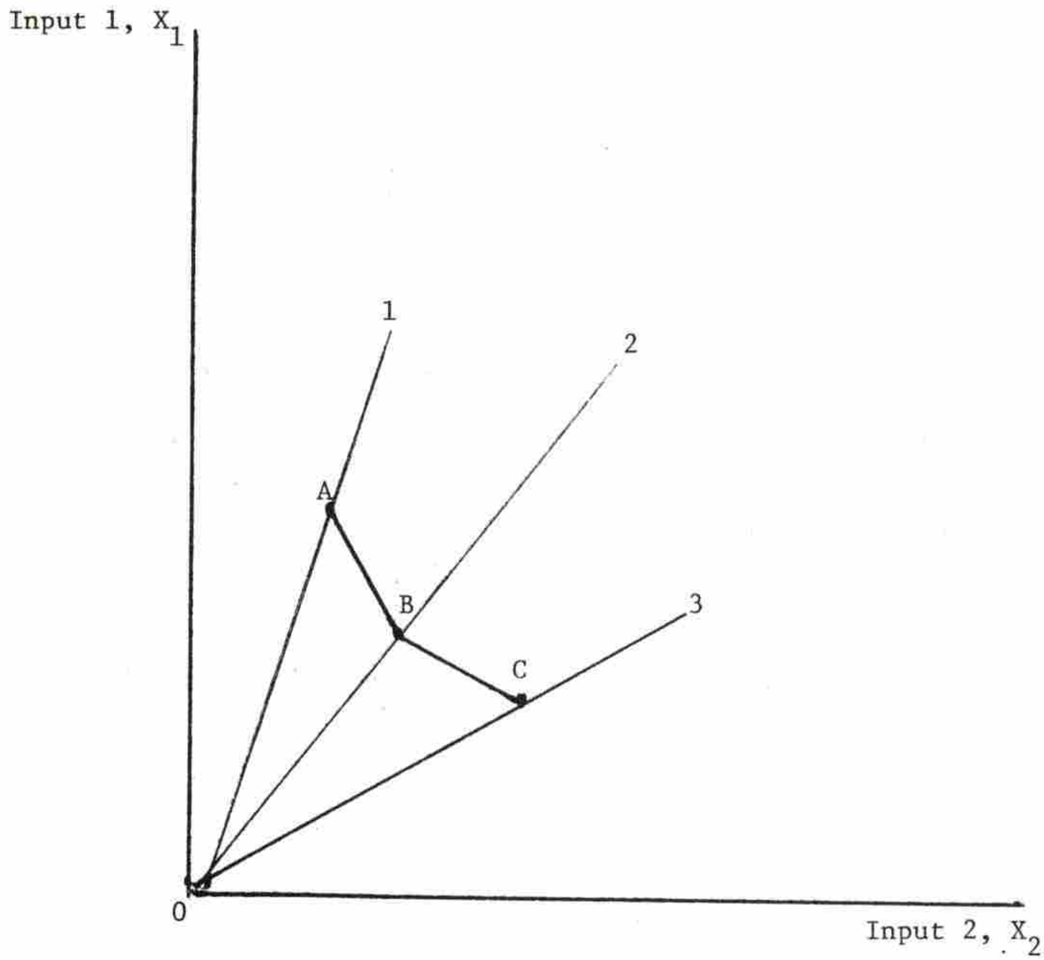

Figure 10. Linear programming production isoquants using three processes.

3 different ways (processes) of producing some output: 01, 02, 03. A, B, and C correspond to a particular output level, Y^1. Therefore, points ABC may be connected to form a kinked production isoquant. Here, only 2 marginal rates of technical substitution for X_1 and X_2 exist. By redefinition of activities, more processes may be developed, hence making ABC in Figure 10 more smooth as with ABCDEF in Figure 11.

The assumption of additivity causes problems with incorporating such things as complementarity of production, when it is more efficient to join two production processes than to produce each separately. For instance, two producers of sheep products, one for wool and the other for meat, would do better and use less inputs if both men produced both wool and meat. Re-definition of the two activities into one joint wool-meat activity can eliminate such a problem (26, p. 33).

Linear programming cannot formulate price expectations, A_{ij}, or bi coefficients. It is the programmer's responsibility to either himself formulate, or obtain from scientists of other disciplines, accurate coefficients. As Timmons (87, p. 378) states, with respect to economic analysis via linear programming, "Economic analyses will yield results no better than the physical and technical coefficients with which the economist works."

Another drawback is the inability to incorporate risk into linear programs. All activities are treated as though they are characterized by the same riskless nature (11, p. 8). For instance, Thompson (83, p. 235) establishes a soybean crop to be more drought-resistant, and hence of a lesser risk, than corn. The linear program cannot incorporate such a risk differential and thus it treats both activities merely as two riskless

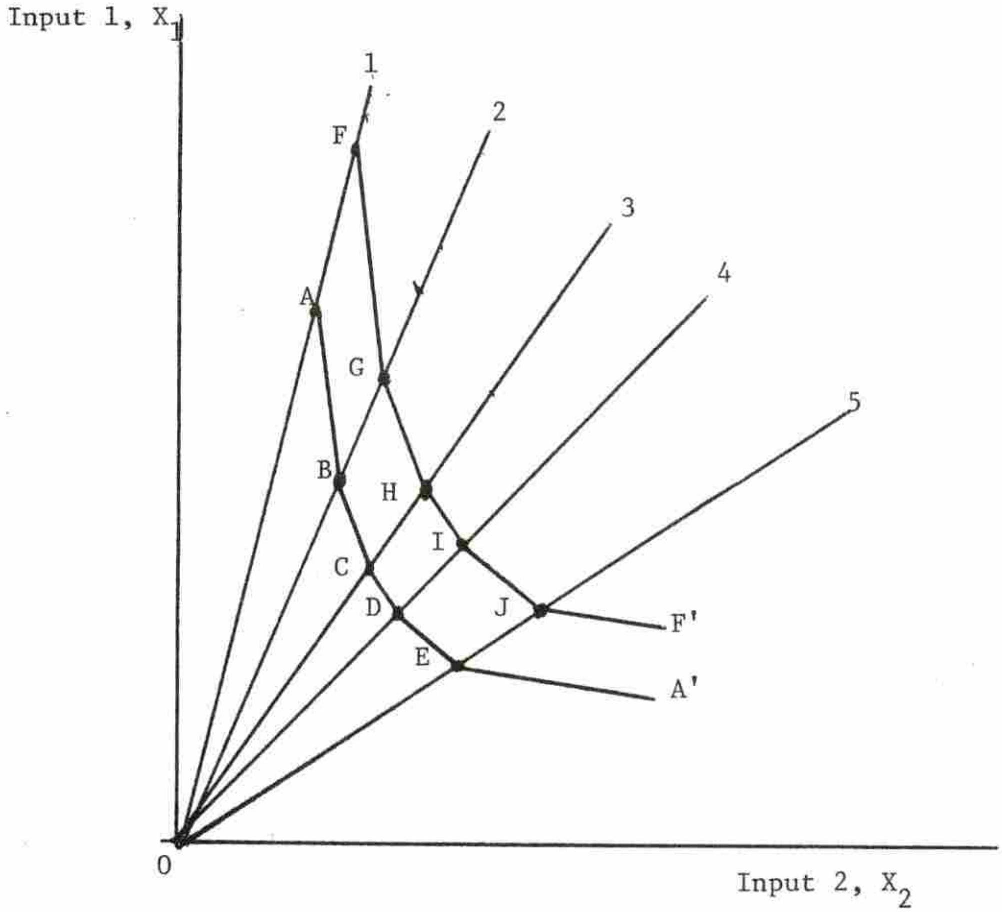

Figure 11. Linear programming production isoquants using five processes.

income-producing activities.

The drawbacks of studying past and future irrigation profitability

Due to a lack of data regarding past price-cost data for machinery, data on yields, etc. past irrigation investment profitability is really not addressed. Rather, the question of whether or not irrigation would have been profitable given 1978's latest and most advanced agricultural technology is addressed. Such renders the best indication for future profitability, since Iowa irrigation profitability hinges upon yearly weather variability, whose future conditions are not predictable.

However, there are also two rising uncertainties of studying future profitability of Iowa irrigation. First of all, farm price expectations are more uncertain with the advent of increased economic exchanges between the United States and the Warsaw Pact nations, the Soviet Union in particular (97, p. 824). According to Warley (97, p. 824), "...permitting Russia free access to Western food supplies impedes the smooth functioning of the food system of the world. Russia's sporadic forays into the world markets have been caused by her failures to gear food production and consumption to her agricultural production, as well as by properly allocating her food via price " (97, p. 824).[1] Given the consequential food shortages, Russia delves unexpectedly into the world grain markets to cause world food price fluctuations whose "...disturbances reach into the furthest corners of national societies and world economies " (97, p. 824). Such food price destabilization adds more uncertainty to food price expecta-

[1]That is, food prices are often kept artificially low, causing shortages.

tions, hence causing more uncertain research conclusions regarding future Iowa irrigation profitability.

The second drawback to extrapolating this Iowa study into the future is the close interrelationship between irrigation profitability of Iowa irrigation and yield responses caused by yearly weather variability. Yearly weather patterns are too variable to predict (31, p. 5). About the only discernable and predictable climatic trend is the so-called sun spot-drought cycle of the U.S. Cornbelt (81, p. 88-89). A full sun spot cycle lasts 20 to 22 years and is comprised of two subcycles, a minor and a major cycle, each of 10 to 11 years duration (81, p. 87). A serious drought has occurred for corn in the U.S. Cornbelt with surprising regularity after the peak of the minor cycle over the last 160 to 170 years (81, p. 88).[1] Nonetheless, the drought occurrence is about the only predictable weather phenomenon, and what occurs climatically between droughts is about as random a variable as exists (31, p. 5). The point made here is that aside from a drought every 20 to 21 years, weather, and hence its impact upon Iowa irrigation profitability, is unpredictable.

Therefore, since weather is unpredictable, and since these unpredictable weather patterns greatly influence yield responses, and hence irrigation profitability, then the prognosis of irrigation is quite uncertain.

However, one important point should be noted. There has been a run of unusually yield-favorable weather during the 1956-1973 period (23, p. 1). Defining "normal" weather as those conditions bringing about above-average

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[1]Thompson (81, p. 87-88) notes that a serious drought occurred in the Cornbelt in the early 1830's, 1850's, early teens, early 1930's, mid 1950's, and mid-1970's.

yields, the 1956-1973 period comprised only 22 percent of the last 80 years, but accounted for 40 percent of "normal" weather patterns experienced over the last 8 decades (31, p. 13). These years were characterized by unusually yield-favorable weather, and although the annual weather patterns are unpredictable, it is quite certain that the degree of 1956-1973 yield-favorability will not persist into the 1990's (23, p. 1). Hallberg (31, p. 12) cites a 100,000 to 1 chance against the 1978-2000 weather patterns having such yield-favorability.

This expected weather deterioration, whose exact workings are unpredictable, may somewhat bolster Iowa irrigation profitability by increasing the magnitudes of longrun irrigation yield responses. In addition, Iowa farmers may increase irrigated crop area as a hedge against income fluctuation caused by increased weather variability.

Finally then, given the uncertainty of farm price trends, the unpredictability of future annual weather patterns, the uncertainty of technological advances, then to attempt and simulate a 1978-1998 model of Iowa irrigation profitability would be less meaningful than reviewing past performance. Therefore, the past is explored under the latest technology, and serves as the best indicator for the farmer as to whether he should invest in future irrigation.

Data Needs of the Model

The data are derived in Chapter 4. This chapter lists only the study's data requirements.

According to Bergmann and Boussard (12, p. 19-47), there are seven classes of data required of a linear programming profitability analysis of irrigation investment: (1) definition and description of the model's application site, (2) the market setting of the studied entity, (3) the irrigated yields, (4) the rain-fed yields, (5) the objective function coefficients or Cj's, (6) the resource-use coefficients or A_{ij}'s and (7) the resource constraints or b_i's. All seven classes of data are derived in Chapter 4.

Required data concerning the model application site include brief descriptions of the area, its relief, soil characteristics, and climatology (9, p. 3).

The data required of the study's market setting include the conditions of competition, characteristics of the farm as a firm, available factors of production (e.g., credit, labor), etc.

The data required for the formulation of the rain-fed scenario's objective function coefficients, C_j's, are those needed to determine the six rain-fed farm activities for each of the 21 years of this study. The variable cost components for P01-K[1] include the variable per-acre costs of producing corn, which include costs of seed, fertilizer, pesticides, herbicides, and machine costs. The variable costs of P02-K, P03-K, and P04-K entail obtaining the wage-rates of hired help for each of the 21 years. P05-K has an annual variable cost equal to half[2] the market interest rates charged by banks each year. Such rates, then, must be found. P06-K requires the yearly corn prices for all twenty-one years.

The irrigated model's Cj's have Q01-K, Q02-K, Q03-K, Q04-K, Q05-K, and Q06-K which are identical to the activity set of the rain-fed model. Hence

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[1]All activities and rows were defined earlier in this chapter.

[2]Production capital is usually borrowed for 6 months, hence the reason for half the annual market interest rate.

the first six activities of the irrigated model are exactly the same as those of the rain-fed model. The years during which irrigation would have been applied have three extra irrigation activities per year, not found in the rain-fed scenario or for those years of the irrigated model when irrigation water would not have been applied.[1] These three activities, defined earlier in this chapter, are Q07-K, Q08-K, Q09-K, and for the formulation of their Cj's, the per-gallon diesel fuel prices, and the rates of diesel consumption of the water pumps must be found.

All Cj's in both scenarios are adjusted with the reverse-discount formula of the multi-period linear program, while the bi's and Aij's are not. The C_j's are multiplied by $(1+.09)^t$, where t is a descending numerical ranking of a post-1956 year and is an exponent to the (1+.09) expression.

The set of A_{ij} coefficients corresponding to P01-K and Q01-K include land requirements of corn production (A_{11}), November labor requirements for growing an acre of corn (A_{21}), the April labor requirements for growing an acre of corn (A_{31}), the May labor requirements for growing an acre of corn (A_{41}), the June labor requirements for growing an acre of corn (A_{51}), the September labor requirements for growing an acre of corn (A_{61}), the October labor requirements for growing an acre of corn (A_{71}), the nominal costs (year-K terms) of growing an acre of corn (A_{81}), and the addition of product per acre of corn in each of the 21 years ($A_{13,1}$). Q01-K and P01-K all have identical yearly A_{i1}, except that the irrigated model's corn activity (Q01-K) has an additional A_{ij}, $A_{14,1}$, corresponding to a minimum acreage (266 acres) planted such that the center-pivot machinery will be guaranteed full use.

[1]These non-irrigation years are 1957, 1960, 1962, 1969, 1972.

P01-K and Q01-K have the same A_{ij}'s.[1] Data are required on the addition to available April labor for P02-K and Q02-K and they are known as A_{22} coefficients. Nominal hourly wage rates for hired labor are required by Q01-K and P01-K and are known as the A_{82} coefficients. Data on the impact of the hired April labor constraint are required for each P02-K and Q02-K and comprise the set of $A_{10,2}$ coefficients.

The A_{ij}'s corresponding to P03-K and Q03-K are exactly the same for all K. Since these two activities are the hiring October labor activities for the rain-fed and irrigated models, respectively, three A_{ij}'s are required for each. A coefficient showing the impact of one unit of the hiring activity upon available May labor is needed for each year, which comprise the set of A_{41}'s. The hourly wage rates of hired labor for each of the twenty-one years are used to show the impact of one P03-K or Q03-K unit upon K's operating capital constraint, and hence constitute the set of A_{83} coefficients. Thirdly, P03-K and Q03-K each require a coefficient showing one activity unit's impact upon the hired May labor constraint and hence constitute the $A_{11,3}$ coefficients.

P04-K and Q04-K are the hiring October labor activities for the rain-fed and irrigated models. An A_{74} coefficient showing the impact of one unit of either activity upon the available October labor constraint is needed for each year. The yearly nominal wage rates for hired labor are needed to show the impact of one P04-K or Q04-K unit upon the operating capital constraint, and hence comprise the set of twenty-one A_{84} coefficients. Thirdly, an $A_{12,4}$ coefficient is needed for each year to show the

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[1]This is true for all activities except Q07-K, Q08-K, and Q09-K which are unique to the irrigated model.

impact of one P04-K or Q04-K unit upon the constraint of hired October labor.

P05-K and Q05-K are the activities of the rain-fed and irrigated model, respectively, which borrow a dollar for operating capital. The A_{ij}'s for both activities are identical for all K. A set of A_{85} coefficients are needed to show the impact during each of the 21 years of one unit of P05-K or Q05-K upon the operating capital constraint. A_{95} coefficients are needed to demonstrate the impact during each of the 21 years of one P05-K or Q05-K unit upon the credit limit constraint.

P06-K and Q06-K are the corn selling activities for the rain-fed and irrigated model, respectively, and each needs only a set of 21 $A_{13,6}$ coefficients to show the impact during all 21 years of the P06-K or Q06-K unit upon the supply of product.

The remaining three activities are irrigation activities which are unique only to the years 1958, 1959, 1961, 1963, 1964, 1965, 1966, 1967, 1968, 1970, 1971, 1973, 1974, 1975, 1976, and 1977 of the rain-fed model. They are Q07-K, Q08-K and Q09-K. All three have a unique set of A_{ij}'s showing the nominal irrigation costs of applying .25 inches upon 266 acres. Each has its own contribution to the product accounting row. Each irrigation activity has its own impact upon that activity's yearly acre-inch limit of scarce irrigation water. All such coefficients are derived in Chapter 4.

Lastly, a set of fixed costs are required each year for both models. The set of constraints (B_i-coefficients) for each year which must be derived are the following resource constraints facing the operator of the rain-fed farm: constrained amount of acreage, constrained amounts of November, April, May, June, September, and October labor available to the farm operator, the limited production capital of the farmer, the farmer's credit limit for borrowing production capital from the bank, limits to the amounts of April, May, and October labor the operator is willing to hire, an income accounting row, and a corn accounting row. All of the above constraints have values for each of the 21 years of this study.

The irrigated model has similar constraints types, although the variates are often different, as seen in Chapter 4. However, the irrigated model has four more constraints for each of the study's 21 years, not found in the rain-fed model. First is a minimum constraint that at least 266 acres of corn are annually grown, so as to guarantee the center-pivot systems a chance each year to generate income. The other three added irrigation model constraints are the available acre-inches of water applicable with each of the three irrigation activities.

CHAPTER IV.

APPLICATION OF THE MODEL

Model Application Site

Lyon County comprises Iowa's northwest corner, bordered on the north by Minnesota, on the west by South Dakota, on the east by Iowa's Osceola County, and on the south by Iowa's Sioux County. The area of Lyon County is 376,320 acres or 500 square miles, which is primarily comprised of two soil associations: the Moody Silty Clay Loam Association[1] on the county's western half, and the Galva-Primghar Association on the east (92, p. 3).

According to Miller (48, p. 27), Lyon County "...is in a subhumid climatic zone, where surplus moisture is rare and drought conditions are common." In the Moody Association, corn yields are limited more by inadequate soil moisture than anything else (92, p. 3). The association lies within the state's droughtiest region, where annual precipitation ranges from 24 to 26 inches (96, p. 5).[2]

The Moody Association, illustrated in Figure 1 comprises 41 percent of Lyon County (92, p. 3).[3] Of this 41 percent, 84 percent is Moody Silty Clay Loam[4] and the remainder area is comprised of various minor

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[1]Hence, this association is referred to as the Moody Association.

[2]This is compared to the 30-32 inch average in Central Iowa and the 32-34 inch average in Southeast Iowa.

[3]Sioux County, Iowa harbors part of the entire Moody Association.

[4]This soil is hence referred to as Moody Soil.

loess soils such as Trent, Ackmore, Calco, and Colo (92, p. 3).

Moody soil has a 48 to 60 inch profile, whose very dark brown topsoil extends to a depth of 11 to 16 inches (92, p. 3; 48, p. 27). Below the topsoil lies a dark brown subsoil (48, p. 27). The third layer, the substratum, is a partially leached brownish clay loam soil (48, p. 27).

Moody is a well-drained soil with a high water-holding capacity (92, p. 3).[1] The average slope of the Doon Farm area is a gentle three percent (48, p. 27).

The Moody Association of Lyon County is primarily cultivated with row crops. The major acreage is cultivated with corn and soybeans and the minor acreage, with oats and hay (92, p. 3).[2]

The specific farm site is a cash-grain farm of 320 cultivated acres, whose operations are simulated for two scenarios, rain-fed and irrigated. Corn, grown under a continuous-corn rotation, is assumed to be the only output.[3] Each cultivated acre is assumed homogeneous in every respect except location, and the 320 acres are assumed so subdivided that the acreage constitutes two, perfectly square sections. As previously noted, the irrigated scenario may represent one half of a 640 acre farm, of which two quarter-sections are cultivated with irrigated corn, and the second two, with soybeans.

[1]Former Doon Experimental Farm Superintendent, Kenneth Ross, indicated in a private communication that the water holding capacity of the first 60 inches of the Doon site profile is 11 inches. Ames, Iowa, March, 1978.

[2]Additional acreage exists for buildings, driveways, etc.

[3]Such an assumption is realistic. Lyon County Extension Director Roger Baldwin indicated that several financially-successful cash-grain operations producing only corn under this rotation actually exist in Lyon County's Moody Association. Private communication, Rock Rapids, Iowa, April, 1978.

The Case Study Approach

Salter (60, p. 71) defines a case study as "...an intensive study of everything that bears on a given unit." Since this study purports to demonstrate the income-effects of irrigation upon the operations of a particular type of farm, then this study is said to employ the case approach of inquiry.

A case study offers useful and evidential information if and only if the interactions and sequences of its experience studied are preserved within the context of the single investigated type of entity--here the cash-grain farm of 320 Moody acres (60, p. 71). The interrelationships among different sorts of entities, say between the farm simulated above and a larger farm with some livestock, are not within the realm of the case method (60, p. 71). Hence, interpretive care is necessary so as not to broadly generalize the case study's conclusions to other sorts of entities not specifically investigated in the study. Care must also be taken not to generalize a case study's conclusions to general areas which are home to entities of sizes, structures, and production processes which differ from those of the studied entity. In order to determine the economic consequences of irrigation upon a farm differing from that of this study, a separate case study must be implemented.

Therefore, this report is a case study, whose conclusions apply only to a 320 acre tract of Moody Association land, which is cultivated by a financially-successful farmer. The conclusions, by the very case nature of this study, may not be extended to different farm-types and/or farms in differing soil associations, aside from the 640 acre situation previously noted.

A "With-Without Analysis"

For reasons stated in Chapter 1, the most effective approach to analyzing an irrigation project's profitability is the "with-without" analysis.

The objective of the "with-without" analysis is to compare the performances of two production scenarios, rain-fed and irrigated, defined for a single farm and over a given time period. Both scenarios should be standardized for as many conditions as possible, such as soil type, managerial competence, input use levels, technology, crops produced, etc.

An income gap is then delimited between the rain-fed and irrigated streams of 1957-77 income. The income gap is thus attributed to irrigation.

Rain-Fed Yield Data

The rain-fed corn yield data kept by the Doon Farm Staff (49) for the 1957-1977 rate of planting experiments serve as the yield data base of this study. Standardized for a continuous corn rotation planted upon Moody soil at a 16,000 planting population, these data are, in Shaw's opinion,[1] good representatives of those of most high-yielding corn rotations grown upon northwest Iowa's Moody Association. These yields are listed in Table 1.

Since the yield data reflect high-yielding experiments, the latest and most advanced 1978 technology is assumed throughout the 1957-1977 or

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[1]This opinion was expressed by Iowa State University Professor of Agronomy and Agricultural Climatology, Dr. R. H. Shaw. Private communication, Ames, Iowa, May, 1978.

study period. Thus the yields must be adjusted for 1978 technology.

Thompson's (81) method of technological adjustment is used, where a time-trend variable is regressed against the yields. At Thompson's advice,[1] the chosen time-trend variates are: $\log_{10}(57)$, $\log_{10}(58)$, ..., $\log_{10}(77)$, where the numbers 57, 58, ..., 77 refer to the years of the study. The resulting yield estimator is $\hat{Y}_j = -338.8 + 233.16X$, where X refers to the above-listed time-trend variates and $\hat{Y}_j$, the estimated yield for year j.[2] The general shape of this estimator is depicted in Figure 12.

The horizontal line TE, extended out from $\hat{Y}_{78}$ in Figure 12, represents the yield incorporating 1978 technology. The shaded area represents yield accruals due to technological advancement. Hence, the difference between TE and any $\hat{Y}_j$ is the yield increment which should be added to the realized Y_j to adjust the yield for 1978 technology. Table 1 lists the adjusted Y_j's.

Irrigated Yield Data

In reviewing Iowa irrigation literature, no irrigated 1957-1977 yield data were located for Northwest Iowa. Such data must be derived from rain-fed yields. Shaw (65, 66, 67, 68, 69) developed a method to estimate irrigated from rain-fed yields. The method incorporates the negative relationship between corn yield levels and the degree of soil

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[1]This suggestion was made by Iowa State University Agronomy Professor and Assistant Dean of Agriculture, Louis M. Thompson. Private communication, Ames, Iowa, April, 1978.

[2]Hence in this study, Y_j refers to year j's realized yield and $\hat{Y}_j$, to its estimate.

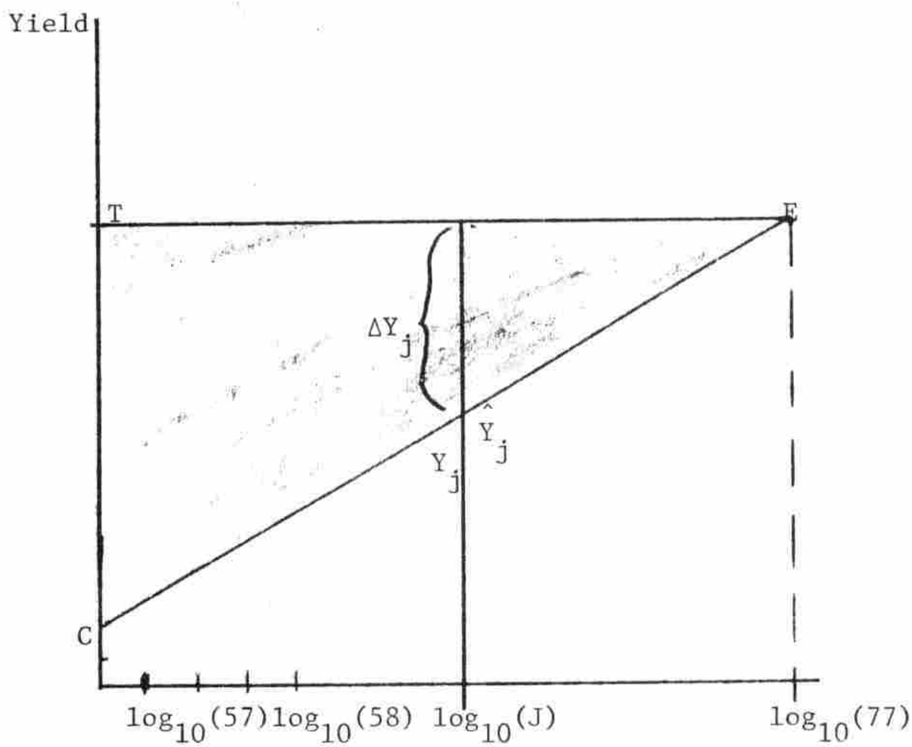

Figure 12. Yield responses to irrigation.

moisture stress borne by a corn plant. Shaw's yield estimation technique is particularly useful because it was largely formulated for the very site of this study, the high-yielding Doon Farm fields (69, p. 106). Thus the irrigated yields obtained from this method and used herein are very accurate, since the estimator equation is formulated for this very site.

Corsi and Shaw (24) regressed the values of four alternative soil moisture stress indices against the yields realized at 21 Iowa sites, the Doon Farm included. The following index, measuring the amount of soil moisture stress borne by a plant because of an inadequate soil moisture supply, resulted repeatedly with the highest correlations:[1] $1 - \frac{ET}{PET}$ (24, pp. 80-81) ET represents the evapotranspiration carried out by the corn plant, given a day's atmospheric demands upon the plant's soil moisture supply (64, p. 358). PET represents the ET which may potentially occur under that day's climatic conditions, given an adequate soil moisture supply (64, p. 358). The greater the soil moisture inadequacy, the smaller the $\frac{ET}{PET}$ ratio, and hence the nearer the index value approaches its upper bound of 1.0 (64, p. 358).[2] Underlying the index's formulation is an assumption that the severity of the stress-induced corn yield reduction is proportional to the ET reduction from PET (24, p. 79).

Stress-induced corn yield reductions are of increased severity as the stress-occurrence date nears the silking date (69, p. 105). Noting this, Shaw (69) accounted for the relationship between increased yield

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[1]In fact, of all the 21 sites, that of the Doon site had the equation reflecting the highest r^2, .98.

[2]The lower bound is zero.

Table 1. Estimated per-acre yields, yield responses, and irrigated yields.[a]

Year	X^b	$\hat{Y}_j$	$\hat{Y}_{j,x\ 10}$	YR_j^c	Y_j^d	Irr. yield
1958	51.7	71.7	132.9	61.2	58.4	119.6
1959	34.2	99.7	132.9	33.2	67.6	100.8
1961	22.6	115.6	132.9	17.3	141.5	158.8
1963	52.9	74.0	132.9	58.9	99.	157.9
1964	26.4	110.4	132.9	22.5	133.4	155.9
1965	19.4	120.	132.9	12.9	128.8	141.7
1966	37.1	95.7	132.9	37.2	94.27	131.47
1967	55.1	71.0	132.9	61.9	41.73	103.63
1968	104.4	3.3	132.9	129.6	18.2	147.8
1970	74.3	44.6	132.9	88.3	46.	134.3
1971	42.5	88.3	132.9	44.6	114.9	159.5
1973	24.1	113.6	132.9	19.3	160.1	179.4
1974	31.3	103.7	132.9	29.2	63.7	92.9
1975	30.6	104.6	132.9	28.3	92.3	120.6
1976	56.5	69.1	132.9	63.8	58.	121.8
1977	24.4	113.2	132.9	19.7	99.	118.7

[a]The years 1957, 1960, 1962, 1969, and 1972 are eliminated since they were years during which irrigation water would not have been applied. All figures herein listed are on a per-acre basis.

[b]X stands for the weighted seasonal value, i.e., Shaw's (69) soil-moisture stress index.

[c]YR_j refers to the per-acre corn yield response to the total seasonal irrigation applications.

[d]Y_j is the realized yield of year j adjusted for technology.

reduction severity and the stress date's proximity to silking by developing a weighted soil moisture stress index. Each daily $(1 - \frac{ET}{PET})$ variate is multiplied by a weight, the magnitude of which increases as the stress and silking dates become more proximal (69, p. 105).

In developing the weighted index, Shaw (69, p. 101) defined the corn growth season over an 85-day interval, subdivided into 17, five-day periods. Each five-day period is assigned a weight. For instance, the eighth period preceding and the ninth period immediately following the silking date have daily index values weighted by .5 (69, p. 103). However, the index values calculated during the periods immediately preceding and immediately following the silking date are weighted with 2.0 (69, p. 103).

Summing a season's 85 weighted daily values renders a weighted seasonal soil moisture stress index variate, hence referred to as a "weighted seasonal value" (69, p. 103). Shaw (69, p. 106)[1] regressed these weighted seasonal values calculated at the Doon Farm for the 1957-1977 continuous-corn rate of planting experiments against the realized yields. The following yield estimator resulted: $\hat{Y}_j = 9196.2 - 86.1 X_j$, where X_j refers to year j's weighted seasonal value, and $\hat{Y}_j$, the estimated year j yield. This equation gives yield in terms of kilograms per hectare, convertible into bushels per acre terms by dividing through by 62.7.

The weighted seasonal values were calculated by Shaw[2] for the 1957-

[1]This regression differs from that of Corsi and Shaw (24) in that the former deals with weighted index variates and the latter, with unweighted ones.

[2]These values were obtained from the private records of Iowa State University Agricultural Climatology and Agronomy Professor, Dr. R. H. Shaw, in a private communication. Ames, Iowa, February, 1978.

1977 period. The yield responses to irrigation may be easily calculated for any year. Noting Figure 13, locate the weighted seasonal value (horizontal axis) for year j, Gj. Now assume a soil moisture stress index down to which a capable irrigator could have decreased Hj.[1] Supposing this reduced soil moisture stress level to be H_j, then $(\hat{Y}_h - \hat{Y}_g)$ is the amount by which yields would have increased in year j because of irrigation. This is under the assumption that H_j is the level down to which a highly-skilled irrigator may have decreased G_j. Therefore, $\hat{Y}_j = \frac{9196.2-86.1(10)}{62.7}$ = 132.9 bushels per acre is the target yield level obtainable when only those variables concerned in X_j's formulation are considered. Many other yield-influencing weather variables exist which are not captured in the $\hat{Y}_j$ equation (68, pp. 1-9). Therefore, when the differences between 132.9 bushels/acre, the estimated $\hat{Y}_j$ at X=10, and $\hat{Y}_j$, the estimated Y_j given a rain-fed X_j, are added to the realized Y_j, then the estimated irrigated yield often falls below or exceeds the $\hat{Y}_j$ target of 132.9 bushels/acre. This because the other non-captured weather variables interact so as to be detrimental to or beneficial to Y_j.

Table 1 summarizes the irrigated yield estimation process. Column 2 lists the weighted seasonal values which, when plugged into the equation, render the rain-fed $\hat{Y}_j$'s in column 3. The fourth column lists the 132.9 bushels/acre yield target. The difference between columns four and three represent the yield response to irrigation when the weather variables

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[1]According to Iowa State University Agricultural Climatologist Dr. Robert Shaw, a good irrigator may decrease Gj down to 10 units. Note, however, that the amount of water required to decrease Gj from 30 to 10 units during year A may greatly differ from the requirements of a similar reduction in year B, due to the vicissitudes of a subhumid Northwest Iowa climate.

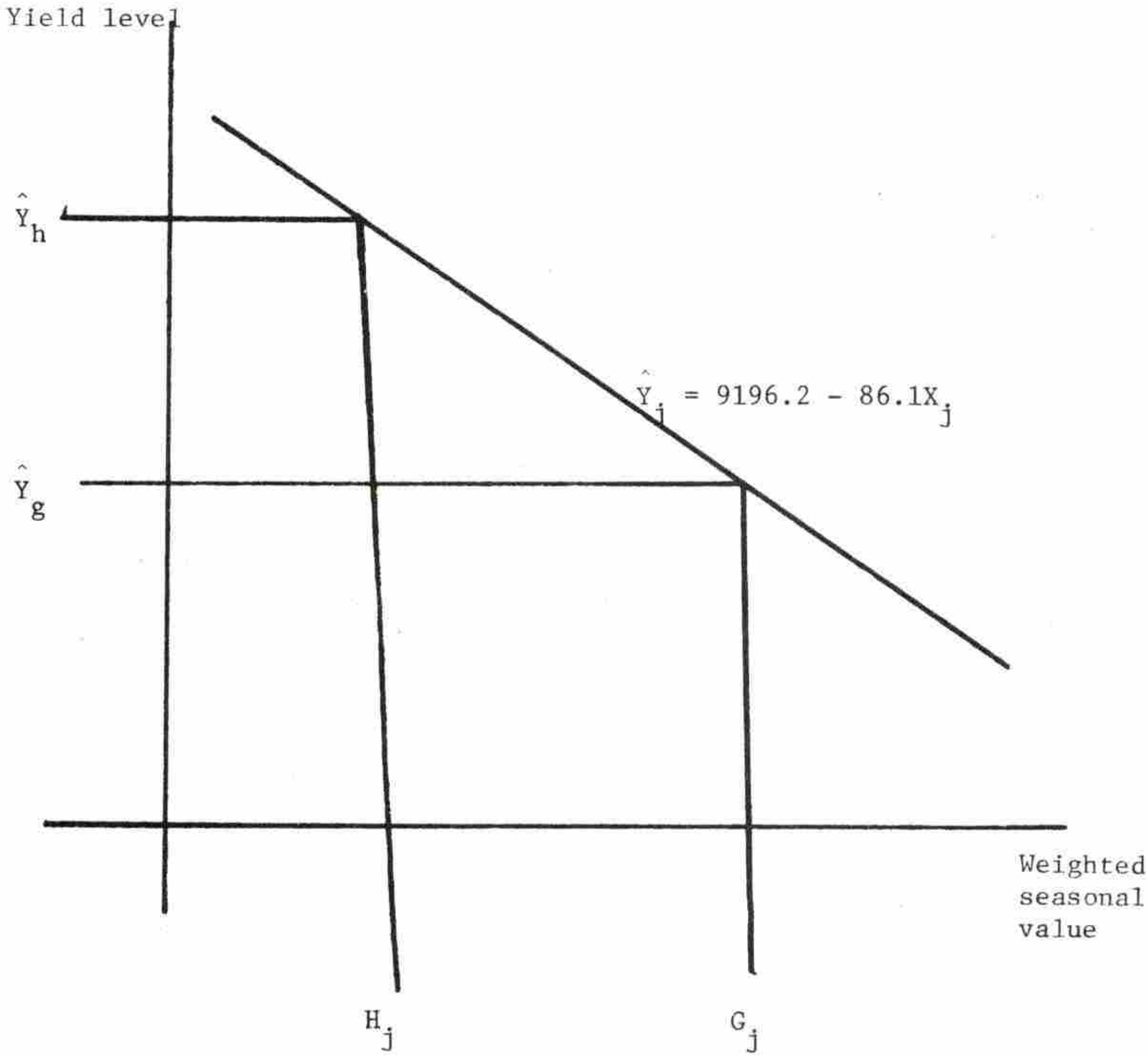

Figure 13. Shaw's yield estimator.

concerned in X_j's calculation are considered. These yield responses, in column 5, are added to the realized yields in column 6 in order to calculate the estimated irrigated yield levels in column 7.

Although Shaw's yield estimator expresses yield as a linear function of X_j, many variables considered in X_j's calculation are not linearly related to yield (68, pp. 1-9). Included in this myriad of variables considered in X_j's calculation are, among many others, such subtle things as windspeed, radiation, and humidity (68, pp. 1-9). Therefore, given the great number of weather variables whose considerations are required of X_j's calculation, given the many other Iowa climatic yield influences not considered in this calculation, and also given the exponentially larger number of possible weather-producing vectors of these variables, a production function for rainfall or irrigation water may not be calculated over time in subhumid areas such as northwest Iowa.[1] Only in arid or semi-arid areas, where weather is reasonably stable, that is always hot and dry, may a setting of climatic near-stability be assumed such that an irrigation water production function over time may be formulated.

Data of the Linear Program

Three classes of data must be derived for the linear program: (1) the objective function coefficients or Cj's, (2) the resource-use coefficients or A_{ij}'s, and (3) the resource constraints or b_i's. The three classes of data are derived below in the order in which they are listed above.

The complete rain-fed and irrigated models are each a summation of

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[1]According to Iowa State University Agricultural Climatologist and Agronomist, R. H. Shaw, this is common knowledge among agronomists. Private communication, Ames, Iowa, May, 1978.

Table 2. General annual matrix format, rain-fed model

	B_i	P01-K	P02-K	P03-K	P04-K	P05-K	P06-K
C-K		C_1	C_2	C_3	C_4	C_5	C_6
R01-K	b_1	A_{11}					
R03-K	b_2	A_{21}					
R03-K	b_3	A_{31}	A_{32}				
R04-K	b_4	A_{41}		A_{43}			
R05-K	b_5	A_{51}					
R06-K	b_6	A_{61}					
R07-K	b_7	A_{71}			A_{74}		
R08-K	b_8	A_{81}	A_{82}	A_{83}	A_{84}	A_{85}	
R09-K	b_9					A_{95}	
R10-K	b_{10}		$A_{10,2}$				
R11-K	b_{11}			$A_{11,3}$			
R12-K	b_{12}				$A_{12,4}$		
R13-K	b_{13}	$A_{13,1}$					
INC-K	b_{14}						$A_{13,6}$

Table 3. General annual matrix format, irrigation model

C-K	b_i	Q01-K	Q02-K	Q03-K	Q04-K	Q05-K	Q06-K	Q07-K	Q08-K	Q09-K
		c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9
S01-K	b_1	A_{11}								
S02-K	b_2	A_{21}								
S03-K	b_3	A_{31}	A_{32}							
S04-K	b_4	A_{41}		A_{43}						
S05-K	b_5	A_{51}								
S06-K	b_6	A_{61}								
S07-K	b_7	A_{71}			A_{74}					
S08-K	b_8	A_{81}	A_{82}	A_{83}	A_{84}	A_{85}		A_{87}	A_{88}	A_{89}
S09-K	b_9					A_{95}				
S10-K	b_{10}		$A_{10,2}$							
S11-K	b_{11}			$A_{11,3}$						
S12-K	b_{12}				$A_{12,4}$					
S13-K	b_{13}	$A_{13,1}$					$A_{13,6}$	$A_{13,7}$	$A_{13,8}$	$A_{13,9}$
S14-K	b_{14}							$A_{14,7}$		
S15-K	b_{15}								$A_{15,8}$	
S16-K	b_{16}									$A_{16,9}$
S17-K	b_{17}	$A_{17,1}$								

twenty-one yearly programs. The general format of a yearly program is illustrated with the coefficients, whose values are herein derived, for each model: the rain-fed model in Table 2 and the irrigated, in Table 3.

Many coefficients are, in addition to being constants over the study period, often equal for both models. In fact, the first six activities and the first 13 rows in each model are identically defined. Rather than encounter redundant derivations by deriving the C_j's, A_{ij}'s, and b_i's for each model separately, the general classes of data are formulated simultaneously for both models. Differences of a certain C_j, A_{ij}, or b_i between the two models are noted as they are encountered. A complete set of C_j's, A_{ij}'s, and b_i's are listed for both models in Appendices A, B, and C, respectively. An asterisk (*) characterizing a column heading signifies a column of values unique to the irrigated model.

Objective function coefficients, C_j's

According to Beneke and Winterboer (11, p. 40), "the entries in the C row (i.e., the coefficients of the objective function) indicate how the total value of the solution will be altered by the addition of one activity...." Thus the C_j is the variable cost of implementing one activity jnit. Activities decreasing income are negatively signed and those adding to income, such as selling corn, are positively signed (11, p. 40).

The C_j's vary annually with inflation, price changes, changes in the supplies and demands of inputs and outputs, etc. Thus, the C_j corresponding to an activity, X_j varies over the 1957-1977 period.

For any year, both models have the same C_1, C_2, C_3, C_4, C_5, and C_6

coefficients. However, the C_7, C_8, and C_9 coefficients are those corresponding to the three irrigation activities, Q07-K, Q08-K, and Q09-K, respectively. These are unique to the irrigation year programs of the irrigated model.

Corn production C_j:C_1 The first activity is defined as the production of one acre of corn. P01-K and Q01-K are identically defined because the irrigated conditions are a combination of a rain-fed corn activity, Q01-K, and one or more of the three irrigation activities.

According to McGrann et al. (47, P. 4), the variable cost components of cultivating an acre of continuous corn are (1) nitrogen fertilizer, (2) phosphate fertilizer, (3) aldrin, (4) thimet, (5) dyfonate, (6) atrazine, (7) lasso, (8) machinery, and (9) seed. These components are listed in Table A-2.

The nitrogen fertilizer application rate coincidental with 1978 technology is 300 pounds per acre per year of 34-0-0 or 100 pounds per acre per year of pure nitrogen (36, p. 3). This application is assumed constant over the 1957-1977 period. The per-pound prices of pure nitrogen fertilizer, listed in Table A-3,[1] are multiplied by the pure nitrogen application rate to obtain the C_1 nitrogen component, listed in Table A-2.

Phosphate fertilizer comprises the second C_1 component. According to Ross,[2] the phosphate application rate coincidental with 1978 technology

[1]Doon Experimental Farm Superintendent Alan Vogel combed through old purchase invoices to obtain these prices for both nitrogen and phosphate, fertilizers. Private communication, Rock Rapids, Iowa, March, 1978.

[2]Former Doon Experimental Farm Superintendent Kenneth Ross rendered this information by private communication. Ames, Iowa, March, 1978.

is 90 pounds per acre biannually, or an average annual application of 45 pounds per acre. The 1957-1977 prices per pound of pure phosphate are listed in Table A-3. The C_1 phosphate component is obtained after multiplying the pound prices by the average application rate. These components are listed in Table A-2.

Pesticide costs stem from the following annual per-acre applications of three pesticides: (1) five pounds of aldrin from 1957 through 1963, (2) 6.5 pounds of thimet from 1964 through 1970, and (3) five pounds of dyfonate from 1971 through 1977.[1] Table A-3 lists the prices[2] of each pesticide, according to its period of use. The pesticide components of C_1 are listed in Table A-2, and are calculated from multiplying the retail prices of each pesticide by its application rate.

The herbicide components of C_1 arise from the use of two herbicides: atrazine and lasso.[3] The annual per-acre atrazine application throughout the 1957-1977 period is 1.5 pounds. The lasso herbicide is used only from 1967 through 1977, at an annual rate of 2.5 pounds per acre. Per-pound atrazine prices are published by the United States Department of Agriculture (89, 1957-1977), hence referred to as the U.S.D.A. The per-pound

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[1] In 1963, aldrin was banned. In 1970, thimet was banned. Information regarding the employed pesticides, their application rates, and use-dates were obtained by private communication from Iowa State University Extension Entomologist, Dr. Harold Stockdale. Ames, Iowa, April, 1978.

[2] The only available pesticide prices are the recommended retail prices obtained from the old invoices through Laverty Sprayers Salesperson, Leo Sterk. Private communication, Indianola, Iowa, April, 1978.

[3] The names, rates of use, and dates of use of atrazine and lasso were obtained by private communication from Iowa State University Extension Botanist, Dr. R. S. Fawcett. Ames, Iowa, April, 1978.

lasso prices were obtained from Sterk.[1] The atrazine and lasso prices, listed in Table A-3, are multiplied by the respective rate of use to get the annual per-acre costs of lasso and atrazine, listed in Table A-2.

Data on the variable machinery costs, another C_1 component, were very difficult to locate. Machinery hire, fuel-oil, repairs, lubrication, and labor must all be found for the following eight machinal operations, used in producing continuous-corn in Lyon County: (1) tandem disk, (2) plow, (3) peg tooth harrow, (4) planter, (5) corn head,[2] (6) grain wagon, (7) bulk fertilizer spreader, and (8) cultivator (47, p. 4).

The Iowa State University Cooperative Extension Service (41, 1971-1977) published such costs for continuous corn over the 1971-1977 period in the annual publication, "Suggested Farm Budgeting Costs and Returns." These figures, listed as general machinery costs in Table A-1, are formulated specifically for Iowa continuous-corn operations, and must be further adjusted for labor and lubrication costs.

Unfortunately, such costs are not available in the above publication prior to 1971. The only available pre-1971 variable machinery costs are obtained from the annual editions of the "Farm Business Summary for Northwest Iowa" (39, 1957-1970). However, these costs are formulated for an "average" Northwest Iowa farm of 260-359 acres, which include some amounts of livestock, soybeans, and pasture enterprises. The 1957-1970 machinery costs must therefore be adjusted for the sort of farm simulated in this study. Therefore, of the four machine variable cost components, machine

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[1]The lasso prices were obtained in a private communication with Leo Sterk, Salesperson, Laverty Sprayers, Indianola, Iowa, April, 1978.

[2]This corn head is the harvesting activity.

hire, fuel, repair, and utilities, Edwards[1] suggests the latter be eliminated. Such an elimination will help subtract out the non-crop machinery costs, since much of the livestock machinery is electrically powered. Therefore, for each year of the 1957-1970 period, the machinery hire, fuel, and machine repair cost components are taken from the annual editions of the "Farm Business Summary for Northwest Iowa" (39) and counted as part of that year's variable per-acre machinery cost. As with the 1971-1977 general variable machinery costs, the adjusted 1957-1970 variable machinery costs, listed also in Table A-1, must be further adjusted for labor and lubrication.

Variable lubrication machinery costs   Machinery costs per acre are adjusted for lubrication by a method developed by Ayers and Boehlje (4, p. 8). Simply calculate 15 percent of a machine's fuel cost to obtain the lubrication portion of the per-acre variable cost of this machine.

Ayers, (3, pp. 1-3) lists the average annual diesel consumption rates in gallon per acre terms. These consumption rates, listed in Table 4, reflect 1978 technology and are treated as constants over the 1957-1977 period. In multiplying a machine's per-acre diesel consumption rate times the prices of diesel fuel published by the U.S.D.A. (89, 1957-1977), times 15 percent, the lubrication costs of that machine are obtained. The per acre lubrication costs for the 1957-1977 are listed by machine in Table A-1.

Variable machinery labor costs   McGrann et al. (47, p. 4) have published the per-acre labor requirement for the eight machines used in

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[1]This adjustment procedure was suggested by Iowa State University Adjunct Instructor, William Edwards. Private communication, Ames, Iowa, May, 1978.

raising continuous corn in the western portion of Northwest Iowa. These labor requirements are listed in Table 4, and they remain constant over the study period because they reflect 1978 technology (47, p. 4). The yearly wage rates for hired farm labor, published by the U.S.D.A. (89, 1957-1977) and listed in Table A-4, are multiplied by a machine's per-acre labor requirement to obtain the 1957-1977 labor costs per acre for that machine. The labor cost components of per-acre machinery variable cost are listed by machine in Table A-1.

Table 4. Machinal per-acre fuel and labor requirements

Machine	Diesel (gallons)	Hours
Tandem disk	1.18	.48
Plow	1.2	.363
Peg tooth harrow	1.6	.09
Planter	1.5	.164
Corn head	1.15	.638
Grain wagon	.2	.34
Continuous plow days	7.5	0
Bulk fert. spr.	.15	.108
Cultivator	.6	.168

Therefore, summing down each annual column of Table A-1 renders the total per-acre variable machinery cost portions of C_1 for 1957-1977. These machinery cost components are listed in Table A-2.

The final C_1 component is the seed cost per acre. The prices per bushel of hybrid seed are published for the 1957-1977 period by the U.S.D.A.

(89, 1957-1977). Assuming .333 bushel of seed per acre is planted,[1] then taking .333 of the bushel price of hybrid corn for the 1957-1977 period renders the acre-cost of seed. These seed components of C_1 are listed in Table A-2.

The total variable costs of producing an acre of continuous-corn are obtained for the 1957-1977 period by summing across all the C_1 components listed in Table A-2. By adjusting these nominal[2] variable costs with the reverse-discount factor, $(1+.09)^t$, then these total variable costs are converted into constant 1978 dollars, and hence the C_1 coefficients are obtained.

Labor hire C_j's: C_2, C_3, C_4 The second, third, and fourth activities are those for hiring an hour of April, May, and October labor, respectively. The C_2, C_3 and C_4 coefficients correspond to the second, third, and fourth activities, respectively. Since each of the three C_j's equals the hourly wage rate[3] for hired labor during any year, then all three coefficients are equal during a year. The wage rates, published by the U.S.D.A. (89, 1957-1977) and listed in Table A-4, are multiplied by the respective $(1+.09)^t$ reverse-discount factor in order to form the C_2, C_3, and C_4 coefficients, listed in Table A-5.

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[1]This rate is revised from the .25 bushel per acre figure published by McGrann et al. (47, p. 4). According to Iowa farmer H. Alan Carver, .333 bushels per acre is more realistic with high-yielding operations. Private communication, Ames, Iowa, June, 1978.

[2]Hence, a cost figure in non-constant dollar terms is referred to as "nominal", whereas "constant dollars" refer to 1978 dollars.

[3]These costs are adjusted with $(1.09)^t$.

<u>Money borrowing C_j:C_5</u> The fifth activity corresponds to borrowing a dollar for production capital. The corresponding C_5 coefficients for the study period are half the annual market interest rates charged by banks times the $(1+.09)^t$ factor.[1] The market interest rates are published by the U.S.D.A. (89, 1957-1977) and are listed in Table A-4.

<u>Corn selling C_j:C_6</u> The sixth activity is that of selling corn, and this represents the only positive C_j in either the rain-fed or irrigated model. For any year, the C_6 coefficient is the bushel price of corn, published by the U.S.D.A. (89, 1957-1977) and listed in Table A-4, multiplied by the respective $(1+.09)^t$.

<u>Irrigation activity C_j's: C_7, C_8, C_9</u> The seventh, eighth, and ninth activities are unique to the irrigation years of the irrigated model.[2] Corresponding to these three activities are C_7, C_8, and C_9. Since an application unit of irrigation water has, for reasons stated below, been defined as the amount needed to apply .25 inches to 266 acres (that is 66.5 acre-inches)[3], then for a year, C_7, C_8, and C_9 equal the constant-dollar cost of applying this unit.

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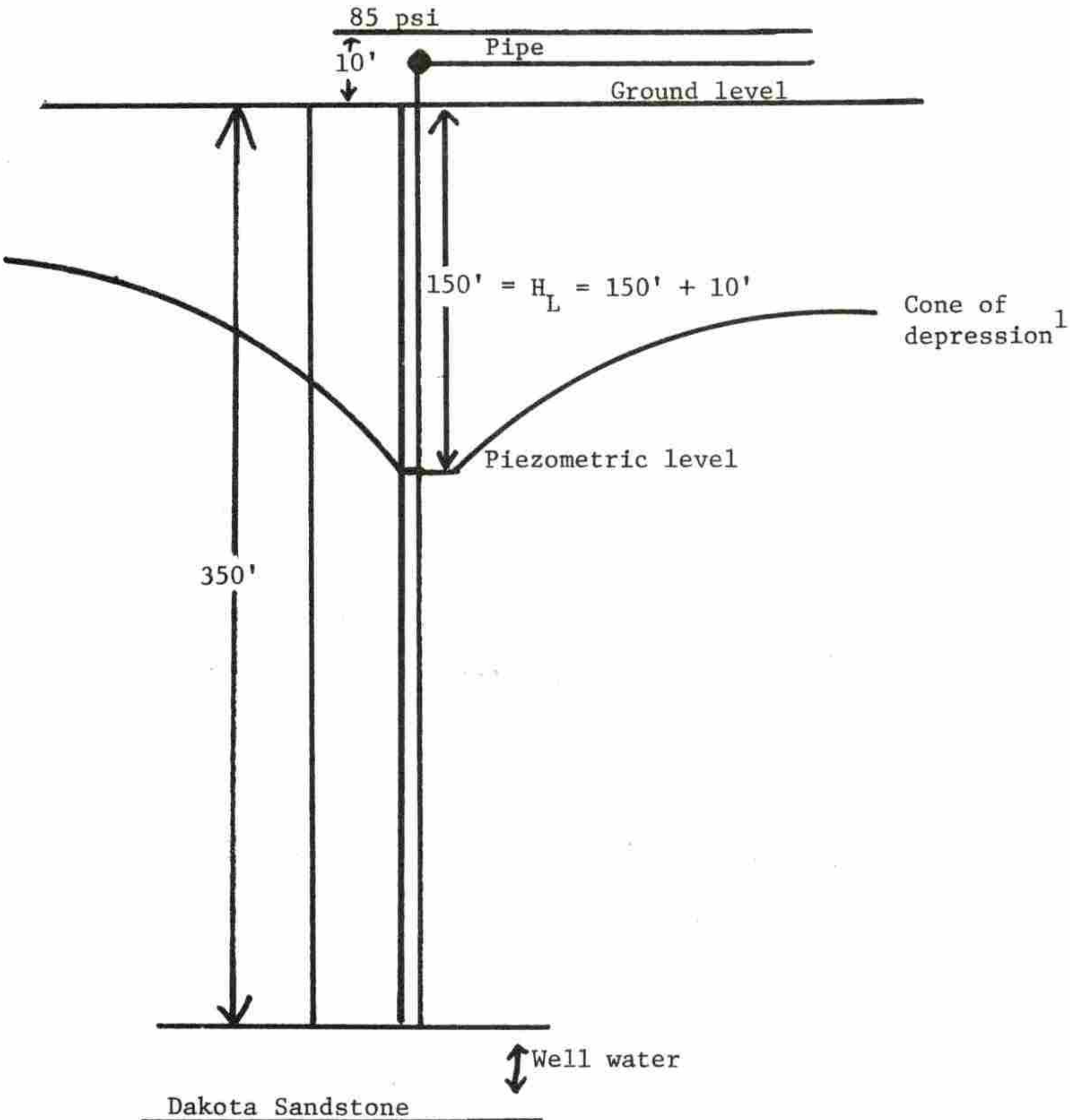
[1]Half of the market rate is taken because production capital is typically borrowed for six months.

[2]Keep in mind that although irrigation was available in the irrigated scenario, the weather was yield beneficial enough so as not to warrant irrigation application in 1957, 1960, 1962, 1969, and 1972.

[3]This unit of application is chosen because according to Sheffield (70, p. 2), the center-pivot system is able to apply as little as .25 inches to a quarter section per application. Given the two center-pivot systems of the simulated farm, and given the 133 acres actually irrigated per quarter section by a single system, then .25 x 266 = 66.5 acre-inches.



[1]This is the water table level down to which the naturally occurring level declines during pumping.

Figure 14. Well scheme.

According to Melvin,[1] irrigating on Lyon County's Moody Association often entails water withdrawal from the Dakota Sandstone aquifer.[2] A reasonable aquifer depth assumption is 350 feet, and the piezometric level,[3] in a pumping well is 150 feet. Given the ten feet of above-ground height to the pivot, the total number of feet that water must be lifted from the piezometric level, that is the lift head of H_L, is 150 + 10 or 160 feet. Assume an 85 pound per square inch, hence p.s.i., pressure maintained at the nozzle by the pump. Also assume a 600 gallon per minute, hence g.p.m., well yield, along with a pump efficiency of .65. Now the variable costs of irrigation water application are derived below.

First total or effective head, H_T, must be determined. In effect, the 85 p.s.i. must be converted to feet of head, H_p, and added to H_L. Thus, $H_T = H_p + H_L$. The p.s.i. conversion to H_p is as follows:

14.7 p.s.i. = 33.87 feet of water at sea level.

Thus, 1 p.s.i. = 2.3 feet of water at sea level.

$H_p = 2.3P$, where P = pressure = 85 p.s.i.

$H_p = 2.3$ (85 p.s.i.) = 195.5 feet

And so: $H_T = H_L + H_p = 160 \text{ feet} + 195.5 \text{ feet} = 355.5 \text{ feet} \cong 356 \text{ feet}$.

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[1] The irrigation setting, summarized in Figure 14, was formulated with the aid of Iowa State University Professor of Agricultural Engineering and Iowa irrigation specialist , Dr. Stewart Melvin. Private communication, Ames, Iowa, May, 1978.

[2] Since 1977, there has been a moratorium on irrigating from the Dakota Sandstone aquifer. However, the period of this study ends before this moratorium was implemented in late-1977.

[3] The piezometric level is the well water level which occurs without pumping.

Now, a flow of cubic feet per second (c.f.s.) terms must be converted into g.p.m.:

$$\frac{1\ \text{foot}^3}{\text{second}} \times \frac{60\ \text{seconds}}{\text{minutes}} \times \frac{60\ \text{minutes}}{\text{hour}} \times \frac{24\ \text{hours}}{\text{day}} = \frac{86{,}400\ \text{feet}^3}{\text{day}}$$

$$1\ \text{acre-foot} = 43560\ \text{feet}^2 \times \text{feet} = 43560\ \text{feet}^3$$

Thus: 1 c.f.s.-day = 1.98 acre-feet

and $$1\ \text{c.f.s.-day} \times \frac{24\ \text{hours}}{\text{day}} = 1.98\ \text{acre-feet} \times \frac{12\ \text{inches}}{\text{foot}}$$

24 c.f.s.-hours = 24 acre-inches

and so: 1 c.f.s. = 450 g.p.m.

Given the 600 g.p.m. well yield, the number of acre-inches of irrigation water reaped from the well every hour is:

$$\frac{\text{acre-inches}}{\text{hour}} = \frac{\text{g.p.m.}}{450} \times \frac{600}{450} \times \frac{1.33\ \text{acre-inches}}{\text{hour}}$$

Therefore, pumping one hour from the hypothesized well setting will deliver 1.33 acre-inches of irrigation water.

Since according to Sheffield (70, pp. 2-3), well over 95 percent of a center-pivot's variable costs are fuel costs, and since labor costs are negligible, then total variable costs of a center-pivot system are assumed entirely comprised of diesel fuel costs.

Therefore, fuel costs of two center-pivot systems are determined by calculating the fuel requirement per unit of irrigation water application, 66.5 acre-inches, and multiplying the fuel usage by diesel prices.

To determine the fuel use of two center pivot systems applying .25 inches of water simultaneously to the respective quarter-section of each, required water horse-power (w.h.p.) of each pump motor must be derived:

$\text{w.h.p.} = \frac{\text{g.p.m.} \times H_T}{3960}$ where the denominator is a conversion term. Thus, w.h.p. = $\frac{600 \text{ gpm} \times 356 \text{ feet}}{3960}$. Now brake horse power (b.h.p.) is calculated:

$$\text{b.h.p.} = \frac{\text{w.h.p.}}{\text{P.E.}} = \frac{600 \text{ g.p.m.} \times 356 \text{ feet}}{3960 \times .65}$$

, where P.E. equals the .65 pump efficiency. So b.h.p. equals 82.98 or roughly 83 h.p., where h.p. refers to horse power. For diesel, there are 14 horse-power-hours per gallon, and so:

$$\frac{83 \text{ h.p.}}{14 \text{ h.p.-hours/gal.}} = 5.9 \text{ gallons of diesel consumed hourly.}$$

Therefore, the fuel use for applying 66.5 acre-inches of irrigation water is calculated.[1] $66.5 \text{ acre-inches } \frac{\text{hour}}{1.33 \text{ acre-inches}} \times \frac{5.9 \text{ gallons}}{\text{hour}} =$ 295 gallons per applied unit of irrigated water. Multiplying this 295 gallons by the 1957-1977 diesel prices renders the nominal variable costs of Q07-K, Q08-K, and Q09-K. These costs, when adjusted with $(1+.09)^t$, become the C_7, C_8, and C_9 coefficients.

Resource-use coefficients, A_{ij}'s

The A_{ij}'s are derived below by rows. Thus, the A_{1j}'s, A_{2j}'s, ..., $A_{17,j}$'s are derived in that order.

Land-use coefficient: A_{11} In a yearly program, one A_{ij} exists for the first row of land use: A_{11}. Each acre planted with corn exhausts one of the limited number of acres of Moody land. Hence for all years and in both models, A_{11} equals 1.0.

November labor-use coefficient: A_{21} The second row in any yearly program corresponds to the use of November labor. This row has one A_{ij},

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[1]Therefore, this fuel use would be equivalent to 2 pumps, each of 83 h.p., pumping from a separate well onto 133 acres. Therefore, 33.25 acre-inches times 2 separate irrigation pumps equal 66.5 acre-inches. Each pump is consuming 147.5 gallons of diesel hourly, 295 gallons in unison.

A_{21}, corresponding to a yearly program's first activity, corn production. McGrann et al. (47, p. 4) have determined an acre of continuous corn in western Northwest Iowa to require .228 hours of November labor every year. Since the first activity of a year consumes this amount of November labor, then A_{21} equals .228, a positive coefficient. This November labor-use reflects 1978 technology and remains unchanged over the study period.

April labor-use coefficients: A_{31}, A_{32} Two April labor-use coefficients exist during any year for both models: A_{31} and A_{32}.

The A_{31} This coefficient represents the per-acre April labor requirement of producing corn during a year. McGrann et al. (47, p. 4) calculate A_{31} as equalling .363 hours per acre per year. Because this coefficient reflects 1978 technology, it remains unchanged over the study period.

The A_{32} This A_{ij} is the April labor-use coefficient corresponding to the second activity during a year, that of hiring April labor. Since one unit of P02-K or Q02-K adds an hour to the year's limited stock of April labor, then A_{32} equals -1. for any year and in both models.

May labor-use coefficients: A_{41}, A_{42}, A_{43} During any year there exists two A_{ij}'s corresponding to the fourth row, that of May labor-use.

The A_{41} Corresponding to a year's first activity, A_{41} represents the acre-requirement of May labor for producing corn. Each acre of a western Northwestern Iowa continuous-corn crop requires .614 hours per year of May labor (47, p. 4). Thus, A_{41} equals .614 hours, which remains unchanged because of its reflection of 1978 technology.

The A_{43} The third activity of a yearly program hires May labor, and the May labor A_{ij} corresponding thereto is A_{43}. Since one unit

P03-K or Q03-K adds to a year's limited May labor supply, then A_{43} equals -1. any year, and for both models.

June labor-use coefficient: A_{51} Only one A_{ij} exists during any year for the fifth row of June labor-use. This A_{ij}, A_{51}, represents the per-acre June labor requirement of producing corn, and is calculated as .168 hours per acre per year (47, p. 4). This A_{51} reflects 1978 technology and hence remains unchanged over the study period.

September labor-use coefficient: A_{61} One A_{ij} exists during any year for the sixth row of September labor-use. This A_{ij}, A_{61}, represents the per-acre June labor requirement of producing corn, and is calculated as .101 hours per acre per year (47, p. 4). Reflecting 1978 technology, this A_{61} remains unchanged throughout the study.

October labor-use coefficients: A_{71}, A_{74} The seventh row in a yearly program, that of October labor-use, contains two A_{ij}'s: A_{71} and A_{74}.

The A_{71} This coefficient represents the per-acre October labor requirement of corn production. This A_{71} equals .978 hours per acre per year and, since it reflects 1978 technology, it remains unchanged throughout the study (47, p. 4).

The A_{74} Corresponding to the fourth October labor hiring activity of a yearly program is A_{74}. Since one unit of P04-K or Q04-K adds to year K's October labor supply, then A_{71} equals -1.

Production capital-use coefficients: $A_{81}, A_{82}, A_{83}, A_{84}, A_{85}, A_{87}, A_{88}, A_{89}$ Five of a yearly program's six activities exhaust production capital and hence carry a negative sign. As seen below, only the A_{85} production capital-use coefficient carries a positive sign. The eighth row in each yearly program is that corresponding to the use of production capital.

The A_{81} This is the A_{8j} reflecting the production capital requirements of a P01-K or Q01-K unit. These are the C_1 coefficients divided by $(1+.09)^t$, that is the nominal variable per acre corn-production costs, previously derived and listed in Table A-2. The A_{81} varies with input prices over the 1957-1977 period.

The A_{82}, A_{83}, and A_{84} The second, third, and fourth activities in each yearly program of both models are those of hiring labor in April, May, and October, respectively. During any year, A_{82}, A_{83}, and A_{84} all equal that year's wage rate for hired labor. These yearly wage rates, listed in Table A-4, are published by the U.S.D.A. (89, 1957-1977).

The A_{85} Borrowing a dollar from the bank as production capital, the fifth activity in a program, adds to the limited stock of production capital resources available to the farmer. Thus, A_{51} equals -1.

The A_{87}, A_{88}, A_{89} These three production capital-use coefficients are unique to the irrigation year programs of the irrigated model. The three coefficients correspond to Q07-K, Q08-K, and Q09-K, respectively. All three activities are defined in terms of 66.5 acre-inch application units, and thus during any year, K, A_{87}, A_{88}, and A_{89} equal the variable costs of applying 66.5 acre-inches of water, in year K dollars. Thus, these coefficients, derived above in the C_7 section, are the C_7's before the $(1+.09)^t$ adjustment.

Credit limit coefficient: A_{95} Each year, the farmer faces a limit on his production capital borrowings,[1] represented by row 9 of a yearly

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[1] These b_9 coefficients are derived in the resource-constraint section of this chapter.

program. Corresponding to this row is one A_{ij}, A_{95}. The A_{95} reflects the effect of one unit of P05-K or Q05-K upon b_9 during year K. Since a unit of this fifth activity exhausts one unit of b_9, the limited stock of production lendable to the farmer, then for any year, A_{95} equals 1.

Hired labor-use coefficients: $A_{10,2}$, $A_{11,3}$, $A_{12,4}$ The farmer is assumed willing to hire limited amounts of labor during April, May, and October of a year. The second, third, and fourth activities in each annual program are those for hiring April, May, and October labor, respectively. Corresponding to activity 2 is $A_{10,2}$, to the third activity, $A_{11,3}$, and to the fourth activity, $A_{12,4}$. Likewise, $A_{10,2}$ corresponds to the hired April labor limit or row 10, $A_{11,3}$ to the hired May labor limit or row 11, and $A_{12,4}$, to the hired October labor limit or row 12.

Thus, $A_{10,2}$, $A_{11,3}$, and $A_{12,4}$ are all positive 1, since a unit of the respective activity of each uses one unit of the respective constraint.

Corn accounting row coefficients: $A_{13,1}$, $A_{13,6}$, $A_{13,7}$, $A_{13,8}$, $A_{13,9}$ In both models, row 13 in a yearly program represents a corn accounting row into which product is stored and out of which product is sold.

The $A_{13,1}$ This A_{ij} corresponds to the corn production activity. Hence, $A_{13,1}$ represents the negative of the rain-fed yields adjusted for 1978 technology. The yields, recorded by the Doon Farm Staff (49), are listed in Table 1.

The $A_{13,1}$ coefficients carry negative signs because they add corn to the thirteenth row (11, p. 40).

The $A_{13,6}$ $A_{13,6}$ is 1, since each unit implemented of the sixth activity subtracts a bushel of corn from row 13.

The $A_{13,7}$, $A_{13,8}$, and $A_{13,9}$ The three irrigation activities are formulated with respect to the three productivity assumptions stated in Chapter 3. The $A_{13,7}$, $A_{13,8}$, and $A_{13,9}$ demonstrate the number of bushels produced by an irrigation application unit of 66.5 acre-inches and correspond to the three irrigation activities, Q07-K, Q08-K, and Q09-K, respectively. All three A_{ij}'s, although not equal to each other during a year, are similarly derived. Hence, only the derivation procedure of $A_{13,7}$ is shown below.

Since Q07-K is defined as 50 percent of the year's total recommended application bringing about 65 percent of the bushel response, then first calculate half the total application and 65 percent of the total bushel response for some year, K. Then divide the 65 percent of the total response by the number of 66.5 acre-inch application units obtainable from half the total application. The quotient renders the bushel response to each 66.5 acre-inch application applied to 266 acres.

The total recommended applications are listed in Table 5, along with the total bushel responses of corn yields to the total applications.

The total recommended irrigation application amounts were calculated with a water-budgeting method developed specifically for the model application site of this study by Ross.[1] According to Shaw,[2] these estimates are the best available, in that they represent accurate soil moisture

[1]These applications were obtained in a private communication with former Doon Experimental Farm Superintendent Kenneth Ross. Ames, Iowa, March, 1978.

[2]This opinion was stated in a private communication with Iowa State Agronomist and Agricultural Climatologist, R. H. Shaw. Ames, Iowa, February, 1978.

Table 5. Total seasonal irrigation applications and yield responses

Year	Applic.[a]	Total acre-in.[b]	Ac. res.[c]	Total res.[d]
1957	0	0	0	0
1958	7.75	2061.5	61.2	16279.2
1959	4.	1064.	33.2	8831.2
1960	0	0	0	0
1961	2.	532.	17.3	4601.8
1962	0	0	0	0
1963	9.5	2527.	58.9	15667.4
1964	2.	0	22.5	5985.
1965	2.	532.	12.9	3431.4
1966	5.	1330.	37.2	9895.2
1967	8.	2128.	61.9	16465.4
1968	10.	2660.	129.6	34473.6
1969	0	0	0	0
1970	9.5	2527.	88.3	23487.8
1971	3.5	931.	44.6	11863.6
1972	0	0	0	0
1973	3.	798.	19.3	5133.8
1974	5.5	1463.	29.2	7767.2
1975	3.	798.	28.3	7527.8
1976	17.2	4575.2	63.8	16970.8
1977	3.5	931.	19.7	5240.2

[a]These data are inches applied per acre.

[b]These are the figures in column 2 times 266 acres, i.e., the total number of acre-inches.

[c]These data are the bushels per acre corn yield response to irrigation.

[d]These data are the bushel yields in column 4 multiplied by the 266 irrigated acres. These figures are in bushel terms.

shortages calculated from a crop's water requirements versus the precipitation realized during the season.

In short, Ross budgets the soil moisture actually present during April, May, June, July, and August of a season against the crop's requirements during these same months. The water deficits are taken as amounts of water to be applied. These deficits are further adjusted for such factors as number of days over 90°, and the date of silking.

The total recommended applications, listed in Table 5, represent minimum amounts of water required to offset soil-moisture stress. Hence, they are minimum figures required to prevent stress-induced corn yield reductions. Actual applications will probably exceed the estimates in Table 5. However, given the fact that the technique for estimating the applications was developed for the very site of this study, and since the water requirements of the corn season months are accurate longterm (1930-1970) averages, then these estimated applications are the most reliable available, given the unavailability of such data recorded by northwest Iowa irrigators.

It should also be noted that since these total recommended applications are those deterring yield-reducing soil moisture stress, and hence stress-induced yield reductions, then these applications are the minimal amounts conceivably needed to maximize yields. Therefore, not until <u>after</u> the last inch of a total application has been applied does the marginal product of water conceivably level off to zero and eventually turn negative. This is the reason for assuming a positive marginal product even for the last 20 percent of a year's total application.

Resource constraints, b_i's

There are 13 resource constraints faced annually by the rain-fed farmer, thereby accounting for 13 x 21 or 273 constraints of the entire 21-year rain-fed model. For the irrigated model, there are 14 constraints faced by the farmer during each of the five non-irrigation years and 17 constraints during each of the irrigation years. Thus there are 342 resource constraints in the entire irrigated model.

The first 13 rows of a yearly program are identically defined for both scenarios. These 13 b_i's are first derived. The last four b_i's are unique to the irrigated model and are the last derived.

The land constraint: b_1 Both farm scenarios are comprised of 320 cultivated acres. Hence, b_1 equals 320 acres in both models and over the entire study period.

Family labor constraints: b_2, b_3, b_4, b_5, b_6, b_7 The family is assumed, in both models, so endowed with children that the farmer has at his disposal the parttime labor of a high-school aged son, in addition to his own 40 hours per week.

November labor constraint, b_2 During November, the per-acre labor requirements of raising continuous-corn is a moderate .228 hours (47, p. 4). With the son's 10 weekly hours and the farmer's 40 hours/week, the b_2 is assumed 200 hours for all years.

April labor constraint, b_3 The per-acre labor requirements of continuous-corn for April, .363 hours, exceeds that of November (47, p. 4). Therefore, the son is expected to work 15 hours, weekly. Together with the full time labor of the farmer, the b_3 equals 220 hours for all years and in both models.

Labor constraints for May (b_4), June (b_5), September (b_6), and October (b_7) During these months, either days are longer and/or the son is off from school part of the month. Thus, the son is assumed able to work 80 hours in each of these months. Available in May, June, September and October are the 160 hours of the farmer and the son's 80 hours. Therefore, b_4, b_5, b_6, and b_7 all equal 240 hours during any year.

Production capital constraint, b_8 The b_8 coefficient represents the limited amount of the farmer's financial resources used in meeting production expenses.[1] The amounts of his own resources a farmer uses for meeting production expenses of a given year were found unavailable in a review of Iowa irrigation literature. Such a data unavailability was further acknowledged by the State Bank of Rock Rapids.[2] Therefore, a "rule of thumb" must be used to formulate the amount of money a farmer has of his own during a year to meet production expenses. According to Panagides,[3] such an estimate would be 25 percent of a year's total farm value product.

For the rain-fed farm, simply multiply the acre-yields, listed in Table 1, times 320 acres times the price of corn, listed in Table A-4, times .25 to obtain the rain-fed model b_8 coefficients for the 1957-1977 period.

For the irrigated model, first multiply the rain-fed yields times the

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[1] Such financial resources are considered production capital.

[2] The Loan Department of the State Bank of Rock Rapids rendered this information in a private communication. Rock Rapids, Iowa, May, 1978.

[3] This information was obtained from Dafnis S. Panagides, a student of agricultural credit and capital accumulation at Iowa State University. Private communication, Ames, Iowa, May, 1978.

54 rain-fed acres times the price of corn times .25. Then multiply the irrigated yields in Table 1 times 266 irrigated acres times the corn prices times .25. The b_8 coefficients of the irrigated model are obtained for the 1957-1977 period by adding together these two products.

Credit limit, b_9 The b_9 coefficient represents the credit limit faced by the farmer during a year on the amount he may borrow as production capital. These data are not available, since a year's b_9 varies between a farmer's consumption functions, risk aversion attributes, etc.

However, a reasonably accurate estimate as to the amount of money a bank will lend, as production capital, to a farmer is two-thirds (.666) of the estimated value product of the corn produced that year.[1]

Therefore, for each scenario, calculate the value product of that year's corn crop. The b_9 is then derived identically as b_8, but instead of taking .25 of the total value product, take .666 of it.

Hired labor constraints: b_{10}, b_{11}, b_{12} The farmer is assumed willing to hire 100 hours per month of non-family labor for the months of April, May, and October. Thus, the hired April labor limit (b_{10}), the hired May labor limit (b_{11}), and the hired October labor limit (b_{12}) equal 100 hours for both models during all years.

Corn accounting row constraint, b_{13} The b_{10} equals zero to ensure that all corn produced is sold.

Minimum acreage constraint, b_{17} For reasons cited earlier, b_{14} equals 266 acres for all the irrigation model's yearly programs.

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[1]This information regarding the estimation of the b_9 coefficients was obtained in a private communication with the Loan Department at the State Bank of Rock Rapids, Iowa. Rock Rapids, Iowa, April, 1978.

Water limits: b_{14}, b_{15}, b_{16} The b_{14} coefficients are half of the total recommended irrigation applications listed in Table 5.

The b_{15} coefficients are 30 percent of the total recommended irrigation applications.

The b_{16} coefficients are 20 percent of the total recommended applications.

Appendix C has listed all b_i coefficients.

Fixed Costs

There are eight classes of fixed cost data required of this study, the first seven of which are common to both the rain-fed and irrigated models, and the last of which is unique to the irrigated model: (1) living expenses, (2) depreciation, (3) insurance, (4) interest paid, (5) building repairs, (6) property taxes, (7) income taxes, and (8) irrigation's fixed costs.

Living expenses

This study deals with economic profit, rather than accounting profit. Therefore, an opportunity cost must be figured in for the farm family workers of the next-best forgone income or salary. The capture of this opportunity cost is attempted through subtracting out a charge for the farm family's labor. These farm family labor charges in Table D-1 are published by the Iowa State University Cooperative Extension Service (39, 1957-1977) for an average Northwest Iowa Farm. Due to the wide differentials between the consumption patterns of individuals, these average figures are used simply as "ballpark" estimates.

Depreciation

Depreciation machinery charges accrue each year to a farm. The straight-line depreciation formula, recommended by Ayers and Boehlje (4, p. 2)[1] was not employable here, since viable original cost estimates for 1978-quality machinery were not located in a review of such literature.

Therefore, average estimates are used. The 1971-1977 annual editions of "Suggested Farm Budgeting Costs and Returns" (41, 1971-1977) listed machinery depreciation costs for Iowa continuous-corn operations, and these estimates are listed for these years as "depreciation" in Table D-1.

The best estimates for machinal depreciation costs prior to 1971 were located in the 1957-1970 editions of another Iowa State University Cooperative Extension Service publication (39). These costs are published for the average Northwest Iowa farm of 260-359 acres, and are listed in Table D-1.

Insurance

Most Iowa farmers insure equipment, along with insuring against such disasters as death and hail. Therefore, a bulk insurance fixed cost component, identical for both models,[2] is subtracted from each yearly income. These estimates, listed in Table D-1, are published for the average Northwest Iowa farm of 260 to 359 acres by the Iowa State University Cooperative Extension Service (39, 1957-1977).

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[1]This formula is $D = \frac{O.C.-S.V.}{Y}$. where D refers to annual depreciation, O.C. to the machine's original cost, s.v. to the machine's salvage value, and Y to the machine's period of use or economic life.

[2]The insurance on the center-pivot systems is included in the irrigation fixed cost component, hence discussed.

Interest paid

Most farmers owe money due to liens on equipment, capital, or the farm itself. These fixed costs vary greatly among Iowa farmers. Hence, the average interest-paid estimates published by the Iowa State University Cooperative Extension Service (39, 1957-1977) are used. These fixed interest costs[1] are listed in Table D-1.

Building repairs

Farmers must repair building damage caused each year by weather, accidents, etc. These fixed costs are estimated for Northwest Iowa farmers each year by the Iowa State Cooperative Extension Service (39, 1957-1977) and are listed in Table D-1. These estimates are assumed identical for both models.[2]

Property taxes

Property taxes for the sort of farm hypothesized in this study were not available from either the Lyon County Assessor's office or from the Lyon County Treasurer's office.[3] Therefore, the property tax estimates of the average Northwest Iowa farm of 260 to 359 acres, published by the

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[1]Interest charges upon irrigation equipment are included in the irrigation fixed costs hence discussed. Hence, the interest paid costs, discussed above, are identical each year for both production scenarios.

[2]The main repair cost difference between the two production scenarios lies with repairs made on irrigation equipment. These irrigation-related repair costs are incorporated in the irrigation-fixed cost component, discussed hence.

[3]In two private communications, either this information was unavailable or the personnel refused to take the time to either retrieve it or enable one to travel to Rock Rapids to retrieve it. Rock Rapids, Iowa, May, 1978.

Iowa State University Cooperative Extension Service (39, 1957-1977) are used. They are listed in Table D-1.

Income tax

Rain-fed model The federal income tax rates used in this study are published by the U.S. Department of Commerce (93, p. 1111-1112) and are listed in Table 6.

The next step in income tax calculation is to derive the nominal yearly taxable incomes.[1] The incomes net of variable costs and adjusted into constant 1978 dollar terms with the reverse-discount rate are obtained from the computer output of the rain-fed linear program. Hence referred to as "constant dollar incomes," these 1978-termed incomes are listed in Table 6. The nominal incomes, the constant-dollar incomes divided by the respective $(1+.09)^t$ terms, are also listed in Table 6.

Then the nominal taxable incomes are calculated. From the nominal incomes, listed in Table 6 and already net of rain-fed variable production costs, the fixed cost components are subtracted. These fixed costs, summed into a "total deductions" column in Table 6, include the following which are already derived and listed in Table D-1: (1) depreciation, (2) insurance fees, (3) interest paid, (4) building repairs, and (5) property taxes.

The rain-fed income taxes are also listed in Table 6.

Irrigated model The income taxes on irrigated incomes are derived in the same way as those of the rain-fed scenario above. However, there

[1]The income tax rates must be multiplied by the incomes in terms of the dollars of the year during which each was generated. Hence, the "nominal" incomes are defined as such.

Table 6. Calculation of income taxes: the rain-fed model

Year	Total deduc.	Constant-dollar incomes	Nominal incomes	Nominal taxable incomes	Income tax rates	Income tax
1957	3529	160566	26284	22755	.240	5457.
1958	4007	38320	6838	2831	.04	113.
1959	4180	51499	10015	5835	.117	685.
1960	3197	142767	30266	27069	.262	7079.
1961	5445	158381	36594	31149	.282	8784.
1962	5085.2	165121	41592	36509	.309	11296.
1963	5098.2	75022	20599	15501	.219	3401.
1964	5492	116815	34954	29462	.244	7192.
1965	7491.2	94889	30949	23458	.201	4713.
1966	6687.6	56570	20110	13423	.151	2030.
1967	7381.6	3852	1493	-5889	0	0
1968	8154.6	0	0	-8155	0	0
1969	8854.6	15953	7345	-1510	0	0
1970	10725	4748	2382	-8343	0	0
1971	10705	37923	20746	10001	.132	1320.
1972	12547	57669	34400	21853	.198	4316.
1973	15082	147561	95881	80799	.40	32352.
1974	15254	40732	28847	13593	.154	2097.
1975	19341	52047	40191	20850	.190	3955.
1976	18378	47.	39.	-18339	0	0
1977	20020	37225	34151	14131	.158	2232.

are two differences: (1) different tax rates due to different income levels and (2) an irrigation fixed cost component. Table 7 summarizes the irrigated income taxes.

The different income levels are obtained from the computer output of the irrigated model's linear program. The tax rates are published by the U.S. Department of Commerce (93, pp. 1111-1112). The fixed costs of irrigation, listed in nominal terms, are listed in Table 6 and are derived later in this chapter.

Subtract the sum of the total deductions and irrigation fixed costs from the nominal taxable incomes to obtain Table 6's income tax charges for the 1957-1977 period.

<u>Irrigation-related fixed costs</u>

According to the Iowa State University Cooperative Extension Service (38, p. 1), there are 5 fixed cost components of center-pivot irrigation (1) well depreciation, (2) pump depreciation, (3) gearhead depreciation, (4) center-pivot depreciation, and (5) financial costs of center-pivot investment.

The example of Sheffield (71, p. 14) is used, where the straight-line depreciation under the assumption of zero salvage value is used to calculate the depreciation estimates of all four irrigation components.

Two problems arise in estimating fixed costs of irrigation-related depreciation over the 1957-1977 period. First is the unavailability of data regarding the purchase price of drilling a well, and of purchasing a pump, gearhead, and center-pivot system in 1957, the year during which

Table 7. Calculation of income taxes: the irrigated model

Year	Total deduc.	Nominal irr. f.c.	Constant dollar incomes	Nominal incomes	Nominal taxable incomes	Income tax rates	Income tax
1957	3529	3418	160038	26197	19250	.337	6487
1958	4007	4884	144749	25830	16938	.316	5352
1959	4180	5460	74716	14531	4891	.185	905
1960	3159	5476	142767	30266	21632	.362	7831
1961	5445	5474	178657	41729	30360	.421	12782
1962	5083	5476	165121	41592	31033	.425	13189
1963	5098	5480	126515	34738	24160	.384	9277
1964	5492	4984	138405	41414	30938	.379	11722
1965	7491	5520	105230	34322	21311	.359	7651
1966	6687	5588	84768	30134	17859	.269	4804
1967	7382	5664	52646	20405	7360	.179	1317
1968	8155	5740	59264	25038	11295	.23	2597
1969	8855	5816	90092	41479	26808	.365	9785
1970	10725	5932	62690	31455	14798	.251	3714
1971	10705	6028	60303	32989	16255	.264	4291
1972	12547	6086	57667	34387	15844	.26	4119
1973	15082	6174	164108	106633	85377	.532	45420
1974	15254	6590	90191	63875	42094	.536	22562
1975	19341	7108	74003	57145	30697	.48	14735
1976	18378	7332	22055	18565	0	0	0
1977	20020	7900	9567	8777	0	0	0

the farmer is assumed to have begun irrigating. In addition, even if these initial prices were available, the assumption of 1978 technology having prevailed throughout the 1957-1977 period would undoubtedly render the depreciation cost estimate inaccuracy. This is so because since 1957, the center-pivot mechanism has been greatly improved and modified (79, pp. 94-95). Hence depreciation estimates derived from 1957 purchase prices would not reflect the more advanced 1978 technology and engineering improvements innate in a 1978 center-pivot mechanism and components.

Therefore, a price index is used to discount the price of a 1978 system back into the dollar terms of former years. These discounted 1978 prices of a gearhead, pump, well, and center-pivot system are then assumed to equal what a 1978 version of these components would have cost, had such versions been possible to produce during the years 1957-1977. These discounted prices are assumed to incorporate the value of the 1978 technological, mechanical, and quality attributes of the latest 1978 center-pivot irrigation equipment.

As advised by Starleaf,[1] the rate at which the 1978 irrigation equipment prices are discounted into past annual terms is the wholesale price index for machinery and equipment, published by Carter (17, pp. 261-262).

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[1]Iowa State University Economist Dr. Dennis Starleaf suggested this rate as one of the best rates to discount 1978 equipment back into past annual terms. Private communication, Ames, Iowa, June, 1978.

component into the dollar terms of a past year involves three steps. First, noting the base year to be 1967, choose a year into whose dollar terms the 1978 price is to be discounted, say 1960. Take the price of the good in 1978, P_{78}, and divide it by the index for 1967, i_{67}, to convert the P_{78} into 1967 terms. Then take i_{60} and multiply it times $\frac{P_{78}}{i_{67}}$, to obtain what the P_{78} would have been in 1960.

The above method is used on the 1978 models of a well, pump, gearhead, and center-pivot mechanism.

Well depreciation A well costs approximately 30 dollars per foot to drill and equip (41, p. 9). Given the 350 foot depth of this study's well, the total cost of such a well is $10,500. Put into 1967 dollars, this P_{78} equals $5211. The index values are multiplied times $5211 to obtain the various annual prices of the 1978 well. The index values and yearly price equivalents are listed in Table 8.

The depreciation costs per-year are calculated using the straight-line depreciation method (no salvage value) and equals the 1957[1] equivalent of the 1978 price divided by the well's economic life of 25 years (41, p. 9). Therefore, $\frac{\$4565}{25 \text{ yrs.}}$ or $183 per year equals the annual well depreciation costs over the study period.[2]

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[1]The well is assumed drilled in 1957.

[2]A constant $183 per year cost is used rather than dividing each year's 1978 well price equivalent by 25 years. This latter approach at first appears to discount for inflation. However, in taking $183 out of every year's income and depositing it in an interest-earning venture, perhaps a bank account, the $183 accrues interest. Hence, indexing for inflation is not needed. Although the interest does not exactly offset inflation, the method used in this study is, according to Samuelson (61, p. 124) "...like an imperfect watch, ... better than none at all." Depreciation methods are but rough cost estimates (61, p. 124).

Table 8. Irrigated-related depreciation.[a]

Year	Index[b]	67,78 well[c]	78 eq well[d]	well dep.[e]	67,78 pump[f]	78 eq pump[g]	Pump dep.[h]	67,78 g.hd.[i]	78 eq g.hd.[j]	G.hd. dep.[k]	67,78 c-p[l]	78 eq c-p[m]	c-p dep.[n]	67,78 f.c.[o]	78 eq f.c.[p]
1957	87.6		4565	183		4625	385		3174	265		14655	698		1030
1958	89.4		4659	183		4720	385		3239	265		14956	698		1051
1959	91.3		4758	183		4821	385		3308	265		15244	698		1074
1960	92.		4794	183		4858	385		3333	265		15391	698		1082
1961	91.9		4789	183		4852	385		3330	265		15374	698		1081
1962	92.		4794	183		4858	385		3333	265		15391	698		1082
1963	92.2		4805	183		4868	385		3340	265		15424	698		1084
1964	92.8		4836	183		4900	385		3362	265		15525	698		1091
1965	93.9		4893	183		4958	385		3402	265		15709	698		1104
1966	96.8		5044	183		5111	385		3507	265		16194	698		1138
1967	100.	5211	5211	183	5280	5280	385	3623	3623	265	16729	16729	698	1176	1176
1968	103.2		5378	183		5449	385		3739	265		17264	698		1214
1969	106.5		5550	183		5623	469		3858	302		17816	698		1252
1970	111.4		5805	183		5882	469		4036	302		18366	698		1310
1971	115.5		6019	183		6098	469		4185	302		19322	698		1358
1972	117.9		6144	183		6225	469		4272	302		19723	698		1387
1973	121.7		6342	183		6426	469		4409	302		20539	698		1431
1974	139.4		7264	183		7360	469		5050	302		23320	698		1639
1975	161.4		8411	183		8522	469		5848	302		27001	698		1898
1976	170.9		8906	183		9024	469		6191	302		28590	698		2010
1977	195.1		10167	183		10301	469		7088	302		32638	698		2294
1978	201.5	10500			10369			7300			33708			2369	

[a]This depreciation charge is on an annual basis.

[b]These are the machinery and equipment wholesale price indices where 1967 is the base year.

[c]These are the 1978 well price and the 1967 dollar equivalent thereof.

[d]These entries are the nominal yearly dollar equivalents of the 1978 well price.

[e]These are the annual depreciation charges for a single well.

[f]This column contains the 1978 pump price and the 1967 equivalent thereof.

[g]These are the 1978 pump price and the 1967 dollar equivalent thereof.

[h]These are the nominal yearly dollar equivalents of the 1978 pump price.

[i]These entries are the annual depreciation charges per pump.

[j]These entries are the 1978 gearhead price and the 1967 dollar equivalent thereof.

[k]These entries are the nominal yearly dollar equivalents of a 1978 gearhead price.

[l]These are the annual depreciation charges for a gearhead.

[m]These entries are the 1978 price of the center-pivot system and the 1967 price equivalent.

[n]These are the nominal yearly dollar equivalents of the 1978 price for a center-pivot system.

[o]These are the 1978 levels of financial costs related to irrigation investment and its 1967 dollar equivalent.

[p]These are the yearly financial charges related to irrigation.

Pump depreciation The cost of a new 1978 model pump is estimated in the vicinity of $10,639 (41, p. 9). P_{78} in 1967 terms equals $5280, as noted in Table 8. The products of $5280 and the various yearly index values render the yearly 1978 pump price equivalents listed in Table 8.

Over the 1957-1977 period, two pumps must be purchased, one in 1957 and the other in 1969, given the 12 to 13 year life of a diesel-powered well pump (41, p. 9).

The 1957-1968 depreciation costs equal the 1957 equivalent of the 1978 pump price, $4625, divided by 12 years. Thus, these costs each equal $385 yearly, and are listed in Table 8.

The 1969-1977 costs are calculated from the 1969 price equivalent, the year during which the second pump is purchased. Thus, the yearly post-1968 pump depreciation costs each equal $\frac{\$5623}{12 \text{ yrs.}}$ or $469 annually, as seen by Table 8.

Gearhead depreciation A gearhead's life is also from 12 to 13 years (41, p. 9). Therefore, the 1978 price equivalent for a gearhead is divided by 12 years to obtain the $265 per year depreciation costs over the 1957-1968 period. A new charge accrues with the second gearhead purchase in 1969: $\frac{\$3623}{12 \text{ yrs.}}$ or $322 yearly, as seen in Table 8.

Center-pivot system depreciation The 1978 price for a center-pivot system fit to irrigate a quarter-section is $33780 (41, p. 9). Its life is 18 to 20 years, assumed 21 years here.[1]

[1] This assumption is reasonable since the years 1957-1973 fall within a period whose weather patterns were, according to Thompson et al. (23, p. 1) unusually yield-favorable. Since the center-pivot system was used less, another year is assumed to the system's life.

The 1957 price equivalent of the 1978 center-pivot system is calculated as \$14655, and hence the annual depreciation charges are \$685 over the 1957-1977 period. These depreciation charges are listed in Table 8.

Financial fixed costs of irrigation The fifth and final component of irrigation-related fixed costs are the financial costs of depreciation, taxes, and interest charges on a center-pivot system.

The same 1978 levels of these costs are also discounted back to the dollar terms of past years. This stems from the assumption of 1978 technology, and hence financial conditions, because in addition to analyzing past performances of irrigation given 1978 conditions and expectations of the farmer pondering re-investment in 1978, the results of this analysis are used as an indication of the 1978-1998 period. Hence the farmer pondering re-investment in 1978 is thinking in 1978 terms with respect to taxes, depreciation, and interest payments.

Financial fixed costs were approximately \$2369 in 1978. The 1967 costs equivalents equal approximately \$1176 in 1967 dollars. As each yearly index is multiplied by \$1176, the annual fixed financial costs of center-pivot irrigation are obtained, listed in Table 8.

Since two independently-operating center-pivot systems (each with its own components) are assumed for the 320 acre farm of this study, then all costs in Table 8 must be added and doubled, as done in Table 9.

Table 10 summarizes the 1957-1977 fixed costs for the rain-fed scenario. They are also adjusted for $(1+.09)^t$, after which they are ready to subtract of the constant-dollar incomes.

Table 11 contains the total fixed costs, in nominal and constant-dollar terms, for the irrigated model.

Despite the zero salvage value assumption, some salvage value was unavoidable because three of the irrigation investment's components did not have lifespans ending exactly in 1977. A well, drilled for each of the two center-pivot systems in 1957, had a life span of 25 years and hence had a three year residual life after 1977, along with a 3 X \$183 or \$549 salvage value. A second water pump with a 12 year lifespan was purchased for each quarter-section in late-1968, thereby implying 3 full years of post-1977 life and a salvage value of 3 X \$454 or \$1362. For the same reasons as the water pump, a new gearhead was purchased for each quarter-section in late 1968, thereby implying each such component to have 3 years of life beyond 1977 along with a salvage value of 3 X \$302 or \$906.

Each center pivot system had a nominal dollar salvage value of \$2817, and a total of \$5634 for the 320 acre farm.

Table 9. Center-pivot irrigation-related fixed costs: one and two systems

Year	Well dep.	Pump dep.	Gear-head dep.	C-P dep.	Fin. costs	Total 1 sep.	Total 2 sep.	$(1.09)^t$	Real total f.c., 2[a]
1957	183	385	265	698	1030	2651	5122	6.109	31290
1958	183	385	265	698	1051	2582	5164	5.604	28939
1959	183	385	265	698	1074	2605	5210	5.142	26790
1960	183	385	265	698	1082	2613	5226	4.717	24651
1961	183	385	265	698	1081	2612	5224	4.328	22609
1962	183	385	265	698	1082	2613	5226	3.97	20747
1963	183	385	265	698	1084	2615	5230	3.642	19048
1964	183	385	265	698	1091	2622	5244	3.342	17525
1965	183	385	265	698	1104	2635	5270	3.066	15158
1966	183	385	265	698	1138	2669	5338	2.813	15016
1967	183	385	265	698	1176	2707	5414	2.58	13968
1968	183	385	265	698	1214	2745	5490	2.367	12995
1969	183	469	302	698	1252	2904	5808	2.172	12615
1970	183	469	302	698	1310	2962	5924	1.993	11807
1971	183	469	302	698	1358	3010	6020	1.828	11005
1972	183	469	302	698	1387	3039	6078	1.677	10193
1973	183	469	302	698	1431	3083	6166	1.539	9489
1974	183	469	302	698	1639	3291	6582	1.412	9294
1975	183	469	302	698	1898	3550	7100	1.295	9195
1976	183	469	302	698	2010	3662	7324	1.188	8701
1977	183	469	302	698	2294	3946	7892	1.09	8602

[a]This is the seventh column multiplied by 2 and then adjusted with $(1.09)^t$ into real constant 1978 dollars.

Table 10. Constant dollar and nominal fixed, variable, and total costs: the rain-fed scenario

Year	Rn.-fd. f.c.[a]	Rn.-fd. v.c.[b]	T.c. con. dol.[c]	Nominal t.c.	Ac.t.c. con. dol.[d]	Ac.t.c. nominal[e]
1957	70058	77219	147277	24108	460.20	75.30
1958	37351	69990	107341	19154	335.4	59.9
1959	38946	64189	103135	20057	322.3	62.7
1960	65264	60784	126048	26722	393.9	83.5
1961	63124	52694	115818	26760	361.9	83.6
1962	77054	50131	127185	32037	397.5	100.1
1963	43190	44310	87500	24025	273.43	75.1
1964	53703	40576	94279	28210	294.6	88.2
1965	51552	38647	90189	29416	281.8	91.9
1966	39376	36006	75382	26798	235.6	83.7
1967	33282	37779	71061	27543	222.1	86.1
1968	32821	0	32821	13866	102.6	43.3
1969	33119	32355	65474	30145	204.6	94.2
1970	33672	32403	66075	33154	206.5	103.6
1971	33407	31142	64549	35311	201.7	110.3
1972	38462	30218	68680	40954	214.6	128.
1973	85354	33548	118902	77259	371.6	241.4
1974	37089	37994	75086	53177	234.6	166.2
1975	41920	38870	80790	62394	252.5	195.
1976	32849	7251	40100	33754	125.3	105.5
1977	32967	32214	65181	59808	203.69	186.9

[a]These data are the annual rain-fed fixed costs.

[b]These data are the annual rain-fed variable costs.

[c]These data are the total cost levels adjusted with $(1.09)^t$.

[d]These data are the total costs per acre adjusted with $(1.09)^t$.

[e]These data are the total costs per acre in nominal dollars.

Table 11. Irrigated farm fixed costs, incomes, and net profits[a]

Year	Farm.lab. charge[b]	Non.irr. dep.[c]	Non-irr. insur.[d]	Prop. tax	Int. paid[e]	Bldg. repairs
1957	2482	1779	214	907	375	254
1958	2544	1981	268	992	526	241
1959	2708	1837	275	854	829	386
1960	2560	1581	392	1113	756	356
1961	3093	1466	312	1272	547	383
1962	3080	1603	429	1326	1158	567
1963	3360	1683	392	1353	1041	629
1964	3385	1744	496	1434	1454	364
1965	4610	3107	517	1612	1817	438
1966	5280	2170	616	1489	1759	654
1967	5521	2506	579	1719	2122	456
1968	5711	2890	597	1597	2479	592
1969	6393	3178	639	1600	2722	716
1970	6170	4128	487	1663	3526	821
1971	6250	3840	704	1712	3872	577
1972	6072	3840	712	2061	5002	932
1973	8437	3952	996	2298	6513	1323
1974	8916	3952	1101	2270	6958	973
1975	9075	6512	1567	2258	7274	1730
1976	9273	7184	2500	5857	1069	0
1977	10003	7876	1382	2832	6292	1638

[a]These data are in dollars adjusted with $(1.09)^t$.

[b]This is the charge for family labor.

[c]These data are depreciation of non-irrigation items.

[d]These data are insurance payments on non-irrigation items.

[e]These data are interest paid on land and non-irrigation machinery.

[f]These data are total fixed costs of two center-pivot systems.

[g]These are the irrigated scenario's total fixed costs in nominal dollars.

[h]These are the farm's total fixed costs adjusted with $(1.09)^t$.

[i]These are the net incomes for the irrigated farm adjusted with $(1.09)^t$

t.f.c. 2sys.f	Income tax	Nominal farm f.c.[g]	$(1.09)^t$	Total farm f.c.,cd.[h]	Real inc.[i]	Net farm profit
5122	6487	17620	6.109	107641	160038	52407
5164	5352	16978	5.604	95145	144749	49604
5210	905	13004	5.142	66867	74716	7849
5226	7831	19815	4.717	93467	142767	49300
5224	12782	25079	4.328	108542	175657	67115
5226	13189	26581	3.97	105527	165121	59594
5280	9277	23015	3.642	83821	126515	42694
5244	11722	25843	3.342	86367	138405	55038
5270	7651	25022	3.066	76717	105230	28513
5338	4804	22110	2.813	62195	84768	22573
5414	1317	19724	2.58	50888	52646	1758
5410	2597	21873	2.367	51773	59264	7491
5808	9785	30841	2.172	66987	90092	23105
5924	3714	26443	1.993	52681	62690	10009
6020	4291	27266	1.828	49842	60303	10461
6078	4119	28815	1.677	48323	57667	9344
6166	45420	75105	1.539	115587	164108	48521
6582	22562	53314	1.412	75279	90191	14912
7100	14735	50251	1.295	65075	74003	8928
7324	0	33207	1.188	39450	22055	-17395
7892	0	37915	1.09	41327	9567	-31760

CHAPTER V.

RESULTS OF MODEL APPLICATION

Stability of the Acreage Solutions

Rain-fed solutions

Table 12 lists the optimal 1957-1977 rain-fed solutions. Only in 1968 was zero planting deemed economically optimal. Aside from 1968, only in 1976 did the corn production activity not enter solution at the upper 320 acre level, but rather at 80 acres. Thus, P01-K entered at upper limits during all years except 1968 and 1976.

Rain-fed acreage sensitivity to rising production costs

The results of the range analyses conducted upon the corn activities, P01-K, are listed in Table 13. Column 1 lists the year, column 2 lists the optimal P01-K level, and column 3, the "upper activity" or the maximal level a P01-K may enter solution, given the farm's 320 acres. Column 4, the "lower activity", is the level down to which the optimal P01-K would have fallen had C_1 in column 7 ("input cost") increased by the "unit cost" amount of column 6 to equal the "upper cost" entry. In other words, the P01-K range created by columns 3 and 4 is the range over which column 5's "unit cost" income penalty is relevant.

The "upper cost" column is the C_1 level required to decrease the optimal activity level (column 2) to the lower activity (column 4). Column 9 is the percent rise in C_1 (or variable production costs) required to drive P01-K down to the lower activity level. Column 10 is the percent by which the optimal P01-K level must decrease if the lower activity entry

Table 12. Rain-fed solutions: 1957-1977

Year	Acres	Hired Apr. hours	Hired May hours	Hired Oct. hours	Borrowed money	Corn sold
1957	320	0	0	73	2951	39072
1958	320	0	0	73	7679	18688
1959	320	0	0	73	8191	23501
1960	320	0	0	73	2149	45088
1961	320	0	0	73	0	45280
1962	320	0	0	73	0	49792
1963	320	0	0	73	4018	31680
1964	320	0	0	73	386	42688
1965	320	0	0	73	1701	41216
1966	320	0	0	73	4597	30166
1967	320	0	0	73	10609	13354
1968	0	0	0	0	0	0
1969	320	0	0	73	873	53376
1970	320	0	0	73	11570	14720
1971	320	0	0	73	7615	36771
1972	320	0	0	73	4966	44000
1973	320	0	0	73	0	51232
1974	320	0	0	73	12816	20182
1975	320	0	0	73	12471	24536
1976	80	0	0	0	0	4662
1977	320	0	0	73	13603	31679

Table 13. Range analysis summaries: P01-K

Year	Activity	Upper activity	Low activity	Unit cost below	Unit[a] cost above
1957	320	320	247	-491.9	-i
1958	320	320	245	-112.79	-i
1959	320	320	268	136.2	-i
1960	320	320	268	-437.2	-i
1961	320	320	245	-491.2	-i
1962	320	320	245	-512.43	-i
1963	320	320	245	-228.4	-i
1964	320	320	310	-360.34	-i
1965	320	320	278	-290.6	-i
1966	320	320	245	-171.9	-i
1967	320	320	245	-8.13	-i
1968	0				
1969	320	320	302	-274.9	-i
1970	320	320	245	-10.7	-i
1971	320	320	245	-113.7	-i
1972	320	320	245	-175	-i
1973	320	320	245	-458.6	-i
1974	320	320	245	-122	-i
1975	320	320	245	-157	-i
1976	80	245	0	-.59	-4.18
1977	320	320	245	-111.4	-i

[a]The "i" refers to infinity.

[b]These entries reflect the required percent increase in C_1 that is required each year to drive the activity column level down to the lower activity.

[c]These entries are the percents that the optimal P01-K levels would drop to reach the lower activity levels if the upper cost level was to be attained.

[d]These are the following ratios: $- \frac{\text{\% drop P01-K}}{\text{\% rise in } C_1}$

Input cost	Upper cost	% rise C_1[b]	% drop P01-K[c]	Sensitivity ratio[d]
-241.31	-733.2	230	23	.1
-218.7	-331.5	51.6	23	.45
-200.59	-336.8	67.9	16	.24
-189.95	-627.1	230.2	16	.07
-164.72	-655.9	298.2	23	.08
-156.66	-669.1	327.1	23	.07
-138.47	-366.9	164.9	23	.14
-126.8	-487.1	284.2	3	.01
-120.74	-411.4	240.7	13	.05
-112.52	-284.4	152.8	23	.15
-118.06	-126.2	7.	23	3.29
-101.11	-376.	271.9	6	.02
-101.26	-112.	11.	23	2.09
-97.32	-210.9	116.8	23	.20
-94.43	-269.5	185.3	23	.12
-104.85	-563.4	437.4	23	.05
-118.7	-240.8	102.8	23	.22
-121.47	-278.5	129.3	23	.01
-109.03	-109.59	0.5	100	200
-100.67	-212.1	110.7	23	.21

is to be realized. And finally, column 11 lists the "sensitivity ratios", which are annual ratios of column 10's entries over those of column 9.

A year's sensitivity ratio, a ratio of two percentages, is a unitless number showing - $\frac{\text{\% decline in P01-K}}{\text{\% rise in production costs}}$. Hence, it reflects the percent acreage response (decline) due to some percent increase in production costs, and herein serves as an indicator of solution stability. The smaller the ratio, the less responsive or "elastic" is the optimal P01-K against rising production costs.

The largest sensitivity ratios occurred during 1967, 1970, and 1976. The average or mean sensitivity ratio is .3984. Therefore, on the average, a one percent production cost increase caused a .3984 decline in 1957-1977 rain-fed acreage levels, a response well below unity. The rain-fed acreage solutions are quite resistant to rising production costs.

Irrigated solutions

The optimal irrigated solutions are summarized in Table 14.[1] Note that each irrigated annual program, unlike the rain-fed model, are subject to an S17-K or minimum acreage constraint of 266 acres, thereby preventing a solution Q01-K below 266 acres.

Only during 1968 and 1976 did the P01-K enter at less than the maximal 320 acre level, that is at 266 acres.

Note that 1968 and 1976 were years of poor price-cost-weather interactions for both scenarios. Thus in both models, the corn production activity is at the lowest of the 21 levels in 1968 and 1976.

[1]Table 14's columns are defined identically to those of Table 12. Hence, Table 14 is not explicitly explained here.

Table 14. Irrigated solutions: 1957-1977

Year	Acres	Hired Apr. hrs.	Hired May hrs.	Hired Oct. hrs.	Money borrowed	Corn sold	Level irr.1[a]	Level irr.2	Level irr.3
1957	320	0	0	73	3031	39072			
1958	320	0	0	73	6263	37910	15.0	9.0	6.0
1959	320	0	0	73	4161	27511	8	5	3
1960	320	0	0	73	2148	45088			
1961	320	0	0	73	0	50059	5	3	2
1962	320	0	0	73	0	49792			
1963	320	0	0	73	1165	46935	19	11	8
1964	320	0	0	73	0	48665	4	2.4	1.6
1965	320	0	0	73	1113	44649	3	1.8	1.2
1966	320	0	0	73	1418	40066	10	6	4
1967	320	0	0	73	8665	29779	16	10	6
1968	266	0	0	20	3607	39304	20	12	8
1969	320	0	0	73	619	53376			
1970	320	0	0	73	5847	38229	19	11	8
1971	320	0	0	73	0	48896	7	4	3
1972	320	0	0	73	4999	44000			
1973	320	0	0	73	0	56233	6	4	2
1974	320	0	0	73	9196	33300	11	7	0
1975	320	0	0	73	9214	37061	6	4	2
1976	266	0	0	20	15764	31553	35	21	0
1977	320	0	0	73	12373	36920	7	4	3

[a]These entries reflect the number of 66.5 acre-inch units of water applied by the respective irrigation activity.

Therefore, irrigation does not eliminate income fluctuation caused by climatic variability. At least the unirrigated 54 acres of the two irrigated quarter-sections will have yields prone to such fluctuation from climate. As seen from comparing the per-acre corn yield responses with the total seasonal irrigation applications in Table 1 of Chapter 4, the irrigated yield levels also fluctuate with weather. As weather worsens and as a larger seasonal irrigation application level is required to maximize yields, irrigated yields are lower (10, p. 13). Such conclusions coincide with those of Beer et al. (10, p. 13), Colbert (22, p. 36), Noffke (52, p. 44), and Palmer-Jones (54, p. 85).

Therefore, irrigation does not eliminate yield and income fluctuation from weather variability. The results indicate that a larger yield-maximizing seasonal irrigation application, i.e., a larger agronomic optimum,[1] is usually coincidental with a lower irrigated yield, thereby implying a diminishing return relationship between applied water and corn yield response.

Irrigated tolerance to rising production cost

Table 15[1] summarizes the range analyses conducted upon the irrigated corn activities, Q01-K.

Noting column 11, it is evident that the optimal Q01-K levels have sensitivity ratios which are generally well below unity.[2] The average

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[1]Hence, the total recommended annual irrigation application estimates obtained from Ross are considered the "agronomically optimal" ones which maximize yield responses to irrigation. The word "application" means "irrigation application" unless specifically noted otherwise.

[2]The columns of Table 15 are identical to those of Table 13.

Table 15. Range analysis summaries: P01-K[a]

Year	Acti-vity	Upper acti-vity	Low acti-vity	Unit cost below	Unit cost above	Input cost	Upper cost	% rise C_1	% drop P01-K	Sensi-tivity ratio
1957	320	320	266	-490.7	-i	-241.3	-732.	203.4	16.9	.08
1958	320	320	266	-166.9	-i	-218.72	-385.6	76.3	16.9	.22
1959	320	320	266	-94	-i	-200.59	-294.6	46.9	16.9	.36
1960	320	320	268	-437.1	-i	-189.95	-627.1	230.1	16.3	.07
1961	320	320	266	-491.2	-i	-164.7	-656.	298.2	16.9	.06
1962	320	320	266	-512.4	-i	-156.66	-669.	332.8	16.9	.051
1963	320	320	290	-228.4	-i	-138.47	-366.9	164.9	9.4	.057
1964	320	320	266	-364.	-i	-126.8	-490.8	287.1	16.9	.059
1965	320	320	293	-290.6	-i	-120.7	-411.4	240.8	8.4	.03
1966	320	320	286	-171.9	-i	-112.52	-284.4	152.8	10.6	.07
1967	320	320	266	-8.14	-i	-118.06	-126.2	6.5	16.9	2.6
1968	266	320	266	-i	-82.21	-119.67	-i	0	0	0
1969	320	320	307	-274.9	-i	-101.11	-376	271.9	4.1	.015
1970	320	320	266	-10.7	-i	-101.26	-112.	10.6	16.9	1.59
1971	320	320	266	-121	-i	-97.32	-218.3	124.3	16.9	.136
1972	320	320	266	-175	-i	-94.43	-269.5	185.3	16.9	.091
1973	320	320	266	-485.5	-i	-104.94	-563.4	436.9	16.9	.04
1974	320	320	266	-124.5	-i	-118.74	-243.3	104.9	16.9	.16
1975	320	320	266	-157.	-i	-121.47	-278.5	129.1	16.9	.131
1976	266	320	266	-i	-7.38	-109.03	-i	0	0	0
1977	320	320	266	-114.6	-i	-100.67	-215.3	113.8	16.9	.15

[a]This table's columns are defined identically to those of Table 13.

irrigated sensitivity ratio is .3142, less than the 1957-1977 ratio of the rain-fed model.

Acreage response to production costs: rain-fed vs. irrigated

Comparing the rain-fed and irrigated sensitivity ratios in Tables 13 and 15, it appears that, despite Q01-K being identical to P01-K, when Q01-K is coupled with one or more of the three irrigation activities, the irrigated activity is more resistant to rising costs than P01-K. Such a conclusion is reflected by the average irrigated sensitivity ratio of .3142 being 27 percent less than the rain-fed average of .3984. Thus, the Q01-K generally would decline by 27 percent less than a P01-K, given some percent rise in production costs.

Profitability of Irrigation[1] and Alternative Options

The two scenarios are identical, save for the irrigated scenario's three annual irrigation activities and the four annual constraints not found in the rain-fed program. Also, profits or returns are economic, rather than accounting, in nature where the farm family's next best forgone income is accounted for. Therefore, the gap between the irrigated and rain-fed scenario incomes represents the net return to center-pivot investment.

In order to compare irrigation returns with those of alternative investments open to the farmer in 1957, four other investment options are considered: (1) high grade municipal bonds, (2) Bbb grade corporate bonds, (3) U.S. treasury bills, and (4) cropland as a source of rental income.

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[1]The center-pivot investment includes 2 wells, 2 pumps, and 2 center-pivot installations.

Nominal, inflation-adjusted, and real constant 1978 dollar terms

All costs, incomes, and returns are considered in three different dollar terms: (1) nominal, (2) inflation-adjusted, and (3) real constant 1978 dollars.

The nominal dollars are those dollar terms of the year during which an income or cost was incurred. They are not adjusted for any of the five time-related costs previously mentioned.

Often, inflation is the only time-related cost for which an investment analyst compensates costs and returns. The inflation component of the 9 percent reverse-discount factor developed by Harris and Nehring (32, p. 162) is 5/9 or five percentage points. Therefore, $(1.05)^t$ is the reverse-discount formula when inflation is the only time-related cost of the five discussed above for which costs and incomes are adjusted.

As discussed earlier, $(1.09)^t$ is the reverse-discount formula accounting for all five time-related costs: (1) eroded nominal dollar purchasing power from inflation, (2) the risk encountered by investing $54,038 into irrigation in 1957, (3) the interest costs incurred by the farmer in waiting for investment returns over time, (4) the uncertainty of time-related phenomena, e.g., weather variability, which affect profits, and (5) time preference of income.[1] When so-adjusted, costs and returns are said to be in real constant 1978 dollars.

The reverse-discount formula, $\overset{21}{\Sigma}(1+r)^t$, is used rather than the discount formula, $\dfrac{\overset{21}{\Sigma}(\text{return})}{(1+r)^{22-t}}$, for several reasons. First the farmer is assumed

[1]A farmer would have preferred to consume the 1957 principal in 1957 rather than invest it and wait for returns.

to have irrigated his 320 acres in 1957 where both center-pivot systems are assumed fully depreciated at 1977's end. Prior to 1978's planting, the farmer is assumed as re-assessing the 1957-1977 center-pivot performance with an idea of what a new 1978 model investment could have done. This 1957-1977 performance assessment serves as the best available indication of future performance, because weather variability, whose yield influence is crucial to irrigation profitability, is unpredictable in Northwest Iowa.

The reverse discounting term increases further into the past. For instance, in 1977, $(1.09)^t$ equals (1.09) and in 1957 when t=21, the term is 6.109.

Suppose 100 nominal dollars were earned in 1957 and 1977. Put into real constant 1978 dollars, the 1957 income equals \$100 $(1.09)^{21}$ or nearly 611 real constant 1978 dollars and that of 1977, only \$100 x (1.09) or \$109. The reason for a past nominal income being worth more in real 1978 terms than a more recently-earned income is simple. The 1957 income, earned 20 years before the 1977 income, incurred (1) less purchasing power erosion from 20 years of inflation, (2) 20 years less interest costs of time, (3) two decades less risk associated with having to wait for an income to be generated, (4) less disutility of having to postpone, for 20 years, the consumption of the \$100 income, and (5) less uncertainty and worry about whether or not some uncertainty of time will prevent the income from being earned and consumed.

Therefore, the $\sum_{t=1=1957}^{1977=21} Ri(1+r)^t$, the reverse-discount formula and $\sum_{t=1957=1}^{1977=21} \frac{R_i}{(1+r)}^{22-t}$ are mirror images. Discount formulas subtract time costs from future incomes and hence places more 1957 value onto incomes of the less-distant future. Likewise, the reverse-discount formula looks back into time and increases a past income's value in terms of 1978 dollars since past incomes were subject to less of the time costs. Therefore both formulas accomplish the same thing. Time is money and hence waiting for income places costs on the investor. With the discount formula, present income is worth more than future income because waiting is avoided, while with the reverse-discount formula, past incomes are worth more in real 1978 terms than at present because time costs were avoided.

According to Panagides[1] a farmer deciding upon re-investment in irrigation does not use a discount formula in the sense that he goes back and calculates the 1957-1977 incomes and returns in terms of 1957 and present value and expectations. Rather, he judges what the past performances are worth in 1978 dollars with 1978 expectations, and hence uses this as an indicator of the investment's future performance.

Net returns to irrigation investment

Tables 16 and 17 summarize the total costs of the rain-fed and irrigated models, respectively. All costs were derived in Chapter 4. The rain-fed variable costs adjusted with $(1.09)^t$ are the C_1 coefficients in Table A-5 times the optimal rain-fed acreages of Table 12.

The year K variable cost for the irrigated scenario is the proper C_1 coefficient in Table A-5 plus the C_7 coefficient in Table A-5 times the number of applied 66.5 acre-inch units of irrigation water. The latter are listed in Table 14.

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[1]This opinion was stated by Agricultural Investment consultant and Iowa State University student of agricultural credit, Mr. Dafnis Panagides. Private communication, Ames, Iowa, April, 1978.

Table 16. Rain-fed fixed costs and net profits

Year	Living exp.	Deprec.	Insur-ance	Prop. tax	Inter-est paid	Bldg. reps.	Income tax	Nom. t.f.c.[a]	$(1.09)^t$	Con. dol. t.f.c.[b]	Profit, unadj. f.c.[c]	Net π, con. dol.[d]
1957	2482	1779.	214	907	375	254	5457	11468	6.109	70058	160566	90508
1958	2544	1981.	268	992	526	241	113	6665	5.604	37351	38320	969.
1959	2708	1837.	275	854	829	386	685	7574	5.142	38946	51499	12553
1960	2560	1581.	392	1113	756	356	7079	13836	4.717	65264	142767	77503
1961	3093	1466.	312	1272	547	383	8784	14585	4.328	63124	158380	90256
1962	3030	1603.	429	1326	1158	567	11296	19409	3.97	77054	165120	88066
1963	3360	1683.	392	1353	1041	629	3401	11859	3.642	43190	75022	31832
1964	3385	1744.	496	1434	1454	364	7192	16069	3.342	53703	116815	63112
1965	4610	3107.2	517	1612	1817	438	4713	16814	3.066	51552	94889	43337
1966	5280	2170.	616	1489	1759	654	2030	13998	2.813	39376	56570	17194
1967	5521	2506.	579	1719	2122	456	0	12902	2.58	33287	3851	-29436
1968	5711	2890.	597	1597	2479	592	0	13866	2.367	32821	0	-32821
1969	6393	3178.	639	1600	2722	716	0	15248	2.172	33119	15953	-17116
1970	6170	4128.	487	1663	3526	821	0	16895	1.993	33672	4748	-28924
1971	6250	3840.	704	1712	3872	577	1320	18275	1.828	33407	37923	4516
1972	6072	3840.	712	2061	5002	932	4316	22935	1.677	38462	57669	19207
1973	8437	3952.	996	2298	6513	1323	32352	55461	1.539	85354	147561	62207
1974	8916	3952.	1101	2270	6958	973	2097	26267	1.412	37089	40732	3643
1975	9075	6512.	1567	2258	7274	1730	3955	32371	1.295	41920	52047	10127
1976	9273	7184.	1368	2500	5857	1469	0	27651	1.188	32849	47	-32802
1977	10003	7876.	1382	2832	6292	1638	2227	30245	1.09	32967	37224	4257

[a]These costs are the rain-fed scenario's total fixed costs in nominal dollars.

[b]These are the rain-fed scenario's total fixed costs adjusted with $(1.09)^t$.

[c]These data are the real constant 1978 dollar profits which are unadjusted for the real constant 1978 dollar total fixed costs.

[d]These data are the net rain-fed profit in real constant 1978 terms.

Table 17. Variable, fixed, and total costs: irrigated scenario

Year	No. app.[a]	Cost app.[b]	Irr. rel. v.c.	Non. irr. v.c.	Irr. scen. f.c.[c]	Total costs irr.[d]	Nominal total c. irr.[e]	Total costs per-acre	Total c.per ac.nom.[f]	irr.t.c. / r.t.c.
1957	0	0	0	77219	107641	184460	30195	576.	94.	1.25
1958	31	288.34	8939	69990	95145	174074	31062	544.	97.	1.64
1959	16	264.67	4235	64189	66867	136576	26561	427.	83.	1.32
1960	0	0	0	60784	93467	154251	32701	482.	102.	1.22
1961	10	204.28	2042.8	52694	108542	163279	37726	510.	118.	1.41
1962	0	0	0	50131	105527	155658	39209	486.	123.	1.22
1963	38	174.09	6615	44310	83821	134726	36992	421.	116.	1.54
1964	8	157.74	1262	40576	86367	128196	38359	401.	120.	1.36
1965	6.0	144.72	868	38637	76717	116222	37907	363.	118.	1.29
1966	20	133.77	2675	36006	62195	100876	35861	315.	112.	1.34
1967	32	122.5	3920	37779	50888	925887	35886	289.	112.	1.30
1968	40	130.69	5228	31832	51773	88833	37530	278.	117.	1.37
1969	0	0	0	32355	66976	97891	45484	309.	142.	1.5
1970	38	103	3914	32403	52681	88998	44655	278.	140.	1.35
1971	14	104.05	1457	31142	49842	82441	45099	257.	141.	1.28
1972	0	0	0	30218	48323	78541	46384	245.	146.	1.14
1973	12	94	1128	33548	115587	150263	97637	305.	198.	1.26
1974	18	145.78	2624	37997	75279	115900	87802	257.	182.	1.10
1975	12	135.98	1632	38870	65075	105577	81526	254.	196.	1.31
1976	55	139.8	7689	29002	39450	76141	68104	238.	212.	1.23
1977	14	117.68	1648	32214	41327	75189	68981	235.	216.	1.15

[a]This column lists the number of 66.5 acre-inch irrigation water units applied each year.

[b]These data are the nominal cost per 66.5 acre-inch unit of applied irrigation water adjusted with $(1.09)^t$.

[c]These real constant 1978 dollar total fixed costs of the irrigated scenario.

[d]These are the total costs of the irrigated scenario in real constant 1978 dollar terms.

[e]These are the total costs of the irrigated scenario in nominal dollars.

[f]These data are the nominal total costs per acre of the irrigated scenario.

Column 11 of Table 17 shows that total irrigated costs rose by an average 31% over rain-fed levels. Irrigated incomes in Table 18 rise by an average 37% over rain-fed levels. However, Table 18's incomes are not yet adjusted for fixed costs. As seen hence, irrigation fixed costs are substantial and are the costs leading to center-pivot unprofitability.

Before calculating irrigation's rates of net return, it must be noted that the rates of return on all 5 investment options dealt with herein are calculated in terms of a quarterly-compounded annual rate of return (above of total costs). The following formula is that from which the quarterly compounded rate of net return, i, is solved for: $R = P(1+\frac{i}{m})^{mt}$. R is the summed annual gross returns net of all costs except depreciation,[1] P is the principal, i the rate, t the 21 years of the study, and m, the number of times annually that the net returns are compounded (4). Thus, solving the equation for i renders the quarterly compounded rate of net return which will cause P to yield R over a period of t years.

Three quarterly compounded rates of return are calculated for each investment option: (1) i_n or the rate when nominal incomes and costs are

[1]Solving this formula for i calculates the rate of return net of total costs associated with an investment, although R does not have depreciation charges subtracted out. In rearranging this formula, $i=m\ (\frac{R}{P}^{1/mt} - M$, note that i will be negative unless R equals or is greater than P. Therefore, i is the rate of net return above all non-depreciation charges, e.g., added income tax charges, which have already been subtracted out as well as the depreciation charges. Therefore, to avoid further confusion, R refers to gross returns which are considered returns net of all costs except depreciation. "Net returns" are those returns net of total costs.

Table 18. Profits of the rain-fed and irrigated scenarios and the net returns to irrigation.

Year	Unadj. r.inc.[a]	T.f.c. rnfd[b]	Unadj. irr. inc.[c]	Irr. t.f.c.[d]	Total costs rnfd[e]
1957	160566	70058	160038	107641	147277
1958	38320	37351	144749	95145	107341
1959	51499	38946	74716	66867	103135
1960	142767	65264	142767	93467	126048
1961	158380	63124	178657	108542	115834
1962	165120	77054	165121	105527	127185
1963	75022	43190	126515	83821	87500
1964	116815	53703	138405	86367	94279
1965	94889	51552	105230	76717	90189
1966	56570	39376	84768	62195	75382
1967	3851	33287	52646	50888	77155
1968	0	32821	59264	51773	71115
1969	15953	33119	90092	66987	67747
1970	4748	33672	62690	52681	66075
1971	37923	33407	60303	49842	64549
1972	57669	38462	57667	48323	68680
1973	147561	85354	164108	115587	118902
1974	40732	37089	90191	75279	75086
1975	52047	41920	74003	65075	80790
1976	47	32849	22055	39450	67739
1977	37224	32967	9567	41327	65181

[a]These data are real constant 1978 dollar rain-fed incomes unadjusted for fixed costs. These data are net of variable costs.

[b]These data are the total fixed costs of the rain-fed scenario adjusted with $(1.09)^t$; π = (Unadj r. inc - t.f.c. rainfed).

[c]These data are the real constant 1978 dollar irrigated incomes net of variable costs but unadjusted for total fixed costs.

[d]These data are the irrigated scenario's total fixed costs adjusted with $(1.09)^t$; π = (Unadj irr. inc - t.f.c. irr.)

[e]These data are the real constant 1978 dollar total rain-fed costs.

[f]These data are the real constant 1978 dollar total irrigated costs.

[g]These are the real constant 1978 dollar net returns to irrigation investment (Col. 8 figures subtracted from col. 7 figures)

[h]These are the nominal net returns to irrigation investment.

[i]These are the inflation-adjusted net returns to irrigation.

Total costs irr.[f]	Net irr.π	Net rnfd.π	Net ret. irr.[g]	Nom. net. ret.irr.[h]	Inf-ad. net-ref. irr.[i]
174450	52407	90508	-38101	-6242	-17390
118948	49604	969	48635	8679	23025
136576	7849	12553	- 4704	- 915	- 2312
155431	49300	77503	-28203	-5979	-14391
16431	67115	90256	-21141	-4885	-11196
156636	59594	88066	-28472	-7172	-15656
135474	42694	31832	10862	2982	6200
127216	55038	63112	- 8074	-2416	- 4783
113989	28513	43337	-14824	-4835	- 9119
101580	22573	17194	5379	1912	3434
93000	1758	29436	31194	12091	20676
88615	7491	32821	40312	17031	27743
97891	23105	17116	40221	18518	28703
87866	10009	28924	38993	19565	28898
81220	10461	4516	5945	3252	4576
77422	9344	19207	- 9863	-5881	- 7881
149235	48521	62207	-13686	-8893	-11347
114957	14912	3643	11269	7981	9705
104712	8928	1017	7911	6109	7074
75823	-17395	32802	15407	13781	15194
74461	-31760	4257	-36017	-33043	-34695

considered, (2) i_f or the rate where incomes and costs are adjusted for inflation, and (3) i_r or the rate where incomes and costs are adjusted for all the time-related costs mentioned above.

In Table 18, subtracting column 3 from 2 calculates the annual net rain-fed farm profits adjusted into real constant 1978 dollars in column 9. Subtracting column 5 from 4 calculates the net annual irrigated farm profits of column 8, also in real constant 1978 dollars.

In Table 18, column 10 contains the real constant 1978 dollar net returns to irrigation investment, column 11 contains the net irrigation returns in nominal dollars, and column 12 contains the nominal net returns to irrigation adjusted for inflation only.

Irrigation's nominal rate of net return The nominal rate of quarterly compounded net return is calculated from the principal of $31,460 (in 1957 dollars) and the summed 1957-1977 nominal gross irrigation returns equals $85498, the latter of which includes the depreciation charges plus the summed nominal returns. As seen in Table 23, irrigation had a small rate of return of 2 percent.

Irrigation's inflation-adjusted rate of net return Often discounting formulas adjust only for inflation, ignoring the other time-related costs mentioned previously. Purchasing power erosion from inflation is captured by $(1.05)^t$ (32, p. 162).

Irrigation's nominal net returns in Table 18, when adjusted with $(1.05)^t$, become the inflation-adjusted net returns of column 12, which sum to $46,958. Adding the summed and adjusted depreciation charges of $125,524 creates an R equalling $172,482.

However, the original principal of $54,038 is re-valued at $150,048 after adjusting for inflation. Thus, the principal as well as the net returns are re-valued.

The quarterly compounded rate of net inflation-adjusted returns is .66 percent, less of a return than i_n indicating irrigation to be even a lower yielding venture against inflation.

Irrigation's real constant 1978 dollar rate of net return However, there are four time-related costs other than inflation incurred over the 1957-1977 period from the 1957 irrigation investment, which were discussed earlier.

Nominal net returns generated by irrigation from 1957 through 1977 sum to \$31460 and, when adjusted with $(1.09)^t$, are re-valued at \$53043. Gross returns equal \$266,785 when depreciation is included. Likewise, the \$54,038 principal in 1957 is revalued at \$330,118. The quarterly compounded rate of net real constant 1978 dollar returns is -1.01 percent, a loss in terms of real constant 1978 dollars.

The i_n, i_f, and i_r are listed for all five investments in Table 23. But before calculating these rates for the other options, the coincidence of the above conclusions of center-pivot unprofitability with those of Colbert are discussed.

Coincidence with Colbert's study These results coincide with Colbert's (22) more general irrigation profitability study for Northwest Iowa. In his study, "The most important indication reached is that irrigation appears to be an economically usable proposition only on a limited number of sites." (22, p. 99). Such sites where irrigation has been profitable are usually on the flood plains of a river or creek, where the soils are of a coarse-textured silty or fine sandy clay loam nature (22, p. 65).

Examples of such sites are found in the Missouri bottomlands, whereas the unprofitable sites are usually located upon the upland areas of Northwest Iowa, and often overlie the Dakota sandstone aquifer (22, p. 65). The model application site of this study is such an unprofitable upland site, as seen by the negative return rates to irrigation in all dollar terms except nominal.

For Colbert's profitable bottomland sites, soils are often of a low moisture storage capacity and have a shallow profile of 8-10 inches (92, p. 2-3). Consequently, rainfall quickly permeates through these soils into the aquifers below, enabling little water to be stored in the soil (22, p. 68). Therefore, moderate time-periods between rainfalls cause soil moisture depletions and soil moisture stress-induced corn yield reductions. Because of the increased likelihood, frequency, and severity of such yield reductions, yield response to irrigation applications is greater on these bottomland soils than on the deeper, moister, and finer loams such as Colo or Moody (22, p. 65). Consequently, net returns on bottomland soils, being greater with larger yield responses to irrigation, exceed those of the more unprofitable upland sites such as the Doon Farm site. Whereas upon "average" soils, an Iowa farmer may expect one crop failure every ten years, on such permeable, coarse, and shallow soils as those of the Missouri bottomlands, a crop failure from drought is expected once every five years (22, p. 68). This indicates a great increase in yield reductions from unfavorable weather, and demonstrates the bottomland soils' greater yield response to irrigation. However, on Moody soils, with a higher waterholding capacity, soil moisture deficits are less common and severe, indicating tempered yield responses from irrigation.

In addition to the low yield response to irrigation upon the Moody

Association, the deeper and lower yielding wells of the Dakota sandstone aquifer cause another profitability problem: increased variable cost. Aside from the high-yielding and shallow alluvial aquifers of the Missouri bottomlands, the only other aquifer from which irrigation is economically feasible in Northwest Iowa is the Dakota sandstone aquifer. Dakota sandstone wells are typically deep (250-400 foot head), of a lower yield than the shallow bottomland alluvial aquifers, and whose constituting matter is of a fine sandy and poorly cemented quality conducive to pumping problems (31, p. 4). Pumping from such a well incurs high levels of diesel costs. As calculated above, nearly 150 gallons of diesel are required for a pump of 83 h.p. to apply .25 inches/acre over 133 irrigated acres of a quarter-section.

The big problem lies with the fact that a single Dakota sandstone well is seldom of a 1200 g.p.m. yield level, that required to irrigate two quarter sections.[1] Thus, as used in this study, two separate wells and pumps are required to fully irrigate a farm of two quarter-sections, i.e., 320 acres.[2] Double levels of pump and well-related fixed costs, as well as higher pumping costs are incurred. Irrigating from such a typical Dakota sandstone well adds $4800 to $6400 more to annual 1978 total costs than irrigating from a shallower bottomland aquifer (22, p. 67).

From Colbert's study (22, p. 99), irrigation on the Missouri bottom-

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[1]Such was stated by I.S.U. Professor Agricultural Engineering, Dr. Stewart Melvin. Also, Hallberg (31, p. 4) implies that seldom, if ever, have sells of a 1200 g.p.m. yield been discovered in the Dakota sandstone aquifer.

[2]However, in a private communication with Dr. Merwin Dougal, I.S.U. Professor of Civil Engineering, raised the possibility of "stretched technology" where one well unit fed two quarter-sections in an alternating sequence. However, no information was located regarding this possibility, one which Dougal suggests as warranting further study. Ames, Iowa, August, 1978.

lands of Northwest Iowa has been and probably will continue to be profitable. However, the conclusions of this case-study support another of Colbert's conclusions, that this study's farmer irrigating 320 Moody acres of corn with Dakota sandstone water has probably done so at a loss. This unprofitability would probably continue over the 1978-1998 period according to this study's results.

For this study's farmer, alternative investment options should have been found over the 1957-1977 period for the 1957 dollar principal of \$54,038 placed by into center-pivot investment given the low nominal i_n and negative i_f and i_r. For the farmer pondering reinvestment in 1978 for the 1978-1998 period, options other than center-pivot irrigation should be sought out.

Alternative investment options

Four alternative options are examined below: (1) U.S. 4 to 6 month treasury bills, (2) grade Bbb corporate bonds, (3) high-grade municipal bonds, and (4) land as a source of rental income.

The three rates of net return discussed above are calculated for the U.S. treasury bills in Table 19, for Bbb grade corporate bonds in Table 20, for municipal bonds in Table 21, and for land in Table 22.

For all options, net interest or incomes are calculated which are returns above income tax charges.[1] In Tables 19-22, the nominal returns are added to the rain-fed income without the option's income and the income tax charge is recalculated. The difference between the rain-fed income tax charges with and without the option's income constitutes the income tax

[1]Note that all net returns in Tables 19-22 are not the gross returns including depreciation, but are net of all costs.

charge attributable to the option and is subtracted from the nominal interest. Thus, the size of the income tax charge[1] upon the option's net returns depends upon the tax brackets in which the farmer finds himself before and after that option's net returns are added to the rain-fed income.

For all options, the initial principal is assumed to be the same, \$54,038 in 1957, which would have been required to irrigate the two quarter-sections.

Treasury bill option The nominal 1957-1977 interest rates realized on U.S. treasury bills (4-6 months) are published by Carter (17, pp. 261 and 262) and are listed in Table 19.

Nominal rate of net return Had the farmer repeatedly invested in treasury bills from 1957 through 1977, 61,259 nominal dollars of net interest would have been generated, and \$115,297 of gross revenues (including depreciation). Using the above formula for calculating a quarterly rate of net nominal return, a 3.6 percent rate is calculated. Such an option proved a better investment than irrigation.

Inflation-adjusted rate of net return The quarterly compounded rate of net return is worse when the net returns, gross returns and original principal of the treasury bills are adjusted for inflation. The summed 1957-1977 nominal net returns of \$61,259 become re-valued at \$93,647, whose gross revenues equal \$211,807 when adjusted depreciation is included. Likewise, the principal of \$54,038 is revalued at \$150,548.

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[1]The income tax rates are published by the U.S. Department of Commerce (94, pp. 1111-1112).

Table 19. Treasury bills rates of return and interest

Year	Rate[a]	Nominal interest	Income tax	Net nom. interest	Con.dol. net interest	Infl. ad. net interest
1957	3.267	1765	428	1337	8169	3725
1958	1.839	1018	45	937	5453	2486
1959	3.405	1919	222	1697	8725	4288
1960	2.928	1700	458	1245	5873	2997
1961	2.378	1410	398	1012	4382	2320
1962	2.778	1675	503	1172	4653	2558
1963	3.157	1941	419	1522	5543	3164
1964	3.549	2236	542	1694	5661	3354
1965	3.954	2558	516	2042	6260	3851
1966	4.881	3257	489	2768	7787	4971
1967	4.321	3003	0	3003	7748	5135
1968	5.339	3871	0	3871	9163	6306
1969	6.677	5099	0	5099	11075	7909
1970	6.458	3542	0	3542	7060	5232
1971	4.348	3696	488	3208	5864	4514
1972	4.071	3592	425	3167	5311	4256
1973	7.041	6435	2542	3893	5991	4967
1974	7.886	7514	2082	5432	7670	6605
1975	5.838	5879	1658	4221	5466	4888
1976	4.989	5235	0	5235	6219	5772
1977	5.102	5671	1529	4142	4515	4349

[a]These data are the annual nominal interest rates earned on treasury bills.

The quarterly compounded rate of net return equalled 2.3 percent, larger than irrigation's i_f.

Real constant 1978 dollar rate of net return When the $61,259 of nominal treasury bill net interest are adjusted for all five of the time-related costs mentioned earlier, they are re-valued at $138,588. When adjusted depreciation charges are added, gross returns equal $468,706, and the original $54,038 of principal in 1957 is re-valued at $330,118.

The quarterly compounded rate of net returns to treasury bills, adjusted for all five time related costs, is 1.7 percent. Treasury bills generated more nominal, inflation-adjusted, and real constant 1978 dollar net interest than center-pivot irrigation, although they were nonetheless the second poorest option of the five considered in Table 23.

Bbb grade corporate bond option Nominal 1957-1977 rates of interest on Standard and Poors ranked Bbb corporate bonds, published in the Economic Report of the President, 1977, are listed in Table 20. Table 20 also lists the nominal, inflation adjusted, and real constant 1978 dollar net interest calculated for these bonds.

Nominal rate of net return The nominal net 1957-1977 interest yields on Bbb bonds sum to $133,911, and the gross returns including depreciation equals $187,949. The quarterly compounded rate of nominal net returns was 5.9 percent, sizeably larger than the i_n calculated for irrigation or treasury bills.

Inflation-adjusted rate of net return The summed nominal interest of $133,911 is revalued for inflation at $195,892, and the gross

[1]Here depreciation is considered the original principal from a bond received back with the interest. Thus, during a 1 year period, investing a $100 bond at 4% would yield back $104 the next year. Assuming no taxes, then the "depreciation" of the bond would be $100, the net returns, $4, and the gross returns, $104.

returns at \$345,940. The \$54,038 principal, is revalued at \$150,048. A positive 4.3 percent quarterly compounded rate of net inflation-adjusted returns is calculated for Bbb bonds. Thus, these bonds yielded returns net of inflation.

Real constant 1978 dollar net rate of return The summed nominal net interest yields of Bbb corporate bonds are re-valued at \$277,390 when they are adjusted for all five of the above-discussed time-related costs, and the revalued gross returns equal \$607,508. The revalued principal equals \$330,118. The real constant 1978 dollar rate of net return is calculated as 2.9 percent.

The three rates of net return to Bbb corporate bonds listed in Table 23, i_n, i_f, and i_r, greatly exceed those calculated for center-pivot investment.

Municipal bond option The nominal rates of interest collected on high-grade municipal bonds are published in the Economic Report of the President, 1977. These rates are listed in Table 21.

Nominal rate of net return The nominal net returns earned by \$54,038 invested into municipal bonds from 1957 through 1977 are listed in Table 21. If the \$54,038 principal originally invested in 1957 was, along with the yield increments, repeatedly invested in municipal bonds throughout the 1957-1977 period, then \$83,061 of nominal interest would have been generated net of taxes. Gross returns would have equalled \$137,099. The nominal rate of quarterly compounded net return is calculated as 4.46 percent.

Table 20. Rates of return and interest on high-grade municipal bonds[a]

Year	Rate	Net nom. interest	Con.dol. net interest	Inf. ad. net interest
1957	3.6	1945	11884	5419
1958	3.56	1993	11169	5287
1959	3.95	2290	11775	5787
1960	3.73	2248	10603	5411
1961	3.46	2163	9361	4958
1962	3.18	2057	8165	4490
1963	3.23	2156	7850	4482
1964	3.22	2218	7413	4392
1965	3.27	2325	7129	4385
1966	3.82	2805	7890	5038
1967	3.98	3034	7828	5188
1968	4.51	3575	8462	5824
1969	5.81	4813	10455	7465
1970	6.51	5425	10811	8013
1971	5.7	4758	8698	6695
1972	5.27	4642	7785	6234
1973	5.18	5044	7762	8213
1974	6.09	6237	8807	7584
1975	6.89	7568	9801	8764
1976	6.49	7620	9053	8401
1977	6.53	8165	8899	8573

[a]These bonds are assumed tax-free.

Table 21. Rates of return and interest on Bbb corporate bonds

Year	Rate	Nominal interest	Income tax	Net nom. interest	Con.dol. net interest	Infl. ad. net interest
1957	4.71	2545	615	1930	11790	5377
1958	4.73	2647	106	2541	14239	6741
1959	5.05	2955	343	2612	13429	6601
1960	5.19	3172	844	2329	10980	5606
1961	5.08	3223	909	2314	10015	5304
1962	5.02	3301	1005	2296	9115	5012
1963	4.86	3308	718	2590	9432	5385
1964	4.83	3412	829	2583	8631	5114
1965	4.87	3566	719	2847	8729	5369
1966	5.67	4313	648	3665	10309	6582
1967	6.23	4968	0	4968	12818	8495
1968	6.94	5879	0	5879	13916	9577
1969	7.81	7075	0	7075	15367	10973
1970	9.11	8897	0	8897	17733	13141
1971	8.56	9878	1304	8574	15673	12064
1972	8.16	10116	2013	8102	13587	10857
1973	8.24	10883	4321	6562	10099	8373
1974	9.5	13507	2076	11431	16140	13900
1975	10.61	16797	3198	13599	17611	15748
1976	9.75	17153	0	17153	20377	18911
1977	9.82	18960	2996	15964	17400	16762

Inflation-adjusted net rate of return When inflation is considered, the summed nominal 1957-1977 net interest and gross returns of municipal bonds are revalued in Table 21 at $140,603, R would have been $280,651 and the principal, $150,048. The quarterly compounded rate of net inflation-adjusted returns is calculated as 3.07 percent, an i_f exceeding that of irrigation.

Real constant 1978 dollar net rate of return In compensating for all five time-related costs, the nominal net returns to municipal bonds, $83,061, are revalued at $191,600 real constant 1978 dollars. Revalued gross returns equal $521,718 and the $54,038 principal is revalued at $330,118. The calculated real constant 1978 dollar net rate of return is 2.18 percent.

Land option Of the five options examined in Table 23, land, as a source of rental income, would have generated the highest positive rates of net return in nominal, inflation-adjusted, and real constant 1978 dollar terms.

Per-acre rents for average cropland of Iowa's crop and livestock reporting district number 1 in Figure 15 were obtained from the U.S.D.A.[1] and are listed in Table 22.

In lieu of irrigation, the farmer could have taken the $54,038 in 1957 and purchased 237 additional acres of land, which he could have rented out.[2]

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[1]These data are net rents for medium to high grade Northwest Iowa cropland. They are unpublished and were obtained by private communication with Dr. Larry Walker of the U.S.D.A. Washington, D.C., February, 1978.

[2]According to I.S.U. Econ. Professor, Duane Harris, land in the shaded area of Figure 18, cost $228 in 1957. Thus, principal of $54,038, originally invested into irrigation could have purchased $54,038/$228 per acre or 237 acres of additional cropland. Private communication, Ames, Iowa, July, 1978.

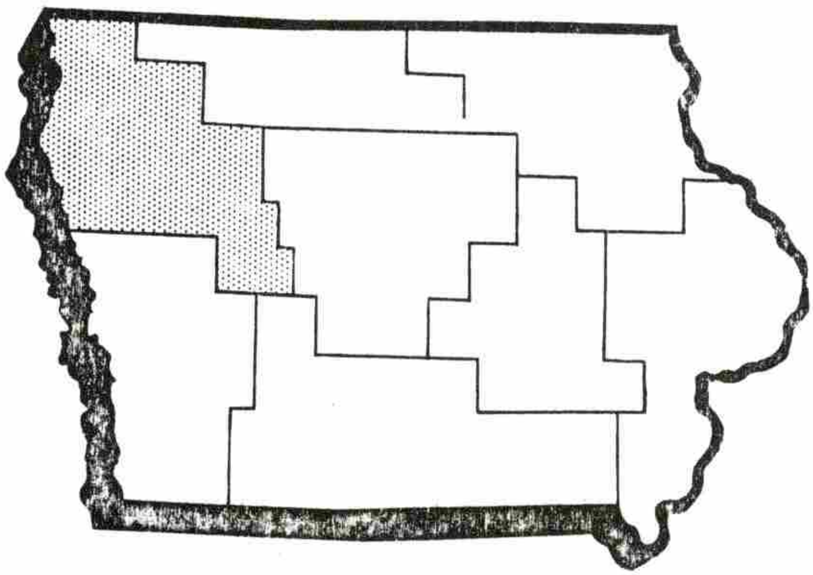

Figure 15. Iowa crop and livestock reporting district number 1.

Table 22. Cropland rents: 237 acres

Year	Acre rents[a]	Total nominal rent[b]	Con.dol. total rent[c]	Inf. ad. total rent[d]
1957	17	4029	24613	11225
1958	17.1	4053	22713	10754
1959	17.2	4076	20959	10230
1960	17.2	4076	19226	9809
1961	17.6	4171	16559	9560
1962	18.2	4313	17123	9415
1963	26.4	6257	22788	13008
1964	19.5	4622	15447	9151
1965	20.5	4859	14898	9162
1966	22.3	5285	14867	9491
1967	31.5	7466	19262	12769
1968	27.0	6399	15146	10423
1969	28.6	6778	14722	10515
1970	31.4	7442	14832	10966
1971	31.5	7466	13648	10505
1972	32.2	7631	12797	10226
1973	37.0	8769	13495	11192
1974	54.0	12798	18071	15556
1975	56.0	13272	17187	15364
1976	69.0	16353	19427	18029
1977	75	17775	19375	18664

[a]These rents are net of property and income taxes.and in dollar terms.

[b]These are the total rents obtainable from the 237 acres of land purchasable back in 1957 with the original principal of $54,038.

[c]These data are the total dollar rents from 237 acres of land adjusted with $(1.09)^t$.

[d]These data are the total dollar rents from 237 acres of land adjusted with $(1.05)^t$.

The third column in Table 22 is 237 acres times column 2's per-acre rent entries. The fourth and fifth columns contain column 3's entries adjusted for inflation with $(1.05)^t$ and for all time-related costs with $(1.09)^t$, respectively.

Nominal rate of net return Over the 1957-1977 period, given the per acre rents of Table 22, $157,890 of net nominal rents would have been generated had the farmer in 1957 invested the $54,038 into land. Gross returns would have equalled $211,928. The calculated rate of quarterly-compounded net nominal return is 6.6 percent.

Inflation-adjusted net rate of return If the nominal rents from the 237 acres are adjusted for inflation, they sum to $240,014. Likewise, the principal, adjusted for inflation with $(1.05)^t$, is re-valued at $150,548. Gross returns, R, are revalued at $390,062. The quarterly-compounded net rate of return to rented land, when rents are adjusted for inflation, would have been 4.55 percent over the 1957-1977 period.

Real constant 1978 dollar rate of net return When all five time-related costs are accounted for, the $157,890 nominal net returns to land are re-valued into $367,155 real constant 1978 dollars; the 1957 dollar principal is re-valuated at $330,118; and R is revalued at $697,293. Therefore, the real constant 1978 dollar rate of net return to rented land would have been a positive 3.57 percent.

The three rates of return are summarized for all five investment options in Table 23. Of these options, land renders the highest rate of real return above the time-related costs of (1) eroded purchasing power from the study period's inflation, (2) the risk encountered in making such an investment as center-pivot irrigation in 1957, (3) the uncertainty, especially of income, of such time-related phenomena as climate variability, (4) the disutility of postponing 1957 consumption of the $54,038 principal and thus waiting over a 21 year period for the total accrued income,[1] and (5) the interest needed to compensate the farmer for waiting for net returns to irrigation.

Table 23a. Nominal, real constant-dollar, and inflation rates of quarterly compounded returns (in percent)

Option	Real constant-dollar	Nominal	Inflation-adjusted
Irrigation	-1.01	2.2	.66
U.S. treasury bills	1.7	3.6	2.3
Bbb corporate bonds	4.3	5.9	2.9
Municipal bonds	3.07	4.46	2.18
Land	4.55	6.6	3.57

Therefore, of all the five investment options discussed, full-center-pivot irrigation of the 320 Moody acres from the Dakota sandstone aquifer appears to have been the worst. However, it is strongly emphasized here that, despite this study's low profitability levels, center-pivot irrigation is profitable in certain areas of Northwest Iowa. As shown by Colbert, (22, p. 70) irrigation appeared profitable even during years of very ample rainfalls along a creek's or river's floodplain such as the Missouri bottomlands.

Note that depreciation for irrigation was computed on the basis of replacement cost in 1977 rather than the original cost in 1957. Therefore,

[1]This is time-preference of income.

in calculating i_f and i_r, a year's depreciation charges were each multiplied by that years $(1.05)^t$ and $(1.09)^t$, respectively. The depreciation charges then did not sum to the replacement 1977 cost in either inflation-adjusted or real constant 1978 dollar values. This would tend to downwardly bias irrigation's i_f and i_r in the formula's, $i_f = 4\ (\frac{R_f}{P_f})^{1/84} - 4$ and $i_r = 4\ (\frac{R_r}{P_r})^{1/84} - 4$, respectively. Such was done in Table 23a.

However, when irrigation's depreciation is computed upon the original 1957 replacement cost, then as seen in Table 23b that i_f and i_r taken on larger values than those in Table 23a. Simply, the original principal of \$54,038 is adjusted with $(1.05)^{21}$ or $(1.09)^{21}$, depending upon whether i_f or i_r is being calculated. These adjusted original principals are added to the net returns (inflation-adjusted or real constant 1978 dollar) to form a larger R_f and R_r for Table 23b's calculations than those used to calculate Table 23a's i_f and i_r. Nonetheless, the i_f and i_r of irrigation still remains the lowest of the 5 options even though irrigation i_f and i_r in Table 23b are slightly larger than those of Table 23a. The basic conclusions remain unchanged.

Table 23b. Irrigation rates using original 1957 replacement costs

Option	i_r	i_f	i_n
Irrigation	2.2	.71	1.3

McGrann et al. (47, pp. 3-8) demonstrate the tillage practices, costs, input requirements, and yields to be similar to those of continuous-corn in the following alternative rotations: (1) soybeans-corn, (2) corn-corn silage, and (3) corn-soybeans. According to Shaw,[1] these yields are similar to those of the continuous-corn rotation when grown by a capable (financially successful) farmer on Moody soil. Therefore, the conclusions of this study regarding irrigation's unprofitability may be extended to such corn rotations. However, the farm cultivating corn under such rotations must be grown upon a scenario identical or similar to that of this study if its conclusions are to be relevant. The conclusions may not be extended to farm operations of different sizes, management levels, soil-types, or crops (e.g., alfalfa or soybeans).[2] Neither may these results be extended to scenarios using alternative methods of irrigation such as tow-line, traveling-gun, or gated pipe which have, relative to the center-pivot method, lesser initial and depreciation costs but more substantial variable costs (40, p. 1-8).

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[1] This option was stated by Robert Shaw, Iowa State University Professor of Agricultural Climatology and Agronomy. Private communication, Ames, Iowa, April, 1978.

[2] As noted previously, these conclusions are applicable to the 320 acre irrigated corn scenario of a 640 Moody acre farm, where the center-pivot systems are alternated each year to a different 320 corn-cultivated acre tract.

Therefore, on the upland sites of the Moody Association, fully-irrigating a corn crop of 320 acres from the Dakota sandstone aquifer by a capable farmer registered small nominal and inflation-adjusted profits, and a negative real constant 1978 dollar loss. Irrigation appeared to be the worst option examined. Providing the price-cost-yield situations of the 1978-1998 period are not substantially different from those of 1957-1977, irrigation will probably continue being unprofitable through 1998.

Irrigation Activities: Tolerance to Rising Fuel Costs

There are three irrigation activities in the irrigated model, listed in order of marginal productivity: irrigation 1 or Q07-K, irrigation 2 or Q08-K, and irrigation 3 or Q09-K.

Since the variable costs of center-pivot irrigation are principally those of pumping, and since total variable costs and diesel pumping costs are herein assumed one and the same, then the irrigation activities' tolerance (or stability) in solution to increased variable costs reflect the impact of rising fossil fuel costs upon irrigation profitability.

The Q07-K's

Table 24[1] summarizes the range analyses conducted upon the Q07-K solutions of the 16 irrigation years. From the table, it is evident that Q07-K entered solution with much tolerance to rising variable, here diesel, costs.

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[1]The column headings of Tables 21, 22 and 23 which summarize the range analyses conducted upon the Q07-K, Q08-K, and Q09-K are defined identically to those of Table 9.

Table 24. Range analysis summaries of irrigation 1: the Q07-K solutions

Year	Activity[a]	Upper act.	Lower act.	Unit cost below	Unit cost above[b]	Input cost	Nom. input cost	Upper cost	Nom. upper cost	% rise C_7[c]
1958	15.49	15.49	0	-3781.29	-i	-228.34	-37.38	-4009.63	-656.35	1655.9
1959	8.0	8.0	0	-3491.83	-i	-264.67	-51.47	- 375.65	730.55	1319.4
1961	5.0	5.0	0	-2578.29	-i	-204.28	-47.2	-2443.44	564.6	1096.2
1963	19.	19.	0	-1771.79	-i	-174.09	-47.8	-1945.88	-534.29	1017.76
1964	4.	4.	0	-3444.3	-i	-157.74	-47.2	-3602.04	-1077.81	2183.5
1965	3.	3.	0	-2669.22	-i	-144.72	-47.2	-2413.94	-699.26	1381.49
1966	10.	10.	0	-1852.45	-i	-132.77	-47.2	-1985.22	-705.73	1395.2
1967	16.	16.	0	-2012.87	-i	-122.50	-47.48	-2135.37	-827.66	1643.18
1968	20.	20.	0	-2620.15	-i	-130.69	-49.56	-2116.11	-894.	1703.87
1970	19.	19.	0	-1989.16	-i	-103.	-51.82	-2092.16	-1049.75	1925.77
1971	7.	7.	0	-1988.31	-i	-104.05	-56.92	-2092.36	-1144.62	1910.93
1973	6.	6.	0	-1796.64	-i	- 94.	-61.08	-1890.64	-1228.49	1911.27
1974	11.	11.	0	-3649.67	-i	-145.78	-103.24	-3795.45	-2688.	2503.64
1975	6.	6.	0	-2395.24	-i	-135.98	-105.	-2531.26	-1954.61	1761.53
1976	34.4	34.4	0	- 460.39	-i	-139.8	117.68	- 600.19	- 505.21	329.3
1977	7.0	7.0	0	- 917.57	-i	-156.71	-143.77	-1074.28	- 985.58	585.53

[a]One unit equals 66.5 acre-inches.

[b]Here, i refers to infinity.

[c]These data refer to the percent rise in C_7 required to drive the activity level of column 2 down to the lower activity levels.

During every irrigation year, the first irrigation activity, Q07-K, entered solution at upper limit levels. The only constraint during each of these irrigation years on a Q07-K was a limited amount of S14-K, i.e., water allotted for irrigation 1. Such is evident from column 3, the upper activity column, equalling the second or "activity" column.

In all years, the lower activity column (4) is zero. Therefore, the upper cost entries of column 9 represent the costs of application which would have eliminated Q07-K during each irrigation year. The "unit cost below" column (5) contains the amounts by which each C_7 (adjusted cost of applying a water unit of 66.5 acre-inches) would have had to rise in order to drive the particular Q07-K from solution. In other words, if the input cost (C_7) of column 7 during some year rose by the unit cost to equal column 9's upper cost entry, then the optimal activity level found in column 2 would have fallen to column 4's lower activity, zero for all irrigation years.

Column 11's entries are the unit costs in column 5 divided by the corresponding input cost of column 7. The resulting ratio is the percent increase in C_7, that is the required percent rise in diesel fuel pumping costs, needed to make Q07-K too expensive and drive it from solution.

Over the 1957-1977 period, the entries of column 11 indicate that the variable costs of irrigation were many times less than the required levels to preclude the implementation of irrigation 1. In all years except 1976 and 1977, the C_7 would have been required to be at least 10 times larger to have driven even one Q07-K from solution. Even during 1976, C_7 would have been required to have been 3.293 times larger than it was, the lowest such figure.

On the average, the cost of diesel fuel should have been 15.2 times larger for a Q07-K to have been eliminated.

Therefore, the Q07-K solutions were not prone to elimination from rising diesel costs. Even if the O.P.E.C. cartel nations decided to do the improbable and again quadruple the barrel prices of crude oil, diesel prices would not rise to the 300 to 500 percent levels required to drive even the least stable Q07-K's, Q07-76 and Q07-77, from solution. During 1973 to 1974, although the prices of crude quadrupled, the nominal price of diesel in Iowa rose by 72 percent from 1973's 20.7 cents per gallon to 1976's 35.6 cents (89, 1973-1976). Prices did not even rise by 100 percent over three years.

And providing the price-cost-yield scenarios of future 1978-1998 Iowa corn production are not drastically worse for the farmer than those of the 1957-1977 period, rising energy prices will not preclude at least the first half of a year's yield maximizing application, i.e., the agronomically optimal amount of irrigation water.[1]

Figure 16 summarizes the Q07-K tolerance to rising diesel prices. The histogram is constructed from the computer results of this study's irrigated linear program. At least for the first half of a year's agronomically optimal seasonal irrigation application, rising diesel prices plainly did not, and apparently will not, preclude its application.

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[1]Throughout the remainder of this study, the agronomically optimal amount of irrigation water refers to the total required to maximize yields. These amounts were obtained from Ross. The economically optimal amount refers to that required to maximize profits.

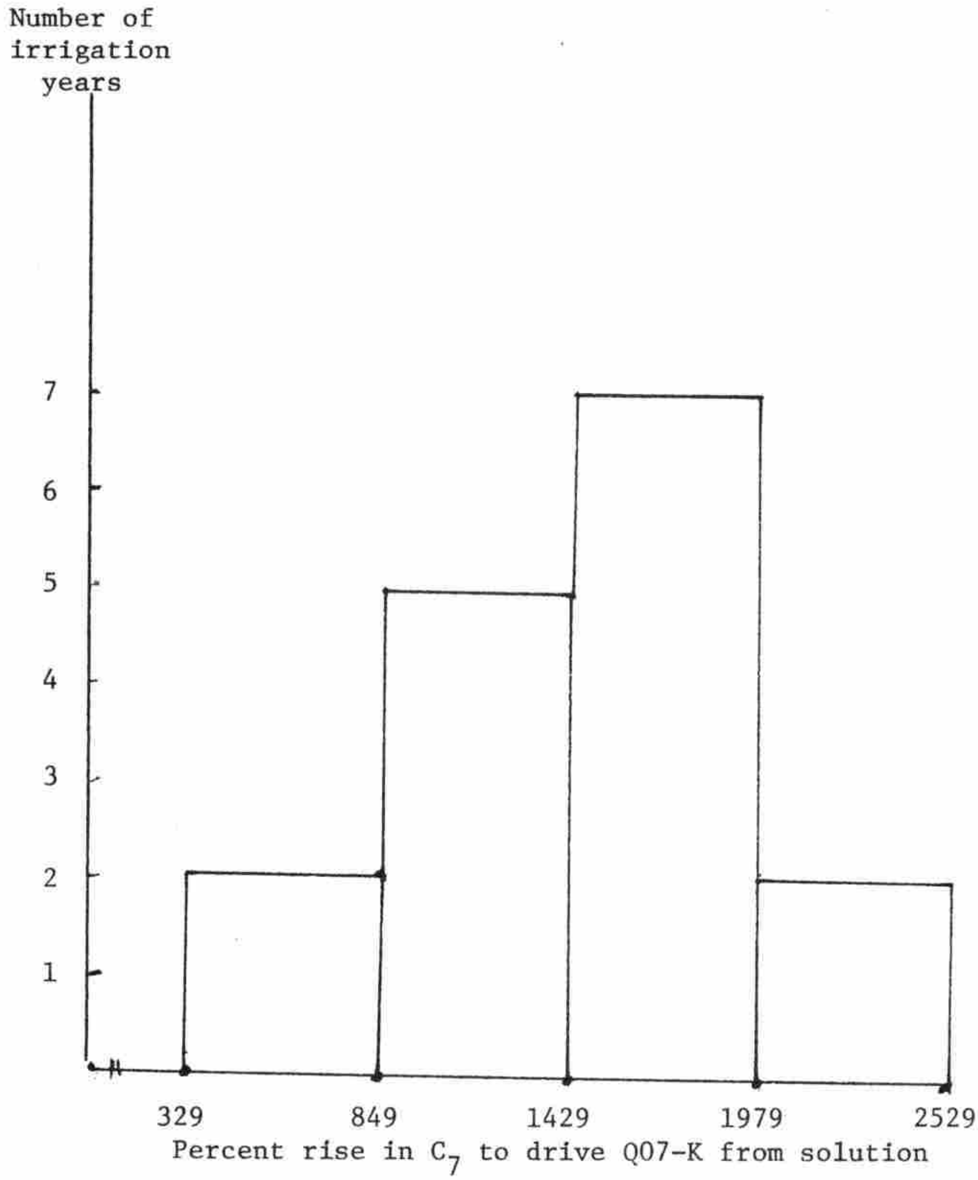

Figure 16. Q07-K sensitivity to rising diesel costs.

The Q08-K's

As explained in Chapter 3, Q08-K is irrigation 2 which applies, after Q07-K has already reached its upper limit, the next 30 percent of the agronomically optimal water application. Such an application is assumed to bring about 30 percent of the total irrigation-induced yield response.

Table 25, whose columns are defined identically with those of Table 24, summarizes the range analyses conducted upon the Q08-K solutions of the 16 irrigation years.

As with irrigation 1, irrigation 2 entered solution at the upper activity level during every irrigation year. During each such year, S15-K, irrigation 2's limit of applied water, was the limiting factor.

As with Q07-K, irrigation 2 or Q08-K solutions also proved tolerant to rising water application (diesel) costs. The range of the percent increases in C_8 required to drive a Q08-K from solution was 229 percent in 1976 to 1659.9 percent in 1964. The average C_8 increase required to eliminate irrigation 2 was 1127.5 percent. That is over the 16 irrigation years of the 1957-1977 period, C_8 could have been, on the average, over 11 times larger and still have been included at upper limit levels in the optimal solution.

Figure 17 summarizes this tolerance of the irrigation 2 activity levels to rising diesel prices.

Thus far, the agronomically and economically optimal amounts of water applied by irrigation coincide through 80 percent of the former. With such a stable 1957-1977 string of Q08-K solutions, rising prices of diesel cannot be seriously considered a factor in making future irrigation unprofitable with respect to the first 2 irrigation activities.

Table 25. Range analysis summaries of irrigation 2: the Q08-K solutions[a]

Year	Activity	Upper act.	Lower act.	Unit cost below	Unit cost above	Input cost	Nom. input cost	Upper cost	Nom. upper cost	% rise C_8
1958	9.3	9.3	0	-2852.19	-i	-228.34	-37.38	-3080.53	-549.7	1249.4
1959	4.8	4.8	0	-2620.68	-i	-264.67	-51.47	-2885.35	-561.13	990.2
1961	3.0	3.0	0	-2239.16	-i	-204.28	-47.2	-2443.44	-564.57	1096.1
1963	11.4	11.4	0	-1380.62	-i	-174.09	-47.8	-1554.75	-426.88	793.
1964	2.4	2.4	0	-2618.31	-i	-157.74	-47.2	-2776.05	-830.66	1659.9
1965	1.8	1.8	0	-1709.9	-i	-144.72	-47.2	-1854.62	-604.76	1181.5
1966	6.0	6.0	0	-1392.17	-i	-132.77	-47.2	-1524.94	-542.1	1048.5
1967	9.6	9.6	0	-1520.	-i	-122.5	-47.48	-1642.5	-636.63	1240.8
1968	12.	12.	0	-1985.42	-i	-130.69	-49.56	-2116.11	-894.	1519.2
1970	11.4	11.4	0	-1511.5	-i	-103.	-51.82	-1614.5	-810.1	1467.5
1971	4.2	4.2	0	-1506.16	-i	-104.05	-56.92	-1610.21	-880.86	1447.5
1973	3.6	3.6	0	-1420.16	-i	- 94.	-61.08	-1514.16	-983.86	1510.8
1974	6.6	6.6	0	-1242.54	-i	-145.78	-103.24	-1388.28	-983.2	852.3
1975	3.6	3.6	0	-1804.58	-i	-135.98	-105.	-1940.56	-1498.5	1327.1
1976	20.64	20.64	0	- 320.17	-i	-139.8	-117.68	- 459.92	-387.14	229.
1977	4.2	4.2	0	- 668.38	-i	-156.71	-143.77	- 825.09	-756.96	426/5

[a]All columns are identified identically to those of Table 24.

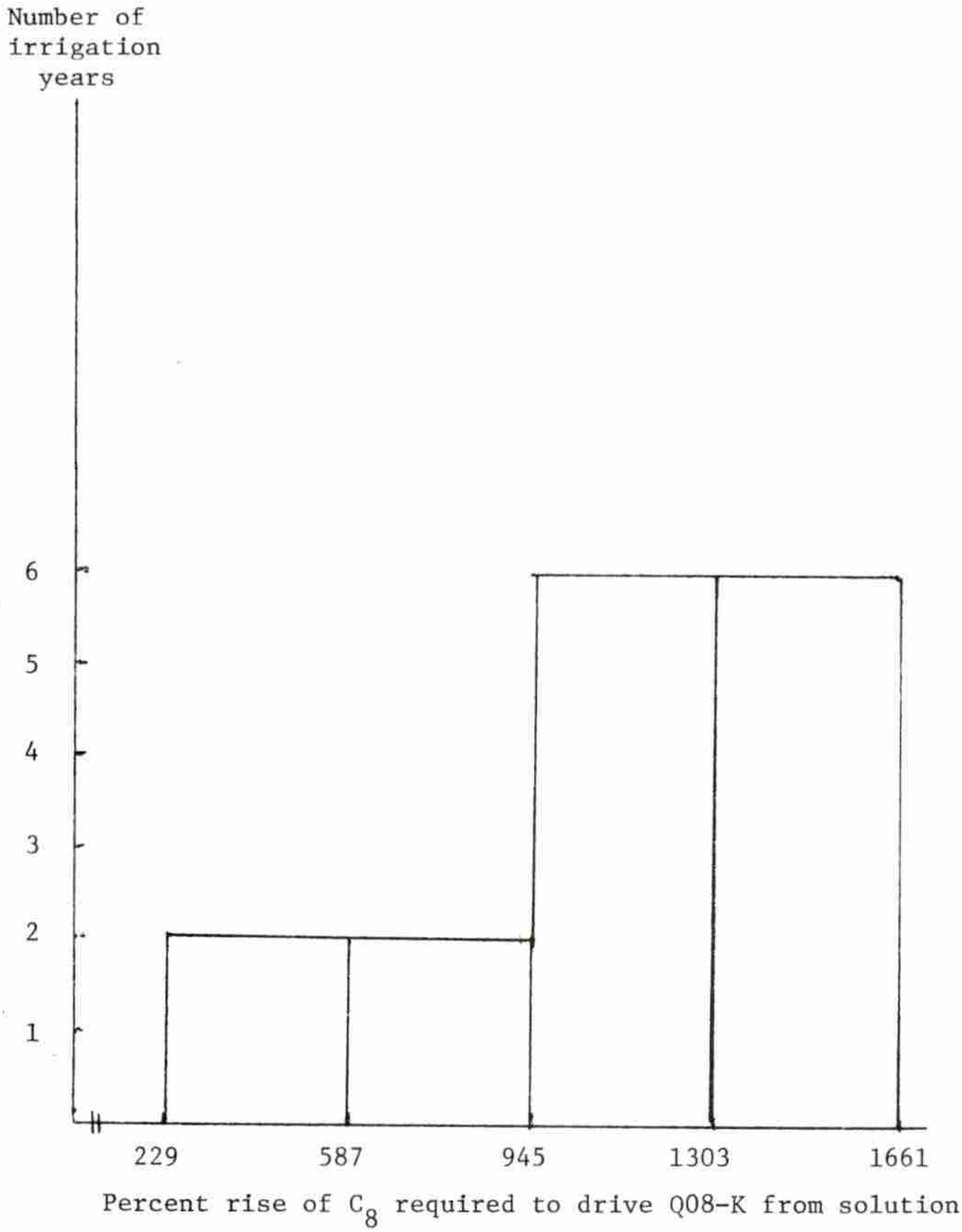

Figure 17. Q08-K sensitivity to rising diesel costs.

The Q09-K's

As expected from Q09's low productivity assumptions, the irrigation 3 activities were the least tolerant to rising diesel costs of the three irrigation activities. Such is demonstrated in Table 26 summarizing the range analyses conducted upon the 16 Q09-K's.

In 1974 and 1976, Q09-K was excluded from solution. As indicated from the irrigated model's range analysis, Q09-76 would have entered at the upper activity level if application costs had been 21 percent smaller. With Q09-76, the C_9 would have been required to be 145.78 percent smaller, that is the C_9 of -145.78 would have had to have been +354.81 if Q09-K was to enter. Thus Q09-76 may be indubitably considered non-solution material. This is consistent with the findings of Beer et al. (10) and of Noffke (52), who contend that the worse the weather and required total yield-maximizing application, the lesser the marginal product per acre-inch of applied water. 1976 had the highest agronomically optimal amount of applied irrigation water, 4522 acre-inches (17 inches per acre upon 266 acres). This is at least 70 percent larger than any other such application calculated by Ross.

Of the 14 Q09-K entering solution, only in 1977 when C_9 was required to be 29 percent larger, could some rise in diesel prices have conceivably driven a Q09-K from solution. In all other years aside from 1975, 1976, and 1977, diesel prices were required to have been at least 121.9 percent higher than the realized levels to have pushed even one Q09-K from solution. Such is evident from column 11 of Table 26. On the average, diesel prices were required to have been 234.3 percent higher for Q09-K to have been driven from solution. So during all years except two,

Table 26. Range analysis summaries of irrigation 3: the Q09-K solutions

Year	Activity	Upper activity	Low activity	Unit cost below	Unit cost above	Input cost	Nom. input cost	Upper cost	Nom. upper cost	% rise C_9
1958	6.2	6.2	0	-537.88	-i	-228.34	-37.38	-765.72	-136.64	235.3
1959	3.2	3.2	0	-429.58	-i	-264.67	-51.47	-694.25	-135.02	162.3
1961	2.0	2.0	0	-333.61	-i	-204.28	-47.2	-537.89	-124.28	163.3
1963	7.6	7.6	0	-212.2	-i	-174.09	-47.8	-386.29	-106.07	121.9
1964	1.6	1.6	0	-532.69	-i	-157.74	-47.2	-690.43	-206.59	337.7
1965	1.2	1.2	0	-316.33	-i	-144.72	-47.2	-461.05	-150.38	218.6
1966	4.0	4.0	0	-245.56	-i	-132.77	-47.2	-378.33	-134.49	185.
1967	6.4	6.4	0	-269.6	-i	-122.8	-47.48	-392.10	-151.98	220.1
1968	8.0	8.0	0	-395.33	-i	-130.69	-49.56	-526.02	-222.23	302.5
1970	7.6	7.6	0	-295.87	-i	-103.	-51.82	-398.87	-200.14	287.3
1971	2.8	2.8	0	-479.17	-i	-104.05	-56.92	-583.22	-319.05	460.5
1973	2.4	2.4	0	-284.53	-i	- 94.	-61.08	-378.53	-245.96	302.7
1974	0				-i	-145.78	-103.24			
1975	2.4	2.4	0	-346.12	-i	-135.98	-105.	-482.10	-372.2	254.5
1976	0				-i	-139.8	-117.68			
1977	2.8	2.8	0	- 45.38	-i	-156.71	-143.77	-202.09	-185.4	29.

Q09-K was found to maximize profits in, rather than out, of solution.

This Q09-K tolerance to rising costs of diesel is summarized in Figure 18. As seen from this figure, more often than not, the economically optimal seasonal application of irrigation water equals 100 percent of the agronomic optimum, even when the last fifth of the agronomic optimum brings about only five percent of the total yield response.

Therefore, it appears that during the study period, the economically and agronomically optimal seasonal water applications coincided through 80 percent of the agronomic optimum. During over 90 percent of the time, the economic optimum equalled the agronomic optimum. This conclusion is realized despite the possible underestimation of the marginal productivity assumption of the last half of a year's agronomically optimal seasonal application.[1]

Therefore, variable or diesel costs did not appear to be a limiting factor in center-pivot irrigation feasibility from 1957 through 1977, even despite the sharp rise in diesel costs since 1973. Even with irrigation 3, whose low marginal product was assumed such that the last fifth of the agronomic optimum brought about 5 percent of a year's total irrigation response, was included in solution at upper limit levels in all irrigation years except 1974 and 1976.

The above implies that rising diesel prices were not an issue greatly affecting irrigation profitability, and providing that the 1978-1998 scenarios of price-cost-yield-weather are not substantially different from those of the study period, neither will diesel costs be

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[1]This problem of underestimation was discussed earlier.

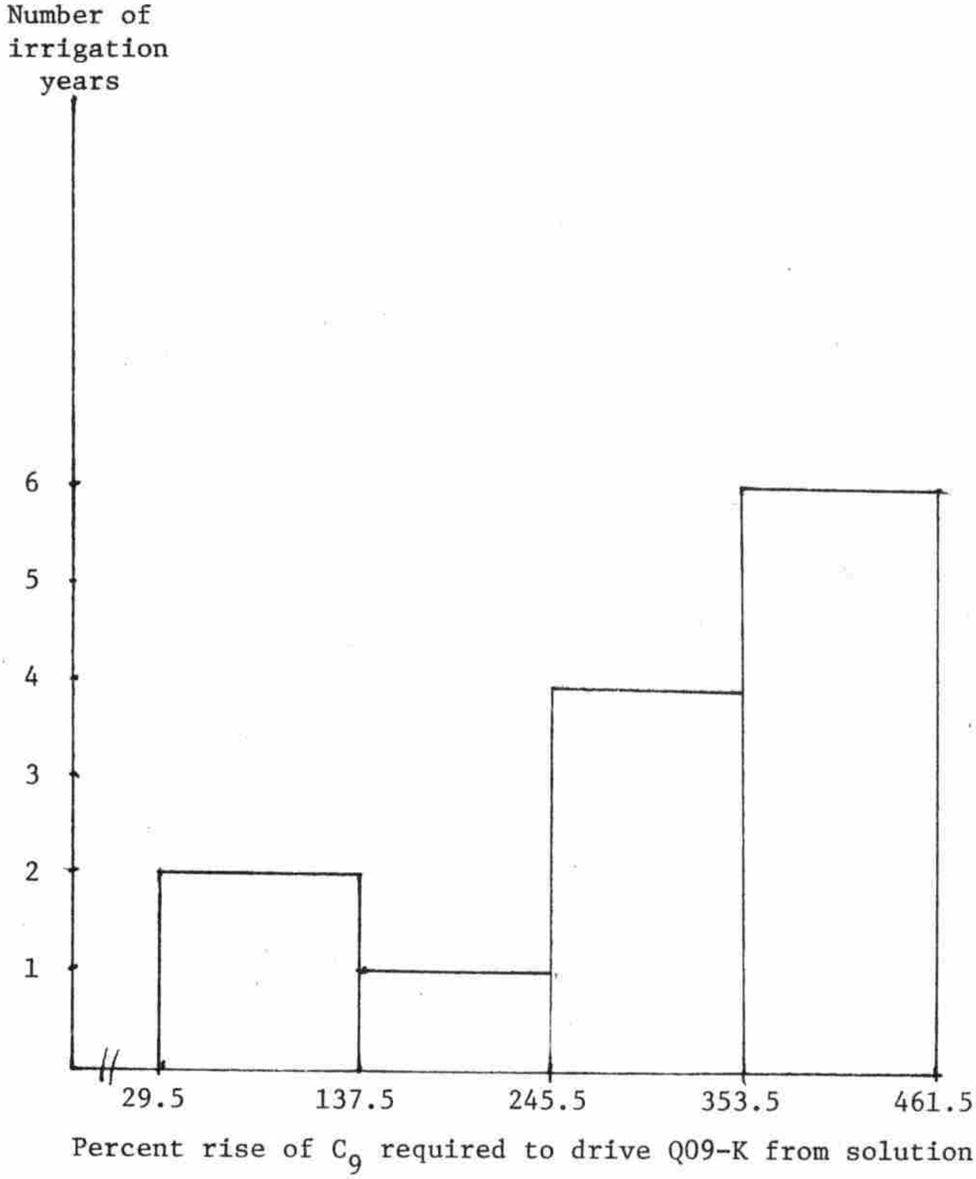

Figure 18. Q09-K sensitivity to rising diesel costs.

a future major limit on irrigation profitability.

The reasons lie in the minor role of variable (diesel) costs in the total cost of the irrigation investment. Table 27 lists variable, fixed, and total costs attributable solely to irrigation. Also listed in column 5 are the annual percentages of the total irrigation-related costs comprised by variable costs. On the average, the irrigation-related variable costs comprised 16 percent of the total costs attributable to irrigation.

In all years, Table 27's entries indicate the fixed costs as being substantial. Therefore, irrigation's unprofitability is, for the most part, attributable to the fixed costs and not the variable costs of irrigation. Therefore, should the farmer of this study re-invest, the optimized solutions will probably include irrigation activities since his investment's unprofitability culprit, the added fixed costs, do not affect the level of the annual irrigation activities.[1] However, such an investment will probably be unprofitable because of the large fixed cost magnitudes.

Value Productivity of Water

In Chapter 3, Iowa water supplies are established as scarce inputs whose volumes superfluous to consumptive demands would be allocated with

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[1] Such is demonstrated by Baumol (9, p. 70). Assume π is profit, Q is output, and C is cost. Assume also that P is Q's market price and K is a level of fixed cost. Thus, $\pi = PQ - C(Q) - K$. In maximizing π :

$$\frac{\partial \pi}{\partial Q} = \frac{\partial (PQ)}{\partial Q} - \frac{\partial C(Q)}{\partial Q} - \frac{\partial K}{\partial Q} = 0$$

Therefore: MC = MR and $\frac{\partial K}{\partial Q} = 0$. Thus, fixed cost levels do not affect optimal solutions.

Table 27. Calculation of irrigation variable cost percentage of total irrigation cost[a]

Year	Irr-related V.C.	Total irr-related fixed costs	Total irr-related costs	% variable costs of total
1957	0	30880	20880	0.
1958	8939	27370	36309	29.
1959	4235	28075	32310	13.
1960	0	25830	25830	0.
1961	2042.8	23691	25733.8	8.
1962	0	21740	21740	0.
1963	6615	19958	26573	25.
1964	1262	16356	17618	7.
1965	868	16924	17792	5.
1966	2675	15719	18394	15.
1967	3920	14613	18533	21.
1968	5228	13587	18815	28.
1969	0	11164	11164	0.
1970	3914	10475	14659	27.
1971	1457	9783	11240	13.
1972	0	9072	9072	0.
1973	1128	8461	9589	12.
1974	2624	8351	10975	24.
1975	1632	8329	9961	16.
1976	7689	7907	15596	49.
1977	1648	7874	9522	17.

[a]All costs are adjusted with $(1.09)^t$.

less waste by the I.N.R.C. if the Council would use marginal analysis criteria (17, p. 877).

To so allocate, three conditions or criteria must be met: (1) Water must be allocated to a use, e.g. a farm, such that "...marginal outlay (cost) equals marginal value product (revenue)." (88, p. 1251). (2) A single user so allocates water among competing sub-uses or enterprises such that his R.P.T. equals the ratio of the two outputs' market prices (88, p. 1251). (3) Water is allocated among users, e.g. farms and factories, such that water's M.V.P. is equal in all uses (9, p. 23).

Only one output, corn, is assumed for this study's farm, and hence criterion 2 is not dealt with here. This study deals only with the economic effect of center-pivot investment on corn production, because, as seen above, less than a mere 5 percent of all Iowa irrigated cropland is cultivated with non-corn crops.[1]

Discussed below are the results of the range analyses conducted upon the irrigation water resource constraints, S14-K, S15-K, and S16-K, which were applied by irrigation activities 1, 2, and 3, respectively.

<u>S14-K of irrigation 1</u>

As explained in Chapter 4, the first one half of a year's seasonal yield maximizing irrigation level, or "agronomic optimum," brings about 65 percent of the season's total corn yield response to irrigation. Row S14-K corresponds to this first 50 percent of the agronomic

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[1]Only 10,000 acres of soybeans are irrigated in Iowa. This information was obtained from the yet unpublished results of a survey by Iowa State University Professor of Agricultural Engineering and Iowa irrigation specialist, Dr. Stewart Melvin. Private communication. Ames, Iowa, April, 1978.

optimum calculated earlier for some year K by Ross.

Table 28 demonstrates that S14-K entered solution at upper limit levels during all irrigation years, as evident with the slack activity entries of column 3 all equalling zero.

Columns 8 and 10 list the real constant 1978 shadow prices and the nominal shadow prices for S14-K, respectively.[1]

The nominal shadow price per acre inch of S14-K applied through irrigation 1 is \$5.82 to \$38.87 and the range of real constant 1978 dollar M.V.P.'s is \$6.92 to \$56.86. This variation cannot be fully explained due to the lack of agronomic research relating corn yield response to levels of irrigation application (22, p. 31). However, it is generally attributable to the variability of the Northwest Iowa subhumid climate and its varying levels of yield benefit over the study period. However, noting Table 28, it is clear that the larger the applied level of S14-K, the lower the water's M.V.P. This negative relationship between amounts applied and S14-K's M.V.P. coincides with the findings of Beer et al. (10, p. 13), Colbert (22, pp. 71-72), Noffke (52, p. 44), and Palmer-Jones (54, p. 85). Thus, the worse the weather, then the larger the agronomic optimum, and hence the lower the M.V.P. of an acre-inch of S14-K.

According to Henderson and Quandt (33, p. 68), a perfectly competitive firm uses a scarce productive input such as water to the point where its M.V.P. (shadow price in Table 28) equals the input price, here the cost per acre-inch in Table 28. In all irrigation years, the S14-K shadow

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[1]According to Beneke and Winterboer (11, p. 122), the shadow price of a resource unit is its marginal value product or M.V.P.

Table 28. Range analysis summaries of irrigation 1 water allotments

Year	Activity[a]	Slack	Lower limit	Upper limit	Lower act.	Upper act.	Shadow price	Nom. shadow price	Con.dol. cost ac.-in.[b]	Nom. cost ac.in.[c]
1958	1030	0	0	1030	0	21363	56.86	10.14	4.34	.77
1959	532	0	0	532	0	28435	52.51	10.21	3.98	.77
1961	332	0	0	332	0	1351	38.77	8.96	3.07	.71
1963	1263	0	0	1263	0	47479	26.64	7.31	2.62	.72
1964	266	0	0	266	0	1999	51.79	15.5	2.37	.71
1965	199	0	0	199	0	43039	34.12	11.2	2.18	.71
1966	665	0	0	665	0	45279	27.85	4.95	2.00	.71
1967	1064	0	0	1064	0	17299	30.27	11.73	1.84	.71
1968	1330	0	0	1330	0	33942	39.40	16.65	1.97	.83
1970	1263	0	0	1263	0	36538	29.91	15.01	1.55	.78
1971	465	0	0	465	0	18876	29.90	16.35	1.56	.85
1973	399	0	0	399	0	10974	27.02	17.56	1.41	.92
1974	731	0	0	731	0	28623	54.88	38.87	2.19	1.55
1975	399	0	0	399	0	32084	36.09	27.87	2.04	1.57
1976	2288	0	0	2288	0	16231	6.92	5.85	2.10	1.77
1977	465	0	0	465	0	21819	13.8	12.66	2.36	2.17

[a]These data are in acre-inch terms.

[b]These data are the application costs of one acre-inch of water applied through Q07-K. These costs are adjusted with $(1.09)^t$.

[c]These are the nominal costs per acre-inch.

prices exceed the marginal input costs, and hence upper limit use of half the agronomic optima from 1957-1977 was justified. Therefore, the economically and agronomically optimal irrigation levels coincided every year through one half of the latter.

S15-K of irrigation 2

As assumed in Chapter 4, after irrigation 1 has reached its upper limit, the program may, if profitable enough, engage irrigation 2 such that 30 percent of the season's agronomic optimum causes thirty percent of the total irrigation yield response. Row S15-K is the resource row corresponding to water applied through irrigation 2. Table 29 summarizes the range analyses conducted upon S15-K.

As with S14-K, S15-K entered solution at maximal levels during all irrigation years. Column 8 lists the annual S15-K shadow prices adjusted with $(1.09)^t$ and column 10, the corresponding nominal figures. The former range from \$4.81 to \$42.89 and the latter, from \$4.05 to \$20.96. The same conclusions regarding the reasons and explicability of this variation as those made above for S14-K hold here.

During every irrigation year, the shadow price per acre-inch of S15-K in Table 29's column 8 exceeds the water unit's marginal outlay of column 11, thereby economically justifying its use.[1]

Therefore, for every irrigation year, full use of S14-K or 50 percent of a year's agronomic optimum as well as S15-K or 30 percent of a

[1]Tables 29 and 30 are set up identically to Table 28. The columns in these three tables are identically defined. Also, note that the same conclusion is obtained by comparing columns 10 and 12 which list the nominal M.V.P.'s and the nominal marginal outlays, respectively.

Table 29. Range analysis summaries of irrigation 2 water allotments[a]

Year	Acti-vity	Slack	Lower limit	Upper limit	Lower act.	Upper act.	Shadow price	Nom. shadow price	Con.dol. cost ac.-in.	Nom. cost ac.-in.
1958	618	0	0	618	0	20951	42.89	7.65	4.34	.77
1959	319	0	0	319	0	28222	39.41	7.66	3.98	.77
1961	199	0	0	199	0	1218	33.67	7.78	3.07	.71
1963	758	0	0	758	0	46974	20.76	5.70	2.62	.72
1964	159	0	0	159	0	1892	51.79	15.5	2.37	.71
1965	120	0	0	120	0	42959	25.71	8.39	2.18	.71
1966	399	0	0	399	0	45013	20.93	7.44	2.00	.71
1967	638	0	0	638	0	16873	22.86	8.86	1.84	.71
1968	798	0	0	798	0	33410	29.86	12.62	1.97	.83
1970	758	0	0	758	0	36032	22.73	11.40	1.55	.78
1971	279	0	0	279	0	18690	22.65	12.39	1.56	.85
1973	159	0	0	159	0	10735	20.28	12.09	1.41	.92
1974	439	0	0	439	0	28330	18.68	13.23	2.19	1.55
1975	239	0	0	239	0	31924	27.14	20.96	2.04	1.57
1976	1373	0	0	1373	0	15315	4.81	4.05	2.10	1.77
1977	279	0	0	279	0	21633	10.05	9.22	2.36	2.17

[a]The columns here are defined identically to those of Table 28.

year's agronomic optimum has been economically justified. Therefore, the economically and agronomically optimal irrigation application levels coincided through 80 percent of the agronomic optimum for every irrigation year of the study.

S16-K of irrigation 3

After irrigation activities 1 and 2 have entered solution at upper levels, if profitable, Q09-K enters such that the final 20 percent of the agronomic optimum of year K brings about five percent of the total irrigation yield response. The last one fifth of the agronomic optima are the S16-K's. Table 30 summarizes the range analyses conducted upon the solution S16-K levels.

Note that despite the low productivity of S16-K, this resource still entered solution at upper limits during all years except 1974[1] and 1976. Since 1976 had the largest agronomic optimum of all irrigation years, 4575 acre-inches,[2] and since Beer et al. (10, p. 13) concluded the larger application levels as having lower M.V.P.'s, then elimination of S16-76 was expected.

As seen in Table 30, the constant 1978 dollar M.V.P.'s of an acre-inch of S16-K ranged from \$8.08 to \$-7.52. In nominal terms, the range was from \$6.06 to \$-5.33. This variation occurred due to Northwest Iowa's climatic variability, as noted in the S14-K discussion.

[1]According to Shaw (66, p. 335), the yield reductions of 1974 were caused largely by excess soil moisture. Shaw's model cannot handle yield reductions from excess moisture, but rather, only reductions from soil moisture stress. Hence, 1974 is not discussed.

[2]17.2 inches/acre x 266 acres = 4575 acre-inches.

Table 30. Range analysis summaries of irrigation 3 water allotments

Year	Acti-vity	Slack	Lower limit	Upper limit	Lower act.	Upper act.	Shadow price	Nom. shadow price	Con.dol. cost ac.-in.	Nom. cost ac.-in.
1958	412	0	0	412	0	20745	8.08	1.44	4.34	.77
1959	213	0	0	213	0	28115	6.46	1.25	3.98	.77
1961	133	0	0	133	0	1152	5.01	.88	3.07	.71
1963	505	0	0	505	0	46721	3.19	2.4	2.62	.72
1964	106	0	0	106	0	1839	8.01	1.55	2.37	.71
1965	80	0	0	80	0	42919	4.76	1.31	2.18	.71
1966	266	0	0	266	0	44880	3.69	1.57	2.00	.71
1967	426	0	0	426	0	16661	4.05	2.51	1.84	.71
1968	532	0	0	532	0	33144	5.94	2.23	1.97	.83
1970	505	0	0	505	0	35780	4.44	6.06	1.55	.78
1971	186	0	0	186	0	18597	7.2	2.77	1.56	.85
1973	160	0	0	160	0	10735	4.27	-5.33	1.41	.92
1974	0	293	0	293	0	27076	-7.52	4.02	2.19	1.55
1975	160	0	0	160	0	31844	5.2	6.06	2.04	1.57
1976	0	915	0	915	0	13943	- .44	- .75	2.10	1.77
1977	186	0	0	186	0	21540	.68	.62	2.36	2.17

Noting the shadow prices and marginal costs (or outlays) per acre-inch of S16-K in Table 30, only during 1974 and 1976 did the marginal outlays exceed the shadow prices. Therefore, in all years except 1974 and 1976, the S14-K were part of the economically optimal irrigation application levels. Hence, aside from 1974 and 1976, the economic and agronomic optima coincided. As discussed later, the I.N.R.C. often allocated up to 18 inches/acre[1] of water to an irrigator, thereby significantly over-allocating water to irrigators during all irrigation years. Therefore, much scarce irrigation water could have been conserved through the I.N.R.C. basing irrigation allocation decisions more in line with the agronomically determined corn crop water requirements based on soil moisture analysis, rather than on a flat "18-inch rule." More on this is discussed below.

<u>1957-1977 allocation policy according to criterion 1</u>

According to Wiegand[2] the I.N.R.C. would have been willing to allocate up to 18 acre-inches of water for each irrigated acre to irrigators over the study period. In the case of this study's 320 acre farm, of which 266 acres are actually irrigated, the I.N.R.C. annual limit would have been 18 inches/acre x 266 acres = 4788 acre-inches. This 4788 acre-inch limit is hence referred to as the "I.N.R.C. allocation," which since 1978, has been changed to 12 inches.[3]

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[1]That is, 18 acre-inches for each irrigated acre.

[2]This information was obtained from Jim Wiegand, Deputy Iowa Water Commissioner. Private communication, Des Moines, Iowa, April, 1978.

[3]This information was obtained from Deputy Iowa Water Commissioner, Jim Wiegand. Private communication, Des Moines, Iowa, August, 1978. Note that this study uses the 18-inch figure because this was the prevailing allocation through 1977, the purview of this study. Thus since 1977, the I.N.R.C. policy has moved more towards an economic optimal one.

The economically optimal and agronomically optimal seasonal application levels are compared with the I.N.R.C. allocations for the 16 irrigation years of the 1957-1977 period in Table 31. Columns 2 and 3 list the agronomic and economic optima, respectively. Column 4 lists the actual I.N.R.C. allocation levels. Column 5 lists the following ratio for the 16 irrigation years: $\frac{\text{I.N.R.C. - economic optimum}}{\text{economic optimum}}$. Thus, the column 5 entries are the amounts of water allocated by the I.N.R.C. over the economically optimal levels, as a percent of the economically optimal level.

In studying Table 31's entries, it is clear that the I.N.R.C. would not have allocated irrigation water to the farm according to the first marginal analysis criterion. During each irrigation year, the I.N.R.C. allocation (column 4) greatly exceeds the economic optimum. Aside from the unusually large 1976 economic optimum, the I.N.R.C. allocation would have exceeded all economic optima by no less than 80 percent. During 1976, the I.N.R.C. allocation was 31 percent above the economically optimal irrigation level of the simulated irrigated scenario.

The I.N.R.C. over-allocations, as percentages of the seasonal economic optima, range from 800 percent in 1961 to the 31 percent in 1976. The average percent is 345. Therefore, the I.N.R.C. would not have allocated irrigation water to the farm such that the M.V.P. per acre-inch equals the marginal cost or outlay. Rather the I.N.R.C. allocated, on the average, nearly three and a half times the amount required to maximize profits each year.

Figure 19 is similar to Figure 3 of Chapter 2, and is drawn for a hypothetical season. The I.N.R.C. did not aim for the economically

Table 31. Summary of profit and yield-maximizing irrigation applications

Year	Agron. opt. (acre-inches)	Econ. opt. (acre-inches)	I.N.R.C. alloc. (acre-inches)	% over-alloc. (acre-inches)
1958	2062	2062	4788	132
1959	1064	1064	4788	350
1961	532	532	4788	800
1963	2527	2527	4788	89
1964	532	532	4788	800
1965	1330	1330	4788	260
1966	2128	2128	4788	125
1967	2660	2660	4788	80
1968	2527	2527	4788	89
1970	665	665	4788	620
1971	931	931	4788	414
1973	798	798	4788	500
1974	1463	1170	4788	309
1975	798	798	4788	500
1976	4575	3660	4788	31
1977	931	931	4788	414

optimal allocations coincidental with point A on water's total value product function, GAL. From the percentages of over-allocation in Table 31's column 5, it is clear that the I.N.R.C. was aiming for point L. In other words, instead of allocating such that M.V.P. equals marginal outlay for water, the I.N.R.C. was allocating according to the cost-benefit analysis criterion of a non-negative M.V.P. (88, p. 1251).

Every increment of water allocated beyond point A has a marginal cost or outlay exceeding marginal value product. This is illustrated by the fact that after point A, the slope of a tangent to GAL, e.g. ZB, is less steep than OL. Instead of maximizing net returns to water at π_M, returns are realized at near or equal to zero at point L.

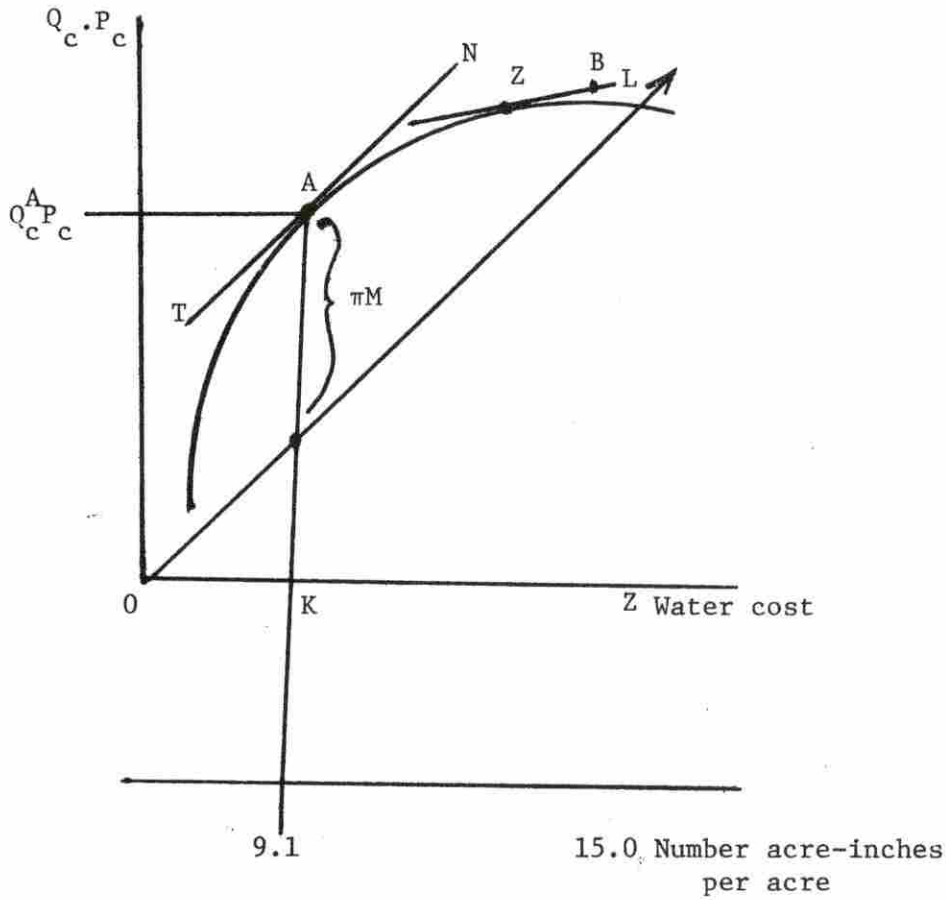

Figure 19. Optimum irrigation water allocation to a use.

Therefore, as Timmons (88, p. 1252) contends to happen frequently, the first criterion of water allocation has been violated by the I.N.R.C. through its use of the unity benefit-cost ratio criterion. The Council would have allocated irrigation water to a use with greater economic efficiency by gearing amounts to Ross' estimated agronomic optima, since they would have coincided with the economically optimal applications in all years except 1974 and 1976. And even in 1974 and 1976 the economic optima were 80 percent of the agronomic optima. In allocating more in line with agronomic water requirements for yield-maximization, rather than the "18 inches/acre rule," the I.N.R.C. allocations would have been closer in line with the amounts required such that irrigation water's M.V.P. and marginal outlay were equated. The over-allocations of irrigation water should have been elsewhere directed so as to have increased the gross value product from water use in production. Since 1978, with the new 12-inch limit, the gap between the I.N.R.C. allocations and the economic optima has narrowed.

<u>1957-1977 allocation policy among competing uses</u>

Criterion 3 established in Chapter 2 deals with water allocation among users such that the M.V.P. for water is the same among users.

According to Iowa's water law, i.e., the Iowa Code (37):

> "It is hereby declared that the general welfare of the people of the state of Iowa requires that the water resources of the State be put to beneficial use that waste or unreasonable methods of the use of water be prevented, and that the conservation of such water be exercised with the view to the reasonable and beneficial use thereof in the interest of the people."

As seen below, the above statement violates criterion 3 of allocating water to competing uses because of the law's lack of defined parameters to

Therefore, as Timmons (88, p. 1252) contends to happen frequently, the first criterion of water allocation has been violated by the I.N.R.C. through its use of the unity benefit-cost ratio criterion. The Council would have allocated irrigation water to a use with greater economic efficiency by gearing amounts to Ross' estimated agronomic optima, since they would have coincided with the economically optimal applications in all years except 1974 and 1976. And even in 1974 and 1976 the economic optima were 80 percent of the agronomic optima. In allocating more in line with agronomic water requirements for yield-maximization, rather than the "18 inches/acre rule," the I.N.R.C. allocations would have been closer in line with the amounts required such that the M.V.P. per unit of irrigation water equalled its marginal outlay. The residuals between the economic optima and the actual I.N.R.C. allocations should have been elsewhere directed so as to have increased the gross value product from water use in production. However, economic optimality was clearly the primary theme underlying the 1978 I.N.R.C. decision to lessen the 18 inch/acre limit to 12 inches.

<u>1957-1977 allocation policy among competing uses</u>

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According to Iowa's water law, i.e., the Iowa Code (37):

> "It is hereby declared that the general welfare of the people of the state of Iowa requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that waste or unreasonable methods of the use of water be prevented, and that the conservation of such water be exercised with the view to the reasonable and beneficial use thereof in the interest of the people."

As seen below, the above statement violates criterion 3 of allocating water to competing uses because of the law's lack of defined parameters to measure relative beneficiality between various water uses (22, pp. 83-84).

The Iowa Code (37), as demonstrated in the above statement, requires only that a water use be beneficial to a user without imposing damage or cost upon another user. Yet no "relative beneficiality" parameters exist which indicate which competing use has the highest marginal benefit, so as to justify allocation thereto of the next scarce water unit, in order to maximize total water use benefits among all uses. Allocating water to uses with the highest marginal benefit will eventually result in an equilibrium where the marginal benefit of all water uses is equal (9, p. 23).[1]

Timmons (87, p. 148) interprets the beneficiality of water use mentioned above in the Iowa Code (37) as a use in which water has a non-negative M.V.P. If benefit of use is positively related with M.V.P., then water M.V.P. data, such as those in Tables 28, 29, and 30, would serve as a parameter set usable in discerning the relative benefit between competing uses. However, data reflecting water's M.V.P. in non-irrigation uses are lacking in Iowa (22, p. 73). Consequently, the I.N.R.C. is unable to discern relative water use beneficiality since no M.V.P. data, or those of any other benefit indicator, are available for non-irrigation Iowa water uses.

<u>Personal income generation of irrigation water</u> Since data reflecting water's M.V.P. in non-irrigation uses were not located in a review of Iowa irrigation literature or by Colbert (22, p. 73), the next

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[1]This is under an assumption of diminishing marginal benefit.

best alternative Iowa water productivity indicator is used: the personal income generated per acre-foot of water calculated by Jeong Rhee.[1]

Rhee is examining the personal income generating power of 1,000,000 gallon increments of water, hence referred to as "water's p.i.g.p." These unpublished results were obtained from Rhee and are converted into p.g.i.p. estimates per acre-foot in Table 32. They are Iowa counterparts developed for Arizona by Young and Martin (102).

For an industry, i, the p.i.g.p. of water per acre-foot is calculated: $\frac{T.R.^i - P.I.P.^i}{No.\ Ac.\text{-}ft.} = \frac{V.A.^i}{No.\ Ac.\text{-}ft.}$, where $T.R.^i$ and $P.I.P.^i$ equal the i's total revenue and payments to intermediate production, respectively, and where $V.A.^i$ equals value added by industry i. $V.A.^i$ equals $(T.R.^i - P.I.P.^i)$. The denominators refer to the number of acre-feet of water used by the industry. According to Rhee,[1] these estimates, listed in Table 33, show a sort of average value added per acre-foot of water used by the industry, where wages, taxes, and profit comprise $V.A.^i$.

However, Rhee's p.i.g.p. data for 10 Iowa industries are not always comparable with such data calculated for the eleventh Iowa water use, the irrigation scenario of this study. Rhee's data are average pre-tax income figures per industry while the M.V.P. data in Tables 28, 29, and 30 reflect the marginal revenue generated per acre-inch of S14-K, S15-K, and S16-K, respectively. In Table 32, these M.V.P. data are converted into p.i.g.p. data.

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[1]Jeong Rhee is a graduate student of Agricultural Economics at Iowa State University. These estimates were obtained in a private communication from him. Ames, Iowa, July, 1978.

Table 32. Derivation of the personal income generating power per acre-foot of irrigation water

Year	Total rev.	Less[a] t.v.c.(r)	Plus charge fam.lab.[b]	Less irr-rel. v.c.	Less int. paid	Less bldg. rep.
1958	36716	12490	2544	1595	526	241
1959	31072	12483	2708	824	829	386
1961	53643	12179	3093	473	547	383
1963	49108	12166	3360	1816	1041	629
1964	54027	12141	3385	378	1454	364
1965	47326	12602	4610	283	1817	438
1966	49752	12800	5280	951	1759	654
1967	30415	14643	5521	1519	2122	456
1968	41123	14522	5711	2209	2479	592
1970	50052	16259	6170	1964	3526	821
1971	50453	17037	6250	797	3872	577
1973	118004	21802	3952	733	6513	1323
1974	77736	25311	3952	1858	6958	973
1975	88953	30016	6512	1260	7274	1730
1976	56494	29370	7184	6472	5857	1469
1977	75317	29555	7876	1512	6292	1638

[a]These data are the nominal total variable costs of the rain-fed scenario.

[b]These data are the annual charges for farm labor.

[c]These data are the annual personal income generating power per acre-inch of irrigation water. These data are in nominal dollars.

[d]These data are the personal income generating power per acre-foot of irrigation water in real constant 1978 dollar terms.

Less ins.	Less irr.-rel. f.c.	Nominal val. added	Econ. opt.	Nom. p.i.g.p. ac.-in.[c]	Nom. p.i.g.p. ac.-ft.	Con.dol. p.i.g.p. ac.ft.[d]
268	4884	19256	2062	9.34	112	628
275	5460	13523	1064	12.71	153	784
312	5474	37368	532	70.24	843	3649
392	5480	30944	2527	12.24	147	535
496	4894	37676	532	70.82	850	2840
517	5520	30579	1330	23.	276	846
616	5588	32664	2128	15.35	184	518
579	5664	10953	2660	4.12	49	127
597	5740	20695	2527	8.19	98	233
587	5256	27809	665	41.8	502	1000
704	5352	28364	931	30.47	366	668
996	5498	77187	798	96.72	1161	1786
1101	5914	39574	1170	33.82	406	573
1530	1567	47186	798	59.13	709	919
1368	6656	12486	3660	3.41	4093	4863
1382	7224	35590	931	38.23	459	500

Table 33. Comparison of water's p.i.g.p.[a] in 11 Iowa uses

	F.I.R.[b]	Ag. prod.[c]	Trans. and wareh.[d]	Ag. serv.	Comm. trade	Live-stock	Gen. serv.[e]	Food proc.	Const.	Mnfg.	Iowa irr.[f]
1958											112
1959											153
1961											843
1963											147
1964											850
1965											276
1966											184
1967	12387	10156	9919	9124	6309	5705	4905	4098	3949	3177	49
1968											98
1970											502
1971											366
1973											1161
1974											406
1975											709
1976											40.9
1977											45.9
Rank	1	2	3	4	5	6	7	8	9	10	11

[a]These figures are in nominal dollar terms. As stated in the text, p.i.g.p. refers to "personal income generating power."

[b]This heading refers to the financial-insurance-real estate industry of Iowa.

[c]This heading refers to general non-irrigation food production.

[d]This heading refers to the transportation and warehousing industry.

[e]This general services column incorporates such industries as legal, medical, etc.

[f]The irrigation use is defined only with respect to the simulated farm of this study.

These are as similar as possible to Rhee's estimates. The value added, i.e., the numerator of the above formula, equals T.R. less irrigation's P.I.P. plus a residual (22, p. 75). This residual, according to Colbert (22, p. 75) represents the value added to personal income by irrigation water.

An indexing problem arises because Rhee's data are based upon the latest available input-output table for the U.S. economy, that of 1967, while the p.i.g.p. data for irrigation reflect 1978 technology. In addition, Rhee's data are in terms of 1967 constant dollars, while this study's p.i.g.p. data are each in the nominal dollar terms for its year of generation. Therefore, a comparison between this study's p.i.g.p. data for irrigation and those of Rhee is difficult and is attempted only for the 1967-1977 period. For this period, if one of Rhee's datum should exceed this study's counterpart for, say 1972, then there is no question that the former exceeds the latter since the former reflects a less-advanced 1967 technology as well as less inflated dollar terms. Thus in reality, the Rhee datum would exceed 1972 p.i.g.p. datum of this study by even more than is reflected. For years prior to 1967, Rhee's data are not comparable with those of this study since the former are not available in pre-1967 dollar terms.[1]

Of interest and importance in Table 33 is that Iowa irrigation, as a water use, is defined within the context of the farm simulated in this case study and is a use which generated less personal income per acre-

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[1]This fact was obtained in a private communication with Iowa State University graduate student of economics, Jeong Rhee. Ames, Iowa, July, 1978.

foot than the first ten uses in the Iowa economy over the 1967-1977 period. This is true despite the fact that Rhee's data in the 1967 year row of Table 32 reflect a less advanced 1967 technology and less inflated 1967 dollars than the p.i.g.p. data calculated per acre-foot of this study's irrigation water.

Noting Table 32, the finance-insurance-real estate sector of the Iowa economy generated at least 10 times the income per acre-foot of water than irrigation during any year of the 1967-1977 period during which irrigation water was applied.

The row following the year 1977 in Table 32 demonstrates the ranking of these various Iowa water uses in terms of the amounts of income generated per acre-foot. They rank in the following order: (1) finance-real estate-insurance industry, (2) non-livestock agricultural production,[1] (3) transportation and warehouse services, (4) agricultural services, (5) commercial trade, (6) livestock production, (7) general services (legal, medical, etc.), (8) food processing, (9) construction, (10) manufacturing, and (11) Iowa irrigation (as simulated in this case study).[2]

Therefore, in the event of a water shortage in some Iowa region, of the eleven uses examined herein, the irrigator of this study should have been the last use warranting water from 1967 through 1977, given that the I.N.R.C. was to have efficiently allocated water among uses such that the

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[1]This does not include irrigation.

[2]Many of these water uses are not very relevant to Northwest Iowa, e.g., manufacturing. Such uses as finance-real estate-insurance can not be considered large water users. However, these were the only uses for which p.i.g.p. data were located. The point made is that compared with the available, and admittedly scarce, p.i.g.p. data, irrigation (as simulated herein) has the lowest p.i.g.p.

M.V.P.'s of water use, here represented by the best alternative M.V.P. proxies of personal income generation power, were equated.

Therefore, the I.N.R.C. has violated both marginal analysis criteria 1 and 2 developed in Chapter 2. The Council has allocated water to a use more according to the benefit-cost analysis criterion of a non-negative water M.V.P. rather than to the economically justifiable criterion of M.V.P. equalling input price. Criterion 3, pertaining to water allocation among users, has been violated as seen from water having been allocated to irrigators despite the low productivity of irrigation water compared with alternative Iowa uses.

The reasons for such violations are two-fold. First, Iowa has been endowed with ample supplies of water where competition for such supplies has not yet become a serious problem (30, p. 76). However, according to Colbert (22, p. 80-81), this situation will not continue and inter-use competition for water will become keener, especially between wells as Iowa irrigation, as seen in Chapter 1, increases. Secondly, the I.N.R.C. does not discriminate or discern the relative benefits between Iowa water uses.

Dougal's proposed charge

Iowa State Water Resources Research Institute Director and I.N.R.C. Chairman Merwin Dougal has proposed a $2 annual charge on each acre-foot of consumptive water withdrawn from such aquifers as the Dakota sandstone, including that for irrigation (22, p. 90). This charge would be paid regardless of the year's water use magnitude.

However, given the unprofitability of irrigation in this study, adding such a charge upon Moody Association irrigators whose operations resemble that simulated herein would only make irrigation more unprofitable. Therefore, the charge is not economically justified on the irrigation scenario simulated in this study. However, Dougal[1] states that many users apply for an irrigation permit prior to the center-pivot purchase as an insurance of irrigation ability during severe droughts. Such a charge would, according to Dougal,[1] help make water sufficiently valuable such that only those prospective irrigators intent on irrigating would file irrigation permits.

Efficacy of the Irrigated Model

The profit function for the irrigated model is $\pi i = \sum_{t=1}^{21} [P^t \cdot Qi - C(Qi) - F]$ where t = 1, 2, .., 21, and refers to the 21 years of the study. P^t is the price of corn during the t-th year, and Qi represents the total bushels of corn produced under irrigated conditions. C(Qi) is a variable cost level which is related to the output level. F is the level of fixed costs during year t. Therefore, there are 21 bracketed yearly profit functions.

The P^t are accurate and are published by the U.S.D.A. (89, 1957-1977). Accurate total costs are derived in Chapter 4. The main model variable of questionable accuracy are the irrigated yield estimates.

Site-specific irrigated yield levels are not available in Northwest Iowa more than three or four years into the past (22, p. 31). As Parvin (55, p. 73) states, "Such data are not available for most regions and crops." Consequently, irrigated yields must be derived from rain-fed data.

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[1]This information was obtained in a private communication with Dr. Merwin Dougal, Ames, Iowa, August, 1978.

In reviewing the literature dealing with irrigation profitability, two methods were found which attempt to estimate irrigated yields from rain-fed yield data. The first is summarized by Parvin (55) and was found to be the basis of several profitability analyses of Illinois irrigation projects (2, 14, 53). The method of irrigated yield estimation summarized by Parvin (55), hence dubbed "Parvin's method," was the most frequently used method of estimating site-specific yields in the Illinois, and Minnesota areas. Shaw's method (69) unique to Iowa, is the second method. As seen below, Shaw's method is more accurate than that of Parvin.

Parvin's method

Parvin's is a method of estimating irrigated corn yields from rain-fed yield data. The method requires the following assumptions:

(1) Yield (irrigated) is a function of weather and trend (55, p. 73).

(2) Trend incorporates technology and average weather conditions (55, p. 73).

(3) Ideal weather, those conditions whose climatic variations have the largest positive yield effects, occurred during at least one of the years of the study's defined time period (55, p. 73).

(4) Irrigation fills the gap between ideal and realized weather conditions (55, p. 73).

Assume that rain-fed corn yields for some five year period were those stated in Table 34. These are denoted as $\hat{Y}_t$. Assume that from a regression analysis, the average or estimated yield levels, $\hat{Y}_t$, equal 4+2t where t refers to the years 1 through 5. The average or estimated $\hat{Y}_t$'s are assumed to be those yields generated with the prevailing technology level and average weather conditions (55, p. 73). Hence, deviations from the $\hat{Y}_t$ of the realized Y_j are assumed caused by weather variations (55, p. 73). If a $(Y_t - \hat{Y}_t)$ is positive, then year t's weather variations from the average patterns were beneficial to yields. If $(Y_t - \hat{Y}_t)$ is negative, then weather variations from average trends were detrimental to yields.

The ideal weather conditions are those nurturing the largest positive $(Y_t - \hat{Y}_t)$, which in Table 34, occurred during year 4. The +3 is the maximal yield increment from weather deviation from average patterns. This is assumed to have been the largest yield benefit of weather variation from average conditions occurrable during the period of years 1-5 (55, p. 73).

Therefore, the irrigated yields of year t equals the average yield level capturing average weather conditions and technology, $\hat{Y}_t$, plus the maximal yield increment obtainable from the weather variation, whereas irrigation is assumed to fill the gap between realized and ideal weather conditions (55, p. 73). From Table 34, $\hat{Y}_t^{\,i} = \hat{Y}_t + 3$ where $Y_t^{\,i}$ equals year t's estimated irrigated yield level, $\hat{Y}_t$ equals the average rain-fed yield level, and 3 is the maximized yield benefit from weather variation. Likewise, year t's yield response from irrigation, YR_t, equals $[\hat{Y}_t + 3] - Y_t$. (55, p. 74).

Table 34. Hypothetical corn yields for years 1-5 for Parvin's method

Year	Y_t	$\hat{Y}_t$	$(Y_t - \hat{Y}_t)$	$Y_t^{\,i} = Y_t + 3$	YR_t
1	5	6	-1	9	4
2	10	8	2	11	1
3	8	10	-2	13	5
4	15	12	3	15	0
5	12	14	-2	17	5

The main drawback of Parvin's method is the unrealistic assumption that the difference between realized and ideal weather is inadequacy of rainfall, which may be remedied with applied irrigation water (54, p. 86). With reference to this assumption, Palmer-Jones (54, p. 85) contends "...that there are very good physiological and climatic reasons for supposing that the assumption will not hold in a wide range of circumstances."

First, rainfall is correlated with a wide array of climatic phenomena such as humidity, radiation, temperature, etc. (54, p. 85). These factors so assemble into a vector of weather conditions of a certain mix such that rain-fall occurs. For instance, windspeed, low temperature, humidity and low radiation are positively correlated with rainfall (54, p. 86). These non-rainfall variables <u>interact</u> with rainfall to produce yields. On a hot, sultry day, when many such non-rainfall variables are at levels not beneficial to yields, are coupled with irrigation application, the irrigation cannot possibly be expected to increase yields as much as if the temperature, humidity, etc. were at levels which complement high yield levels. Therefore, "...irrigation will not generally have the same effect of yield as rainfall or 'ideal' weather due to different associations between rain-fall, atmospheric, and environmental variables which affect yield response to soil moisture conditions" (54, p. 87).

However, Parvin takes the other non-rainfall variables at constant levels while only rainfall varies, ceteris paribus, during year 4 above, when weather variation caused the largest yield benefit. Parvin's method cannot capture the yield benefits or decrements which would occur if, although rain-fall was similar between two years, the levels of non-rainfall weather variables, e.g., temperature, wind, humidity, etc., were drastically different. For instance, in the above example, the weather conditions of year 4 brought about the highest yield benefit from weather variation. This yield benefit is assumed a result of non-average rainfall. However, many non-rainfall variables interacted simultaneously with year 4's rainfall to produce the yield benefit. Perhaps the non-rainfall variables of another year besides year 4 are such that a more or less yield benefit of +3 is possible. Thus, the assumed +3 maximal yield benefit from weather variability may hold only in year 4 and not during other years.

Parvin's method is concerned only with rainfall yield influences while many more non-rainfall yield influences exist.

Shaw's model

Shaw's method of yield estimation based upon soil moisture is discussed in Chapter 4. A discussion of the method with respect only to Parvin's method is undertaken here.

The response to irrigation, when calculated with Shaw's equation, varies from year to year, rather than being treated as a constant. The yield equation is $\hat{Y}_t = 9196.2 - 86.1X$ (69, p. 106). X is a weighted seasonal soil moisture stress value which is a sum of 85 daily soil moisture stress variates (xi), each weighted with respect to its nearness to the crop's silking date (69, p. 101). The nearer the stress occurrence is to the silking date, the greater its influence on corn yields, and the greater the weight assigned to the daily stress value (69, p. 103).

Therefore, suppose there were 10 days of unusually hot temperatures, low humidity, and strong dry winds. Such factors would greatly increase soil moisture stress borne by the corn plant (68, pp. 6-7). Therefore, 10 of the 85 weighted daily stress values, because of the high temperatures, dry winds, and low humidity, would be larger than the average conditions. Hence, the summed X for that year would be larger. Consequently, the $\hat{Y}_t = 9196.2 - 86.1X$ would be smaller. Assuming that a capable irrigator can so time irrigation applications so as to decrease X down to 10,[1] then $\hat{Y}_t/_{x=10}$ less $\hat{Y}_t$, equals the yield response to irrigation and would be larger than average because these other non-rainfall phenomena, along with rainfall, also deviated from average conditions.

There are three points, then, which make Shaw's method superior to that of Parvin:

(1) An irrigator is assumed unable to eliminate soil moisture stress. In other words, ideal weather is not necessarily brought about through irrigation. Such concurrs with the findings of Beer et al. (10, p. 14).

(2) Whereas Parvin's method assumes rain-fall to be the only climatic variable keeping realized weather from being ideal, the calculation of Shaw's soil moisture stress index incorporates the yield-effects of the variations of other non-rainfall, although yield-influencing, phenomena such as temperature, humidity, wind, etc. Thus, yield responses are better estimated from Shaw's method than with that of Parvin. The former calculates yield effects of the movements from average conditions of many climatic variables, whereas the latter is concerned only with rain-fall.

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[1]According to Shaw, no irrigator can totally eliminate soil moisture stress. At best, he may hope to decrease the weighted seasonal value down to approximately 10 units. Private communication, Ames, Iowa, March, 1978.

(3) In calculating Shaw's soil moisture stress values, the timing of stress and water requirements of a crop at different stages of growth are also accounted for.

Therefore, Shaw's method of irrigated yield estimation appears superior to Parvin's method. In accounting for many climatic yield influences in addition to rainfall, rather than assuming average non-rainfall variable levels, more accurate yield responses are calculated. In addition, Shaw's method lends insight regarding the crop's water requirements.

CHAPTER VI.

CONCLUSIONS, SUMMARY, AND FURTHER RESEARCH NEEDS

The conclusions detailed in Chapter 5 are briefly presented, after which several recommendations for further research are suggested as an outgrowth of this study. Finally, a brief summary is presented.

Conclusions

As shown in Tables 13 and 15, both the rain-fed and irrigated corn production activities, P01-K and Q01-K respectively, appeared resistant to rising production costs from 1957 through 1977. This was demonstrated by the rain-fed average sensitivity ratio[1] of .3984 and the irrigated scenario average of .3142 both being well below unity. From Tables 13 and 15, it was shown that irrigated acreage was 27 percent less responsive to a percent rise in variable corn production costs than was rain-fed acreage over the 21 year study period.

Irrigation did not guarantee optimal weather, maximal yield levels, and the elimination of annual income fluctuation from climatic variability. From Table 1, it is seen that the more detrimental the rain-fed climatic effects on yields, then the larger the required yield-maximizing seasonal irrigation application, and hence the lower the irrigated yield level. In addition, since a center-pivot system equipping a 160 acre tract effectively irrigates only 133 acres, then there were 54 rain-fed acres

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[1]The sensitivity ratio is a parameter detailed in Chapter 5 measuring the percent decline in acreage caused by a percent rise in C_1 or variable corn production cost.

in the irrigated 320 acre scenario. These 54 rain-fed acres had yields varying with the vicissitudes of Northwest Iowa's subhumid climate which increased the irrigated scenario's climate-induced income fluctuation. These conclusions coincide with the findings of Palmer-Jones (54, p. 85), that irrigation does not guarantee optimal weather, maximal yields, and hence does not eliminate climate-induced annual income fluctuation.

The net returns and quarterly compounded rates of net return were calculated for center-pivot irrigation, U.S. treasury bills, Bbb grade corporate bonds, high-grade municipal bonds, and land in Tables 18, 19, 20, 21, and 22, respectively. The costs and returns of each option were treated in three terms and a separate rate of return calculated for each term: (1) nominal dollars where costs and returns of an investment are not adjusted for any time-related cost such as inflation, (2) inflation-adjusted dollars where costs and returns are adjusted for inflation, and (3) real constant 1978 dollars where costs and returns are adjusted for the time-related costs of inflation, risk, interest, time preference of income, and uncertainty of time-related events such as weather variability which affect income.

All quarterly compounded rates of net return are summarized for the five alternative investment options in Table 23. Irrigation appeared the worst investment, generating the lowest returns of the five examined options from 1957 through 1977. Land appeared to have generated the largest streams of nominal, inflation-adjusted, and real constant 1978 dollar income streams.

There are two reasons for irrigation's low net returns. The first and major reason was the high levels of fixed cost characterizing the center-pivot system, particularly the double pump and well depreciation charges incurred by the need for two wells. Few single wells from the Dakota sandstone aquifer in the Moody Association are capable of serving 320 irrigated acres.[1] The second reason was because of the high levels of pumping costs, as compared to bottomland wells, required to pump from the Dakota sandstone aquifer with, as calculated in Chapter 3, a 356 foot pumping head. However, pumping costs had only a minor negative influence on center-pivot profitability.

Range analyses were conducted upon the irrigation activities Q07-K, Q08-K, and Q09-K which are summarized in Tables 24, 25, and 26, respectively. Since Sheffield (71, p. 12) contends pumping (diesel) costs to be 95 percent of total center-pivot variable costs, then the C_7, C_8, and C_9 coefficients are assumed entirely comprised of diesel pumping costs. From Table 24, it appears that pumping costs could have been, on the average, 15.5 times higher than the realized levels before prohibitive variable costs would have driven Q07-K to zero levels. From Table 25, it appears such costs were required to have been more than 11 times greater than realized levels if Q08-K was to have been eliminated from solution. Even with the less productive Q09-K activity, the C_9 coefficients of Table 26 were required to have been an average 2.3 times larger for irrigation 3 to have been precluded from solution because of high pumping costs. Therefore, the rising diesel fuel costs did little to affect the optimal irrigation levels.

The reason for the small influence of variable (diesel) irrigation

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[1]This opinion was obtained in a private communication with I.S.U. Agri. Engineer, Stewart Melvin. Ames, Iowa, March, 1978. However, as earlier cited, Dougal feels that alternately irrigating two quarter-sections with a single well and pump may be possible and merit further inquiry.

costs upon center-pivot profitability was the small portion that such diesel costs comprised of total center-pivot costs. From Table 27, variable irrigation costs were calculated as an average 16 percent of the total irrigation costs.[1]

Despite irrigation's unprofitability, the center-pivot investment did reduce the annual variability of farm profits over the 1957-1977 period. In noting Table 18, it appears that during the years of large rain-fed farm financial losses, the irrigated farm usually earned a profit. However, during years of high rain-fed profits, irrigated profits were generally much lower.

Conclusions were obtained regarding irrigation water value productivity and the I.N.R.C. 1957-1977 water allocation policy.

In Chapter 2, criterion were established to efficiently allocate water, according to marginal analysis: (1) to a use, (2) among a use's competing enterprises, and (3) between competing uses. With only one production activity, corn, developed for each model, criterion 2 is not discussed.

The I.N.R.C. violated criterion 1 from 1957 through 1977. Rather than efficiently allocating water to a use such that the user's marginal water outlay equalled water's M.V.P., the Council followed the economically unjustifiable benefit-cost analysis criterion of a non-negative M.V.P. for water. So long as a water use was "beneficial" to the user without interfering with the rights of another use, the I.N.R.C.

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[1]These are costs attributable only to irrigation itself and should not be confused with the total costs of the irrigated scenario.

justified water allocation thereto. As evident from the differences between the economically optimal and realized I.N.R.C. allocations in Table 31, the I.N.R.C. water allocation policy from 1957 through 1977 resulted in repeated and significant over allocations to the irrigator. If requested by the irrigator, the I.N.R.C., under the "18-inch rule,"[1] may have been willing to grant an average of 350 percent more than the economically optimal amounts of irrigation water over the 1957-1977 period. As demonstrated in Table 17, the agronomic optimal irrigation application estimates developed by Ross are better guides than the "18-inch rule" upon which to base the allocation decisions for irrigators, since in all years except 1974 and 1976, the economic and agronomic optima were the same. Meanwhile, the "18-inch rule" lead to large over allocations during every year of this study. Yet since 1978, the I.N.R.C. has moved a step towards economic optimality by reducing the 18-inch limit by 33.3 percent to 12 acre/inches per irrigated acre, hence closing the I.N.R.C. allocation-economic optima gaps in future years.

Criterion 3, allocating water among competing uses such that water's M.V.P.'s are equal, was also violated for two reasons. First, the I.N.R.C. had no real need to discriminate between the relative benefits of competing uses since Iowa had, generally speaking, ample water supplies to eliminate serious competition problems (22, p. 80).[2] However, this is a situation which Geiseke (30, p. 76) contends will quickly disappear as water demands swell with Iowa's future economic development and population growth.

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[1]As discussed in Chapter 5, this rule refers to the 18 acre-inch per acre limit placed upon the irrigators by the I.N.R.C. from 1957 through 1977. Since 1978, the "18-inch rule" has become the "12-inch rule."

[2]There are isolated exceptions. During the summer of 1977, Story County was in the peak of a drought. Consequently, household water usage was rationed. Some production uses, e.g., irrigating the Ames area golf course, were even banned temporarily.

Secondly, a set of parameters measuring the relative benefits between Iowa water uses did not exist. In the event of water competition problems, such parameters are needed to discern relative benefits between uses and to allocate water to the use with the highest marginal benefit, thereby maximizing total benefit among all uses. However, water use benefit criteria, as seen in the Iowa Code (37), are vague with no concrete definition. Such criteria must be defined and a set of "relative benefit" parameters formulated in order to judge past I.N.R.C. inter-use water allocation. This formulation will enable policy corrections to meet criterion 3 and help fashion solutions to water competition problems in areas prone to such problems before such problems arise.

Timmons (87, p. 148) suggests that the "benefit criterion" of water use, espoused in the Iowa Code (37), be measured in terms of water's M.V.P. However, water M.V.P. data for non-irrigation uses were not located in a literature review for this study nor by Colbert (22). Therefore, the M.V.P. data for S14-K, S15-K, and S16-K calculated in Tables 28, 29, and 30 had no basis of comparison. Thus, the next best parameters available, the estimated personal income generation powers (p.i.g.p.) of 10 Iowa water uses were obtained from Jeong Rhee, and similar data were calculated for this study's eleventh water use, irrigation. These data are in Table 33. As explained in Chapter 5, these p.i.g.p. data are Iowa counterparts to those developed for Arizona by Young and Martin (102).

Rhee's p.i.g.p. estimates were not comparable to those calculated for this study's irrigation water before 1967 because of indexing and technology differences in the two data sets.[1] Yet despite their partial

[1]These problems are detailed in Chapter 5.

non-comparability, the two data sets were compared for the 1967-1977 period in Table 33.

Irrigation water was shown to have been the least productive in terms of personal income generated per acre-foot than of the 10 other listed Iowa water uses. In the event of some severe competition problem, where these income generation data serve as the best available water M.V.P. proxies, irrigation should have been and probably will continue to be, the first of the 11 uses to be denied water. This holds insofar as criterion 3 serves as a basis for I.N.R.C. water allocation policy.

Also, Dougal's proposed charge of $2 per acre-foot on applied irrigation water was found not affordable, by the irrigator, since such a charge would inflict more costs on an already unprofitable venture. This conclusion applies to farms similar or identical to this study's simulated scenario.

Recommendations for Further Research

Listed and discussed below are four areas in which more research efforts are needed regarding irrigation in Iowa, especially in Northwest Iowa:

(1) More case studies dealing with Iowa irrigation profitability are needed which incorporate specific Iowa soils and particular production scenarios. This is needed particularly in Northwest Iowa where increased irrigation is most pronounced.

(2) Data reflecting water's M.V.P., a set of economic parameters suggested by Timmons (87, p. 148) as a measure of relative water-use beneficiality, must be generated for as many water uses as feasible.

(3) Information and data regarding the geohydrologic aspects of the

Dakota sandstone aquifer are badly needed.

(4) More study is needed concerning the potential soil erosion and depletion problems related to irrigation.

Additional case studies

Colbert's study (22) is the only report located which examines the economic profitability of Iowa irrigation. His study uses "average" soil, climate, and yield estimation models to answer the irrigation profitability question generally for Northwest Iowa. His most important conclusion is that irrigation may or may not be profitable on Northwest Iowa sites, depending upon an area's soil type, well scheme, and climate (22, p. 96). Thus, "the most important research need is to find a method of predicting yield increases on specific soils in Iowa." (22, p. 96).

Shaw's yield estimator used herein, $Y = 9196.2 - 86.1X$, does just this for the Moody soils of Northwest Iowa (69, p. 106). However, Corsi and Shaw (24) and Shaw (69) have already developed similar yield equations for nine other Iowa locations and soil types.

Therefore, irrigation profitability models similar to that developed here for the Doon Farm site may be developed for all 10 soil types listed in Table 35. Additional case studies are needed to determine just where irrigation is and is not profitable, so as to lend implications to the I.N.R.C. water managers and policy makers.

In addition, the case studies should be extended to farmers not only of differing locations and soils, but to farms with different production scenarios. Preliminary research has proven some alfalfa yield response

Table 35. Sites of available soil moisture stress and yield data

Name	Iowa location	Soil types
Ames agron. farm	Central	Webster silty clay loam
Shelby-Grundy farm	Beaconsfield, S.W. Ia.	Grundy silty clay loam
Southern Iowa farm	Bloomfield, S.E. Ia.	Edina silt loam
Western Iowa farm	Castana, S.W. Ia.	Ida silt loam
Carrington-Clyde farm	Independence, N.E. Ia.	Kenyon loam
Northern Iowa farm	Kanawha, N.C. Ia.	Webster silty clay loam
Marshalltown, pvt.farm	Marshalltown, Cen. Ia.	Muscatine silty clay loam
Soil conservation farm	Norwich, N.W. Ia.	Marshall silty clay loam
Galva-Primghar farm	Sutherland, N.W. Ia.	Galva silty clay loam
Doon exp. farm	Doon, N.W. Ia.	Moody silty clay loam

to irrigation, although very little Iowa alfalfa is irrigated.[1] Many Iowa farms contain livestock and soybean enterprises, in addition to corn. Also, different farm sizes should be examined.

As Salter (60, p. 71) clearly states, "It will but rarely be true that analyses of a single case will suffice for a full inquiry. There have to be as many cases as there are combinations of means-ends factors for a full analysis of a problem."

Water's M.V.P. in various uses

Data reflecting water's M.V.P. in productive (non-consumptive) uses would serve as the best set of "relative benefit" parameters between water uses (87, p. 148). Such benefit discrimination is needed among uses to allocate water: (1) to a use according to criterion 1 where water's M.V.P. and marginal cost in that use are equated and (2) according to criterion 3 such that the M.V.P.'s for water in different uses are equated.

Such M.V.P. information must then be generated for as many Northwest Iowa water uses as possible, so as to bring the area's water allocation as near to an economically optimal state as possible. The time will soon pass when ample water quantities eliminate serious water competition and well interference problems in Iowa. Therefore, the availability of such M.V.P. information is all the more urgent and necessary (30, p. 76).

The additional case studies of irrigation projects mentioned above

[1]This information is yet unpublished and was obtained in a private communication with Iowa State University Professor of Agricultural Engineering and Iowa irrigation specialist, Stewart Melvin. Ames, Iowa, May, 1978.

are needed to formulate a more general M.V.P. indicator for irrigation water.

Aquifer depletion by Dakota sandstone wells

Since 1977, there has been a ban on drilling new irrigation wells from the Dakota sandstone aquifer because, according to Hallberg (31, p. 4):

> "...less substantive information is available for this aquifer than for any other aquifer in Iowa. The stratigraphy is poorly understood and the hydrologic data is insufficient for predicting either the short or long term effects of heavy pumping."

The amounts of water, well yields, and water quality of the Dakota sandstone aquifer are questions whose answers are vague (31, p. 5). Wells have ranged in yield from less than 50 g.p.m. to 750 g.p.m. in Osceola, Sioux, O'Brien, and Cherokee counties (31, p. 4). There are also serious contentions about the water quality in some Dakota sandstone wells and its effect on corn yields and soil fertility (31, p. 5).

Northwest Iowa is the area where the greater proportion of the increased irrigation has occurred (31, p. 1). Although little irrigation occurs presently from the Dakota sandstone aquifer, this aquifer "...is the only other potential aquifer of Northwestern Iowa for developing irrigation supplies," (31, p. 4).[1] Therefore, if the I.N.R.C. is to grant permits to irrigate, so that adequate supplies for consumptive uses are ensured and that well-interference is avoided, then answers to the

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[1]That is, the Dakota sandstone aquifer is the only aquifer aside from many bottomland and floodplain alluvial aquifers in the area from which irrigation is considered feasible.

following questions regarding the Dakota sandstone aquifer must be obtained: (1) What are the possible well yields? (2) What is the aquifer's recharge rate? (3) How much water and of what qualities exist in the aquifer? (4) What are the peak demands, especially during droughty periods in areas especially prone to water competition problems?

Irrigation-related soil erosion and depletion

Portions of Northwest Iowa terrain are characterized by a slope gradient ranging from 5 to 15 percent (24, pp. 82-83). Irrigating land with such a slope "...seriously increases the potential for severe erosion problems " (31, p. 37).

Additional case studies of irrigation profitability are suggested for the Doon and Castana areas in Northwest Iowa, whose surrounding farmlands are characterized with slopes within the above slope range (24, pp. 82-83). The Castana area is particularly hilly with slopes approaching 15 percent (24, p. 82). Therefore, Hallberg (31, p. 37) states that:

> "When upland soils that are prone to erosion are considered for irrigation . . . the permitting procedure should include a review of or implementation of soil conservation measures by the Soil Conservation District to ensure adequate protection of the land involved and to ensure compliance with the soil loss limit regulations established by Iowa's Soil Conservation Districts."

Irrigation appears profitable on some Northwest Iowa sites such as the Missouri bottomlands (22, p. 99). Increased irrigation has been particularly pronounced in the Lyon County's Rock River Basin and Rock River Valley areas.[1] However, at present, a minor .5 percent of Iowa cropland is

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[1]This information was obtained in a private communication with Dr. Merwin Dougal, Chairperson of the I.N.R.C. Ames, Iowa, August, 1978.

irrigated (31, p. 30). Until recently, potential irrigation related soil erosion problems have been ignored because of irrigation's insignificant role in Iowa agriculture. But irrigation, profitable or not, has been increasing in Northwest Iowa since 1957. Resulting erosion problems are also growing in importance.

Therefore, future irrigation research should at least in part address the evaluation of alternative soil conservation measures potentially implementable with irrigation, along with the monitoring of possible soil erosion and non-point source pollution in the areas of upland irrigation (31, pp. 40-41).

Summary

Objective 1 was to develop a methodology for analyzing the profitability of site-specific center-pivot irrigation investment, which incorporate specific well schemes, soil types, and production scenarios for Northwest Iowa. This objective was emphasized as an important research need in the Colbert study (22, p. 100) of center-pivot profitability in the general area of Northwest Iowa.

The multi-period linear program developed in Chapter 3 incorporates the "with-without" irrigation approach. The reverse-discount formula was used to enable the farmer to travel back through time and reassess 1957-1977 center-pivot performance in terms of 1978 expectations, technology, prices, and costs. Such a reassessment is demonstrated in Chapter 3 to be the best available indicator of future irrigation profitability, since the profitability of Northwest Iowa irrigation hinges upon the vicissitudes of an unpredictable subhumid climate.

The second objective, applying the model to a case study in the Moody Association, was accomplished in Chapter 4, where the site of inquiry was the Doon Farm site where 320 Moody acres were irrigated from the Dakota Sandstone aquifer over the 1957-1977 period. As seen above, conclusions were drawn concerning (1) irrigation's tolerance to rising fuel and production costs, (2) center-pivot's net returns as compared with those of U.S. treasury bills, Bbb grade corporate bonds, high-grade municipal bonds, and rented cropland, and (3) the past and future economic efficiency of the I.N.R.C. water allocation policy.

In general, center-pivot irrigation on the site of inquiry of this study appeared quite an unprofitable venture, whose net returns incurred the most loss of all five options considered. Land appeared, of the five options, the best investment. Given that the price-cost-yield-weather interactions of the 1978-1998 period are not substantially different from those of the 1957-1977 period, these unprofitability conclusions will probably hold in the former period.

It was also shown that the I.N.R.C. violated criteria 1 and 2 of marginal analysis in allocating water to this study's irrigator. In lieu of using the agronomically optimal irrigation applications which proved to be most often the economically optimal levels, the I.N.R.C. repeatedly over allocated irrigation by basing allocative limits on a flat "18 inch /acre" rule. Criteria 3 was violated because, in addition to the I.N.R.C. not being compelled to allocate such that all water M.V.P.'s of an area are equal, the I.N.R.C. had no relative water use benefit parameters to discriminate between competing users.

Future research needs, objective 3, was accomplished by prescribing further inquiry into the following four areas: (1) additional site-specific case analyses of irrigation profitability, (2) generation of water's M.V.P. data in various uses, (3) possible aquifer depletion problems, and (4) possible soil erosion costs resulting from irrigation.

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APPENDIX A: OBJECTIVE FUNCTION COEFFICIENT DATA

Table A-1. Annual machinery costs per acre

Component	1957	1958	1959	1960	1961	1962	1963	1964	1965
General machinery									
Machine hire	3.46	3.69	3.32	3.98	3.5	4.75	4.14	3.99	4.66
Fuel and oil	2.56	3.11	3.16	3.34	2.97	3.66	3.15	3.10	3.73
Repairs	4.44	2.95	3.02	3.57	2.9	4.06	3.40	3.61	4.73
Tan. disk lube.	.04	.02	.05	.04	.02	.04	.04	.02	.02
Tan. disk labor	.52	.52	.41	.55	.56	.58	.59	.60	.60
Plow lube.	.03	.03	.03	.03	.03	.03	.03	.03	.03
Plow labor	.39	.40	.1	.41	.42	.44	.44	.45	.45
Peg tooth har. lube.	.04	.04	.04	.04	.04	.04	.04	.04	.04
Peg tooth har. labor	.10	.10	.10	.10	.10	.11	.11	.11	.11
Planter lube.	.03	.04	.04	.03	.04	.04	.04	.04	.04
Planter labor	.18	.18	.19	.19	.19	.20	.20	.21	.21
Corn head lube.	.03	.03	.03	.03	.03	.03	.03	.03	.03
Corn head labor	.69	.70	.73	.73	.74	.77	.78	.81	.80
Gr. wagon lube.	0	0	0	0	0	0	0	0	0
Gr. wagon labor	.37	.37	.39	.39	.39	.41	.41	.43	.43
Cont. Flo. dry lube	.17	.19	.19	.17	.18	.18	.18	.18	.18
Cont. Flo. dry labor	0	0	0	0	0	0	0	0	0
Blk. fert. spread. lube.	0	0	0	0	0	0	0	0	0
Blk. fert. spread. labor	.12	.12	.12	.12	.13	.13	.13	.14	.14
Cultivator lube.	.01	.02	.02	.01	.02	.02	.02	.02	.02
Cultivator labor	.18	.18	.19	.19	.19	.20	.20	.21	.21
Nominal machine v.c.	13.36	12.67	12.54	13.92	12.45	15.68	13.93	14.00	16.42

1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
					15.00	15.00	17.45	17.45	22.70	22.90	23.00
3.50	4.43	4.25	5.09	4.85							
3.90	3.48	3.57	3.88	3.70							
5.12	4.62	4.86	5.74	5.87							
.02	.04	.05	.05	.05	.05	.05	.06	.09	.1	.12	.12
.61	.70	.73	.80	.86	.91	.96	1.06	1.16	1.16	1.27	1.35
.03	.03	.03	.03	.03	.03	.03	.04	.06	.06	.05	.08
.46	.53	.55	.61	.65	.69	.73	.80	.87	.88	.96	1.02
.04	.04	.04	.04	.04	.04	.05	.05	.08	.08	.11	.11
.11	.13	.14	.15	.16	.17	.18	.20	.22	.22	.24	.25
.04	.04	.04	.04	.04	.04	.04	.05	.08	.08	.10	.10
.21	.24	.25	.27	.30	.31	.33	.36	.40	.40	.43	.46
.03	.03	.03	.03	.03	.03	.03	.04	.06	.06	.08	.08
.81	.93	.97	1.07	1.15	1.21	1.28	1.41	1.54	1.54	1.68	1.8
0	0	0	0	0	.01	.01	.01	.01	.01	.01	.01
.43	.49	.52	.54	.61	.64	.75	.82	.82	.82	.90	.91
.18	.18	.19	0	.20	.22	.22	.23	.39	.40	.51	.51
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	.19	0	0	0	0	.01	.01	0	.01
.14	.16	.16	.18	.19	.20	.22	.24	.26	.26	.29	.3
.02	.02	.02	.02	.02	.02	.02	.02	.03	.03	.04	.04
.21	.24	.26	.28	.30	.32	.34	.37	.40	.41	.44	.47
15.85	16.33	16.65	19.03	19.06	19.90	20.28	22.91	23.93	29.22	30.13	30.23

Table A-2 Variable corn production costs per acre

Component Year	Nitrogen	Phosphate	Aldrin	Thimet	Dyfonate	Atrazine
1957	11.8	3.78	1.85			5.25
1958	11.8	3.83	1.85			5.25
1959	11.75	3.87	1.80			5.25
1960	11.50	3.92	1.80			5.33
1961	11.53	3.92	1.70			4.50
1962	10.60	3.87	1.30			4.05
1963	11.00	3.78	1.30			4.05
1964	10.70	3.74		1.43		4.05
1965	10.00	3.65		1.43		3.75
1966	10.20	3.92		2.15		3.75
1967	9.00	3.96		2.15		3.75
1968	8.60	3.65		2.21		3.38
1969	7.60	3.29		2.21		3.23
1970	10.40	3.47		2.21		3.23
1971	8.70	4.50			3.80	3.15
1972	10.10	3.69			3.80	3.30
1973	18.80	4.19			3.80	3.30
1974	30.10	6.53			3.90	3.38
1975	24.20	10.76			4.90	4.43
1976	22.00	9.18			5.10	4.05
1977	22.00	8.19			5.40	3.60

Lasso	Machinery	Seed	Total nominal	$(1.09)^t$	Total real (C_1)
	13.36	3.56	39.50	6.109	-241.31
	12.67	3.63	39.03	5.604	-218.72
	12.54	3.80	39.01	5.142	-200.59
	13.92	3.80	40.27	4.717	-189.95
	12.45	3.96	38.06	4.328	-164.72
	15.68	3.96	39.46	3.97	-156.66
	13.93	3.96	38.02	3.642	-138.47
	14.00	4.02	37.94	3.342	-126.8
	16.42	4.13	39.38	3.066	-120.94
	15.85	4.13	40.00	2.813	-112.52
6.20	16.33	4.37	45.76	2.58	-118.06
6.20	16.65	4.69	45.38	2.637	-119.67
6.50	19.03	4.69	46.55	2.172	-101.11
6.83	19.06	5.61	50.81	1.993	-101.26
7.08	19.90	6.11	53.24	1.828	- 97.32
7.38	20.28	7.76	56.31	1.677	- 94.43
7.70	22.91	7.43	68.13	1.539	=104.85
8.0	23.93	8.25	84.09	1.412	-118.74
8.08	29.22	12.21	93.80	1.295	-121.47
8.45	30.13	12.87	91.78	1.188	=109.03
8.75	30.23	14.19	92.31	1.09	-100.67

Table A-3 Annual per-pound costs of fertilizers, pesticides, and herbicides

Year	Nitrogen	Phosphate	Aldrin	Thimet	Dyfonate	Atrazine	Lasso
1957	.118	.084	.37			3.50	
1958	.118	.085	.37				
1959	.118	.085	.36			3.50	
1960	.115	.087	.36			3.55	
1961	.115	.087	.34			3.00	
1962	.106	.086	.26			2.70	
1963	.110	.084	.26			2.70	
1964	.107	.083		.22		2.70	
1965	.10	.081		.22		2.50	
1966	.102	.087		.33		2.50	
1967	.102	.088		.33		2.50	2.48
1968	.09	.081		.34		2.25	2.48
1969	.086	.073		.34		2.15	2.60
1970	.076	.77		.34		2.15	2.73
1971	.104	.100			.76	2.10	2.83
1972	.087	.082			.76	2.20	2.95
1973	.101	.093			.78	2.20	3.08
1974	.188	.145			.92	2.25	3.20
1975	.301	.239			.98	2.95	3.23
1976	.242	.204			1.02	2.70	3.38
1977	.22	.159			1.08	2.40	3.50

Table A-4 Prices of fuel, labor, corn, irrigation application, and borrowing money

Year	Diesel[a]	Wage (hr)	Int. rate	Corn (bu)	Irr. appl.[b]	$(1+.09)^t$
1957	.155	1.08	.0517	1.00	11.43	6.109
1958	.16	1.09	.0524	1.05	11.8	5.604
1959	.164	1.14	.0551	1.02	12.09	5.142
1960	.155	1.14	.06	.96	11.43	4.717
1961	.16	1.16	.0564	1.08	11.80	4.328
1962	.163	1.2	.056	1.09	12.02	3.97
1963	.162	1.22	.056	1.04	11.95	3.642
1964	.16	1.25	.056	1.11	11.80	3.342
1965	.16	1.25	.056	1.06	11.80	3.066
1966	.16	1.27	.0582	1.24	11.8	2.813
1967	.161	1.45	.0602	1.02	11.87	2.58
1968	.168	1.52	.0684	1.04	12.39	2.637
1969	.169	1.67	.0782	1.06	12.46	2.172
1970	.174	1.80	.0868	1.31	12.83	1.993
1971	.193	1.89	.0786	1.04	14.23	1.828
1972	.193	2.01	.0742	1.20	14.23	1.677
1973	.207	2.21	.0748	2.30	15.27	1.539
1974	.35	2.41	.0814	2.80	25.81	1.412
1975	.356	2.42	.0869	2.4	26.25	1.295
1976	.399	2.64	.0866	1.59	29.42	1.188
1977	.45	2.82	.09	2.04	33.19	1.09

[a]These prices are per gallon.

[b]These are the costs of applying 66.5 acre-inches of water, i.e., .24 inches to 266 acres.

Table A-5 Objective function coefficients

Year	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9
1957	-241.31	-6.6	-6.6	-6.6	-.157	6.11			
1958	-218.72	-6.11	-6.11	-6.11	-.147	5.88	-66.127	-66.127	-66.127
1959	-200.59	-5.86	-5.86	-5.86	-.142	5.24	-62.167	-66.167	-66.167
1960	-189.95	-5.38	-5.38	-5.38	-.142	4.53			
1961	-164.72	-5.02	-5.02	-5.02	-.122	4.67	-51.07	-51.07	-51.07
1962	-156.66	-4.76	-4.76	-4.76	-.111	4.33			
1963	-138.47	-4.44	-4.44	-4.44	-.102	3.79	-43.522	-43.522	-43.522
1964	-126.80	-4.18	-4.18	-4.18	-.094	3.71	-39.436	-39.436	-39.436
1965	-120.74	-3.83	-3.83	-3.83	-.086	3.25	-36.179	-36.179	-36.179
1966	-112.52	-3.57	-3.57	-3.57	-.082	3.09	-33.193	-33.193	-33.193
1967	-118.06	-3.74	-3.74	-3.74	-.078	3.20	-30.625	-30.625	-30.625
1968	-119.67	-3.6	-3.6	-3.6	-.081	2.46	-32.672	-32.672	-32.672
1969	-101.11	-3.63	-3.63	-3.63	-.085	2.30			
1970	-101.26	-3.59	-3.59	-3.59	-.087	2.61	-25.570	-25.57	-25.57
1971	- 97.32	-3.45	-3.45	-3.45	-.072	1.90	-26.012	-26.012	-26.012
1972	- 94.43	-3.37	-3.37	-3.37	-.062	2.01			
1973	-104.85	-3.40	-3.40	-3.40	-.058	3.54	-23.501	-23.501	-23.501
1974	-118.74	-3.40	-3.40	-3.40	-.058	3.95	-36.444	-36.444	-36.444
1975	-121.47	-3.13	-3.13	-3.13	-.057	3.11	-33.994	-33.994	-33.994
1976	-109.03	-3.14	-3.14	-3.14	-.052	1.89	-34.951	-34.951	-34.951
1977	-100.67	-3.07	-3.07	-3.07	-.049	2.22	-36.177	-36.177	-36.177

APPENDIX B: RESOURCE USE COEFFICIENT DATA

Table B-1 Resource-use coefficients for rows 1-7

Year	A_{11}	A_{21}	A_{31}	A_{32}	A_{41}	A_{43}	A_{51}	A_{61}	A_{71}	A_{74}
1957	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1958	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1959	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1960	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1961	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1962	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1963	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1964	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1965	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1966	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1967	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1968	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1969	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1970	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1971	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1972	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1973	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1974	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1975	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1976	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.
1977	1.	.228	.363	-1.	.614	-1.	.168	.101	.978	-1.

Table B-2 Resource-use coefficients for rows 8-10

Year	A_{81}*	A_{82}*	A_{83}*	A_{84}*	A_{85}*	A_{87} *	A_{88}*	A_{89}*	A_{95}	$A_{10,2}$
1957	39.50	1.08	1.08	1.08	-1.				1.	1.
1958	39.03	1.09	1.09	1.09	-1.	47.2	47.2	47.2	1.	1.
1959	39.01	1.14	1.14	1.14	-1.	48.36	48.36	48.36	1.	1.
1960	40.27	1.14	1.14	1.14	-1.				1.	1.
1961	38.06	1.16	1.16	1.16	-1.	47.2	47.2	47.2	1.	1.
1962	39.46	1.20	1.20	1.20	-1.				1.	1.
1963	38.02	1.22	1.22	1.22	-1.	47.8	47.8	47.8	1.	1.
1964	37.94	1.25	1.25	1.25	-1.	47.2	47.2	47.2	1.	1.
1965	39.38	1.25	1.25	1.25	-1.	47.2	47.2	47.2	1.	1.
1966	40.	1.27	1.27	1.27	-1.	47.2	47.2	47.2	1.	1.
1967	45.76	1.45	1.45	1.45	-1.	47.48	47.48	47.48	1.	1.
1968	45.38	1.52	1.52	1.52	-1.	49.56	49.56	49.56	1.	1.
1969	46.55	1.67	1.67	1.67	-1.				1.	1.
1970	50.81	1.80	1.80	1.80	-1.	51.82	51.82	51.82	1.	1.
1971	53.24	1.89	1.89	1.89	-1.	56.92	56.92	56.92	1.	1.
1972	56.31	2.01	2.01	2.01	-1.				1.	1.
1973	68.13	2.21	2.21	2.21	-1.	61.08	61.08	61.08	1.	1.
1974	84.09	2.41	2.41	2.41	-1.	103.24	103.24	103.24	1.	1.
1975	93.80	2.42	2.42	2.42	-1.	105.	105.	105.	1.	1.
1976	91.78	2.64	2.64	2.64	-1.	117.68	117.68	117.68	1.	1.
1977	92.36	2.82	2.82	2.82	-1.	117.68	117.68	117.68	1.	1.

*Refers to coefficients unique to the irrigated model.

Table B-3 Resource-use coefficients for rows 11-17

Year	$A_{11,3}$	$A_{12,4}$	$A_{13,1}$	$A_{13,7}$*	$A_{13,8}$*	$A_{13,9}$*	$A_{14,7}$*	$A_{15,8}$*	$A_{16,9}$*	$A_{17,1}$*
1957	1.	1.	-122.1							
1958	1.	1.	- 67.6	-683.09	-525.08	-131.4	66.5	66.5	66.5	266.
1959	1.	1.	- 58.4	-718.2	-551.95	-133.8	66.5	66.5	66.5	266.
1960	1.	1.	-140.9							
1961	1.	1.	-141.5	-595.84	-523.22	-115.18	66.5	66.5	66.5	266.
1962	1.	1.	-155.6							
1963	1.	1.	- 99.	-514.71	-411.5	-103.21	66.5	66.5	66.5	266.
1964	1.	1.	-133.4	-970.9	-748.26	-186.1	66.5	66.5	66.5	266.
1965	1.	1.	-128.8	-744.	-571.9	-143.11	66.5	66.5	66.5	266.
1966	1.	1.	- 94.3	-643.72	-494.76	-123.69	66.5	66.5	66.5	266.
1967	1.	1.	- 41.73	-686.46	-514.44	-123.69	66.5	66.5	66.5	266.
1968	1.	1.	- 18.2	-1119.86	-861.84	-215.46	66.5	66.5	66.5	266.
1969	1.	1.	-166.8							
1970	1.	1.	- 46.	-803.32	-620.31	-154.55	66.5	66.5	66.5	266.
1971	1.	1.	-114.9	-1101.24	-847.48	-306.96	66.5	66.5	66.5	266.
1972	1.	1.	-137.5							
1973	1.	1.	-160.1	-534.1	-427.73	-106.93	66.5	66.5	66.5	266.
1974	1.	1.	- 63.7	-962.4	-352.98	- 88.31	66.5	66.5	66.5	266.
1975	1.	1.	- 92.3	-815.82	-625.9	-156.7	66.5	66.5	66.5	266.
1976	1.	1.	- 58.	-320.8	-246.58	- 61.71	66.5	66.5	66.5	266.
1977	1.	1.	- 99.	-486.5	-394.26	- 93.63	66.5	66.5	66.5	266.

*Refers to coefficients unique to the irrigated model.

APPENDIX C: RESOURCE CONSTRAINT DATA

Table C-1 The right-hand side coefficients b_i's: rows 1-8

Year	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_8^*
1957	320.	200.	220.	240.	240.	240.	240.	5516	9179
1958	320.	200.	220.	240.	240.	240.	240.	4906	7768
1959	320.	200.	220.	240.	240.	240.	240.	5516	9179
1960	320.	200.	220.	240.	240.	240.	240.	10821	10821
1961	320.	200.	220.	240.	240.	240.	240.	12266	13459
1962	320.	200.	220.	240.	240.	240.	240.	13682	13682
1963	320.	200.	220.	240.	240.	240.	240.	8237	12907
1964	320.	200.	220.	240.	240.	240.	240.	11846	13839
1965	320.	200.	220.	240.	240.	240.	240.	10922	11831
1966	320.	200.	220.	240.	240.	240.	240.	8296	12419
1967	320.	200.	220.	240.	240.	240.	240.	4410	7604
1968	320.	200.	220.	240.	240.	240.	240.	1514	10477
1969	320.	200.	220.	240.	240.	240.	240.	14399	14399
1970	320.	200.	220.	240.	240.	240.	240.	4821	12513
1971	320.	200.	220.	240.	240.	240.	240.	9560	12609
1972	320.	200.	220.	240.	240.	240.	240.	13200	13166
1973	320.	200.	220.	240.	240.	240.	240.	29460	32409
1974	320.	200.	220.	240.	240.	240.	240.	14269	19706
1975	320.	200.	220.	240.	240.	240.	240.	17727	22238
1976	320.	200.	220.	240.	240.	240.	240.	7378	15179
1977	320.	200.	220.	240.	240.	240.	240.	16157	18829

*This asterisk signifies b_i's unique to the irrigated model.

Table C-2 The right-hand-side coefficients, b_i's, rows 9-17

Year	b_9	b_9*	b_{10}	b_{11}	b_{12}	b_{13}	b_{14}*	b_{15}*	b_{16}*	b_{17}*
1957	25809	25809	100	100	100	0	0	0	0	266
1958	13068	20695	100	100	100	0	1030	618.45	412.3	266
1959	14695	24453	100	100	100	0	532	319.2	212.8	266
1960	28827	28827	100	100	100	0	0	0	0	266
1961	32569	35855	100	100	100	0	332.5	119.5	133	266
1962	36146	36146	100	100	100	0	0	0	0	266
1963	21943	34384	100	100	100	0	1263.5	758.1	505.4	266
1964	31558	36868	100	100	100	0	266.	159.6	106.4	266
1965	29097	31519	100	100	100	0	199.5	199.7	79.8	266
1966	22100	31513	100	100	100	0	665	399	266	266
1967	11028	33084	100	100	100	0	1064	638.4	425.6	266
1968	4034	20256	100	100	100	0	1330	798	532	266
1969	37681	37681	100	100	100	0	0	0	0	266
1970	12843	33334	100	100	100	0	1263.5	758.1	505.4	266
1971	25467	33592	100	100	100	0	465.6	279.3	186.2	266
1972	35165	35165	100	100	100	0	0	0	0	266
1973	78477	86338	100	100	100	0	399	239.4	159.6	266
1974	38012	52496	100	100	100	0	731.5	438.9	292.6	266
1975	47210	59243	100	100	100	0	399	159.6	159.6	266
1976	19654	40438	100	100	100	0	2287.6	1372.56	915.04	266
1977	43042	50161	100	100	100	0	465.6	279.3	186.2	266

*This asterisk refers to columns listing coefficients unique to the irrigated model.

APPENDIX D: FIXED COST DATA

Table D-1 Fixed costs common to the rain-fed and irrigated scenarios

Year	Deprec.	Farm family salary	Insur.	Int. paid	Prop. tax	Bldg. repairs
1957	1779	2482	214	375	907	254
1958	1981	2544	268	526	992	241
1959	1836	2708	275	829	854	386
1960	1581	2560	392	756	1113	356
1961	1466	3093	312	547	1272	383
1962	1603	3080	429	1158	1326	567
1963	1683	3360	392	1041	1353	629
1964	1744	3385	496	1454	1434	364
1965	3107	4610	517	1817	1612	438
1966	2170	5280	616	1759	1489	654
1967	2506	5521	579	2212	1719	456
1968	2890	5711	597	2479	1597	592
1969	3178	6393	639	2722	1600	716
1970	4128	6170	587	3526	1663	821
1971	3840	6250	704	3872	1712	577
1972	3840	6072	712	5002	2061	932
1973	3952	8437	996	6513	2298	1323
1974	3952	8916	1101	6958	2270	973
1975	6512	9075	1567	7274	2258	1730
1976	7184	9273	1368	5857	2500	1469
1977	7876	10003	1382	6292	2832	1638