REPORT OF

North Dakota State Water Commission

900 Boulevard

BISMARCK, NORTH DAKOTA 58501

Interim North Dakota State Water Resources Development Plan

SWC Project No. 322

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Appendix D

An Economic Analysis of Water Resource Development for Irrigation in North Dakota

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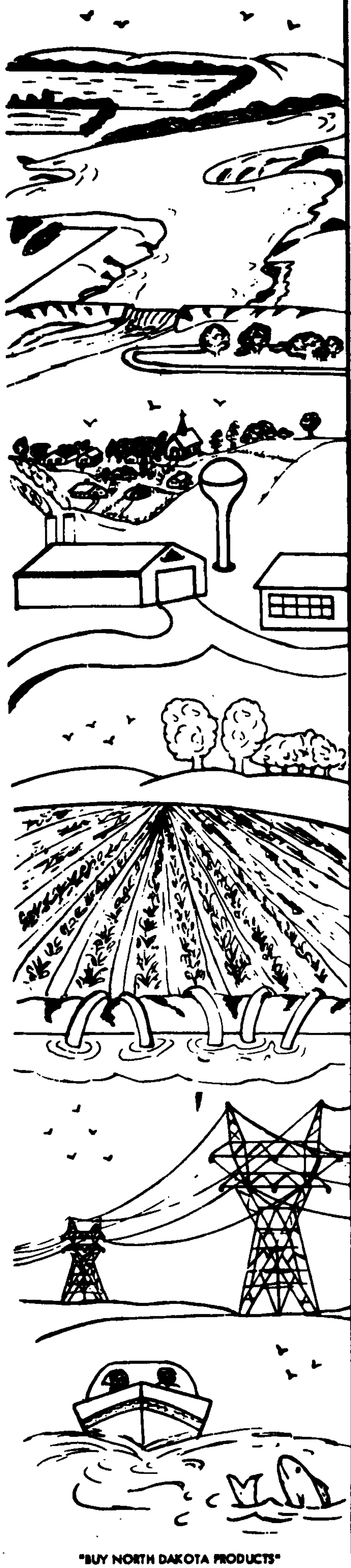
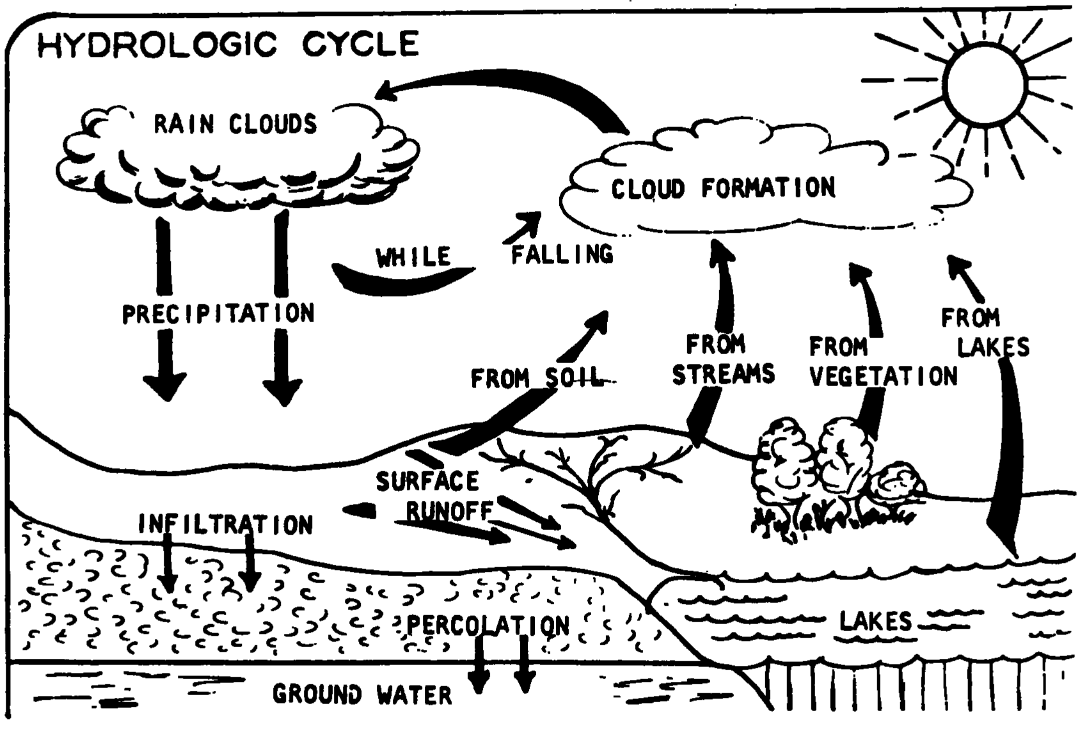
JUNE, 1968



"BUY NORTH DAKOTA PRODUCTS"



APPENDIX D

INTERIM NORTH DAKOTA

STATE WATER RESOURCES DEVELOPMENT PLAN

SWC PROJECT #322

AN ECONOMIC ANALYSIS OF WATER RESOURCE DEVELOPMENT FOR IRRIGATION IN NORTH DAKOTA

By

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NORTH DAKOTA STATE WATER COMMISSION
STATE OFFICE BUILDING
BISMARCK, NORTH DAKOTA

May, 1968

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CHAPTER I

INTRODUCTION

The demand for water in the Upper Midwest is increasing rapidly as the result of several factors including: an expanding population, increasing per capita consumption of water, increase in emphasis on water based recreation, municipal and industrial uses, and increasing amounts of land being irrigated. As the demands for water increase, given relatively stable supply, careful planning of water development becomes increasingly important.

Although the supply of water is adequate for its many uses, it has to be available at the time and location it is demanded to be of any social or economic use. Therefore, careful planning must be inaugurated at the present time to insure adequate water availability in the future.

Irrigation Development

Development of irrigation is of major importance to both North Dakota and the United States. Each year, the acres of productive farmland in the United States decreases by about one million acres due to individual and municipal expansion and the construction of highways, airports, golf courses, defense areas, parks, and other development projects. Increased production on the remaining land will be necessary to provide the food and fiber needed to meet the consumption demand both in the United States and in foreign countries. Irrigation in the United States has now developed until about 37 million acres[1] are irrigated. About 1,070 million acres are cultivated by dry farming, but the greater part of suitable land that is still uncultivated is not productive because of the unavailability of water.

The irrigation of agricultural land is increasing in North Dakota. In 1954, about 37,672 acres[2] were irrigated with land under irrigation increasing to 50,548 acres[3] in 1964. Most of this irrigation takes place along the Missouri River and its tributaries. Land that is potentially irrigable but removed from natural waterways, cannot be economically irrigated without state and federal assistance because of the large capital outlays necessary to deliver water to these areas.

The use of water for irrigation will become a reality as Garrison Diversion moves towards its conclusion. At present, the interest in supplemental irrigation is increasing rapidly. Supplemental irrigation is essentially a method of providing water for plant use when the natural rainfall is inadequate. Many farmers in North Dakota have found that supplemental irrigation is necessary almost every year to obtain acceptable yield and quality of crops. Although droughts cannot be prevented,

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[1]United States Department of Commerce, Bureau of Census, 1964 Census of Agriculture, Washington, D.C., 1968, p. 913.

[2]United States Department of Commerce, Bureau of Census, 1954 Census of Agriculture for North Dakota, Washington, D.C., 1956, p. 2.

[3]Taylor, Fred R., and Heltemes, C. J., North Dakota Weather--Crop Bulletin 1950-1965, Agricultural Experiment Station, North Dakota State University and Statistical Reporting Service, United States Department of Agriculture, Fargo, North Dakota, October, 1965, p. 2.

their severity can be lessened by making the most efficient use of rainfall and water which may be available for irrigation.

A large acreage of land in North Dakota is marginal producing land or remains uncultivated due to insufficient rainfall. Average annual rainfall in North Dakota varies from approximately 19 inches in the Red River Valley to less than 15 inches in Western North Dakota. Wide variation in yearly precipitation occurs and has resulted in variations from about 15 inches annually to over 36 inches annually in the same area.[4] This fluctuation in yearly rainfall contributes to the economic instability of agriculture. Consequently, because North Dakota has an agriculturally oriented economy, the economic growth of the state is dependent upon the growth and stability of the agricultural sector.

The importance of irrigation on income level and stability is that the overall risk and uncertainty in farming operations are reduced when irrigation is integrated with dryland farming. For example, a study comparing dryland and irrigation farming in North Dakota indicated that physical production of crops and the resulting net income were increased by the use of irrigation.[5] Also, the study concluded that variability in yield, gross income, and net income per farm was reduced by irrigation. The farm yields were stabilized more by irrigation than was net farm income.

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[4] Ibid., p. 2.

[5] Vockrodt, Duane C., Risk Measures for Income of Crops and Livestock on Irrigation and Dryland, Unpublished M.S. Thesis, North Dakota State University, Fargo, North Dakota, 1961, pp. 75-79.

The North Dakota State Water Commission is charged with the responsibility of planning for the development of North Dakota's water resources on a state-wide basis. To meet this challenge, the State Water Commission has authorized this study as a part of the overall plan to allocate water within the state to its most effective and efficient use.[6]

Need for Study

The State of North Dakota is endowed with abundant supplies of water from various sources. It is available in natural streams and lakes, underground acquifiers, and man-made impoundments. However, much of this water is not available in sufficient quantities at the time and location to fulfill particular demands.

The value of a natural resource depends upon its availability at the time and location most critically needed. In most cases, capital and labor must be employed to make water available at the time and location to fulfill a particular demand. Planning agencies are charged with the responsibility of developing and implementing plans for resource development and use. The implementation of any resource development project requires an outlay of capital, either private or public, or both. The amount of capital available is limited relative to the demand for it. Thus, planners must determine the relative economic benefits that would result from investing a given amount of money in alternative

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[6]North Dakota State Water Conservation Commission, An Interim State Water Resource Development Plan, Chapters I-VII, SWC Project No. 322, Bismarck, North Dakota, 1968, pp. 1-3 (preliminary draft).

water development projects. One criteria available to planners in making this allocation decision is value in use. Therefore, it is necessary to determine the value of water developed for agricultural purposes, in particular, irrigation.

Objectives

The general objective of this research is to determine the most profitable level of irrigation development in the state. The specific objectives were:

1. To develop methodology for determining the most profitable level of water resource development for irrigation in North Dakota
2. To make tentative estimates of future water use and development and the corresponding levels of aggregate supply of agricultural products
3. To estimate the potential net farm income attributable to water resource development for irrigation in North Dakota.

Area of Study

The geographic areas to which the results of this study apply include the Missouri, Souris, Devils Lake, James, and Red River Drainage Basins of North Dakota (Figure 1). The largest basin is the Missouri River Basin which contains an area of 33,902 square miles, which is nearly half of the total area of the state of 70,665 square miles (Table 1). The smallest drainage basin is Devils Lake with 4,710 square miles.

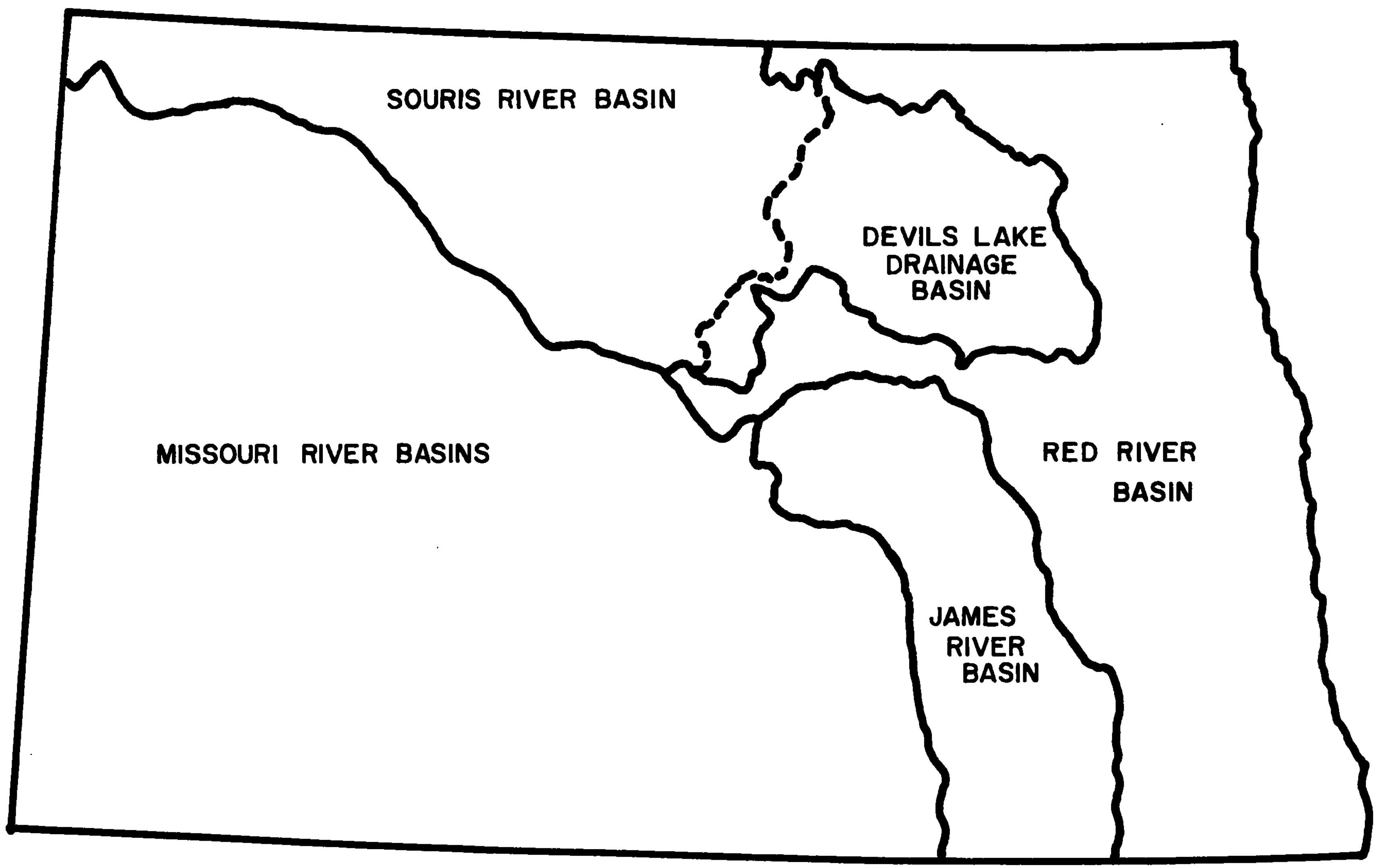

Figure 1. Hydrologic Boundaries of Major Drainage Basins in North Dakota

TABLE 1. AREA AND POPULATION OF EACH MAJOR DRAINAGE BASIN IN NORTH DAKOTA AND TOTALS FOR THE STATE

Item	Drainage Basins					State Total
	Missouri	James	Souris	Devils Lake	Red River	
Area (Sq. Mi.)						
Hydrologic	33,902	6,910	9,321	4,710	15,822	70,665
Economic	33,408	7,133	11,102	4,829	14,193	70,665
1960 Population	204,283	61,523	103,671	35,536	227,433	632,446

SOURCE: United States Department of Commerce, Bureau of Census, United States Census of Population, 1960, North Dakota General Population Characteristics, PC (1), 36 B, North Dakota, pp. 27-28.

Land areas on an economic region basis (Figure 2), whose boundaries follow county lines but closely approximate the actual river basin boundaries, are presented in Table 1. Hydrological basins (Figure 1), whose areas are also presented in Table 1, are determined on the basis of area drained. These include the four major rivers in the state and the Devils Lake area, which is a closed basin.

Organization of Thesis

The remainder of this thesis is divided into five chapters. The following chapter contains a review of literature, the third chapter presents theoretical concepts appropriate to this resource allocation problem, discusses concepts of linear programming, and develops the empirical models. The results of this study are set forth in Chapter IV. Chapter V presents the resource requirements and the value of water.

The final chapter summarizes the study and presents conclusions relevant to North Dakota.

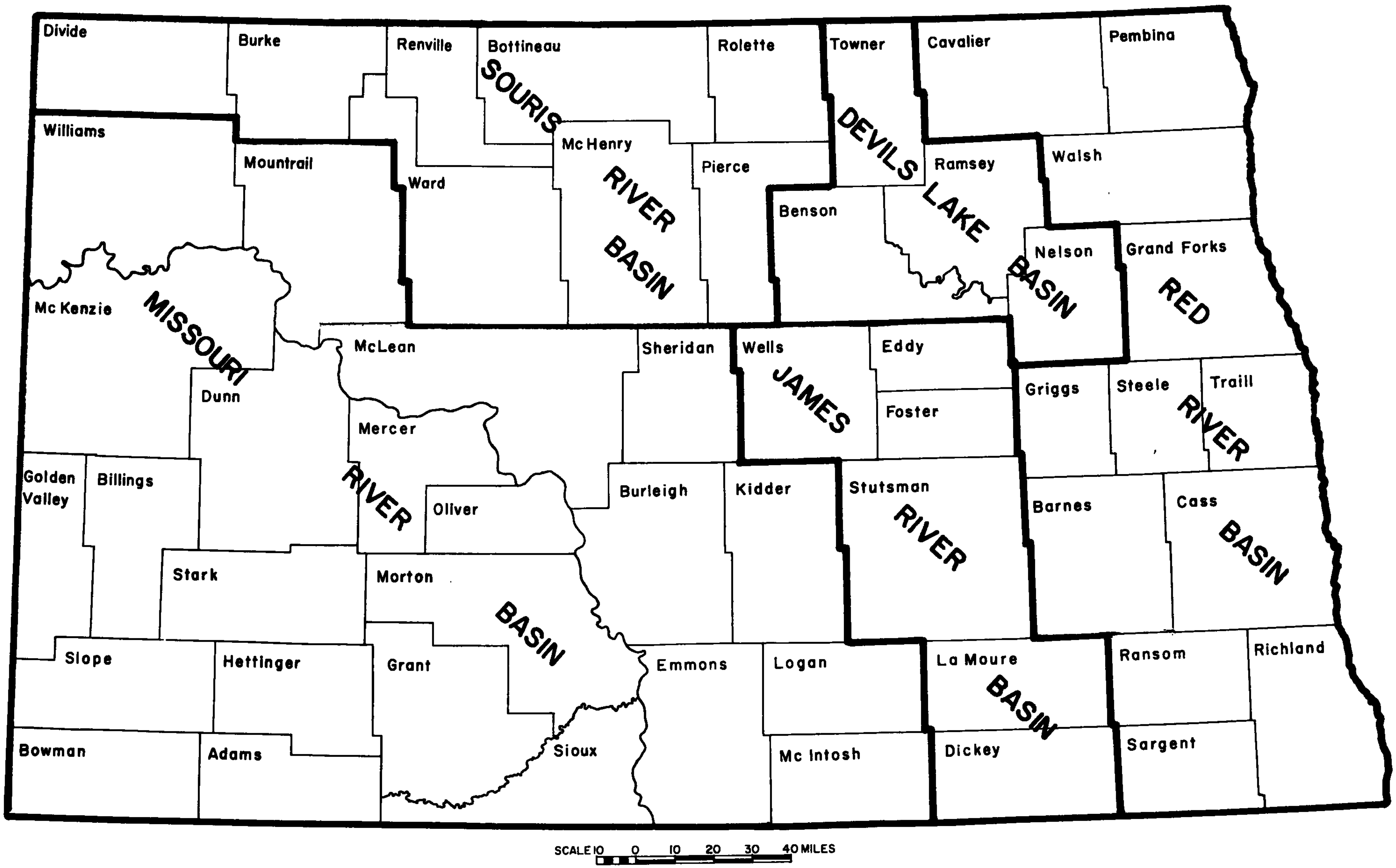

Figure 2. Economic Boundaries of Major Drainage Basins in North Dakota

CHAPTER II

REVIEW OF LITERATURE

Profit maximization has been the objective of a great number of research studies conducted throughout the United States. A large percentage of these studies concentrate strictly on dryland farming. Also, they are concerned with only one economic area or some other convenient division of a state. Research studies dealing with irrigation are relatively limited. Most of these studies are concerned with costs and returns from irrigated crops and comparing irrigation with dryland farming. Very few studies have been conducted to find the optimum combination of enterprises, irrigated and dryland, which will maximize profits. Research studies of this nature with an entire state as the study area are almost non-existent.

Anderson[1] conducted a study on the value of irrigation water. The purpose of this research was to appraise and evaluate the potential value of water for irrigation in the Washita River Basin in Oklahoma. The profit maximizing allocation of water and other resources and corresponding farm enterprise organizations was determined by linear programming. Activities considered in the model included several dryland and irrigated crop activities plus alternative beef and dairy enterprises. A series of programs consisting of four different water levels were run

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[1]Anderson, Dale O., The Value of Irrigation Water in the Washita River Basin of Roger Mills County, Oklahoma, Ph.D. Thesis, Oklahoma State University, Stillwater, Oklahoma, May, 1965, pp. 94-95.

for each of three different rainfall conditions: below average, average, and above average. The first water level programmed was zero. In other words, irrigation was not considered an alternative. The results from this program were used as a benchmark to evaluate the added returns from the other three water levels which were assumed to be a low, medium, and high level of water application. The above average rainfall condition was excluded from the programming analysis on the basis of preliminary results which indicated that the cost of adding the water was greater than the added returns. In general, the optimum level of irrigation for most crops was at the high level of water application. Even at very limited levels of water supply, it was more profitable to irrigate fewer acres at the highest level than irrigate more acres at a lower level.

The maximum annual increase in net farm income attributable to irrigation was $254,667 and $406,911 for average and below average rainfall, respectively. These increases in net income are realized from 18,905 acres analyzed and assumes an adequate water supply. Gross and net farm income increased for all farms as water supply per farm increased.

A study to determine the effects of irrigation on stabilizing income and accumulating capital for dryland farmers who can irrigate a part of their farm acreage was conducted by Schaffner, Loftsgard, and Vockrodt.[2] Both dryland and irrigated crop enterprises were analyzed

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[2] Schaffner, LeRoy W., Loftsgard, Laurel D., and Vockrodt, Duane C., Production and Income Variability for Farm Enterprises on Irrigation and Dryland, Bulletin No. 445, Department of Agricultural Economics, Agricultural Experiment Station, North Dakota State University, Fargo, North Dakota, June, 1963, p. 4.

for yield variability. Coefficients of variation were calculated for both which indicated yields from irrigated crop enterprises were more stable than dryland crop enterprises. Coefficient of variation ranged from 14-28 per cent for irrigated crop and from 31-48 per cent for the same crops grown under dryland conditions. The results of this study show that irrigation will help stabilize income. When wheat, oats, barley, corn, and alfalfa grown under irrigation are compared with the same crops grown under dryland conditions, irrigation will stabilize income in the following ways:

1. Increase the stability of production by 44 per cent
2. Increase the stability of gross income by 14 per cent
3. Increase the stability of net income by 18 per cent
4. Increase the returns per $100 of all costs by 24 per cent
5. None of the crops grown under irrigation exhibited cycles in gross income.

Linear programming was used by Skold and Epp[3] to determine the optimal farm organizations for irrigated farms in South Central Nebraska. Three classes of farms were defined according to size. Each class of farm was termed moderately irrigable or highly irrigable depending upon the number of acres under irrigation. Profit maximizing farm organizations were computed for nine sets of product prices, three classes of farms were defined according to size and each class of farms was termed moderately irrigable depending upon the number of acres under

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[3]Skold, M. D., and Epp, A. W., Optimal Farm Organizations for Irrigated Farms in South Central Nebraska, Bulletin No. 222, Farm Production Economics Division, Nebraska Agricultural Experiment Station, University of Nebraska College of Agriculture and Home Economics, Lincoln, Nebraska, February, 1966, p. 3.

irrigation. Profit maximizing farm organizations were computed for nine sets of product prices, three prices each for hogs, beef, and feed grains. Results from this study indicate that the optimum farm organization is conditioned by the particular set of price assumptions.

Although cropping plans did not differ significantly from current operations, all farm plans at each price combination did indicate livestock production should be expanded to maximize profits. With the increase in livestock numbers, roughage production would be increased also.

Return to family labor and management is high relative to current earnings. Although summer and fall labor is the limiting and deciding factor in the level of livestock production and which livestock enterprises appear in the profit maximizing solution.

CHAPTER III

DEVELOPMENT OF METHODOLOGY

The purposes of this chapter are to discuss the economic theory relevant to this study, applications and limitations of linear programming, and the development of the empirical model. Each facet of the development of the empirical model will be described as to the assumptions and data used in this study.

Static Analysis

Static analysis is concerned with a changeless, timeless state in which knowledge is perfect. Decision-makers are assumed to have complete knowledge of costs, yields, and prices. Although this is not an entirely valid assumption, aggregate agricultural production is highly stable. Year to year variations in aggregate production of farm products are small. During the period 1910-1954, year-to-year changes in output of agricultural products were less than five per cent in 29 years.[1]

Returns in static analysis are forthcoming instantaneously from a combination of inputs. Profit maximization or cost minimization is assumed to be the objective of the managers. To maximize profits, limited quantities of resources must be allocated among competing production alternatives in such a manner that no reallocation of these resources

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[1] Bishop, C. E., and Toussaint, W. D., *Introduction to Agricultural Economic Analysis*, John Wiley and Sons, Inc., New York, 1963, p. 173.

can result in an increase of net income. To minimize costs, limited resources are allocated among competing alternatives to obtain a predetermined level of profit. As this study is concerned with profit maximization, the concepts of profit maximization will be discussed and illustrated.

Profit Maximization

The combination of enterprises which maximize profits from available resources are illustrated in Figure 3. The production possibility curves (P_1P_1-P_3P_3) indicate all possible combinations of wheat and barley that can be produced with a given outlay of land, labor, capital, and management. Given the prices of wheat and barley, the isorevenue lines (R_1R_1-R_3R_3) reflect the ratio of the barley price to the wheat price. The point of tangency (point b) of the production possibility curve, P_3P_3, and the isorevenue line, R_3R_3, represents the profit maximizing combination of wheat and barley production. The further out from the origin the isorevenue line exists, the larger the total revenue. Any other point on P_3P_3 below b would decrease total revenue. To obtain a revenue greater than is possible at point b would require an outlay of resources in excess of P_3P_3. Also, any change in the price of wheat or barley would change the slope of the isorevenue curve and thus alter the present profit maximizing combination of enterprises.

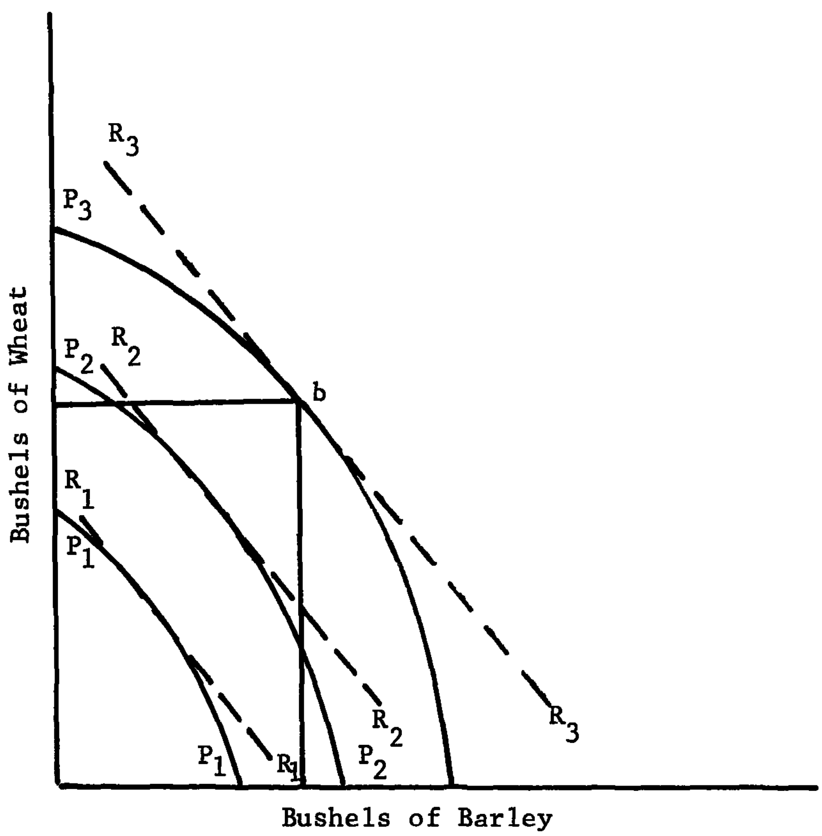

Figure 3. Profit Maximizing Combination of Enterprises for Given Quantities of Resources

Linear Programming

The conceptual analysis in the preceding section assumed that the existing transformation relationships were continuous and nonlinear. However, the discrete nature of the data available for this study were linear and discontinuous. Linear programming is a highly efficient mathematical technique for determining the optimum allocation of resources such as land, labor, and capital.

In order to have a linear programming problem, three components must be present. There must be:[2] (1) An objective, (2) alternative methods for attaining the objective, and (3) one or more resource restrictions. However, certain fundamental assumptions are involved in applying the linear programming model to management problems for precise solutions. They are linearity, divisibility, additivity, and finiteness.[3] The assumption of linearity demands that the ratio between inputs and outputs be fixed independently of the level of production. The divisibility assumption means that given the activity, all non-negative levels of output are possible. The additivity assumption implies that, with the simultaneous operation of the two or more activities, the total product produced is the sum of the products produced by the individual activities, and the quantities of input required are the sum of the requirements of each individual activity. Finally, the assumption

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[2]Heady, Earl O., and Candler, Wilfred, Linear Programming Methods, The Iowa State University Press, Ames, Iowa, 1958, pp. 2-41.

[3]Swanson, Earl R., "Programming Optimal Farm Plans," Farm Size and Output Research, Southern Cooperative Series, Bulletin No. 56, June, 1958, pp. 47-49.

of finiteness means that, of all the possible activities, only a relatively small number are considered as feasible alternatives.

In this study, linear programming was used to determine the profit maximizing combination of enterprises for each respective major drainage basin in North Dakota subject to specified resource restrictions.

The objective function of the profit maximizing model is of the general form

(1) $$Z = \sum_{j=1}^{n} C_j X_j,$$

where Z represents profit, the C_j's are costs per unit of input or net returns per unit of output, the X_j's are the activities or enterprises, and n is the number of activities considered. The objective function is maximized subject to a set of restrictions expressed as follows

(2) $$\sum_{j=1}^{m} A_{ij} X_j \leq b_i$$

(3) $$X_j \geq 0$$

In equation (2), A_{ij} is the quantity of the i^{th} resource required in the production of one unit of the j^{th} product (X_j). The b_i's are the resource restrictions with m being the number of restrictions.[4] Equation (3) stipulates that no product can be produced at a negative level.

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[4]Equation (2) is a non-identity, indicating that the quantity of any given resource used cannot exceed but can be equal to or less than the restriction, b_i.

If $\sum_{j=1}^{m} A_{ij} X_j < b_i$, a portion of the resource is unused.

Production possibility curves for a profit maximizing model are illustrated in Figure 4. Each isoresource curve defines the combinations of wheat and barley that can be produced with a specific quantity of land, labor, and capital, respectively, that is available. The graph is drawn such that land and capital prohibit the utilization of all the labor available. Above point b, land is the limiting factor, and below point b, capital restricts the output of barley and wheat. Therefore, the relevant part of the production possibility curves becomes abc (Figure 5).

The Empirical Model[5]

The accuracy of the solutions obtained with any linear programming model is directly related to the exactness of the data pertaining to the variables analyzed. Data for dryland enterprises were obtained from North Dakota Crop Costs and Returns.[6] Transformation coefficients representing above average management practices were incorporated into the enterprise budgets to simulate results applicable to 1980. The economic areas, as defined by the North Dakota Extension Service, and the River Basins, as defined by the North Dakota State Water Commission, are not synonymous geographically. Therefore, costs were weighted proportionately to areas in each basin. For example, economic areas 1,

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[5]An example of a linear programming tableau used in this study is presented in Appendix A, Table 2.

[6]Rice, Billy B., and Paul, Rodney R., Crop Costs and Returns, FM Circulars 3-9, Cooperative Extension Service and Economic Research Service, North Dakota State University, Fargo, North Dakota, October, 1967.

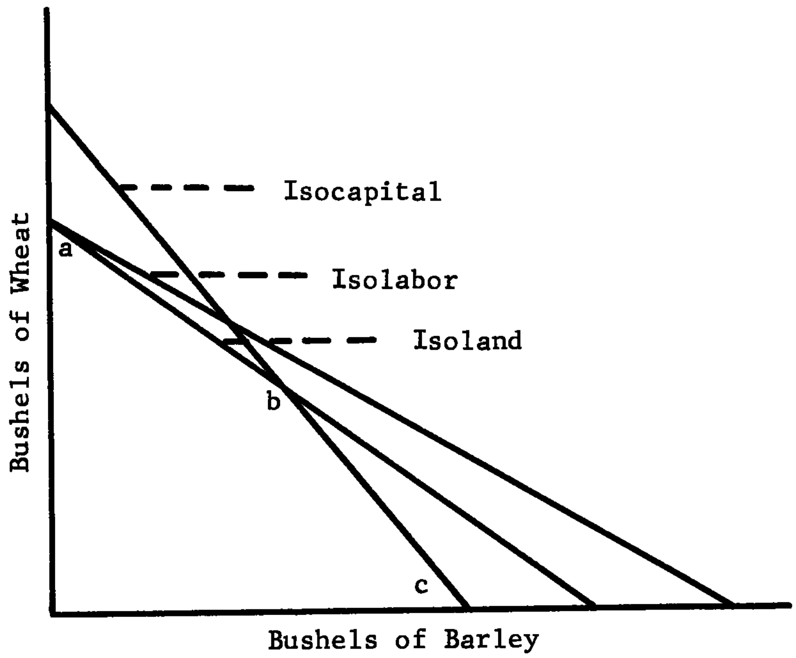

Figure 4. Production Possibility Curves as Defined by the Limited Resources in a Linear Programming Model

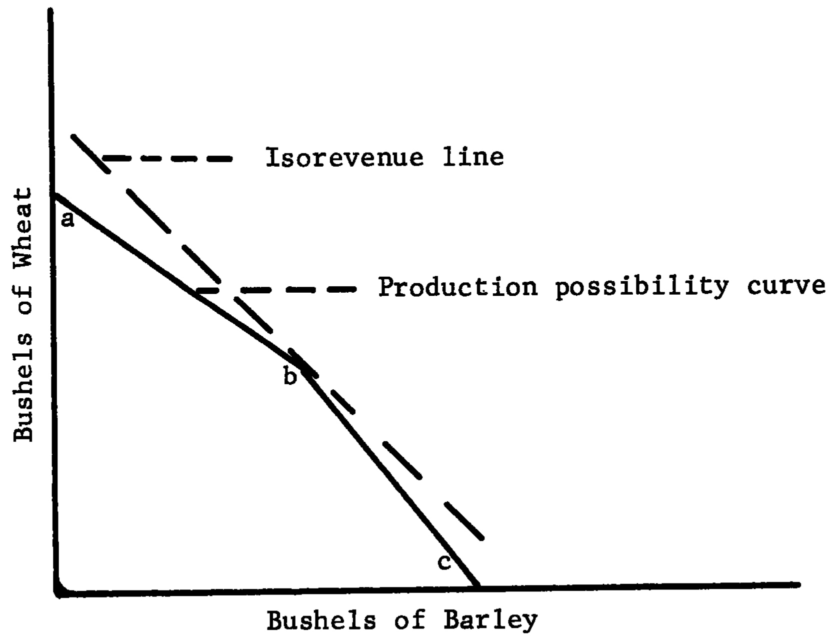

Figure 5. Relevant Production Possibility Curve in a Profit Maximizing Linear Programming Model

2A, and 2B are included in the Missouri River Basin, but area 1 has approximately four times as many square miles as either area 2A or 2B. Therefore, coefficients for area 1 were given proportionately more weight than the other two areas.

Potential irrigable acres within each basin were supplied by the North Dakota State University Soils Department[7] at the request of the North Dakota State Water Commission.

Crop Enterprises

The dryland crop enterprises considered as production alternatives in each basin included wheat, barley, oats, flax, corn silage, alfalfa, and pasture. Corn grain, soybeans, potatoes, and sugar beets were also included as alternatives in the Red River Basin. Wheat on fallow was an activity in each drainage basin except the Red River Basin. The Missouri River Basin was the only basin which required that wheat be produced from a wheat-fallow rotation only. Sugar beets were also assumed planted on fallow.

All dryland production alternatives were considered as potentially irrigable in all basins except corn grain and soybeans, which were alternatives only in the Red and James Drainage Basins. Yields for production alternatives included in this study are presented in Appendix C, Tables 1 and 2.

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[7]See Appendix B for an explanation of procedure.

Livestock Enterprises[8]

Livestock enterprises considered were restricted to beef cattle. The type of livestock activities varied among the basins. Livestock enterprises in the Missouri and Souris Basins considered only a cow-calf operation which included selling the calf at 400 pounds. Plans in the James and Red Basins were restricted to a buy-calf operation, but only to the limitation of the calves that were produced in the Missouri and Souris Basins. The basis for this decision was the high ratio of cropland to total land area, and the availability of three feed grain alternatives in the James and Red Basins. A buy-calf operation presumes buying a calf at 400 pounds and selling at 1,000 pounds. Activities in the Devils Lake Basin included a cow-calf operation. Alternatives with this operation included selling the calves at 400 pounds, wintering and grain feeding to 700 or 1,000 pounds.

In each basin, the option was present either to feed hay or hay and silage. A choice was also provided for feeding barley or oats. Feeding corn was also a choice in the James and Red Basins.[9]

Resource Restrictions

Resource restrictions are an intricate part of a profit maximizing linear programming model. Returns are maximized subject to restraints

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[8]Regional Project GP-5, "Economic Problems in Production and Marketing of Great Plains Wheat."

[9]A hundredweight of oats equals 90 pounds of corn and 90 pounds of barley.

placed on one or more available resources. The resource restrictions for each basin included in this study are presented in Appendix C, Table 4.

Water Levels

The quantity of water available for irrigation in each drainage basin was assumed at four levels. The first level programmed was an unlimited supply represented by water level 4 in Table 2. The purpose of programming the unlimited supply first was to determine the water

TABLE 2. WATER APPLIED AT EACH WATER USE LEVEL AS USED IN THE PROGRAMMING ANALYSIS FOR EACH DRAINAGE BASIN IN NORTH DAKOTA

Water Use Level	Water Applied[a]
0	0
1	1/4 X_1
2	1/2 X_2
3	3/4 X_3
4	X_1

[a]X_1 represents the quantity of water necessary to satisfy the following equilibrium condition:

$$MVP_{w1} = MVP_{w2} = \ldots = MVP_{w6} \geq MC_w.$$

requirement necessary to satisfy the following equilibrium condition:

$$MVP_{w1} = MVP_{w2} = \ldots MVP_{wn} \geq MC_w$$

where $MVP_{w1} \ldots MVP_{wn}$ represents the marginal value product of water in the production of n products and MC_w is the marginal cost of the last unit of water applied.

Water use levels 1, 2, and 3 were set at one-fourth, one-half, and three-fourths, respectively, of the quantity of water necessary to satisfy the above equilibrium conditions for each basin. Water use level 0 was programmed as a dryland situation for each basin. The dryland optimum plan provided a basis for analysis of changes in the profit maximizing combination of enterprises, resource requirements, and net and marginal returns of increasing water availability for irrigation.

Land and Allotments

The amount of cropland, native hay, and native pasture in each drainage basin was determined by correlating soil characteristics of the five drainage basins with land resource areas in North Dakota as outlined in the Missouri River Basin Study.[10] The Missouri River Basin Study defines acres of cropland, native hay, and native pasture contained in each land resource area. The boundaries of these land resource areas follows closely the boundaries of river drainage basins, therefore, facilitating the correlation. Acreages of cropland in each basin suitable for irrigation was provided by the North Dakota State University Soils Department and are presented in Table 3.

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[10]Austin, Morris E., Land Resource Regions and Major Land Resource Areas of the United States, Agriculture Handbook 296, Soil Conservation Service, United States Department of Agriculture, Washington, D.C., December, 1965, pp. 23-25.

TABLE 3. ESTIMATE OF POTENTIALLY IRRIGABLE ACRES OF LAND IN EACH MAJOR DRAINAGE BASIN IN NORTH DAKOTA

Drainage Basin	Irrigable Land (Acres)
Souris River	739,146
Devils Lake	210,210
Red River	1,578,570
James River	203,682
Missouri River	1,171,396

SOURCE: Omodt, Hollis, Soils Department, North Dakota State University, Fargo, North Dakota (unpublished data).

Due to the uncertainty of government programs, it was assumed that wheat acreage would not exceed the average acreage planted during the period 1962-66.[11] The same procedure was used to establish corn and potato acreages for the Red River Basin, but these acreages were adjusted upward 15 per cent to meet expected demand in 1980. Potential potato acreage under irrigation in the other four basins had to be estimated due to the negligible acres planted at the present time.[12] Sugar beet allotments for the Red River Basin were based on acreage presently planted, and new acreage to be assigned to the two plants proposed at Harwood and Wahpeton, North Dakota. Present sugar beet processing plants

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[11]Heltemes, C. J., and Taylor, Fred R., <u>North Dakota Crop and Livestock Statistics</u>, Agricultural Statistics 13-17, United States Department of Agricultural Statistical Reporting Service, Department of Agricultural Economics, North Dakota State University, Fargo, North Dakota, 1963-67.

[12]Potato allotments were based on consultation with Agricultural Economics staff members, North Dakota State University, Fargo, North Dakota.

have the capacity to handle the production from approximately 66,000 acres of sugar beets. Therefore, each of the other basins were allotted acreage to supply one sugar beet processing plant.

Prices

The assumed input and product prices used in the study are summarized in Appendix C, Table 3. Crop commodity prices were taken from *Crop Costs and Returns*.[13] When differences in prices of the individual commodities occurred among economic areas, the weighted average price was used.

Livestock prices were derived from yearly average price quotations of selected livestock at the West Fargo Union Stockyards. To include all different classes of livestock into one selling activity in the Devils Lake Basin, the only basin in which more than one class of livestock was an alternative, a statistical regression was used to express the price of each class of livestock in terms of a base price for livestock. Then the selling price for all classes of other livestock was expressed as a function of the price established for the base livestock class. For this study, the base price for a 400 pound feeder steer was used.

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[13] Rice and Paul, *op. cit.*

Capital

No restrictions were placed on the availability of capital in this study. It was assumed that as much capital could be acquired as was profitable to borrow. Capital costs varied, depending on its use. An interest rate of seven per cent was charged on capital used for irrigation equipment and operating expenses for crop and livestock enterprises.[14] Capital used for machinery and equipment carried a six per cent interest charge on the average annual investment. An interest charge of 5.5 per cent of the current value of cropland was also included as a cost to each crop enterprise.

Labor

This study assumed no free operator labor supply was available. There was no restriction placed on the amount of labor available at $1.50 per hour. However, unless a return of $1.50 per hour was realized, labor was not hired. Migrant labor for sugar beets was included as a production cost.

Land under irrigation required 1.8 hours per acre of additional labor.[15] This included time spent getting the system ready for operation in the spring and preparing it for storage in the fall. An additional

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[14]Cost of operating capital was charged for the five month period it was used.

[15]McMartin, Wallace, and Bergan, Ronald O., Irrigation Practices and Costs in North Dakota, Bulletin No. 474, Economic Research Service, United States Department of Agriculture, Agricultural Economics Department, North Dakota State University, Fargo, North Dakota, 1968.

0.5 hour per acre was needed for each application of water applied. This additional labor includes turning the irrigation sprinkler system on and off, changing the sets, and moving the irrigation equipment from one field to the next.

Irrigation Costs

Irrigation costs[16] used in developing the irrigation enterprise budgets are summarized in Table 4. Due to new innovations in sprinkler

TABLE 4. SPECIFIED ADDITIONAL COST COEFFICIENTS ASSOCIATED WITH IRRIGATED CROP ENTERPRISES INCLUDED IN THIS STUDY, NORTH DAKOTA, 1968

Item	Cost Per Acre
	(Dollars)
Capital investment	91.75
Fixed cost	8.81
Variable cost	4.15
Additional fertilizer	
Small grains	5.16
Corn	9.78
Alfalfa	3.75
Potatoes	15.00
Sugar beets	15.00

SOURCE: McMartin, Wallace, and Bergan, Ronald O., Irrigation Practices and Costs in North Dakota, Bulletin No. 474, Economic Research Service, United States Department of Agriculture, Agricultural Economics Department, North Dakota State University, Fargo, North Dakota, 1968.

[16] Ibid.

systems having increased the irrigable acres in North Dakota, it was the only method of irrigation considered in this study. Sprinkler irrigation has advantages which are more relevant to the future than does surface irrigation. For example, less labor is required to operate a sprinkler system, more efficient use of water is possible, and potential irrigable acres are increased because land leveling is reduced or eliminated and drainage problems are reduced.

Variable costs associated with irrigation include the cost of energy required for pumping, lubricants, repairs, and maintenance of all irrigation facilities and equipment. Other variable costs associated with irrigation include additional field labor, fertilizer, seed, spray, and machine costs. Fixed costs include depreciation, insurance, and taxes. Interest on investment in irrigation equipment is not included in the fixed cost figure, but was charged for in a borrow capital activity in the linear programming model. Capital investment per acre in irrigation equipment was accounted for separately in the borrow capital activity in each model to provide a record of capital used.

Linear Programming Procedure

Two objectives were pursued through the linear programming models. The first objective was to determine the profit maximizing organization of production at each water use level. The second objective was to determine the net return and change in net return from water for each acre-foot applied.

The programming procedure followed in this study was to determine optimum organization of enterprises within each drainage basin assuming the strategy of profit maximization. Each basin was programmed at five different levels of irrigation water application. The first level programmed was an unlimited supply to determine the optimum amount of water necessary for irrigation consistent with profit maximization. Water levels 1, 2, and 3 were set at one-fourth, one-half, and three-fourths, respectively, of the quantity of water necessary at level 4. Water level 0 was programmed as a dryland situation for each basin to simulate present farming methods. This made possible a comparative analysis of output income and resource requirements resulting from irrigation. Throughout the remainder of this discussion, the return realized shall be interpreted as return to management and irrigation water applied.

CHAPTER IV

RESULTS OF LINEAR PROGRAMMING ANALYSIS

This chapter contains the results of the linear programming analysis for each of the five major drainage basins in North Dakota: Missouri, Souris, Devils Lake, James, and Red. Each basin was programmed assuming five levels of water available for irrigation. A dryland farming operation was simulated in each basin as a basis to analyze the effect of irrigation on enterprise organization and resulting net farm income. Results showing the changes in enterprises and the level of the enterprises are presented in this chapter. The results of each basin will be analyzed separately and then aggregated to obtain a state total.

Programmed Livestock Production and Land Use

Missouri Drainage Basin

The Missouri Basin is the largest drainage basin in North Dakota. There are 17,831,589 acres of land area in the basin. Cropland comprises approximately 30 per cent of the total area, or 5,678,409 acres. The economy in this area is livestock oriented due to the large acreage suitable only for grazing. It is also the area of the state where the greatest amount of irrigation is practiced. An estimated 1,171,396 acres are potentially available for irrigation.

Livestock Production

The basic livestock activity included in the analysis for this basin was a cow-calf operation. It was assumed that calves born in the spring would be marketed in the fall weighing 400 pounds. Two variations in feed combinations were incorporated into the linear programming model. A choice was provided between feeding hay and grain or substituting silage for a part of the hay.

Under dryland farming, approximately 300,000 calves (Table 5) were raised through the alternative which required no silage. Irrigation under water use levels 1, 2, and 3 changes the feed alternative to include silage and also increases the number of head produced to 592,000; 909,000; and 953,000, respectively. As each successive increment of water was applied, additional alfalfa acreage was irrigated to fulfill hay requirements, thus releasing native hay for grazing purposes.

The cow-calf without silage enterprise entered the optimum solution when unlimited water was available. Although the number of livestock did not change as more water was added beyond water level 3, additional profits were realized by producing cash grain crops and more alfalfa to substitute for corn silage at level 4 on acreage producing corn silage at level 3.

Although an irrigated grazing activity was included as a production activity in the programming model, this activity was never included in any of the optimum solutions, thus the return from irrigated grazing enterprise was low relative to other land based production alternatives.

TABLE 5. PROGRAMMED OPTIMUM CROPLAND USES AND LIVESTOCK ENTERPRISES UNDER DRYLAND AND FOUR LEVELS OF IRRIGATION WATER AVAILABILITY, MISSOURI DRAINAGE BASIN, NORTH DAKOTA

Enterprise	Unit	Irrigation Water Availability Level[a]				
		0	1	2	3	4
Non-irrigated						
Wheat-fallow	Acre	2,496,300	2,496,300	2,496,300	2,401,591	2,071,229
Barley	Acre	21,250	41,835	64,182	67,290	67,290
Flax	Acre	664,558	385,184	104,049		297,263
Irrigated						
Corn silage	Acre		54,408	83,470	87,512	
Sugar beets	Acre		66,000	66,000	66,000	66,000
Potatoes	Acre		50,000	50,000	50,000	50,000
Alfalfa	Acre		88,380	318,107	509,714	630,325
Wheat	Acre				94,708	425,070
Livestock[b]						
Cow-calf with silage	Calf		592,346	908,748	952,758	
Cow-calf without silage	Calf	300,876				952,758

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]This activity assumed calves were marketed at 400 pounds.

Land Use

Wheat and barley were raised at each alternative level of water use (Table 5). The wheat allotment was fully utilized at each water use level and livestock requirements for feed grain determined the acreage of barley grown. Flax was produced in four of the five water use alternatives, but only as the other activities reached a limiting restriction.

In general, potatoes and sugar beets were the first crops to be irrigated under limited water supply. The maximum allotted acres for each were grown under irrigation. Alfalfa was the only other activity which was irrigated under each water level. Acres of alfalfa increased at successive water availability levels. At water use levels 1, 2, and 3, alfalfa production increased the livestock enterprise by substituting for native hay, which was released for grazing. Alfalfa was sold whenever produced in excess of livestock requirements.

The shifting portion of the wheat enterprise from dryland to irrigation at water use levels 3 and 4 resulted in a shift from summer-fallow to crop production. A part of this acreage produced the additional alfalfa required for livestock production at level 4. Thus, land was released from corn silage production for use in the production of cash grain crops.

Red Drainage Basin

The Red Drainage Basin is the second largest basin in North Dakota. Due to a greater average annual rainfall than other areas of the state, it is also the most productive under present farming conditions. It has a total of 8,472,660 acres of cropland and 1,377,082 acres of native land. This is the highest ratio of cropland to total land acres in the study area. The Red Drainage Basin has 1,578,570 acres of potentially irrigable land, the highest among the five basins. It is the only basin in which specialty crops are grown economically to any great extent without irrigation.

Livestock Production

Although cow-calf operations are present in the Red Drainage Basin, this enterprise is minor compared to its importance in the other four basins. Therefore, a buy-calf operation was the only livestock alternative considered for this area. Calves were bought weighing 400 pounds, fattened to 1,000 pounds, and then sold. It was assumed in this study that the maximum number of head that could be purchased was approximately 50 per cent of the production in the Missouri and Souris Basins. This amounted to 500,000 head. At each water use level programmed, this restriction limited the size of the enterprise (Table 6).

Feed requirements for this activity were fulfilled by native hay and barley. Feed grain alternatives were barley, corn, and oats. Due to the price relationship between barley and corn and the yield relationship between barley and oats, barley was the profit maximizing alternative selected in the program.

TABLE 6. PROGRAMMED OPTIMUM CROPLAND USES AND LIVESTOCK ENTERPRISES UNDER DRYLAND AND FOUR LEVELS OF IRRIGATION WATER AVAILABILITY, RED RIVER DRAINAGE BASIN, NORTH DAKOTA

Enterprise	Unit	Irrigation Water Availability Level[a] 0	1	2	3	4
Non-irrigated						
Wheat	Acre	1,676,200	1,676,200	1,676,200	1,676,200	1,676,200
Barley	Acre	4,226,144	4,345,322	4,144,717	3,687,947	3,217,890
Flax	Acre	1,250,000	1,250,000	1,250,000	1,250,000	1,250,000
Corn grain	Acre	137,766	137,766			
Soybeans	Acre	250,000	250,000	250,000	250,000	250,000
Potatoes	Acre	98,550				
Sugar beets	Acre	167,000				
Irrigated						
Soybeans	Acre		47,821	100,000	100,000	100,000
Potatoes	Acre		98,550	98,550	98,550	98,550
Sugar beets	Acre		167,000	167,000	167,000	167,000
Corn grain	Acre			137,766	137,766	137,766
Alfalfa	Acre			73,426	100,000	100,000
Barley	Acre				430,197	900,254
Flax	Acre				75,000	75,000
Livestock[b]						
Buy-calf without silage	Calf	500,000	500,000	500,000	500,000	500,000

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]This activity assumed calves were bought at 400 pounds and sold at 1,000 pounds.

<u>Land Use</u>

Organization of crop activities for the Red Drainage Basin are presented in Table 6. Due to the nature of the linear programming problem, restrictions were imposed to limit the acres of soybeans, alfalfa, and flax, in addition to the allotments discussed in Chapter III. Although the acreage of these crops produced is not normally restricted, a restriction on acreage was necessary to insure a realistic combination of crop enterprises for this basin. Barley was not restricted, thus it utilized the remaining cropland acres.

Eight different crop activities entered into the profit maximizing solutions. These included wheat, barley, flax, corn grain, soybeans, potatoes, sugar beets, and alfalfa. Wheat was the only crop raised strictly on dryland at all water use levels, whereas at least part of the total acreage of the remaining crops was produced under irrigation at levels 3 and 4.

Potatoes were the most profitable activity to irrigate, followed in order by sugar beets, soybeans, corn grain, alfalfa, flax, and barley.

James Drainage Basin

The James River Basin has the smallest number of irrigable acres among the five basins. Only 203,682 acres were considered for irrigation out of a possible 3,274,995 total cropland acres. The entire basin is comprised of 4,396,786 acres of native grass and cropland. Although potential acres feasible for irrigation are limited, this area was considered to possess a wider range of production alternatives than the

Missouri, Souris, or Devils Lake Basins. Due to its location in the southern part of the state and a longer growing season, corn for grain and soybeans were considered as production alternatives under irrigation.

Livestock Production

The livestock activity considered in the linear programming model for the James Basin was a buy-calf operation. It was assumed in this model that calves raised in the Missouri and Souris Basins would be purchased at 400 pounds and marketed at 1,000 pounds. A restriction of 500,000 head placed on the number of calves that could be fattened, was the limiting factor for this enterprise in this basin (Table 7).

Two alternative methods were available for fattening the calves. The first method was feeding hay and barley equivalent; the second method included the same proportion of grain, but substituted corn silage for a portion of the hay. The latter was the profit maximizing method of fattening calves in this basin.

Land Use

Wheat, barley, and corn silage were raised at each of the alternative water use levels, although wheat and barley were grown only on dryland (Table 7). The two most profitable crop enterprises produced under irrigation were potatoes and sugar beets. At level 2, the supply of irrigation water was sufficient to utilize the potato and sugar beet allotments and to irrigate a substantial portion of the corn silage acreage needed to produce necessary forage required by the livestock.

TABLE 7. PROGRAMMED OPTIMUM CROPLAND USES AND LIVESTOCK ENTERPRISES UNDER DRYLAND AND FOUR LEVELS OF IRRIGATION WATER AVAILABILITY, JAMES RIVER DRAINAGE BASIN, NORTH DAKOTA

		Irrigation Water Availability Level[a]				
Enterprise	Unit	0	1	2	3	4
Non-irrigated						
Wheat	Acre	608,000	608,000	608,000	608,000	608,000
Barley	Acre	2,590,382	2,539,458	2,563,576	2,514,289	2,463,313
Corn silage	Acre	76,612	76,612	1,570		
Irrigated						
Potatoes	Acre		10,000	10,000	10,000	10,000
Sugar beets	Acre		40,924	66,000	66,000	66,000
Corn silage	Acre			25,848	26,388	26,388
Soybeans	Acre				50,316	101,293
Livestock[b]						
Buy-calf with silage	Calf	500,000	500,000	500,000	500,000	500,000

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]This activity assumed calves were bought at 400 pounds and sold at 1,000 pounds.

The additional water supply available at level 3 was adequate to produce all the corn silage under irrigation plus 50,316 acres of soybeans.

All potentially irrigable cropland was irrigated under water level 4. The soybean enterprise was expanded to 101,293 acres, consuming the additional water available at this level. This 50,977 acre increase in the soybean enterprise over level 3 was responsible for a similar decrease in the dryland barley enterprise.

Souris Drainage Basin

The Souris Basin encompasses 5,988,315 acres of land which includes 3,928,184 acres of cropland. It was estimated there were 739,146 acres potentially irrigable in this basin. The lack of profitable alternative irrigation enterprises and the restriction imposed on irrigation enterprises that were considered profitable, limited the land actually irrigated to 308,816 acres at the high water use level.

Livestock Production

The livestock activity incorporated into the programming model for this basin was a cow-calf operation. This activity remained constant under alternative water use levels 0-2 with 282,888 head of livestock raised (Table 8). Pasture for spring grazing and a limitation on alfalfa production available to substitute for native hay restricted the output of livestock at these water supplies. At water use level 4, alfalfa production increased sufficiently to supply the assumed cash market (250,000 tons) and also released native hay for grazing, increasing

TABLE 8. PROGRAMMED OPTIMUM CROPLAND USES AND LIVESTOCK ENTERPRISES UNDER DRYLAND AND FOUR LEVELS OF IRRIGATION WATER AVAILABILITY, SOURIS DRAINAGE BASIN, NORTH DAKOTA

Enterprise	Unit	Irrigation Water Availability Level[a]				
		0	1	2	3	4
Non-irrigated						
Wheat	Acre	1,258,200	1,258,200	1,258,200	1,258,200	1,258,200
Barley	Acre	2,122,602	2,048,274	2,155,502	2,163,372	2,086,167
Flax	Acre	275,000	275,000	275,000	275,000	275,000
Alfalfa	Acre	272,381	269,505	85,073		
Irrigated						
Alfalfa	Acre		1,204	78,408	155,612	232,816
Potatoes	Acre		10,000	10,000	10,000	10,000
Sugar beets	Acre		66,000	66,000	66,000	66,000
Livestock[b]						
Cow-calf without silage	Calf	282,888	282,888	282,888	282,888	323,754

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]This activity assumed calves were marketed at 400 pounds.

livestock production to 323,754 head. Spring pasture was the limiting resource for the cow-calf enterprise under water use level 4. Although tame pasture was an alternative in the model, native pasture provided the necessary grazing requirement. It was not profitable to pasture potential cropland.

Land Use

Wheat, barley, and flax were grown on dryland under each water alternative (Table 8). Acreage restrictions determined wheat and flax acreage, whereas barley acreage was determined by the amount of land remaining after all other activities had reached a restriction.

Potatoes and sugar beets were the most profitable crops to irrigate and entered the optimum combination of enterprises at level 1. The only other crop profitable to irrigate was alfalfa, therefore, any irrigation water not utilized by potatoes and sugar beets was used to irrigate alfalfa. At level 4 (the unlimited water supply), the assumed market demand and the livestock requirement were the limiting factors in alfalfa production.

Although irrigating small grains was an alternative in the model, cost and yield coefficients were such that irrigation of small grains was not profitable. For example, the per acre cost of producing irrigated wheat was $2.11 greater than the return realized.

Devils Lake Drainage Basin

The Devils Lake Basin is the smallest basin in the state. Total land in this basin consists of 2,487,741 acres of cropland and 541,321 acres of native hay and native pasture. It is also the only closed basin in North Dakota. There are 210,210 acres considered feasible for irrigation or approximately 10 per cent of the total cropland.

Livestock Production

Three livestock activities were considered as alternatives in the Devils Lake Basin. Each consisted of a cow-calf operation, but with different options as to the selling weight of the calves. The first option required selling a 400 pound calf, the second a 700 pound grain-fed calf, and the third a 1,000 pound grain-fattened calf. The cow-calf enterprise with a calf marketed at 400 pounds was included in the profit maximizing combination of enterprises. At water use levels 3 and 4, a reallocation of resources took place to increase the number of animals sold from 56,253 head at the three lower water use levels, to 80,443 and 85,332 head at levels 3 and 4, respectively (Table 9). This reallocation of resources was accomplished due to the additional water available at levels 3 and 4 of which a part was used to irrigate alfalfa. The availability of alfalfa made it possible to transfer native hay to native pasture for grazing purposes and thus support a larger livestock enterprise.

TABLE 9. PROGRAMMED OPTIMUM CROPLAND USES AND LIVESTOCK ENTERPRISES UNDER DRYLAND AND FOUR LEVELS OF IRRIGATION WATER AVAILABILITY, DEVILS LAKE DRAINAGE BASIN, NORTH DAKOTA

Enterprise	Unit	Irrigation Water Availability Level[a]				
		0	1	2	3	4
Non-irrigated						
Wheat	Acre	627,266	627,266	627,266	627,266	627,266
Barley	Acre	1,660,475	1,618,585	1,576,696	1,534,807	1,492,917
Flax	Acre	200,000	200,000	200,000	200,000	200,000
Irrigated						
Potatoes	Acre		25,000	25,000	25,000	25,000
Sugar beets	Acre		16,889	58,788	66,000	66,000
Alfalfa	Acre				34,668	76,557
Livestock[b]						
Cow-calf without silage	Calf	56,253	56,253	56,253	80,443	85,332

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]This activity assumed calves were marketed at 400 pounds.

Land Use

Dryland activities under each alternative water level included wheat, barley, and flax (Table 9). Acreage planted to wheat and flax was limited by restrictions, whereas barley acreage was determined by the remaining cropland acres available after the limits of other enterprises had been reached.

Potatoes, sugar beets, and alfalfa were the only crops that were profitable for irrigation in this basin. A yield increase of four bushels per acre for irrigated wheat would have been necessary to include this activity in the profit maximizing solution at level 4. Therefore, 42,643 acres of cropland feasible for irrigation remained in dryland production due to a shortage of profitable crop alternatives under irrigation.

At water use levels 1 and 2, potatoes were raised on the maximum allotted acres, whereas water limited sugar beet acres to 16,889 and 58,788 acres, respectively. Irrigated alfalfa was included in the optimum enterprise organization at levels 3 and 4. The available supply of water limited alfalfa production to 34,668 acres at level 3. At level 4, the livestock enterprise increases over level 3 by approximately 5,000 head due to increased alfalfa production due to irrigation.

North Dakota State

The programmed optimum aggregate total of livestock production and land use for North Dakota is presented in Table 10. Wheat and barley were the only crops produced in each basin under all alternative water

TABLE 10. AGGREGATE TOTALS OF PROGRAMMED OPTIMAL CROPLAND USED AND LIVESTOCK ENTERPRISES UNDER DRYLAND AND FOUR LEVELS OF IRRIGATION WATER AVAILABILITY, NORTH DAKOTA

Enterprise	Unit	Irrigation Water Availability Level[a]				
		0	1	2	3	4
Non-irrigated						
Wheat	Acre	7,565,966	7,565,966	7,565,966	6,571,257	6,240,895
Barley	Acre	10,620,853	10,593,474	10,504,673	9,967,705	9,327,577
Flax	Acre	2,389,558	2,110,184	1,829,049	1,725,000	2,022,263
Corn grain	Acre	137,766	137,766			
Soybeans	Acre	250,000	250,000	250,000	250,000	250,000
Potatoes	Acre	98,550				
Sugar beets	Acre	167,000				
Corn silage	Acre	76,612	76,612	1,570		
Alfalfa	Acre	272,381	269,505	85,073		
Irrigated						
Soybeans	Acre		47,821	100,000	150,316	201,293
Potatoes	Acre		193,550	193,550	193,550	193,550
Sugar beets	Acre		339,924	365,000	431,000	431,000
Corn grain	Acre			137,766	137,766	137,766
Alfalfa	Acre		89,584	469,941	799,994	1,039,698
Barley	Acre				430,197	900,254
Flax	Acre				75,000	75,000
Corn silage	Acre		54,408	109,318	113,900	26,388
Wheat	Acre				94,708	425,070
Livestock[b]						
Cow-calf with silage	Calf		592,346	908,748	952,758	
Cow-calf without silage	Calf	640,017	339,141	339,141	336,331	1,361,844
Buy-calf with silage	Calf	500,000	500,000	500,000	500,000	500,000
Buy-calf without silage	Calf	500,000	500,000	500,000	500,000	500,000

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]This activity assumed calves were marketed at 400 pounds.

levels. The maximum allotted acres of wheat were raised in each basin, but only in the Missouri Basin was wheat produced under irrigation. Barley was grown on dryland in every basin and under irrigation in the Red Basin only. It was used both as a feed for livestock and as a cash crop in each basin except the Missouri, where it was raised just for feed. The James Basin did not raise any flax and the Red Basin was the only area in which flax was irrigated. Corn silage was grown both under dryland conditions and irrigation in the James Basin, but only under irrigation in the Missouri Basin. Dryland alfalfa was profitable in every basin except the James.

Potatoes and sugar beets were the most profitable crops produced under irrigation. These enterprises entered the profit maximizing solution in each basin as irrigation water became available. Soybeans was the third most profitable irrigated activity, but was a production alternative only in the Red and James Basins. Finally, corn for grain was produced both on dryland and irrigation in the Red Basin; the only other area in which it was considered a production alternative was in the James Basin.

CHAPTER V

RESOURCE REQUIREMENTS AND VALUE OF WATER

This chapter presents the resource requirements and net income attributable to the integration of irrigation into the present farming operation in each of the five drainage basins. Labor requirements were divided into the four seasons of the year for programming purposes. The discussion of labor requirements is confined to an analysis of total labor required. The irrigation capital required represents capital needed to develop irrigation on the farms in any given area. However, it does not include any capital that might be required to deliver the water to a farm.

Programmed Resource Requirements and Income

Missouri Drainage Basin

Labor, capital, water requirements, and net income resulting from irrigation for the Missouri Basin are presented in Table 11.

Labor and Irrigation Capital Requirement

Labor requirements for the Missouri Basin vary from approximately 13 million man-hours at level 0 to over 27 million man-hours at level 4. The added labor required at water level 1 is approximately 50 per cent greater than the amount of labor required for dryland farming. Thus, farm operators would have to work one-third more at level 1 than at

TABLE 11. PROGRAMMED OPTIMUM RESOURCE REQUIREMENTS AND INCOME BY IRRIGATION WATER AVAILABILITY LEVELS, MISSOURI DRAINAGE BASIN, NORTH DAKOTA

Item	Irrigation Water Availability Level[a]				
	0	1	2	3	4
Total water used, acre-feet		388,183	776,366	1,164,550	1,544,558
Land irrigated, acres		258,788	517,577	807,936	1,171,396
Capital required, dollars[b]		23,743,799	47,487,690	74,127,944	107,475,491
Labor required, hours	12,989,700	19,634,635	24,796,832	26,040,184	27,524,213
Net income, dollars	32,704,566	47,315,751	52,188,687	56,062,336	59,285,138
Changes in net income:					
From no irrigation, dollars		14,611,185	19,484,121	23,257,770	26,580,572
From preceding level of irrigation, dollars		14,611,185	4,872,936	3,873,649	3,222,802
Net income per acre, dollars	1.83	2.65	2.92	3.14	3.32
Net income from irrigation per acre-foot, dollars		37.63	25.09	20.05	17.20

[a] Irrigation water availability levels are defined in Table 2, page 23.

[b] Capital requirements associated only with irrigation.

level 0 with over 80 per cent of this labor required during the first three time periods of the year. Increasing water application from level 1 to level 2, a similar increase is noted. The relatively large increases in labor requirements at levels 1 and 2 result from increases in livestock numbers and the irrigation of crops with relatively high labor requirements. The change in labor requirements from the preceding level to irrigate at water levels 3 and 4 were lower than at preceding water levels because large acreages of wheat were irrigated, which requires less labor than other activities. Furthermore, livestock numbers were approaching or had reached the optimum level.

Capital requirements for irrigation were directly related to acres irrigated and water used. It ranged from a low of 23 million dollars at level 1 to a high of 107 million dollars at level 4.

Levels of Income

Net income increased with each additional increment of water, however, the increase in net income from preceding water levels declined. The first increment of water added almost 15 million dollars, while the fourth added only three million dollars to net income.

Net income per acre of land ranged from $1.83 from dryland farming to $3.32 under irrigation with unlimited water supply. Levels 1, 2, and 3 returned $2.65, $2.92, and $3.14 per acre of land, respectively.

The net income resulting from irrigation per acre-foot of water applied declined as each additional increment of water was added. For example, at water level 1 the return to irrigation was $37.63 per acre-foot, then declined to $25.09 at level 2. This decline resulted because the high value crops (potatoes and sugar beets) enter the optimum enterprise organization at level 1 and lower valued crops enter the solution as the water supply is increased, thus reducing the return per acre-foot of water.

Red Drainage Basin

Resource requirements and net income generated by irrigation for the Red Basin are presented in Table 12.

Labor and Irrigation Capital Requirement

Labor requirements increased as each increment of water was added. These increases in labor were confined to the production period of the cropping activities. Winter labor remained constant at each water level due to the restriction on the livestock activity. Changes in labor requirements as each additional increment of water was applied, remained relatively stable. This stability, which ranged from 1.5 million hours at level 1 to 1.3 million hours at level 4, resulted from the inclusion of high consuming labor activities such as potatoes and sugar beets into the dryland farming operation. Furthermore, the changes from the preceding water level indicate the additional labor needed for irrigation, rather than any changes due to new activities introduced into the optimum solution.

Capital requirements for irrigation were directly related to acres irrigated and water used. The largest increases occurred as the

TABLE 12. PROGRAMMED OPTIMUM RESOURCE REQUIREMENTS AND INCOME BY IRRIGATION WATER AVAILABILITY LEVELS, RED DRAINAGE BASIN, NORTH DAKOTA

Item	Irrigation Water Availability Level[a]				
	0	1	2	3	4
Total water used, acre-feet		470,057	940,114	1,410,171	1,880,228
Land irrigated, acres		313,371	651,742	1,108,513	1,578,570
Capital required, dollars[b]		28,751,789	59,797,328	101,706,068	144,833,797
Labor required, hours	25,025,635	26,530,631	27,869,950	29,215,074	30,531,234
Net income, dollars	57,793,708	78,958,325	84,000,610	84,834,279	85,529,961
Changes in net income:					
From no irrigation, dollars		21,174,617	26,206,902	27,040,569	27,736,253
From preceding level of irrigation, dollars		21,164,617	5,042,285	833,667	695,684
Net income per acre, dollars	5.87	8.02	8.53	8.61	8.68
Net income from irrigation per acre-foot, dollars		45.03	27.88	19.18	14.75

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]Capital requirements associated only with irrigation.

third and fourth increments of water were added. Irrigation of small grain, which required less water than row crops, was included in the solution at these water levels.

Levels of Income

Net income increased with each additional increment of water, however, the change in net income from the preceding level of irrigation declined sharply. The change in net income as the first level of water was applied amounted to about 21 million dollars. This large increase reflects the profitability of irrigating potatoes and sugar beets. At water level 4, the change in net income from level 3 was only $696,000. Also at level 4, irrigated cropland had increased about 470,000 acres over level 3. This represents a marginal return of $1.46 per added acre irrigated at level 4.

The net income per acre in the Red Basin ranged from $5.87 per acre for dryland to $8.68 per acre under unlimited water. The largest increase was $2.15 going from level 0 to level 1, while the difference between level 3 and level 4 was only seven cents per acre. Although the barley activity provides the only new irrigated crop at level 4, this is not the net income per acre realized from irrigating barley. It is only an indication that profit per acre for irrigated barley is low.

The net income from irrigation per acre-foot declined as each additional increment of water was applied. For example, at water level 1 the return to irrigation was $45.03 per acre-foot. This measure of water efficiency declined to $14.75 per acre-foot at level 4. This decline occurred because the high value crops were irrigated first and as water supplies increased, lower valued crops entered the optimum solution lowering the net income per acre-foot.

James Drainage Basin

Labor, capital, water requirements, and net income from irrigation for the James Basin are presented in Table 13.

Labor and Irrigation Capital Requirement

Labor requirements increased as irrigation was integrated into the farming operation in the James Basin. Although labor required during the winter months for livestock remained constant at each water level, the additional labor necessary for irrigation increased the total demand for labor as additional irrigation water became available. The smallest increase in labor required from the preceding water level occurred at level 2. This was due to a shift in corn silage acres from dryland to irrigation. This shift to irrigation necessitated less acres of corn silage (a relatively high labor requirement crop) to be grown, thus tending to minimize the increase in labor.

Capital requirement for irrigation ranged from approximately five million dollars at level 1 to almost $19 million at level 4. Irrigation capital is directly related to acres irrigated and acre-feet of water used.

TABLE 13. PROGRAMMED OPTIMUM RESOURCE REQUIREMENTS AND INCOME BY IRRIGATION WATER AVAILABILITY LEVELS, JAMES DRAINAGE BASIN, NORTH DAKOTA

Item	Irrigation Water Availability Level[a]				
	0	1	2	3	4
Total water used, acre-feet		76,386	152,772	229,058	305,523
Land irrigated, acres		50,924	101,848	152,705	203,682
Capital required, dollars[b]		4,672,277	9,344,554	14,010,683	18,687,823
Labor required, hours	9,619,525	10,121,171	10,235,376	10,541,751	10,854,238
Net income, dollars	40,099,865	44,796,383	48,052,588	50,429,123	52,804,254
Changes in net income:					
From no irrigation, dollars		4,696,518	7,952,723	10,329,258	12,704,389
From preceding level of irrigation, dollars		4,696,518	3,256,518	2,366,535	2,375,131
Net income per acre, dollars	9.12	10.18	10.93	11.47	12.01
Net income from irrigation per acre-foot, dollars		61.48	52.06	45.09	41.58

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]Capital requirements associated only with irrigation.

Levels of Income

The net income to management and irrigation water ranged from $40 million at level 0 to over $52 million at level 4, an increase of over $12 million attributable to irrigation. The greatest change occurred as irrigation was first integrated into the farming operation and potatoes and sugar beets became a production alternative. The marginal return to irrigation decreased approximately one million dollars at levels 2 and 3, whereas at level 4 it remained almost constant. This relatively constant change in net income resulted because soybeans was the only new activity to be irrigated, and included 98 per cent of new irrigated acres at level 3 and 100 per cent of the new irrigated acres at level 4.

Net income per acre of land ranged from $9.12 at level 0 to $12.01 at level 4. This relatively high return per acre reflects the profitability of the calf-fattening activity and the high utilization of native hayland for which the opportunity cost was considered zero.

The net income to irrigation per acre-foot of water applied declined as each additional increment of water was applied. This measure of water efficiency ranged from $61.48 at level 1 to $41.58 at level 4, a decrease of $19.90. The limited amount of potential irrigable land, together with the inclusion of soybeans (a relatively high profit enterprise) in the optimum solution at levels 3 and 4, contributed to this relatively small decrease in net income per acre for the James Basin as compared to the other basins.

Souris Drainage Basin

Labor, capital, water requirements, and net income resulting from irrigation in the Souris Basin are presented in Table 14.

Labor and Irrigation Capital Requirement

Labor required under irrigation for the Souris Basin increased at each water level over the labor required for dryland farming. A large shift in alfalfa acres from dryland to irrigation at water levels 2 and 3 contributed to a decrease in labor required from water level. At level 2, a decrease in labor required of 161,913 hours was noted, while at level 3, the labor requirement was 66,489 hours less than was required at level 1. Due to the increased yields of alfalfa on irrigation which reduced the acres of alfalfa produced, the total labor required to harvest the necessary alfalfa decreased more than the increase in labor for barley which was produced on land previously used for the production of alfalfa.

Capital requirements for irrigation were directly related to acres irrigated and water used. It ranged from approximately seven million dollars at level 1 to over $28 million at level 4.

Levels of Income

Net income increased with each additional increment of water, however, the change in net income from the preceding level of irrigation declined. At level 1, the change in net income from dryland farming was

TABLE 14. PROGRAMMED OPTIMUM RESOURCE REQUIREMENTS AND INCOME BY IRRIGATION WATER AVAILABILITY LEVELS, SOURIS DRAINAGE BASIN, NORTH DAKOTA

Item	Irrigation Water Availability Level[a]				
	0	1	2	3	4
Total water used, acre-feet		115,806	231,612	347,418	463,224
Land irrigated, acres		77,204	154,408	231,612	308,816
Capital required, dollars[b]		7,083,467	14,166,934	21,250,401	28,333,868
Labor required, hours	9,625,428	10,339,722	10,177,809	10,273,233	10,810,931
Net income, dollars	24,196,590	29,137,710	29,971,299	30,721,924	31,146,115
Changes in net income:					
From no irrigation, dollars		4,941,120	5,774,709	6,525,334	6,949,525
From preceding level of irrigation, dollars		4,941,120	833,589	750,625	424,191
Net income per acre, dollars	4.04	4.87	5.00	5.13	5.20
Net income from irrigation per acre-foot, dollars		42.67	24.93	18.78	15.00

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]Capital requirements associated only with irrigation.

over four million dollars, however, at level 2, the change in net income from level 1 was only $833,589. This sharp drop in net income from level 1 indicates that it is relatively more profitable to irrigate potatoes and sugar beets than alfalfa, which was the only new activity irrigated at level 2.

The net income per acre of land ranged from a low of $4.04 at level 0 to a high of $5.20 at level 4. Net income per acre at water levels 1, 2, and 3 were $4.87, $5.00, and $5.13 per acre, respectively. The relatively high ratio of native land to the total land area contributes to this relatively stable return per acre.

The net income to irrigation per acre-foot of water applied declined as each increment of water was added. The largest decrease occurred from level 1 ($42.67) to level 2 ($24.93). Potato and sugar beet acreage comprised 76,000 acres out of the total of 77,204 acres which were irrigated at level 1. This high ratio of potato and sugar beet acreage to total irrigated acres accounts for the relatively high return at level 1. At levels 3 and 4, the return per acre-foot was $18.78 and $15.00, respectively. Alfalfa (a relatively low value crop) contributed to the decreasing returns to water exhibited at levels 3 and 4.

Devils Lake Drainage Basin

Labor, capital, water requirements, and net returns for the Devils Lake Basin are presented in Table 15.

TABLE 15. PROGRAMMED OPTIMUM RESOURCE REQUIREMENTS AND INCOME BY IRRIGATION WATER AVAILABILITY LEVELS, DEVILS LAKE DRAINAGE BASIN, NORTH DAKOTA

Item	Irrigation Water Availability Level[a]				
	0	1	2	3	4
Total water used, acre-feet		62,834	125,668	188,502	251,336
Land irrigated, acres		41,889	83,778	125,668	167,557
Capital required, dollars[b]		3,843,315	7,686,631	11,530,039	15,373,354
Labor required, hours	3,850,015	4,380,161	4,737,060	5,071,751	5,269,627
Net income, dollars	17,582,097	22,311,363	24,364,255	25,014,349	25,320,222
Changes in net income:					
From no irrigation, dollars		4,729,266	6,782,158	7,432,252	7,738,125
From preceding level of irrigation, dollars		4,729,266	2,052,892	650,094	305,873
Net income per acre, dollars	5.80	7.37	8.04	8.26	8.36
Net income from irrigation per acre-foot, dollars		75.27	53.97	39.43	30.79

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]Capital requirements associated only with irrigation.

Labor and Irrigation Capital Requirement

Integration of irrigation into the farming operation demanded additional labor at each water level. At levels 1 and 2, the increase in labor was confined to the production period of the cropping activities, whereas at levels 3 and 4, the livestock activity expanded, thus requiring additional winter labor. The production of potatoes and sugar beets at levels 1 and 2 resulted in an increase of 530,146 hours of labor at level 1 and 887,045 hours at level 2. The amount of labor required at levels 3 and 4 exceeded the dryland requirement by approximately 32 and 37 per cent, respectively.

Capital for irrigation ranged from about four million dollars at level 1 to $15 million at level 4. It is directly related to the number of acres under irrigation and the water supply available.

Levels of Income

Net income increased with each increment of water added. Net income from dryland farming was about $17.5 million, while the net income generated with unlimited water increased to $25.3 million. The change in net income from the preceding water level declined from $530,146 at level 1 to $305,873 at level 4. This decrease occurs because the high profit activities (potatoes and sugar beets) enter the solution at limited water supplies and as additional water becomes available, lower profit activities enter the profit maximizing combination of enterprises.

The net income per acre of land ranged from $5.80 at level 1 to $8.36 at level 4. The largest increase was $1.57. This occurred between levels 1 and 2 in response to potato and sugar beet production.

The net income to irrigation per acre-foot declined as each additional increment of water was applied. For example, at water level 1, the net income to irrigation was $75.27 per acre-foot. This measure of water efficiency declined to $30.79 at level 4, indicating a relatively low return to alfalfa as compared with potatoes and sugar beets.

Aggregate State Totals

Aggregate state totals for labor, capital, water requirements, and net income resulting from irrigation are presented in Table 16.

Labor and Irrigation Capital Requirement

Labor requirement for the State of North Dakota varied from approximately 61 million hours at level 0 to 85 million hours at level 5. The largest increase from the preceding level of irrigation occurred at level 1. The entry of potatoes and sugar beets as production alternatives at level 1 was largely responsible for a 16 per cent increase in labor requirements at this level. The percentage increase in labor as each succeeding increment of water was applied amounted to about nine per cent at level 2, and four per cent at levels 3 and 4.

TABLE 16. PROGRAMMED OPTIMUM RESOURCE REQUIREMENTS AND INCOME BY IRRIGATION WATER AVAILABILITY LEVELS, STATE OF NORTH DAKOTA

Item	Irrigation Water Availability Level[a]				
	0	1	2	3	4
Total water used, acre-feet		1,113,266	2,226,532	3,339,699	4,444,869
Land irrigated, acres		742,176	1,509,353	2,426,434	3,430,021
Capital required, dollars[b]		68,094,648	138,483,238	222,625,320	314,704,427
Labor required, hours	61,110,303	71,006,320	77,817,027	81,141,993	84,990,243
Net income, dollars	172,376,826	222,519,532	238,577,439	247,062,011	254,085,690
Changes in net income:					
From no irrigation, dollars		50,142,706	66,200,613	74,685,185	81,708,864
From preceding level of irrigation, dollars		50,142,706	16,057,907	8,484,572	7,023,679
Net income from irrigation per acre-foot, dollars		45.04	29.73	22.36	18.38

[a]Irrigation water availability levels are defined in Table 2, page 23.

[b]Capital requirements associated only with irrigation.

Capital required for irrigation ranged from approximately $68 million at level 1 to $315 million at level 4. Capital varies directly with acres irrigated and acre-feet of water applied.

Irrigation Water Requirement

The total amount of water required to irrigate the 3.43 million acres of potentially irrigable land in North Dakota was approximately 4.4 million acre-feet at water level 4 (Table 16). The water requirement at all other levels was in proportion to the unlimited level (level 4).

The water requirement by drainage basin ranged from 251,336 acre-feet in the Devils Lake Drainage Basin (Table 15) to 1,880,228 acre-feet in the Red Drainage Basin (Table 12). The amount of water required in each drainage basin was a function of the acres potentially irrigable.

Levels of Income

Net income increased as each additional increment of water was applied, however, the change in net income from the preceding level of irrigation increased at a decreasing rate. Net income varied from about $172 million at level 0 to $254 million at level 4, an increase of $82 million. The change in net income from the preceding level of irrigation amounted to about $50 million at level 1, $16 million at level 2, $8 million at level 3, and $7 million at level 4, indicating diminishing returns to water.

The net income attributable to irrigation per acre-foot of water declined from $45.04 at level 1 to $18.38 at level 4. This decline is explained by the entry of high profit enterprises into the solution at low levels of water supply and lower profit enterprises into the solution as the water supply is increased. At levels 2 and 3, the return to irrigation per acre-foot of water was $29.73 and $22.36, respectively.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The demand for water in the Upper Midwest is increasing rapidly as the result of several factors, including an expanding population, increasing per capita consumption of water, increase in emphasis on water based recreation, municipal and industrial uses, and increasing amounts of land being irrigated. As the demands for water increase, given relatively stable supply, careful planning of water development becomes increasingly important.

Although the supply of water is adequate for its many uses, it has to be available at the time and location it is demanded to be of any social or economic use. Therefore, careful planning must be inaugurated at the present time to insure adequate water availability in the future.

The State of North Dakota is endowed with abundant supplies of water from various sources. It is available in natural streams and lakes, underground acquifiers, and man-made impoundments. However, much of this water is not available in sufficient quantities at the time and location to fulfill particular demands.

The value of a natural resource depends upon its availability at the time and location most critically needed. In most cases, capital and labor must be employed to make water available at the time and location to fulfill a particular demand. Planning agencies are charged with the responsibility of developing and implementing plans for resource development and use. The implementation of any resource development project requires an outlay of capital, either private or public, or both. The amount of capital available is limited relative to the demand for it. Thus, planners must determine the relative economic benefits that would result from investing a given amount of money in alternative water development projects. One criteria available to planners in making this allocation decision is value in use. Therefore, it is necessary to determine the value of water developed for agricultural purposes, in particular, irrigation.

Objectives and Methodology

This study was undertaken to develop the methodology for determining the most profitable level of water resource development for irrigation in North Dakota, to make tentative estimates of future water requirements for irrigation, and to estimate potential net farm income from irrigation. Linear programming was used in this study to determine the profit maximizing combination of enterprise organization. The state was divided into five major drainage basins. The soil characteristics of each basin were correlated with the Missouri River Basin Study to determine the acreage of cropland, native hay, and native pasture within the respective basin boundary. Secondary data developed for previous studies conducted in the Department of Agricultural Economics, North Dakota State University, and Economic Research Service, United States

Department of Agriculture, was the basis for the transformation coefficients used in developing the enterprise budgets included in the linear programming model. Only those livestock and crop enterprises which are commonly produced in North Dakota were included in the programming model. However, certain assumptions relative to each basin were incorporated into the models for each respective basin. For example, it was projected that the James, Devils Lake, Souris, and Missouri Drainage Basins could each support a sugar beet processing plant under irrigation. Furthermore, potatoes were considered a production alternative under irrigation in each of the above named basins. It was also assumed that calves raised in the Missouri and Souris Basins would be fattened for market in the Red and James Basins.

The programming procedure followed in this study was to determine optimum organization of enterprises under alternative water levels. Five profit maximizing organizations were determined for each basin. The first organization simulated dryland farming. The second organization included irrigation with no restriction in the supply of water available. The third, fourth, and fifth organizations included a restriction on the supply of irrigation water available. These restrictions on water were calculated by reducing the optimum supply of water determined in the second organization by one-fourth, one-half, and three-fourth, respectively.

Results of the Programming Analysis

In the profit maximizing enterprise organization, irrigation provided a means for attaining higher levels of income for each basin. However, large amounts of labor and capital were required for irrigated enterprises. Furthermore, the most profitable activities to irrigate, potatoes and sugar beets, are high labor enterprises without irrigation, thus labor requirements increased substantially as water became available to irrigate these crops.

Enterprises were included in the profit maximizing solutions which provided the highest returns to limiting resources. Net income increased as each additional increment of water was applied, although the change in net income from the preceding level of water decreased. The lack of profitable alternative crop enterprises limited potential net income in the Devils Lake and Souris Basins. Neither of these basins irrigated all potentially irrigable land.

Livestock activities were included in the final solutions of each basin at all water levels. Native hayland and native pasture fulfilled livestock grazing and roughage requirements under dryland conditions, but as irrigation was integrated into the farming operation, livestock production increased in the Missouri, Souris, and Devils Lake Basins.

In general, very little shifting of crops from dryland to irrigation took place. The greatest amount of shifting occurred in the Red Basin where a large amount of irrigable land was available and all crop enterprises were considered both as dryland and irrigation alternatives. In the other four basins, potatoes and sugar beets, which were not dryland alternatives, were the first crops irrigated. Corn silage shifted from dryland to irrigation in the James Basin, a portion of the wheat acres shifted from dryland to irrigation in the Missouri and alfalfa shifted from dryland to irrigation in the Souris Basin.

Conclusions

The results of this study indicate a large increase in primary income would be forthcoming to North Dakota farmers if the irrigation potential of this state is developed. This study also indicates that linear programming is a useful tool to determine the level of water resources development which is profitable.

Due to a considerable variation from one area to another within each basin, the organization of enterprises in this study is not intended to be applicable to any specific area. Rather, it is intended to indicate the aggregate results that could be expected at varying levels of water resource development. Furthermore, as irrigation development progresses in the state, additional studies of a more refined nature will be needed to guide farmers in their decision making.

APPENDIXES

APPENDIX A

Linear Programming Tableau

APPENDIX A, TABLE 1. IDENTIFICATION OF ACTIVITIES IN PROFIT MAXIMIZING LINEAR PROGRAMMING TABLEAU FOR DEVILS LAKE

Activity	Unit	Identification
Wheat after fallow	Acre	P_1
Wheat after small grain	Acre	P_2
Barley after small grain	Acre	P_3
Oats after small grain	Acre	P_4
Flax after small grain	Acre	P_5
Corn silage	Acre	P_6
Tame hay	Acre	P_7
Native hay	Acre	P_8
Tame pasture	Acre	P_9
Native pasture	Acre	P_{10}
Feed alfalfa	Acre	P_{11}
Buy barley	Acre	P_{12}
Sell alfalfa	Acre	P_{13}
Sell feed grain	Acre	P_{14}
Sell wheat	Acre	P_{15}
Cow-calf operation, calf sold at 400 lb., silage fed	A.U.	P_{16}
Cow-calf operation, calf grain fattened, sold at 1,000 lb., silage fed	A.U.	P_{17}
Cow-calf operation, calf grain fattened, sold at 700 lb., silage fed	A.U.	P_{18}
Cow-calf operation, calf sold at 400 lb., no silage	A.U.	P_{19}
Cow-calf operation, calf grain fattened, sold at 1,000 lb., no silage	A.U.	P_{20}

APPENDIX A, TABLE 1 (Continued)

Activity	Unit	Identification
Cow-calf operation, calf grain fattened, sold at 700 lb., no silage	A.U.	P_{21}
Irrigate corn silage	Acre	P_{22}
Irrigate tame hay	Acre	P_{23}
Irrigate wheat	Acre	P_{24}
Irrigate barley	Acre	P_{25}
Borrow capital	Dollar	P_{26}
Labor, spring	Man-Hr.	P_{27}
Labor, summer	Man-Hr.	P_{28}
Labor, fall	Man-Hr.	P_{29}
Labor, winter	Man-Hr.	P_{30}
Sell beef	Dollar	P_{31}
Irrigate potatoes	Acre	P_{32}
Irrigate sugar beets	Acre	P_{33}
Irrigate pasture	Acre	P_{34}
Irrigate oats	Acre	P_{35}
Sell potatoes	Dollar	P_{36}
Native hay transfer	Acre	P_{37}
Native pasture transfer	Acre	P_{38}

APPENDIX A, TABLE 2. A PROFIT MAXIMIZING LAND LINEAR PROGRAMMING TABLEAU USED IN THIS STUDY, DEVILS LAKE DRAINAGE BASIN

Restriction	Row	Unit	P_0	P_1	P_2	P_3	P_4	P_5
Profit	c_j	Dollar	0	-34.35	-24.40	-24.05	-22.85	8.60
Cropland	1	Acre	2,487,741	2.00	1.00	1.00	1.00	1.00
Native hay	2	Acre	66,686					
Native pasture	3	Acre	474,635					
Wheat allotment	4	Acre	627,266	1.00	1.00			
Wheat transfer	5	Bushel	0	-28.00	-22.00			
Feed grain transfer	6	Bushel	0			-35.00	-27.00	
Corn silage transfer	7	Ton	0					
Alfalfa transfer	8	Ton	0					
Hay transfer	9	Ton						
Water	10	Ac.-Ft.	Variable					
Labor, spring	11	Man-Hr.	0	.64	.55	.55	.64	.42
Labor, summer	12	Man-Hr.	0	1.23	.12	.12	.23	.12
Labor, fall	13	Man-Hr.	0	.53	.42	.42	.42	.67
Labor, winter	14	Man-Hr.	0					
Pasture, spring	15	A.U.	0					
Pasture, summer	16	A.U.	0					
Pasture, fall	17	A.U.	0	-.05	-.05	-.05	-.05	
Capital	18	Dollar	0					
Beef	19	Dollar	0					
Potato transfer	20	Cwt.	0					
Irrigable land	21	Acre	210,210					

APPENDIX A, TABLE 2 (Continued)

Row	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
c_j	-31.05	-18.20	-6.18	-6.62			-1.05	14.00
1	1.00	1.00		1.00				
2			1.00					
3					1.00			
4								
5								
6							-1.00	
7	-6.00							
8		-1.8				1.00		1.00
9			-.75					
10						-1.00		
11	.59	.19		.12	.12			
12	.80	3.12	1.56					
13	2.67	.37	.19	.05				
14								
15				-.80	-.20			
16				-.40	-.40			
17				-.10	-.30			
18								
19								
20								
21								

APPENDIX A, TABLE 2 (Continued)

Row	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}	P_{19}	P_{20}	P_{21}
c_j	.85	1.85	-21.73	-21.82	-16.24	-21.73	-21.82	-16.82
1								
2								
3								
4								
5		1.00						
6	-1.00		2.50	52.92	13.98	2.50	52.92	13.98
7			1.24	2.19	1.24			
8								
9			1.82	2.45	2.75	2.10	3.25	3.25
10								
11			5.12	6.05	5.44	5.12	6.05	5.44
12			1.79	2.11	1.90	1.79	2.11	1.90
13			2.69	3.16	2.84	2.69	3.16	2.84
14			4.53	10.33	4.79	4.53	10.33	4.79
15			1.30	1.30	3.25	1.30	1.30	3.25
16			2.00	2.00	2.25	2.00	2.00	2.25
17			2.00	2.00	2.00	2.00	2.00	2.00
18			254.88	332.10	332.10	254.88	332.10	332.10
19			-4.03	-5.69	-5.02	-4.03	-5.69	-5.02
20								
21								

APPENDIX A, TABLE 2 (Continued)

Row	P_{22}	P_{23}	P_{24}	P_{25}	P_{26}	P_{27}	P_{28}	P_{29}
c_j	-53.77	-34.89	-43.50	-42.15	-7.00	-1.50	-1.50	-1.50
1	1.00	1.00	1.00	1.00				
2								
3								
4								
5			-36.00					
6				-54.00				
7	-13.50							
8		-4.30						
9								
10	1.50	1.50	1.00	1.00				
11	1.19	.19	1.15	1.15		-1.00		
12	2.40	4.12	.28	.28			-1.00	
13	3.68	.87	1.52	1.52				-1.00
14								
15								
16								
17			-.05	-.05				
18	91.75	91.75	91.75	91.75		-100.00		
19								
20								
21	1.00	1.00	1.00	1.00				

APPENDIX A, TABLE 2 (Continued)

Row	P_{30}	P_{31}	P_{32}	P_{33}	P_{34}	P_{35}	P_{36}	P_{37}	P_{38}
c_j	-1.50	26.00	-148.84	73.91	-23.31	-40.95	1.40		
1			1.00	1.00	1.00	1.00			
2								1.00	-1.00
3								-1.20	1.20
4									
5									
6						-43.20			
7									
8									
9									
10			1.50	1.50	1.50	1.00			
11			4.75	1.46	1.00	1.24			
12			2.80	4.11	1.00	1.83			
13			8.98	4.04	.50	1.52			
14	-1.00					-.05			
15					-3.00				
16					-3.00				
17					-3.00				
18			91.75	91.75	91.75	91.75			
19		1.00							
20			-243.00				1.00		
21			1.00	1.00	1.00	1.00			

APPENDIX B

Procedure for Estimating Irrigable Land

APPENDIX B

ESTIMATE OF IRRIGABLE LAND IN NORTH DAKOTA[a]

The estimated acreage of irrigable land in North Dakota was prepared at the request of the North Dakota State Water Commission.

The river basins on which estimates are presented were selected by the State Water Commission. The river basin boundaries were plotted on the General Soil Map of North Dakota (North Dakota Agricultural Experiment Station, 1961). The area of each soil association within each river basin was measured and reported in square miles and acres by the State Water Commission.

The following procedure was used in determining the acreage of irrigable land within each river basin:

1. Townships within each soil association on the state map were selected as representative samples of the association.

2. The acreage of the various soils in the sample townships were compiled from acreage measurements of soil associations in these townships from the county general soil maps.

3. The acreage of irrigable soils in the sample townships were determined and calculated as a percentage of the total area of the sample townships.

4. The area of the state soil associations within each river basin was then multiplied by the percentage figure for each association to obtain the total irrigable acreage for each river basin.

The total irrigable acreage was then reduced on the basis of the experience gained in making detailed soil surveys of areas proposed for

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[a]Prepared by Hollis W. Omodt, Associate Professor of Soils, North Dakota State University, Fargo, North Dakota, December 18, 1967.

irrigation and because of the general nature of the data used to arrive at the irrigable acreage.

In making these estimates, it was assumed that water was available and the location and size of the soil areas were satisfactory.

One additional factor deserves consideration. The sample townships were selected as representative of the soil association on the state map. Thus, the sample townships which are representative of the soil association on the state map are also assumed to be representative of the parts of the soil association in the respective drainage basins.

APPENDIX C

Input Data and Resource Restrictions

APPENDIX C, TABLE 1. CROP YIELDS PER ACRE USED IN THIS STUDY FOR DRYLAND CROP ALTERNATIVES FOR THE FIVE MAJOR DRAINAGE BASINS IN NORTH DAKOTA

Dryland Item	Unit	Drainage Basin				
		Missouri	Souris	Devils Lake	James	Red River
Wheat fallow	Bu.	25.7	28.0	28.0	29.0	32.5
Wheat	Bu.		22.0	22.0	23.5	27.5
Barley	Bu.	30.3	31.5	31.5	35.0	40.0
Oats	Bu.	41.7	40.5	40.5	46.0	55.0
Flax	Bu.	8.9	9.0	9.0	10.0	11.0
Corn silage	Ton	5.0	5.4	5.4	6.2	8.3
Corn grain	Bu.					45.0
Alfalfa	Ton	1.5	1.6	1.6	2.0	2.4
Soybeans	Bu.					20.0
Potatoes	Cwt.					140.0
Sugar beets	Ton					13.5

SOURCE: Rice, Billy B., and Paul, Rodney R., Crop Costs and Returns, FM Circulars 3-9, Cooperative Extension Service and Economic Research Service, North Dakota State University, Fargo, North Dakota, October, 1967.

APPENDIX C, TABLE 2. CROP YIELDS PER ACRE USED IN THIS STUDY FOR IRRIGATION CROP ALTERNATIVES FOR THE FIVE MAJOR DRAINAGE BASINS IN NORTH DAKOTA

Irrigation Item	Unit	Drainage Basin				
		Missouri	Souris	Devils Lake	James	Red River
Wheat	Bu.	36.0	36.0	36.0	36.0	36.0
Barley	Bu.	54.0	54.0	54.0	58.5	65.0
Corn silage	Ton	13.5	13.5	13.5	18.0	18.0
Corn grain	Bu.				90.0	90.0
Alfalfa	Ton	4.3	4.3	4.3	5.0	5.0
Soybeans	Bu.				31.5	31.5
Potatoes	Cwt.	243.0	243.0	243.0	270.0	270.0
Sugar beets	Ton	16.2	16.2	16.2	18.0	18.0
Oats	Bu.	72.0	72.0	72.0	85.5	85.5
Flax	Bu.	8.7	8.7	8.6	10.0	11.0

SOURCE: Rice, Billy B., and Paul, Rodney R., Crop Costs and Returns, FM Circulars 3-9, Cooperative Extension Service and Economic Research Service, North Dakota State University, Fargo, North Dakota, October, 1967.

APPENDIX C, TABLE 3. ASSUMED CROP COMMODITY PRICES USED IN PROGRAMMING ANALYSIS FOR DRAINAGE BASINS IN NORTH DAKOTA

Items	Unit	Drainage Basin				
		Missouri	Souris	Devils Lake	James	Red River
				- dollars -		
Wheat	Bu.	1.80	1.80	1.85	1.85	1.90
Barley	Bu.	.80	.80	.85	.90	.95
Oats	Bu.	.58	.58	.64	.67	.70
Flax	Bu.	2.80	2.80	2.85	2.85	2.90
Corn	Bu.				1.10	1.15
Alfalfa	Ton	14.0	14.0	14.0	14.0	14.0
Sugar beets	Ton	13.50	13.50	13.50	13.50	13.50
Potatoes	Cwt.	1.40	1.40	1.40	1.40	1.40
Barley purchased	Cwt.			1.05	1.10	1.15
Sell beef	Cwt.	26.0	26.0	26.0	24.0	24.0

SOURCE: Rice, Billy B., and Paul, Rodney R., Crop Costs and Returns, FM Circulars 3-9, Cooperative Extension Service and Economic Research Service, North Dakota State University, Fargo, North Dakota, October, 1967.

APPENDIX C, TABLE 4. RESOURCE RESTRICTIONS USED IN PROGRAMMING ANALYSIS FOR DRAINAGE BASINS IN NORTH DAKOTA

Items	Unit	Drainage Basin				
		Missouri	Souris	Devils Lake	James	Red River
Cropland	Acre	4,678,409	3,928,184	2,487,741	3,274,995	8,472,660
Native hay	Acre	1,163,398	221,354	66,686	123,981	245,242
Native pasture	Acre	11,989,791	1,838,777	474,635	997,810	1,131,840
Wheat allotment	Acre	2,496,300	1,258,200	627,266	608,000	1,676,200
Sugar beet allotment	Acre	66,000	66,000	66,000	66,000	150,000
Potato allotment	Acre	50,000	10,000	25,000	10,000	125,000
Corn allotment	Acre					175,000
Irrigation land	Acre	1,171,396	739,146	210,210	203,682	1,578,570

SOURCE: Rice, Billy B., and Paul, Rodney R., Crop Costs and Returns, FM Circulars 3-9, Cooperative Extension Service and Economic Research Service, North Dakota State University, Fargo, North Dakota, October, 1967.

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