THE UNIVERSITY OF MANITOBA

AN ECONOMIC EVALUATION OF GROUNDWATER ALLOCATION

by

DOUGLAS V. McNAIR

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ECONOMICS

WINNIPEG, MANITOBA

October, 1981

AN ECONOMIC EVALUATION OF GROUNDWATER ALLOCATION

BY

DOUGLAS V. McNAIR

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

AN ECONOMIC EVALUATION OF GROUNDWATER ALLOCATION

By: Douglas V. McNair

Major Advisor: Dr. Daryl F. Kraft

The water resource is fixed in quantity yet the demand for this limited supply continues to increase. As supply becomes scarce in relation to demand, an increasing number of conflicts among competing users will develop. As well, this situation results in the resource increasing in value. Hence the requirement for some form of allocation of the available supply to minimize these conflicts and to allocate the water to the most efficient users. Alternative methods of allocation provide different results and should be compared. This study provided information on the implementation and the implications of various regulatory policies for the allocation of groundwater for irrigation in the Carberry area of Manitoba.

The study proceeded in four stages. The first stage is an examination of the theoretical aspects of the failure of the market to efficiently allocate a common property resource. The common property resource characteristic of non-excludability and the interrelationship of resource use between users results in an over-exploitation. Quota limitations, taxation of use and a regulated market for water were the theoretical measures examined as means to ration water.

Stage Two of the study involved an investigation into the feasibility of implementing the associated institutional arrangements. Four alternatives were considered, each more appropriate as the development of the resource expands. Present management was considered to be inadequate; improved management by enforcing existing regulation was considered an immediate worthwhile objective. Eventually a system of saleable quotas, or even the establishment of a market for water, are probably necessary for the regulation of the supply from the Carberry Aquifer.

To test some of the implications of alternative approaches to water management, a linear programming model, representing agricultural production in the Carberry area, was specified. The results of the different model treatments were examined, as Stage Three of the study.

Net revenue, land use, capital use, and water use effects were compared between four different treatments. Treatment 1 had the most restricted transferability of water rights, one priority rights, and water use was limited to that amount virtually available every year. Transferability of water rights was less restrictive for Treatment 2. Treatment 3 allowed for varying priority rights, water availability was thus increased. However, transferability was still restricted by tieing the right to a specific piece of land. In Treatment 4, transferability was the least restricted of all Treatments and therefore was most representative of the establishment of a market for water rights.

Results of the study indicated that water would become the limiting factor for irrigation development in the area. Even when considering Treatment 4, which had the most efficient use of available water, only 36,000 acres out of 190,000 acres of irrigable land could actually be irrigated. This indicated the eventual need for the allocation of a water supply that will indeed become scarce.

Potatoes were the most attractive of all crops to be grown under irrigation and utilized the higher priority rights most efficiently.

Results also indicated that net revenue due to irrigation greatly increased as the regulation of the resource became more rigorous. The desirability for varying priority rights and transferability of water rights was illustrated.

ACKNOWLEDGEMENTS

I am indebted to my major advisor, Daryl Kraft, for sharing his knowledge and experience in the preparation of this thesis. No other individual could have provided a more thorough contribution to a graduate student and his study.

I thank my thesis committee members. Rea Josephson provided many helpful suggestions throughout this study, especially with regards to the model development. I appreciated Herb Schellenberg's practical approach to the perusals and comments on the various drafts. A special note of appreciation is extended to Jim Dean for agreeing to become a member of the committee at a later stage of the study. I thank him for his productive comments and worthwhile contributions.

I extend my appreciation to Cathy for her enthusiastic co-operation in typing corrections, preparing the final copy and buying donuts for the oral examination.

Finally, I thank my fellow graduate students for their advice, encouragement, support and recreational distractions which contributed greatly to the thesis that follows.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

In Manitoba, irrigation has provided only a minor contribution to the agricultural production of field crops. Recent indications suggest future contributions will be more significant. Dramatic increases have occurred in the number of applications for irrigation water rights, an average of 74 per year between 1977 and 1980, an increase of 60 above the average of the previous four years.[1] The amount of land irrigated in the province has increased from 15,000 acres in 1979 to almost 23,000 acres one year later.[2]

These indications pertain to the Carberry area where suitable land, favourable climate and water availability propitiates irrigation (see Figure 1.1). The most notable of these factors is the availability of water. The Deltaic Sand Aquifer[3] lies below this region and is a readily available source of water for irrigation. There are approximately 740,000 acres lying directly above this aquifer of which 200,000 acres are considered by this study to be suitable for irrigation. Only 4,000 acres actually were irrigated in 1979. A potential exists for a large

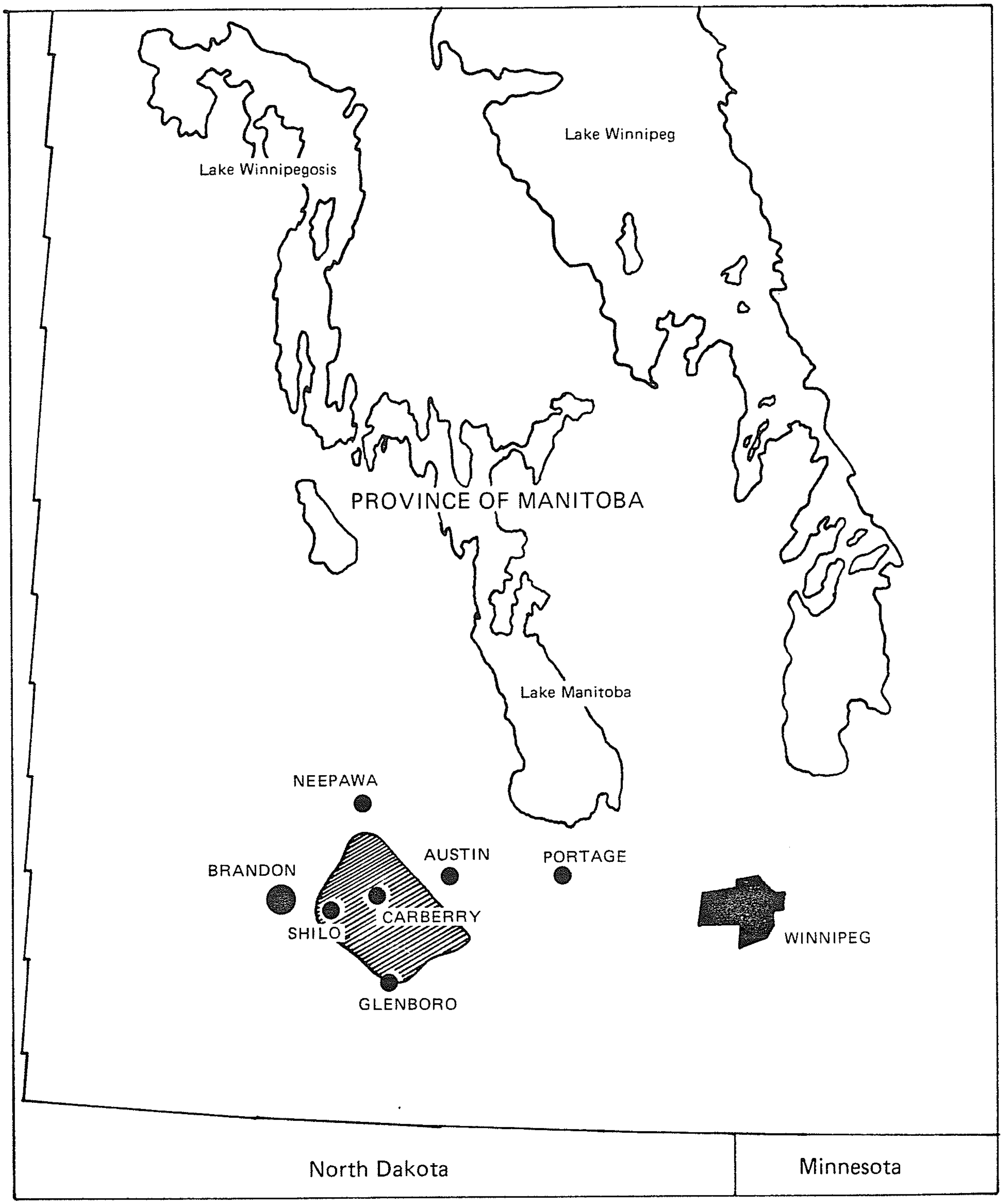
---

1 Figures are approximate and were obtained from Water Resources Branch, Manitoba Department of Natural Resources.

2 H.H. Austman, "Agricultural Water Use in Manitoba," The Manitoba Agricultural Sector Report For the Committee on Water Demand, Jan. 1981.

3 In this study, the aquifer is also referred to as the "Carberry Aquifer."

Figure 1.1 - The Carberry Aquifer Area



increase in irrigation development in the area, subject to water availability and adequate economic incentive.

There are some obvious advantages to irrigation in the Carberry area. It is a semi-arid region with an average annual rainfall of 19 inches. Of this total, only 11 inches falls between May and September, resulting in soil water deficits during the growing season.[4] Therefore farmers can expect higher crop yields by irrigating. As well, irrigation can provide consistently higher levels of crop quality and more stable farm production levels, as irrigated crops are less susceptible to drought conditions. In addition, the following recent economic developments have contributed significantly to the increased interest in irrigation:

1. Expanding capital use in agriculture is becoming more financially attractive than increasing the land base of an individual farm. In the past, low land prices made additional land purchase a feasible option for increasing production. Recent years have seen land prices rise dramatically, encouraging farmers to consider irrigation as a means to increase production, while maintaining the same land base.

2. Increases in yield may not be sufficient cause to irrigate a particular crop until crop prices increase to the level required to justify the necessary capital expenditure. In the 1970's, crop prices rose about 11 per cent per year. Continuing price increases will result in a greater variety of crops becoming eco-

---

4 "The difference between potential evapotranspiration and stored soil moisture plus precipitation may be defined as soil moisture deficit." On average, there is a soil moisture deficit in the Carberry area of 4.9 inches on August 13. See: University of Manitoba, Principles and Practices of Commercial Farming in Manitoba, Fifth Edition, Winnipeg, Manitoba, 1977, p. 14.

nomically feasible to irrigate.[5]

3. Over the past decade, increases in farm output prices have actually out-paced increases in input costs. This larger spread between prices and costs encourages obtaining higher yields by increasing the levels of use of inputs such as fertilizers and chemicals. As a result, the amount of moisture available to the growing plant becomes more and more the limiting factor to crop yield.
4. With continuing annual increases in the prices of variable inputs, partial substitution of these inputs by capital equipment investment helps to alleviate some of the adverse effects of these rising costs. The annual cost of a capital investment which is fixed for a number of years makes long term financial planning easier.
5. Inflating energy costs, higher land prices and higher costs of other inputs result in greater average costs of production. Thus, a farmer's level of business risk, associated with this expanding financial requirement, is increased. Annual income can be severely affected when yields fall due to inadequate moisture. Irrigation can be a major advantage in coping with business risk by reducing the variability of crop yields and, subsequently, the

[5] See the following world demand studies: FAO, "Cereals: Supply, Demand and Trade Projections 1985," FAO Commodity Projections 1985, prepared by the Commodities and Trade Division, Economic and Social Policy Department, FAO, Rome; Ministry of Agriculture and Forestry, Outline of the World Food Model and the Projections of Agricultural Products for 1980, 1985, Japan, August, 1974; United States Department of Agriculture, Alternative Futures for World Food in 1985, Volume 2, World GOL Model Supply-Distribution and Related Tables, Economics, Statistics, and Cooperative Service, Foreign Agricultural Economics Report No. 149, Washington, D.C., September 1978.

variability of incomes.

6. The quantity demanded for particular crops can influence the level of irrigation. In Manitoba, this is especially true for potatoes, with processing plants in Carberry and Portage la Prairie.
7. Centre-pivot irrigation, a recent technical innovation, enables land with undulating topography and low moisture holding capacity to be irrigated. As well, centre-pivot irrigation requires relatively less labour than other water application techniques. Because of these advantages and because highly productive land is becoming more expensive, the production of field crops on lower quality land under centre-pivot irrigation is an additional investment opportunity for the farmer.

These circumstances suggest that increased irrigation development in Manitoba will continue. Consequently, there is a high likelihood that the Carberry Aquifer will see increasing demands placed upon it, yet the amount of water available from this supply is fixed.

In an early stage of development, the amount demanded from an aquifer is small in comparison to total supply, so few conflicts occur between users. However, more conflicts between competing users can be envisaged as resource availability limits usage. As demand increases, the resource becomes more valuable and problems of misallocation of the water may result. This potential misallocation can be attributed to two factors typical of an unregulated common property resource. First, if all users have open access to the resource, they have no assurance of an indefinite supply and therefore will not consider water as having any present or future value. Consequently, the user has no incentive to maximize the present value of water-use over time. Second, not all of the water costs are taken into account when a user decides on a level of use. A user tends to ignore, or is unaware of, any cost that may be incurred by other users as a result of his actions.

For these concerns to be considered, appropriate groundwater regulation is necessary in order to allocate the available supply between competing users in an efficient manner. A number of different regulatory policies could be used, however each will have a different effect on who receives the greatest benefits from water use and how efficiently the water is utilized. As well, administrative feasibility will vary among alternative types of programs.

This study has three major objectives:

1. a discussion of the economic theory behind (a) the failure of the market to optimally allocate a common property resource and (b) the means of market intervention to ensure a more efficient allocation.
2. a discussion of the alternative institutional arrangements of various allocative policies and their feasibility.
3. an examination of the economic impacts of different regulatory procedures for the Carberry area.

Three aspects regarding the scope and extent of this study are suitably explained here:

1. This study focuses upon groundwater demand for irrigation, not surface water demand. Most of the irrigation in the area will be from wells due to the greater accessibility of groundwater supplies.[6]

2. The study examines alternative procedures for allocating groundwater among irrigators, but not among other users. It is acknowledged that the demands for water for domestic, municipal, industrial, and other uses are also increasing, along with irrigation demand. These uses, however, account for a small share of the potential total demand.[7]

3. Concerns over the effect irrigation development will have on water quality are not addressed in this study. As irrigation development becomes more extensive, leaching of nitrate-nitrogen into the groundwater supplies will probably increase as a result,

---

[6] The inter-relationship between these two sources of supply (groundwater and surface water) is not addressed in this study. Irrigation water in the area is presently being pumped from both surface and groundwater supplies. Because these two sources of water are inter-related, surface water usage and groundwater usage are inter-related. The water-ways that pass through the area, such as Pine Creek and the Assiniboine River, are partially replenished from the aquifer. In times of high stream flow, the opposite may be true, whereby water seeps into the aquifer from the streams. With regards to the Assiniboine, flow must be maintained because of downstream demands. For example, industry depends upon water supplied by the river at the city of Portage la Prairie. Indeed, the city itself uses the river as its source of water supply.

[7] In fact, proper sewage treatment enables the consumptive use of domestic, municipal and industrial purposes to be relatively small, yet agricultural use is highly consumptive.

[8] This is because application levels of fertilizer may increase, the amount of land in crop may expand, and water return flows to the aquifer will rise. These three factors increase the likelihood of higher levels of nitrate-nitrogen contamination in the groundwater, and eventually surface supplies.

affecting water quality.[8] Increased concentrations of nitrate-nitrogen in the watercourses can pose a health hazard and create an aesthetically repugnant natural environment.[9] Considerations of these concerns are beyond the scope of this study.

Chapter 2 provides theory related to the problems of water allocation and their possible solutions. A brief discussion on the institutional arrangements for the various policy options is presented in Chapter 3. Chapter 4 provides a description of the analytical model used in the study. The analysis and results of the alternative simulated regulatory options are discussed in Chapter 5. The final chapter, Chapter 6, summarizes the study and provides the major conclusions.

---

[9] D.F. Kraft, "Economics of Agricultural Adjustments to the Water Quality in an Irrigated River Basin," unpublished Ph.D. thesis, Department of Agricultural Economics, Washington State University, 1975, p. 1.

Chapter II

ECONOMIC THEORY AND RELATED STUDIES

Economic theory is useful in recognizing and explaining a resource allocation problem and aids in providing alternative methods of regulating the water resource to obtain a more efficient allocation. These theories are presented in this chapter. As well, previous studies related to the determination of water demand, the efficient allocation of resources and policy effects are reviewed.

2.1 THEORETICAL BACKGROUND

2.1.1 Economic Efficiency and the Market

The purpose of an economic system is to provide for the allocation of resources in the production of goods and services and to allocate these goods and services among competing users. A Pareto-optimal allocation of resources exists in an economy if no individual can be made better off through a reallocation of resources without another individual being made worse off.[10] An economically efficient allocation of resources, in terms of the principle of Pareto-optimality, means there are no net economic gains to be made by a reallocation of resources.[11] A perfectly

---

[10] For this discussion see: F.M. Bator, "The Simple Analytics of Welfare Maximization," American Economic Review, March, 1957.

[11] For the purposes of this study, economic efficiency, as defined, is deemed to be the ultimate objective of water management.

competitive market assures this optimal allocation will occur.[12] A competitive market achieves this efficient allocation through prices. The market functions as an auction system with consumers bidding for goods, thereby revealing their preferences to the producers. This bidding provides information to the producers regarding the type of product to produce.

In actuality, there are many instances whereby a market will not successfully allocate resources to achieve Pareto-optimality. Many of these instances are the consequence of markets rarely being perfectly competitive because of imperfect knowledge, resistance to change and uncertainty. As well, inefficiencies result because of complications commonly referred to as "market failures." Market failures can be said to exist when the competitive market finds an equilibrium which is not a Pareto-optimal solution because of a divergence between marginal private benefits and marginal social costs.[13] One such market failure is termed an "externality" and appears when an external diseconomy or external economy exists in the market.

---

[12] See, for a general discussion: R.W. Boadway, "Economic Efficiency and the Competitive Price System," Public Sector Economics, Winthrop Publishers, Inc., Cambridge, 1979.

[13] J.R. Davis and J.R. Hulett, "An Analysis of Market Failure," University of Florida Social Sciences, Monograph #61, University Presses of Florida, Gainsville, 1977.

2.1.2 Externalities

An externality occurs when the activity of one individual, or firm, affects the utility, or production function, of another individual, or firm. Thus, an externality is present when:

$$U_a = U_a(X_1, X_2, X_3 \ldots\ldots\ldots X_n, Y_1) \qquad (2.1)$$

where the utility of a is dependent upon it's own activities X; i=1,2,3,4,...n, as well as the activity (or activities) Y of another individual.

The activities of an individual user of groundwater can affect the activity of another because of the interrelation of the water supply between them. Since the water used by all the irrigators is obtained from the same water source, and agricultural use is highly consumptive, the water that one irrigator pumps out and uses is largely unavailable to the other users. The irrigator is not only decreasing the supply of water left for himself, but also for all of the rest of the irrigators. If enough water is pumped, then he will eventually affect the cost at which others can obtain the remaining available water. As the level of the aquifer falls, capital costs increase because wells have to be made deeper. As well, variable costs will increase because water will have to be pumped from a greater depth. As the development of the aquifer proceeds, externality effects will be of a greater concern.

2.2 COMMON PROPERTY RESOURCES

Water in an undeveloped, unregulated aquifer has the characteristics of a common property resource. A common property resource exhibits the property of "non-excludability;" an individual can not be prevented from consuming the good if he does not pay for it. In this case, the individual has no need to indicate his true preference for the good through a price that he is willing to pay. Due to the open accessibility of an unregulated aquifer, exclusion can not take place until property rights are assigned (making the resource a private good) to enable the market mechanism to function.

Initially, when the demand for water from an aquifer is low and the supply is high, one user's actions may have no effects on another user. The common property resource displays the public good characteristic of "non-rivalness" when the consumption of a good by one individual will not affect the amount that another individual consumes. The additional cost of another individual consuming the good is zero. Under these conditions regulation is unnecessary; any charges, quotas or other forms of market intervention are not required.

However, at a specific level of resource use, the resource becomes congested and externality effects occur.

The presence of external effects between users of a common property resource and open accessibility are two conditions which encourage expansion of the resource use. Farmers currently irrigating expand their pumping effort to capture the water "before someone else does." Other farmers are encouraged to enter into irrigated production to capture their share of the accruing economic rent.

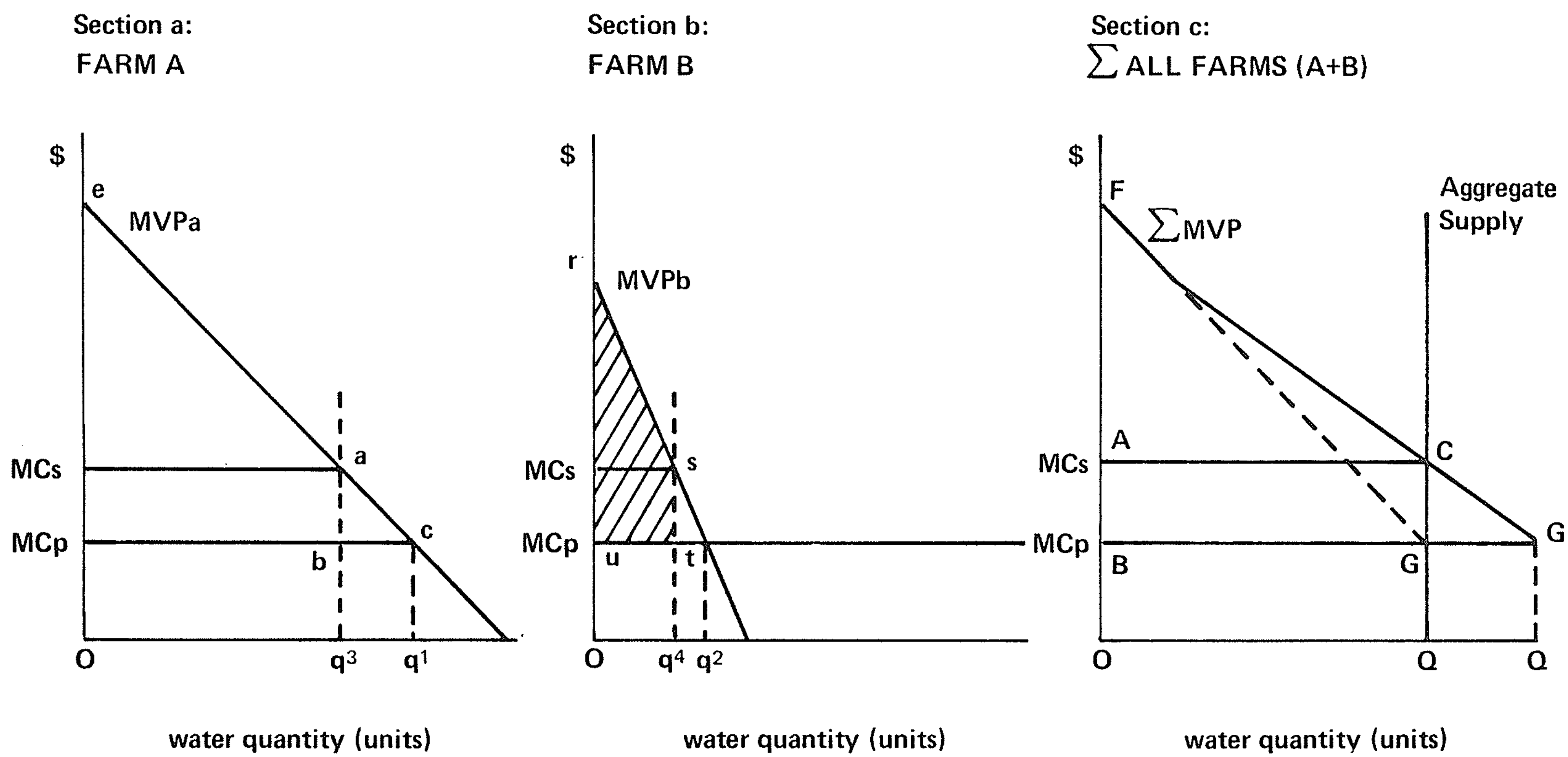
2.2.1 Common Property Resource Effects

Once captured through a groundwater well, water is regarded as a free factor of production, except for the costs of pumping and distribution in the field. The irrigator does not consider the additional unit of water as having an opportunity cost and assumes the added cost of acquiring water is not influenced by the incremental amount used. Therefore, marginal cost per unit of additional water is assumed constant and average cost equals marginal cost.

However, the marginal increase in production per unit of water will not be constant. As more water is used on a crop, the marginal additional yield increases at a decreasing rate and could eventually become negative, as soil becomes saturated and the crop experiences harmful effects from too much moisture. As well, as water is used increasingly for less valuable crops, the effect will be to decrease the marginal product. Since marginal product is falling, so is the average product. If output prices are not affected by a declining marginal product, then the marginal value of additional water declines.

Figure 2.1 illustrates the derived demand curve of a single water user, Farm A. As the quantity of water increases, the value of the marginal unit of use decreases, thus the marginal value product curve MVPa slopes downward to the right. The marginal private cost curve of Farm A is considered to be constant, as represented by curve MCp. The profit maximizing farm will expand water use up to quantity q1, where the marginal value product of water equals the marginal cost to the farm.

Figure 2.1 - The Demand and Allocation of Water



If this farm is the only user of the resource (or is representative of a number of users) and q1 is the amount demanded, as well as the amount of supply available, then there is no need for an alternative allocation of the resource.

However, suppose Farm B sets up an irrigation pivot and begins to use water from the same aquifer. This user also experiences a downward sloping demand curve for water (MVPb), albeit Farm B has a differently sloped curve due to a different level of efficiency of use. If Farm B also has a marginal private cost curve equal to MCp, then the amount of water demanded is equal to q2. Now both Farm A and Farm B are competing for the same water. The combined demand function for Farms A and B appears in section c of Figure 2.1 and is equal to FG′. The total demand function without Farm B′s demand is equal to FG and, by assumption, the same as ec in section a. The total quantity of water demanded when Farm B′s use is added is 0Q′ in section c. Since 0Q is the total aggregate supply of water, the demand for water in excess of supply is equal to QQ′. Eventually, unless either of the farms′ demands are somehow influenced, one or both will be unable to pump the amount of water that they desire. The question is how to ration this limited supply among competing individuals. Total supply equals aggregate demand at point C in section c. To allocate this supply between the users there is an opportunity cost per unit of water equal to AB. Farm A should be allowed to irrigate up to point q3 and Farm B should be allowed to use q4.

After Farm A uses quantity q3, then the Farm′s marginal value of additional water use, although greater than the MCp, is less then if Farm B is allowed to irrigate the remaining water, up to point q4. If Farm A continues to use all the water, the loss in total welfare or rents imputed to the fixed factors of production in Farms A and B is the difference between areas abc and urst.

As long as the natural resource is owned in common, or at least easily accessible, and exploited under conditions of individualistic competition, Farm A will expand water use. Farm A will not voluntarily stop pumping at q3, but will continue to use ql. If allowed to do so, the economic rent of the common property resource is dissipated. Water has been used beyond the point where marginal value equals marginal social cost. This social cost is the opportunity cost of not allowing the water to be used more productively by Farm B. If Farm A was restricted to the optimal quantity, and Farm B was allowed to use q4, economic rent will be maximized.

2.3 CORRECTING FOR MARKET FAILURES

The market is unable to determine a solution for the efficient allocation of groundwater due to the characteristics of a common property resource. These characteristics could be altered by intervention in the market. If these interventions can provide incentive for a common property resource user to consider external, as well as private use costs, then allocation will be more efficient.[14] Three alternative approaches to market intervention are considered in this study:

1)the use of quotas, limiting the quantity of water use, along with penalties for violators.

2)the use of taxes or subsidies ("charges", "fines" or "rebates")

---

[14] Alan Randall, "Market Solutions to Externality Problems: Theory and Practice," American Journal of Agricultural Economics, May, 1972, p. 175.

3)the establishment, through regulation, of a market for water rights. This market must be regulated to ensure external effects are considered.

These three approaches are now discussed in more detail.

2.3.1 The Use of Quotas

The setting of quotas could be imposed if the legal framework was in place that allowed for such regulation. Resource allocation through quotas is in extreme contrast to a private market system of allocation. The regulating authority entitles to an individual the right to use a resource with respect to quantity, time and space. Any subsequent transfer of these rights from one individual to another is prohibited.

The most efficient number of quotas created would be that quantity at which the marginal social cost of an additional unit of water is equal to the marginal revenue of the additional unit of water. (In Figure 2.1, Farm A's quota would be equal to q3, Farm B's, q4.) Enforcement of this allocation is achieved through fines or penalties.

However, efficient allocation of the available quantity through quota regulation may be difficult. Since the marginal value of applying additional water will vary between users, due to different physical and technical characteristics of a particular irrigation enterprise and varied managerial capabilities of individual users, inefficiencies will occur unless these factors are properly considered. Such considerations would require very sophisticated quotas. As well, as market conditions change over time, the user's marginal value of water is affected differently. An efficient allocation of rights at one point in time will not hold for another.

The more efficient users will have a higher marginal value for water than the inefficient user. If the quota is set at a universal rate (say on a per irrigated acre basis), the inefficient user receives an over allocation and the efficient user is under allocated.

Krier and Montgomery suggest such "inefficiencies may, however, be counterbalanced by the savings which result from the minimal need for information in systems of the uniform standards (quotas)."[15] Efficiency of water use could be increased with variable quotas, assuming the users' marginal revenue relationships can be determined, but the informational requirements and the necessary administration may be costly. These costs could exceed any possible gains in economic efficiency.

Quota restrictions may initially be a sufficient form of regulation. If the value of the resource is small, then additional costs of imposing regulation to obtain greater efficiencies of use will not be justified. However, the cost of allowing these inefficiencies to occur becomes too great as the value of the resource increases.

2.3.2 The Use of Taxes or Subsidies

A pricing program, via taxes or subsidies, for the regulation of the externality may more closely satisfy efficiency criteria at a lesser cost than the necessary variable quantity restrictions that would be re-

---

[15] James E. Krier and W. David Montgomery, "Resource Allocation, Information Cost and the Form of Governmental Intervention," Natural Resources Journal, January, 1973, p. 98.

[16] Baumol states that, unlike quantity restrictions, a pricing system "promises at least in principle, to achieve decreases in pollution or other types of damage to the environment at minimum cost to society." William J. Baumol, "On Taxation and the Control of Externalities," The American Economic Review June, 1972, p. 319.

quired to achieve similar efficiency objectives.[16]

Since irrigators will use water up to the level where private marginal cost equals marginal revenue, it may seem simple enough to levy a tax on the irrigator equal to the difference between marginal private and marginal social costs (a per unit tax equal to AB in Figure 2.1). The irrigator now regards the marginal cost to be equal to that represented by the MCs curve (MCp + AB) in Figure 2.1 and will operate where marginal revenue equals the marginal private cost plus the tax, at the optimal levels of q3 for Farm A and q4 for Farm B. In a more competitive case, where negotiation is impractical, this should ensure an efficient level of resource use will occur.[17] Only the more efficient users (and the more efficient uses) will utilize the water because there is incentive to compare the marginal value of a unit of water to the per unit charge plus procurement cost.

The same result would occur if the offending user is given a subsidy equal to the marginal social costs for each reduction in water use. If the offending irrigator decides to keep pumping at the higher level, the subsidy is forgone and the opportunity cost of production will equal the marginal private cost plus the forgone subsidy. Such a program, of course, could involve large governmental expenditure to cover the cost of the subsidy. Under either taxation or subsidization, the opportunity cost to the causal user is the same. As a result, the net social gain is the same with either method. The causal party is better off with a subsidy program. With taxation, the opposite is true. The taxation method provides revenue for the government and could either be totally

---

[17] Ibid., p. 313.

or partially self-supporting of the resource administration costs. Hence, resource regulation through taxation appears more attractive than through subsidization.

There are, however, implementation problems with the taxation scheme. The price (tax level) of the water is not determined by the forces of supply and demand, as in a private market, but has to be established by other means. The problem lies in estimating the difference between marginal private and marginal social costs. Baumol suggests setting taxes by trial and error to achieve a desired standard. This would require less information since it "utilizes global measures and avoids direct controls with all of their heavy administrative costs."[18] However, trial and error can possibly take too long, even leading to the destruction of the resource if taxes are set too low.

2.3.3 Market For Water Rights

If a market is created for the allocation of water, then the price determines who will obtain the rights to use a specific amount. This price is determined by the individuals who competitively bid for the rights in the market place. Assuming no financial limitation, individuals able to obtain the greatest benefit will be able to afford the highest price. At the margin, the individuals will be paying the same because the marginal benefit will be the same. (This price would be the same as the appropriate tax.)

---

[18] Baumol, p. 319.

Although a market may be appropriate for the efficient allocation of water, there is some doubt as to whether the market forces are able to provide sufficient corrective pressures on externality effects. Coase[19] emphasized the role of property rights[20] to enable market processes to occur for the control of externalities. Initially, a resource user may be given the right to use a certain quantity of water. Individuals who do not have rights must be excluded from using the resource. If the rate of use of a second user increases, causing externality effects on the first user, then the second user is charged the cost of restitution for such effects. The first user has the right to a particular quantity of water and the second user is legally liable for any infringement upon that right. The causal irrigator must pay the marginal damage that occurs as the result of any increase in water use.[21] In effect, the liable irrigator has a marginal cost that is now equal to the marginal private cost plus the marginal social cost. As a result, the resources are allocated efficiently and output is at an optimal level.

If property rights are given to the individual causing the effect, Coase argued further, it is in the common interest of the harmed user to voluntarily compensate the causal individual for a reduction in usage in order to reduce the externality effect. The amount of compensation worthwhile is any amount up to the total amount of the damage inflicted. The causal user is willing to reduce output as long as the difference

---

19 R.H. Coase, "The Problem of Social Cost," Journal of Law and Economics, October, 1960.

20 Simply, "property rights" here refers to the rights of action over the property, in this case, the right to use water.

21 Here, damage is regarded as any harmful or counterproductive external effects.

between marginal private benefit and marginal social cost is received.

Two important assumptions should be noted. One is that the compensation payments for damage, or the bribes to reduce damage, can be costlessly imposed. The other, that the actual "affecting" and "affected" parties can be identified and these effects can be measured. These assumptions become more unrealistic as the numbers of the parties grow, making any type of bargaining impossible, or extremely expensive, and therefore prohibitive. Furthermore, some form of legal framework of ownership is required to enable negotiation to take place; liability rules must be known. Another problem is the likelihood of individuals inflating their claims above actual damage in an attempt to increase their compensation payment.

In practise, therefore, it is questionable whether simply assigning property rights will create market forces that are able to provide sufficient corrective pressures on individuals for the consideration of externality effects. These pressures would therefore have to be provided through institutional means, supplementary to the assignment of property rights. Granted, these "institutional means" would not be costless. Eventually, however, creating a private market system from a common property system will result in sufficient increased economic efficiency to offset the costs of these necessary institutional arrangements.[22] The costs that are involved are those resulting from the requirement to define the property rights and the necessary protection of these rights.

---

[22] See: Harold Demsetz, "Toward a Theory of Property Rights," Vol. 57, American Economic Association Papers and Proceedings, 1967.

2.4 RELATED STUDIES

A number of previous studies developed procedures to derive the demand for groundwater for irrigation purposes. Burt[23] utilized the methods of dynamic programming, permitting the derivation of a functional equation for optimal resource allocation over time. Bredhoeft and Young[24] criticized the simplifing assumptions made to make dynamic programming acceptable to the problem. For example, Burt assumes pumping costs are related directly to the stock of water present in the aquifer. Bredehoeft and Young argue that it is incorrect to relate pumping costs to the average drawdown for the basin because the drawdown, and hence the pumping lift, at the particular location is not related to a basin wide average.

They suggest a model which "incorporates the interdependency and heterogenity of aquifers, whose output brings out the time dependency of response of water levels, can represent groundwater systems significantly better than the more simplified approaches."[25] Bredehoeft and Young use linear programming as the method to represent the resource allocation of the firm. Thus, the short run water use decision of irrigators

---

[23] O.R. Burt, "Optimal Resource Use Over Time with an Application to Groundwater," Management Science Vol. 11, No. 1, September, 1964.

[24] I.D. Bredehoeft and R.A. Young, "The Temporal Allocation of Groundwater-A Simulation Approach," Water Resources Research, Vol. 6, 1970.

[25] Bredehoeft, p. 6.

is solved for in the simulation by a relatively simple linear programming model.

Craddock[26] investigated the use of linear programming models for determining irrigation demand for water and compares the relative merits and disadvantages of ordinary, recursive or multi-period specifications. With ordinary linear programming the price of water can be parametically varied. Successively solving the model for alternative water prices will approximate the demand curve. In practical terms, it is impossible to solve recursive and multi-period with more than two or three integer variables.

Mapp and Eidman[27] developed a bioeconomic evaluation that was capable of determining yields for the major irrigated and dryland crops. These yields were determined as a function of soil moisture and atmospheric stress. The model was used to evaluate three methods of regulating groundwater irrigation; no restrictions, a quantity restriction and a user fee for use above the quantity restriction. The General Agricultural Firm simulator developed by Hutton and Hinman[28] was modified to simulate a representative farm for each resource situation depicted. A major revision to the simulator was made to include a production subset to simulate yields and irrigation water use.

---

[26] W.J. Craddock, "Linear Programming Models for Determining Irrigation Demand for Water," Canadian Journal of Agricultural Economics Vol. 19, No. 3, November, 1971.

[27] Harry P. Mapp Jr., and Vernon R. Eidman, "A Bioeconomic Simulation Analysis of Regulating Groundwater Irrigation," American Journal of Agricultural Economics Vol. 58, 1976.

[28] R.F. Hutton and H.R. Hinman, "A General Agricultural Firm Simulator," Agricultural Economics and Rural Sociality Report 72, Pennsylvania State University, 1968.

Kraft's[29] analytical model concentrated upon the allocation of private and common property resources, through different policy instruments, to achieve potential water quality standards in an irrigated river basin. Separable programming was used to enable inclusion of the water quality variables. The objective was specified to be a net revenue maximizing function. Kraft identified two types of constraints that restricted the attainment of the objective: 1) political and legal restrictions including water quality standards and the distribution of water rights, and 2) physical and hydrological constraints defining the availability of land and water for irrigation. By changing constraints or prices, Kraft simulated political, legal and technical restrictions, with such changes intended to achieve the same quality standard.

Hassenmiller[30] was interested in determining the "optimal dimensions of a proposed irrigation development when that development is viewed from a societal perspective."[31] He emphasized that it may not be desirable to satisfy all water demands and the nature of development can not be determined by technological factors alone. He concluded that satisfactory development planning requires careful integration of at least three elements; crop characteristics, water costs and commodity demands. Since each of these three elements must be considered simultaneously to obtain the optimal pattern of development, separable programming was

---

[29] D.F. Kraft, "Economics of Agricultural Adjustments to Water Quality Standards in an Irrigated River Basin," unpublished Ph.D. thesis, Department of Agricultural Economics, Washington State University, 1975.

[30] K.W. Hassenmillar, "Planning for Irrigation Development in the State of Washington," unpublished Ph.D. thesis, Washington State University, 1972.

[31] Ibid., p. 65.

used to obtain more accurate and refined results than traditional methods of linear programming.

This review of literature indicates various procedures to model water demand and water resource allocation problems. Mapp and Eidman's study demonstrated the acceptibility of using a linear programming model to represent the resource allocation function of the firm. Mapp and Eidmans' study, as well as Kraft's, provided insight into the simulation of different methods of regulating groundwater; an objective of this study. Hassenmiller's study served to illustrate the weaknesses of an "optimal" level of irrigation development when viewed from a purely technical point of view.

2.5 SUMMARY

A competitive market for a resource serves to act as an auctioning process which can result in the efficient allocation. The nature of a common property resource prevents the functioning of a competitive market. Initially, when the resource is abundant, there is no need for concern about allocation. It only becomes necessary as the value increases and public intervention, and the associated costs, become more worthwhile. Then, the increased efficiency of use will offset the cost of intervention. Without public intervention, externality effects will also be neglected. Quotas and taxation or subsidization are alternative allocative measures which may initially provide adequate regulation. Eventually, however, intervention more closely approximating a competitive market may be desirable from an efficiency point of view. Still, extra-market requirements will be necessary to handle consideration of externality effects.

Chapter III

ALTERNATIVE INSTITUTIONAL ARRANGEMENTS

If no adverse interactions occur between users of a common property resource, then access should not be denied. Since regulation is not necessary, no institutional arrangement for the management of the resource is required. Eventually, as usage increases and conflicts occur, regulation denying free access enables the authority controlling access to manage the resource more efficiently.

Initially, the management objective of this authority may be simply to limit water use so apparent adverse externality effects do not occur. However, as the resource becomes more scarce and increases in value, a more efficient allocation of the resource becomes a worthwhile objective. As this value becomes larger, more thorough regulation is desirable because welfare losses from inefficiencies are now greater. As the development of the resource progresses, regulation requirements change. If an objective of water management is the efficient use of available water, then the ultimate goal of water regulation is to ensure the allocation of resources is such that the marginal value of the resource is equal to all users. If this goal is achieved, then the income from the resource is as large as possible.

Economic theory provided the concepts for alternative regulatory tools (quotas, pricing and the establishment of a market). These alternatives are considered in this chapter from a more practical standpoint, in the context of how acceptable and feasible the institutional arrangement necessary for their implementation would be. Four alternatives are considered here. The first alternative is to continue with present regulation, thus accepting the status quo. Alternative II is to maintain the quota system as the regulatory instrument, while improving management control of the resource within existing legislative guidelines. Alternative III is a pricing system. Alternative IV, a "market" for water, would incorporate the characteristics of pricing water and allowing for transferability of water rights.

3.1 CURRENT WATER MANAGEMENT IN MANITOBA- ALTERNATIVE I

Presently, in Manitoba, allocating water among users is removed from the market, largely ignoring the concept of economic efficiency.[32] Many of the weaknesses of present allocation are not unique to the Manitoba situation but are a consequence of basic principles of the "appropriative doctrine."

Under this doctrine, water is allocated on the principle of "first in time-first in right"- the exclusive right of the earliest appropriator of water to use his total allocation as long as supply is available- any later appropriator has the same right with respect to those who were later than himself. The licensing board determines priority "according to the respective dates of...filing" an application.[33] The appropriative right relates to a specific quantity of water (a quota) and has a time limit on it's validity, usually five years for irrigation. As well,

---

[32] Granted, the Manitoba Water Rights Act does rank uses with the intention of representing efficiency aspects somewhat.

[33] The Water Rights Act R.S.M., c. 289, s. 12(2).

there are broad categories of precedence depending on purpose, and in the following order: domestic, municipal, industrial, irrigation and other purposes.

Present regulation is inefficient in many ways, largely because there are no assurances that water is used in a beneficial and reasonable way:

1. Priority within a category based upon seniority inhibits a lower priority irrigator from using the water in a more efficient manner. Water continues to be allocated to present day uses which may be less valuable. Thus, an opportunity cost is inflicted on society and total benefits are restrained.
2. Within a category, there is no system of allocation on the basis of beneficial use. And legislation establishes automatic priority of use between two uses that fall into different categories. As well, there is no consideration for the priority of a particular use changing over time.
3. The right of a senior holder to use the total quantity specified on the permit is absolute, with no regard for the benefits of such use. There is no incentive to use the water prudently since there are no economic gains for doing so.
4. Water rights are non-transferable between users. If a permit holder finds himself with supply in excess of actual requirements, he is unable to transfer rights to someone else. This encourages use of the total allotment, perhaps even past the level where marginal net value is equal to zero.
5. Contingency arrangements do not exist with provisions for special management during drought. Even if only enough water for a few

more senior holders is available, resulting in many other established users receiving no supplies, there is no form of emergency rationing to lessen the impact on the area. Obviously, the marginal values of irrigation supplied to farms with short supply are higher than to farms with more adequate supplies. Furthermore, the marginal value of additional water increases for most crops as the season progresses, yet available water may be consumed before the critical stages of plant development.

The lack of enforcement of existing legislation also has an impact on efficiency. Many irrigators presently do not hold water licenses and, conversely, many license holders do not irrigate. Therefore, the actual amount of water usage is unknown, as is the amount still available for use.

3.2 IMPROVED MANAGEMENT UNDER EXISTING LEGISLATION- ALTERNATIVE II

Under existing legislation the Lieutenant Governor in Council may reserve any unappropriated water and "may thereafter authorize the allocation of the whole or any part of the water so reserved among the applicants therefor, or otherwise, as he may deem best in the public interest..."[34] In this way provisions do exist for changes in current management to increase efficiency while maintaining quota restrictions as a basic regulatory tool.

Without changing water management regulation to any extent, there are three areas that would improve distribution:

---

[34] The Water Rights Act R.S.M., c. 289, s. 12(8).

1. Enforcement of the requirement for a license to use water, as required by statute, is a first step before any control can be established. Thus, property rights are assigned to individuals and the resource acquires the private good characteristic of excludability.
2. If a licensee fails to use his allotment, or part of it, after a specific period of time, then the license should be forfeited. Provision for this course of action is already provided for in section 38 (1 and 2) of the Act. Therefore, the holders of licenses obtained for security or speculative reasons would be made to give up their rights. Otherwise, the carrying capacity of the aquifer is not fully utilized. If quota allocation is enforced, a quantity of water which has been assigned is unavailable for another user, whether actually used or not.
3. The use of water, as stipulated in the licence, should be monitored to ensure compliance with the terms of the water agreement. Failure to observe or perform any stipulations in the license or under the Water Rights Act is grounds for forfeiture of the license, as specified in section 38(3). Without such follow-up enforcement, after issuance, adequate control is not possible. It

is important to allocate water, and enforce this allocation, to ensure security of an individual's entitlement.[35]

The cost of public enforcement of existing legislation, ie. enlarging the size of the civil service, should also be weighed against the gains. These initial measures will significantly improve control of the resource, but may not be sufficient to achieve public objectives. Additional measures would then be necessary.

3.3 WATER MANAGEMENT BASED ON TAXATION- ALTERNATIVE III

Establishing a per unit tax on water use sets a price for the resource. Water will be used more prudently as the per unit tax becomes larger in relation to the per unit returns. In principle, tax-subsidy approaches to problems of externality are sound, but the informational requirement is large because social costs are difficult to measure. Modified approaches to taxation are more attractive as means to effectively achieve resource management objectives.

Once the desired quantity of use is determined (perhaps where recharge equals use), a tax capable of regulating use to this level is sought. Understandably, the exact level of the tax would be hard to determine and may be established only after some trial and error. Simulation methods and econometric methods can be used in the determination of

---

[35] While "tenure security" is important, "physical security" could be improved through the construction of storage projects and water control structures. The equity of distribution could be increased, enabling a junior right-holder to be no less secure than a senior holder, within limits. Spring run-off in excess of water requirements could be held back, then later released into streams to ensure a more even flow later in the season. However, these projects may not be feasible in their own right. In actuality, such projects are very rare due to large initial capital costs and environmental constraints.

the tax to assess how demand is affected by the different levels. Finer adjustments can be determined from information provided after initial implementation. This method would result in a more efficient allocation of water even if the farms are not perfect competitors or profit maximizers. Only a small amount of information is required in comparison to the basic theoretical approaches.

Enforcement of the taxation regulations would be required to prevent or minimize abuses. Indeed, the enforcement may be technically difficult, or very costly, to ensure proper payment and to exclude those who do not pay. In the case of the Carberry aquifer, pumping rates could be recorded from guages on the wells. Then periodical monitoring of an individuals usage could be possible, similarly to the monitoring of residential water use.

Since the crops grown within the area are grown extensively throughout western Canada, the producers in the Carberry area are a small part of a much larger industry and therefore operate as price takers. Consequently, with a perfectly elastic demand with respect to price, the tax is not shared by producers and consumers, but falls on the producers alone.

An alternative taxation scheme would involve a lump sum payment, or a fixed charge per quota (acre, pivot, or other unit, but not per unit of water) and for a specific time period. The charge would not be influenced by the actual amount of water used. It may be sufficiently large that only the most profitable irrigated crops are grown and the level of water use is such that external diseconomies are minimal. Unfortunately, once the initial fixed tax rate is paid, there is no incentive to further decrease water use. Further reductions would enable more water to be used elsewhere, assuming provisions for transferability. (As with an individual quota, as long as water use is kept at the specified level, there is no incentive for further reductions.) Therefore, this form of taxation is more simply implemented, yet less effective.

3.4 WATER MANAGEMENT BASED ON MARKET PRINCIPLES- ALTERNATIVE IV

Since a "free" market for water would fail, a possible alternative is a regulated market system. An adequate institutional structure would be required which may incorporate theoretical quantity restrictions and taxation principles. There are two types of approaches to this proposal:

1. the modification of current water right procedure, allowing for transferability of "quotas"
2. the formation of an authoritative organization to administer the sale of water rights.

Each of these approaches are considered separately.

3.4.1 Transferability of Quotas

In some areas of the United States, where water rights can be transferred, a state authoritative board is responsible for collecting data on the effects of a proposed transfer and then evaluating these technical facts and the laws pertaining to the case.[36] Such a procedure replaces the market transaction, allows for consideration of externality

---

[36] For additional discussion see: L.M. Hartman and D. Seastone, Water Transfers: Economic Efficiency and Alternative Institutions, John Hopkins Press, Baltimore, 1970.

effects and enables an evaluation of benefits.[37] A water right is not considered to be a saleable entity until an ownership transfer is requested and then the transfer is made subject to the approval of the board. Once approved, a price for the water could either be determined by the board or agreed upon by the buyer and seller. This system is intended to facilitate transfer between differential uses and therefore categories of priority users are not necessary.

Under this arrangement, the actual amount of water transferred could be determined by the board and may be different than the initial appropriation, depending on use and externality effects. The actual transaction should involve an amount of water not exceeding the consumptive use of the original purpose, if return flows have been previously allocated. As well, rights should not be granted that allow for more water than can be used beneficially. The establishment of beneficial use could also be required before the renewal of licenses. The applicant could be allowed to appeal decisions made by the authoritative board by using the courts.

A requirement to publicly post the intended water use informs potentially affected parties of an impending transfer. The applicant would be responsible to answer any concerns raised by these parties. The board would then determine if the transfer should be allowed.

Other responsibilities of the authoritative board could include the monitoring of use, the responsibility to cancel licenses which are not in use for a minimum number of consecutive years, hydrological studies,

---

[37] In other western states, the above responsibilities are handled judicially and the onus is on the individual parties to provide the courts with assurances of consideration of the effects of the proposed transfers. These presentations can tend to be biased in favour of the applicant and less favourable to the social viewpoint, suggesting administrative boards are preferable to the courts.

and measurements of quantities pumped. As well, field surveys of proposed water use, and the collection of information for the transfer process, would be the board's responsibilities.

Difficulties associated with this procedure are the quantifying of rights, due to fluctuating seasonal and annual recharge, and the effects due to the interdependency of users. These problems may be partially relieved through obtaining sufficient hydrological data.

3.4.2 The Sale of Water Rights

If a permit holder's allotment is in excess of needs, this "excess" water could be used by someone else, provided there is adequate incentive to transfer the right of use. Such incentive could be provided through the pricing of water rights. Thus, a water right would be a saleable commodity.

The price required to facilitate the transfer of a water right could be determined by the two parties involved. An administrative board would serve as an "auctioneer," expediting the sale of the water to the highest bidder. All transfers would be subject to the board's right to refuse a transfer in excess of the amount that can be beneficially used. The board will also be responsible for ensuring sufficient protection and adequate compensation to other users who may be affected by the transfer. These "third party" effects, such as may be caused by a lowering of the water table, would otherwise most likely not be considered.[38]

Because rights are transferable, a buyer will be willing to pay up to the net value of the increase in crop yield as a result of the additional water purchased. The more efficient users can afford a higher price for each unit of water. The less efficient user can afford water only when the price is lower. Since price is an indication of scarcity and value in use, the more efficient firm will be able to out-bid the less efficient. This process allows for adjustments to be made as benefits change over time.

The value of the agricultural production is thus maximized in the area, given the availability of water, because of this re-distribution among users. Incentive, by way of a price, is provided for a water right holder to sell off rights not in use or rights that are of more value to someone else. Water will be much better utilized than under a system of no transfers.

Prices could be determined and set by the board. If kept reasonably low, windfall gains accrueing to the original holders of the right would be limited.[39] Unfortunately, the consequences of this procedure on economic efficiency are not desirable. By restricting the price of water

---

[38] In areas where water development becomes very intensive, local administrative boards should be responsible for overseeing development. In general, the more comprehensive the management required, the more appropriate is the district form of organization. Local organizations would be in a better position to implement regulation allowing for the transfer of rights in a manner more similar to the market.

[39] Windfall gains, if provable or adequately defined, could also be taxed.

to a nominal basis, the allocative function of the market is inhibited.[40]

Some water distribution procedures in the United States allow for the temporary transfer of water rights. These "rentals" help alleviate problems of insufficient water supplies resulting from changes in crop requirements due to weather, type of crop or mis-managed water requirements. Additional needs for water may be partially or completely filled by excess water from lands that, at the time, have no need for all the water allocated to them. This increased flexibility ensures greater efficiency in use. As before, price incentives would be required to facilitate transfers.

Prices for these temporary transfers could be either uncontrolled or controlled by the management board. Uncontrolled prices would ensure that normal market processes would divert water to the most beneficial use. Or, the board could set a price. This will, of course, inhibit water from going to the most efficient use.

3.5 SUMMARY

The current deficiencies in water regulation in Manitoba have created few problems, but, as demands increase, the requirements for more rigorous regulation is obvious.[41] Present quota regulation is only adequate when externality effects are minimal and quantity demanded in relation

---

[40] For example, if the board will buy a right back for \$5 per acre-foot yet the marginal return to the irrigator is \$7 per acre foot, he will not sell even if the marginal value of another irrigator is \$10 per acre-foot. Under normal market processes, he would sell his right to the other user who would be willing to pay up to \$10.

[41] Presently, there is concern over how to handle the large influx of water right applications.

to availability is small. Legislation should be enforced to ensure all users are licensed and all licenses are being used. The monitoring of water use and water drawdown is also necessary. These actions will provide information on actual water usage, insight into the behavior of the aquifer and estimates of the availability of water.

Taxation, in itself, while encouraging efficient use, is difficult to use as a tool to limit use. The informational requirement necessary to determine the exact size of the tax that would limit use to a particular level is large.

Eventually, regulation enabling the transfer and pricing of quotas is desirable. Even then, an organization outside of the market would be required to consider external effects. For Carberry, a district form of organization is most appealing to properly consider both efficiency and externality effects.

Chapter IV

ANALYTICAL MODEL AND DATA

This analysis of irrigation development in the Carberry area uses a linear programming model to maximize net agricultural income given the available resources.[42] The linear programming model is ideally suited to this type of analysis because it allocates the available limited resources so they are utilized as efficiently as possible. A solution is obtained where net income is maximized because the limited resources are used in activities which provide the largest contribution to the objective function. For this study, a maximum net income is deemed to be directly indicative of social well-being. As well, the linear programming model is appropriate because it is able to accommodate a problem which has many complicated relationships among a large number of variables.

Specifically, the study's analysis is concerned with how model solutions are affected by simulating various institutional allocative factors such as quotas on water use, taxing water use, transferability of water rights, and priority right systems. In this way, the researcher can test how irrigation development may be influenced by a particular policy.

---

42 "Rational development of water resources presupposes desirable consequences on real income, whether it be at the level of an individual, some local region, or the nation at large." Michael F. Brewer, "The Economics of Water Transfer," Natural Resources Journal, January, 1965, p. 522.

Linear programming makes use of theory, programming logic and large amounts of data to represent a simplified version of a complex real world problem. This type of analysis involves two major steps. First, a model must be developed that adequately represents the actual situation. Second, upon completion of a satisfactory model, changes reflecting managerial and institutional developments are simulated to determine influences on the model solutions. The linear programming model is abstract, but is a useful tool to aid in managerial decisions.

This model assigns acres of land between dryland and irrigated production and into specific crops subject to physical, technical, economic, institutional, and water availability constraints. Since numerous interacting factors influence the actual level and direction of development, many of these factors must be represented in the model in order to properly influence the quantitative information provided by the analysis. At the same time, while it is necessary to include the more relevant and influential factors, the model must be kept simple enough to be manageable and useful.

The boundary of the Deltaic Sand Aquifer itself provides the discrete area of study. All irrigation is assumed to use the underground water supply and therefore all irrigation can be considered interdependent. The method of irrigation considered in this model is the centre pivot system since this type is most suited to the conditions in the Carberry area. Although the centre pivot is one of the most capital intensive systems available, it also has a minimal labour requirement. Corner attachments for the pivot system are not considered due to their high per acre investment cost.

4.1 MODEL SPECIFICATION

The linear programming model has the general form:

$$\text{MAXIMIZE: } PX \tag{4.1}$$

$$\text{SUBJECT TO: } CX < B,\ X > 0 \tag{4.2}$$

where P is a vector of prices; X is a vector of activity levels; C is a matrix of technical coefficients; and B is a vector of resource constraint levels.

The price vector P contains (c + i + d + w + r) variables including the market prices received for selling a unit of crop c produced in the aquifer area; the purchase prices for the package of variable resources required as inputs for an acre of irrigated crop i on a particular land class; the purchase prices for the package of variable resources required for an acre of crop d under dryland production on either stubble or fallow, and on a particular land class, plus the purchase prices for w water use activities and capital investment requirements, r.

The variables derived by the programming model are included in vector X and include (c + i + d + w + r) variables representing: output production levels of each crop; levels of irrigated production activity for each crop, in acres; dryland production activity for each crop, in acres; levels of water pumped and consumed, in acre-inches; and the total additional capital investment, in dollars.

The B vector is comprised of (f + g + c + t + j + k) variables, including f pre-determined levels of the maximum net irrigable lands and improved pasture; g levels of arable, fallow and summerfallow lands;

equality constraints on c crops produced; t rotational restrictions; equality constraints on j water availability levels; and k quantity restrictions on water use.

Matrix C is comprised of technical coefficients which define the relationships between crop production and the resource constraint levels.

The model can be expressed mathematically in the following form:

$$\text{MAXIMIZE:} \quad \sum_{c=1}^{9} P_c X_c - \sum_{i=1}^{74} P_i X_i - \sum_{d=1}^{34} P_d X_d - \sum_{w=1}^{5} P_w X_w - P_r X_r \qquad (4.3)$$

where: P_c = price per unit for selling crop c

X_c = level of crop c sold, in bushels, pounds, tons, or AUM

P_i = cost of resource requirements per acre of irrigated activity i

X_i = acres of irrigated activity i

P_d = cost of resource requirements per acre of dryland activity d

X_d = acres of dryland activity d

P_w = per unit cost of water use activity w

X_w = level, in acre-inches, of water use activity w

P_r = price per dollar of investment

X_r = additional investment, in dollars

4.2 OBJECTIVE FUNCTION

The levels of the activities in the objective function are determined by the model. The price coefficients of the objective function are, of course, pre-determined and include product output prices, variable costs of the irrigated and dryland activities and input costs of water and capital resource use.

4.2.1 Product Prices

Agricultural production, for the purposes of the model, consists of eight major crops grown in the area plus pasture. These crops are: wheat, barley, grain corn, rapeseed, sunflowers, potatoes, tame hay, and silage corn. The prices received for the crops are based upon average 1979 prices received in Manitoba (Appendix B Table 3). The value of the pasture land production is assumed to be equal to the cost for grazing charged by Crown Lands in 1979, which becomes the "price" received in the model for each AUM produced.[43] These base values are assumed to adequately reflect the price relationships between the various economic outputs and their required inputs. The demand functions for the crops are assumed to be perfectly elastic; therefore a specific crop price is unaffected by the level of production.

---

[43] AUM stands for "Animal Unit Month," the amount of forage required to supply the feed requirements of a 1,000 pound cow, with or without a calf, for a month.

4.2.2 Input Costs

The amount of water pumped and the additional capital investment requirement for irrigation and growing specialty crops (potatoes and corn) are treated as separate activities in the model. Pumping costs were determined to be $1.57 per acre inch of water pumped, the average variable costs of irrigating farmers surveyed in Manitoba in 1979.[44] An interest rate of 16 per cent is used in the model as the "price" of obtaining additional capital for investment purposes. This rate was considered to be reasonable to attract capital into the irrigation investment option in 1979.

4.2.3 Variable Costs

Variable cost estimates were obtained from the "Economic Analysis of Irrigation Investment" study.[45] These base costs are those experienced in 1979 to enable fair relationships with the 1979 base prices of outputs. (See: Appendix B Table 4.) Operating costs are considered basic to both dryland and irrigated cropping practises because costs of fuel, repairs, labour, and other inputs are essential for dryland as well as irrigated land.

A dryland and irrigated base variable cost was determined for each crop. Different variable costs between stubble and fallow cropping, and

---

[44] Twenty-one farmers were surveyed in the fall of 1979 for the study: D.F. Kraft and R.M. Josephson, et al, "Economic Analysis of Irrigation Investment in Manitoba," Department of Agricultural Economics and Farm Management, University of Manitoba, Winnipeg, March, 1981.

[45] Ibid.

[46] The land in the aquifer area is divided into three classes for purposes of the model. For further explanation, see Section 4.3.1.

between land classes, are only attributed to differences in yield.[46] Higher yields result in higher harvesting and handling costs, which are added on to the base variable cost. The same unit cost of handling and harvesting the additional yield not represented by the base cost is used for both irrigated and dryland crops. Since variable costs are only determined by yield and the type of cropping (irrigated or dryland), and since irrigated yields are the same for each land class, the variable cost for each irrigated crop is the same for each land class.

The variable costs for both native and improved pasture include annual cost of water and fencing. Improved pasture is also charged a cost for re-grassing. Land costs, including investment costs and taxes, are not included. For improved pasture it was assumed that 1.5 miles of fencing and .5 dugouts are required per quarter. Native pasture requires the same amount of fencing, but the dugout requirement is reduced to .3 per quarter. Costs were obtained from the Saskatchewan Department of Agriculture.[47]

Summerfallow costs were obtained from the surveyed sample of farmers included in the "Economic Analysis of Irrigation Investment." Summerfallow acreage is assumed to be constant and therefore is not determined through economic considerations. Hence, the cost of summerfallow is not allocated or attributed to any specific crop grown on fallow. In effect, the cost of summerfallow is treated as a fixed cost to dryland farming. No irrigated crops are assumed to be grown on fallow land.

---

[47] Saskatchewan Department of Agriculture, "Pasture Costs," Farm Business Management Section Publication, Saskatchewan Department of Agriculture, July, 1979.

4.3 CONSTRAINTS

The maximization of the objective function is subject to a number of limitations. The land resource itself is limited and the number of acres in a specific crop are limited due to cropping restrictions. Water available for irrigation is a constraining value which is varied externally from the model to simulate different levels of water availability.

4.3.1 Land Inventory

The extent of the model is the area within the boundaries of the Deltaic Sand Aquifer, estimated for this study to be 739,374 acres.[48] The total land resource is fixed at pre-determined levels and does not change, but the use of land does vary between cropping activities.

This total area is divided into three different land classes based primarily on the characteristics of the different soil associates.[49] Land classified as A land is the most productive, B classified land is moderately productive and class C land includes all associates which have major limitations to arable agriculture.

---

[48] Acreage figures are compiled from information obtained from the following report: W.A. Ehrlich, et al., "Report of Soil Reconnaissance Soil Survey," Manitoba Soil Survey Report, No. 7, 1957.

[49] The soil associate is the basic unit of soil classification systems. "A soil associate consists of soils that are similar in physical features and chemical composition as revealed by profile characteristics." Associated soils from similar parent material form an association. W.A. Ehrlich, et al., "Report of Soil Reconnaissance Soil Survey," p. 32.

Class A land includes the Wellwood, Glenboro and Carroll Associations which have soil textures that vary from very fine sandy loam to clay loam, with the dominant texture being loam. The topography is level and drainage is generally good, as is crop productivity potential. Small areas of marsh (128 acres) and low productivity solenetizic soils are deducted from the total area to obtain the "gross arable acres" of the soil class. These 99,550 acres are reduced further by seven percent to allow for area taken up by farm yards, roads, towns, and drainage ditches. After this adjustment, the net area of A class land suitable for agricultural production is 92,581 acres.

Since the only method of irrigation in this model is the centre pivot system, the amount of land available for irrigation is determined to be 85 percent of the total gross arable acres of A class land. This percentage is based on a pivot capable of irrigating 136 acres out of 160. Hence, there are a maximum of 78,694 acres of A land available for irrigation (Appendix B Table 1).

Included in class B land are the Stockton fine sandy loam, the Firdale clay loam and Firdale loam associates, and the Assiniboine Complex. The Stockton fine sandy loam soil texture varies from loamy sand to very fine sandy loam and the Firdale soils vary from loamy fine sand to very fine sandy clay loam. The Assiniboine Complex consists of variable textured soils ranging from loamy fine sand to clay. All of these soils are moderately productive.

The topography of the Stockton associate is mainly level and drainage is good. However, natural fertility is low and water retention capacity is less than A land which results in their B classification. A forest reserve covers a large part of this associate and is excluded from the arable land total, as are 1,232 acres of marshland. A further 1,520 acres is reclassified as C land due to the presence of dunes and is consequently limited to pasture land.

The Firdale soil topography varies from level to hilly. The topography is level or gently sloping on some fields, but many areas have deep ravines and channels. Therefore, potential irrigation is limited, in the model, to 320 acres in the Firdale loam associate. These soils are well drained internally and surface runoff in many areas is rapid.

The Assiniboine Complex occurs along the Assiniboine River valley and consequently has very irregular topography, characterized by oxbows, terraces and old stream courses. In many areas the rough topography would not permit cultivation of large fields. Rough non-arable land can only be utilized as pasture. Because of these limitations, only 50 percent of this complex is included as B land and only 50 percent of this reduced amount is assumed to be suitable for irrigation. (The remaining 50 percent of the complex is included as C land, suitable for pasture.) A small amount of the Assiniboine Complex is forest reserve and is excluded from the gross acres available for agriculture. The rich, fertile alluvial soils along the valley are excellent for agriculture if adequate drainage is provided.

The total land in class B available for agricultural production is 78,998 acres after the seven percent adjustment for roads, farm yards and towns. Eighty-five percent of the gross irrigable land base provides a figure of 60,448 acres of land available for irrigation.

The Manitoba Soil Survey describes soils in class C land as being suitable for pasture, hay, forestry or grazing (Class V and VI land).[50] This land is not generally suited to arable culture. The largest associate in this group, the Stockton loamy sands, has a texture varying from sand to loamy fine sand and includes extensive areas of sharp faced sand dunes, making irrigation impossible. Drainage is good to excessive. Grain production should be excluded from these soils due to low fertility and high susceptibility to wind erosion. Therefore, these lands are most suitable for grazing. A large portion of this associate is excluded from any agricultural production because of the forest reserve.

The textures of the Miniota Sands vary from sand to loamy sand. The topography is generally level to slightly undulating, except in the duned areas. The sands are mainly suited for pasture because of their low natural fertility and low moisture holding capacity. However, the areas without dunes are assumed to be suitable for cropping if adequate moisture is supplied through irrigation, excluding the area in the forest reserve.

The Marringhurst soils have a predominately loamy coarse sand texture, but vary to sandy loam. The topography is level to gently undulating and drainage is good due to rapid percolation. These soils are low in natural fertility and have a very low moisture holding capacity. The Marringhurst soils, although best utilized for pasture, are also assumed to be capable of crop production given adequate moisture through irrigation.

---

[50] Ehrlich, p. 73.

The remaining 50 percent of the Assiniboine Complex not previously included in class B land is assumed to be suitable as pasture. As well, the areas of duned sand in the Stockton fine sandy loam associate are also included in C land as being suitable for pasture.

The net amount of C land available for dryland pasture, including all soil associates, is 270,972 acres. Of this total, 50,952 acres are available for irrigation.

The remaining land above the aquifer, for the purposes of this model, is excluded from agricultural production and therefore is not included in either of the above three classes. Eroded slopes, comprising 1,192 acres, are steep, rough, hilly and highly susceptible to erosion. Marsh land, totaling 35,217 acres, is most suited to wild life and recreation. Table 4.1 provides a summary of the model's land inventory for agriculture.

Table 4.1

Land Inventory Summary of Agricultural Land (acres)

	Net Arable	Net Irrigable
A Land	92581	78694
B Land	78998	60448
C Land	270972	50952
Total	442551	190094

4.3.2 Crop Rotations

Wheat, barley, hay, grain corn, and silage corn acreages are not restricted due to crop rotation constraints. It is assumed these crops can be produced continually.[51] However, sunflowers, rapeseed and potatoes are susceptible to common diseases and also experience similar weed control problems. Therefore, these three crops are considered as one-crop type with production being restricted to one out of every four years on each acre of land.

Summerfallow is set at 16 percent of the acreage in a dryland cropping program and therefore fallow cropping is 16 percent of the dryland crop as well. This percentage is based upon Crop Insurance Data for the years 1970-1979 inclusive, for the Carberry area.

4.3.3 Water Availability

The groundwater balance of an aquifer is characterized by the recharge rate and the discharge rate. Recharge to the Deltaic Sand Aquifer is derived entirely through precipitation.[52] Discharge is made up of evaporation and transpiration, surface water discharge, subsurface out-

---

[51] There may be some concern over the feasibility of growing corn in the Carberry area, and continuously without rotational restrictions. An indication of the suitability of an area for growing corn is the level of "heat units" available. Most recent hybrid grain corn requires 2,300 heat units, silage corn requires 2,100 heat units. The heat units available on average in the Carberry area are marginal for grain corn.

Growing corn continuously, as in areas of the corn belt in the United States, must be done only after consideration of a possible build-up of diseases, pests and weeds as a consequence of this practise.

[52] Manitoba Department of Mines, Resources and Environmental Management, "Ground Water Availability in the Carberry Area," <u>Groundwater Availability Studies Report No. 2</u>, November, 1970, p. 14.

flow, and groundwater use.

Since a soil moisture deficit exists in the area during the growing season, it is assumed that recharge only occurs from precipitation between October and April. This level averages 6.23 inches.[53] Readily available moisture in the soil is assumed to be depleted at the conclusion of the growing season. Thus readily available moisture must be replenished before any percolation into the aquifer. Considering the soil types in each land class, 4.4 inches of water is required for A land, 2.6 inches for B land and 1.8 inches for C land.[54] Subtracting these values from the 6.23 inches of average winter precipitation results in 1.83, 3.63 and 4.43 inches of water available for recharge for each acre of class A, B and C land, respectively. Land excluded from agricultural production is assumed to allow 4.43 inches of water per acre to infiltrate into the aquifer.

There is an observed water table rise in the aquifer of 1.2 inches for each inch of available water.[55] Weighting the values for water availability subject to the different amounts of land, and adjusting for the ratio of table rise per inch of available water, results in an average 4.80 inch rise in the water table throughout the aquifer. With a specific yield of 15 per cent,[56] the average rate of recharge for the aquifer is determined to be 532,350 acre inches per year, or .72 inches

---

[53] This value is based on precipitation data for 1942-1979 inclusive at two stations, Portage la Prairie and Brandon.

[54] From: Hal D. Werner, "Irrigation Scheduling," Minnesota Department of Agriculture Extension Bulletin.

[55] Manitoba Department of Mines, Resources and Environmental Management, "Groundwater Availability in the Carberry Area," p. 19.

[56] Ibid., p. 19.

of recharge per acre. This compares to .85 inches of recharge determined by the Water Resources Branch Study.[57]

Water available for development occurs from natural discharge. If half of the natural discharge can be retained, then the amount of available water for use is equal to 266,175 acre-inches. (Reducing natural discharge by 50 per cent is assumed to have no adverse effects.) This value is an average availability because average precipitation values are used in its calculation. That is, this is the amount of water that will be available for use 50 percent of the time. Over time, one-half of the years would see more water available, and the other half would see less water available.

Assuming a normal distribution for winter precipitation, and therefore annual recharge, enables estimates to be made of the varying levels of water availability due to fluctuating yearly precipitation. The amount of water available 20 out of 20 years was determined at a 95% probability level, and equal to 88,587 acre inches. Fifteen out of 20 year availability, a 75% level, was equal to 190,202 acre inches, or an additional 101,615[58] acre inches once 20 out of 20 year supply is utilized. Ten out of 20 year availability, or 50% probability, is equal to the average availability, determined previously to be 266,175 acre inches, or an additional 75,973[59] acre inches once the 20 out of 20 and the 15 out of 20 year supplies are utilized.

---

57 Ibid., p. 19.

58 Or, an average yearly availability of .75(101,615)=76211 acre inches.

59 Or, an average yearly availability of .50(75,973)=37987 acre inches.

4.4 TECHNICAL COEFFICIENTS

Technical coefficients specify the relationship between resource use and the activities of the objective function. They are equal to the number of units of each resource required to produce a unit of a particular activity.

4.4.1 Yields

The dryland yields used in this study for wheat, barley, rapeseed, sunflowers, and corn silage, and for each land class, are based upon the Manitoba Crop Insurance coverage yields for the corresponding soil zones in the risk area around Carberry (Appendix B Table 2).

The dryland yield for grain corn is based upon coverage for areas in the province where grain corn is insurable. Potato and hay dryland yields are estimates that correspond closely to the median dryland yields determined for the "Economic Analysis of Irrigation Investment."[60] In the model, these yields represent those obtainable under dryland conditions on stubble land. Dryland yields of crops grown on summerfallow are increased 10 percent, based upon approximate average yield increases from Manitoba Crop Insurance Data, 1970-1979 inclusive, for the Carberry area.

The irrigated crop yields are estimated to closely approximate median obtainable yields and correspond closely to the median yields determined for the Economic Analysis of Irrigation Investment. Moisture deficit for the purposes of this study is assumed to be the limiting factor affecting dryland yields between different land types. Therefore, irri-

---

[60] D.F. Kraft, R.M. Josephson, et al.

gated yields for types A, B and C land are the same.

If not irrigated, class C land is utilized as pasture. The productivity of this pasture is measured in AUM and is influenced by the productivity of the soil and the vegetative associations. For the purposes of the model, the various land types occurring in C land were divided into two categories; native pasture and improved pasture. Productivity of different land types are based on the Manitoba Soil Survey. The duned area of the Stockton associates and the Miniota sand associate has been considered as native "open bush" pasture with low productivity. The Assiniboine Complex is classed as follows: 50 percent native pasture and 50 percent improved pasture, with fair productivity. The rest of the Miniota sand associate and the Marringhurst associate are classified as improved pasture, but poor, and low in productivity.

Estimated AUM ratings for both types of pasture are determined by information provided by Crown Lands.[61] A value of .7 AUM is used in the model as the yield of one acre of native pasture. The yield of one acre of improved pasture is 1.6 AUM. This figure compares favourably with the estimated native pasture stocking rates provided by the Saskatchewan Department of Agriculture for black soil zones.[62]

---

[61] Information provided by Crown Lands, Winnipeg, Manitoba.

[62] Saskatchewan Department of Agriculture, "Pasture Costs," Farm Business Management Section Publication, Saskatchewan Department of Agriculture, July, 1979.

4.4.2 Water Use

A knowledge of climate is of particular importance when considering irrigation. Seasonal precipitation, temperature, wind conditions, and humidity all have an influence on the amount of additional water required for optimal crop growth. Climatic parameters, such as length of growing season and heat units, affect the types of crops that can be grown. Different crops have different moisture requirements.

Available precipitation data for the years 1942-79 inclusive was used to determine an average precipitation of 18.78 inches per year for the aquifer area. Of this total amount, 10.76 inches falls within the months of May, June, July, and August, which is assumed to include the growing season for wheat, barley, grain corn, rapeseed, and silage corn. When September's precipitation is included, an average of 12.55 inches of precipitation falls during the period considered the growing season for sunflowers, potatoes and hay.

Long-term precipitation averages can be misleading because any given location can have a drier or wetter month (or years) due to the randomness of scattered showers. However, because the analysis is concerned with a large area, it is assumed average precipitation is adequately estimated by the average of the levels recorded at Brandon and Portage la Prairie. The aquifer area actually lies between these stations but stations within the aquifer area itself fail to provide sufficient data.

The actual water requirements of a crop growing under optimal conditions is called potential evapotranspiration. Evapotraspiration (ET) includes water used up by the plant, water evaporated through the leaves and from the ground. The difference between potential evapotranspiration and growing season rainfall, less the available moisture in the soil at the beginning of the growing season, is the soil deficit. Optimal irrigation practises for obtaining maximum crop yield would keep this soil deficit value close to zero.

The growing season rainfall (GSR) is the amount of rainfall that falls during the time in which the crop is growing. When determining irrigation requirements, however, not all precipitation can be considered to remain in the soil. To convert average rainfall to "effective rainfall," a factor of .7 is used in this study to adjust for evaporation and run-off losses.[63]

The available moisture is the amount of water held in the soil between wilting point and field capacity. The wilting point occurs when no more moisture is available to the plant. Field capacity is the maximum amount of water held in the soil after excess water has been drained away. As the moisture level moves closer to the wilting point, it becomes more difficult for the plant to use this moisture. Readily available moisture (RAM) is usually considered to be 50 percent of the total available moisture and is the amount of water easily used by the plant. Available moisture, and consequently readily available water, is most dependent upon soil texture. The readily available water for A land (mainly loam) is determined to be 2.2 inches per foot; B land (loamy sand to sandy loam), 1.3 inches per foot and C land (coarse sand to

---

[63] See: F. Penkava, "Irrigation and Drainage," Principles and Practises of Commercial Farming, Fifth Edition, Winnipeg, Manitoba, 1977, p. 369. In reality the effective rainfall will vary considerably, depending on factors such as soil type, slope, stage of crop growth, and crop type.

[64] H. D. Werner, "Irrigation Scheduling."

sandy loam), .9 inches per foot.[64]

The rooting depth of plants determines how much water holding capacity the plant can make use of. Obviously, deeper rooting plants have access to greater amounts of stored moisture. Readily available water is calculated on the basis of a rooting depth of two feet for wheat, barley, rapeseed and potatoes; three feet for corn and sunflowers; and four feet for hay.

Finally, the efficiency of irrigation application has to be considered. The efficiency factor accounts for water losses occurring in the actual irrigation process. Efficiency decreases because of high winds and high temperature, soils which are heavy or extremely permeable, and where topography has steep slopes and is irregular. Irrigation water efficiency also varies between the different methods of application. Sprinkler application is usually 75 percent to 85 percent efficient. Therefore water must be pumped in excess of actual consumptive requirements. In this model, to acknowledge some efficiency distinction between class A, B and C land, efficiency coefficients of .85, .80 and .75, respectively, are used. Ten percent of the applied water is assumed to be lost due to evaporation. The remaining water is assumed to be return flow to the aquifer. Therefore, the light, coarse C land has a return flow rate of 15% of the amount pumped, B land has a 10% return flow rate, and heavier A land has return flow equal to 5% of the water applied. Thus, the equation for return flow is:

$$\mathrm{Irr} - \mathrm{CU} - .10(\mathrm{Irr}) = \mathrm{RF} \tag{4.4}$$

where: Irr = irrigation water requirements (amount pumped)

CU = consumptive use

.10(Irr)= 10% evaporation loss

RF = return flow

The total water used (the consumptive use plus the evaporation loss) is considered to be the important value when determining model solutions under quantity restrictions. Water availability limits are set equal to total water use limits. Likewise, taxation would be placed on units of total water used (versus units of water pumped).

The amount of irrigation water that must be applied to meet crop requirements, for each land class, is derived from equation (4.5).

$$Irr = \frac{ET - .7(GSR) - RAM}{E} \tag{4.5}$$

where:

Irr = irrigation water requirements (inches)

ET = evapotranspiration of the crop

GSR = growing season rainfall

RAM = readily available moisture

E = efficiency of irrigation

Table 6 (Appendix B) illustrates the coefficients used in deriving irrigation requirements for the various crops grown on the different land types.

4.4.3 Fixed Costs

The fixed cost, or investment requirement, for irrigation is based upon the findings of the "Economic Analysis of Irrigation Investment." The basic investment cost for irrigation is $523 per acre which is the

1979 replacement value for the various capital assets used by the 21 irrigators surveyed. All investment figures are in 1979 dollars. Included in this cost are: costs of well(s) and pipe, sprinkler system, pump and motor, land leveling, and drainage; consulting fees; and miscellaneous costs specified by the farmer.

Additional investment requirements for irrigating class A and B land are a consequence of obtaining higher yields under irrigation than under dryland production. Fixed storage costs per unit of yield increase are added onto the base cost, except in the case of hay. Additional storage costs were not included for irrigated hay because hay is assumed to be either stored on the field or delivered directly to the market.

Additional investment requirements are included when growing either corn or potatoes on A and B land. It is assumed that growing these specialized crops would require equipment not already on the farm. For corn, a planter and either a header or a harvestor would be required. This would mean an added investment cost for corn of $36 per acre. For potatoes the additional equipment cost would be considerable, $727 per acre, allowing for the additional requirements of row crop cultivators and sprayers, harvestors and trucks.

Further additional investment costs are not included on A and B land for two reasons: (1) Farmers irrigating other crops besides corn or potatoes were assumed to have the necessary machinery and equipment- a farmer would not have to purchase specialized equipment to plant and harvest these more common crops. (2) Farmers irrigating were assumed to have machinery with the capacity to handle increases in yield. The land base of these farmers would not change with the decision to irrigate.

Class C land investment requirements were treated differently. Because this land is not cropped under dryland conditions, the decision to irrigate would require new storage facilities with the capacity to hold the whole crop. As well, investment in a complete complement of farm equipment would be required because cropping the C land resource would be an addition to the land base already under crop in the area. It is assumed that existing equipment would be unable to handle this increased requirement. These investment requirements are based on information obtained from the "Economic Analysis of Irrigation Investment" and were determined to be \$108 per cultivated acre. The additional machinery investment costs for corn and potatoes of \$36 and \$727, respectively, are additional to this value (Appendix B Table 5).

4.5 INCORPORATING VARIABLE WATER SUPPLY INTO THE BASIC MODEL

In order to obtain maximum benefit from the aquifer, development should be allowed to take place such that the water available each year is utilized as much as possible. Because of the fluctuating nature of this supply, and in order to enable maximum usage, yearly water use must vary. Incorporated into the model are considerations for the event that some irrigators will receive a lower priority right, one which will not guarantee the holder the right to use water every year, but only when supply is adequate. If returns to irrigation are significant enough, some irrigation development will take place under the understanding that water will not be available every year. To simulate this situation, the irrigation activities in the objective function of the basic model are expanded into three sets. The first set is representative of the condition where water use is assured 20 out of 20 years; the second set, 15 out of 20 years; and the third, 10 out of 20 years.

Under the various levels of priority (the 20 out of 20 year permit holder having the highest priority) the investment costs for a specific crop are the same because farm equipment, storage facilities, pivot, well, and pump have to be available, irregardless of the priority of a particular right.

Crops grown on A or B class land can be grown under irrigated or dryland conditions. Therefore, if water is only available either 15 out of 20 years or ten out of 20 years, the same crop can still be grown in the years without irrigation. For example, if a farmer intends to irrigate a crop of potatoes in accordance with cropping rotation this coming season, and is then informed no water is available, potatoes can still be grown. On class C land only hay can be grown without irrigation. It is assumed that if no water is available then the land is summerfallowed in the "dry" years. However, hay can be grown in these years, being previously established during an irrigation period. The yield, of course, is less.

Variable costs for each crop for A and B land, and for hay on C land, change in the model based upon the following formulas:

$$20/20VC_i = 1.0(VCI_i) \tag{4.6}$$

$$15/20VC_i = .75(VCI_i) + .25(VCD_i) \tag{4.7}$$

$$10/20VC_i = .50(VCI_i) + .50(VCD_i) \tag{4.8}$$

where: $20/20VC_i$ = variable cost per acre of producing crop i; under conditions of 20/20 year supply

$_{15/20}VC_i$ = variable cost per acre for producing crop i; under conditions of 15/20 year supply

$_{10/20}VC_i$ = variable cost per acre for producing crop i; under conditions of 10/20 year supply

VCI_i = variable cost per acre of producing crop i; under irrigation

VCD_i = variable cost per acre of producing crop i; under dryland production

Variable costs for each crop on C land, except hay, are determined by substituting summerfallow costs into the formulas, replacing dryland costs.

These calculations result in a weighted variable cost representing the relative costs between crops, land types and level of water availability.

Water use values also change due to the "dry" years, based on a weighting procedure similar to the one used for variable cost, as do the yields of the various crops under these alternative production activities. Table 7 (Appendix B) summarizes the resulting weighted coefficients for the various production activities.

4.6 SUMMARY

The linear programming model in this study determines the optimal cropping alternatives for agricultural production in the Carberry area, recognizing the relationships between the costs and benefits of these alternatives, subject to the resource constraints imposed. The model analysis is confined to the area which is over-lying the Deltaic Sand Aquifer. Cropping alternatives are restricted to eight major crops grown in the area plus pasture.

Price and cost coefficients and investment requirements are largely obtained from the "Economic Analysis of Irrigation Investment" done at the University of Manitoba. Costs and prices are from 1979 and are expressed in 1979 dollars. Various reference sources enabled judgement to be made for the determination of technical coefficients, including crop yields and crop water requirements.

The study area is divided into three land types, based primarily on dryland productivity potential. After considerations for forest reserves, dunes and other restrictions to arable agriculture, 93,000 acres of A land, 79,000 acres of B land and 271,000 acres of C land are assumed suitable for field crop production. After accounting for irrigation restrictions, 79,000 acres of A land, 60,000 acres of B land and 51,000 acres of C land are regarded as irrigable.

Finally, since water availability varies from year to year, three separate sets of irrigation activities are incorporated into the model. Irrigation occurs using water which is available either 20/20 years, 15/20 yearss or 10/20 years. The amounts determined to be available for each set of activities are: 88,587 acre inches for 20/20 year water availability, 101,615 acre inches for 15/20 year water availability and 75,973 acre inches available 10/20 years.

Chapter V

RESULTS AND ANALYSIS

In this chapter, the results obtained from the linear programming model are presented. For this study, six different versions of the same basic model are used, two versions provide "benchmark" solutions and four "treatments" simulate alternative water allocation policies. Between each treatment, water resource limitations, water-use activities and water availability levels are changed. The resultant effects on net revenue, production levels, water use, value of water, and investment requirements are then evaluated and compared relative to each different type of policy.

5.1 MODEL "TREATMENT" DESCRIPTIONS

The benchmark solutions to the basic model establish the bounds between the extremes of allowing for no irrigation versus irrigation limited only by available land. The no-irrigation scenario allocates the resources, subject to land, agronomic and water constraints, into the activities contributing most to the objective function which maximizes net revenue for the area. Only dryland production is permissible under this arrangement because the model sets the water quantity available for irrigation equal to zero.

When water is not considered a constrained resource, resulting in the second benchmark solution, the model efficiently allocates all resources either between dryland or irrigated production, subject only to constraints regarding land and agronomic practises.

In Treatment 1, water availability is limited to 88,587 acre inches, the amount previously determined to be available virtually 20 out of 20 years. Water in excess of this amount, due to higher than average recharge from snowmelt, is regarded as unavailable for appropriation since its presence can not be guaranteed and no water right has precedence or priviledge over another. This treatment simulates an appropriative type system of quota allocation since the maximum amount of water available for appropriation is predetermined. Since the model allocates the water efficiently to the use which contributes the most to net revenue, it is simulating an event where the users of the resource have incentive to use each unit of water to the best advantage. A similar result could be arrived at by pricing water. This treatment is representative of regulation which charges on the basis of water consumed.

When reallocation of water from a low value use to a higher value use is prevented, or is somehow restricted, efficiency suffers. In Treatment 1, in an attempt to illustrate the effects of transfer restrictions, water use (quotas) is limited in a particular land class to a portion of total availability (eg. water initially allocated to A

---

[65] The percentages of recharge available for each land type were determined to be 23.47% for A, 39.73% for B, and 36.79% for C, based on the relative amounts of irrigable land for each area and the amount of recharge expected for each area due to annual precipitation. Therefore the water rights are apportioned out among the areas as follows:

A land	20791 acre inches
B land	35196 acre inches
C land	32591 acre inches

land can not be transferred to C land and visa versa).[65] These transferability constraints in the model serve to simulate, somewhat, a restriction in quota transferability.

However, the model is still uninhibited from transferring water (quotas) between farmers within a land class to achieve optimal allocation. The restriction of such allocation can not be incorporated into the model because of the assumption of equal efficiency for each cropping activity.[66] Therefore, the restriction between land classes is only an attempt to illustrate the inefficiency effects of non-transferable quotas. Transferability is restricted in another way. The right is simulated to be tied to a specific piece of land. An irrigator obtains the right to a quantity of water which must be used every year on the same field.

The transferability restrictions among land classes are removed to obtain Treatment 2, which still maintains the quantity restriction equal to the amount available 20 out of 20 years. Now rights may be transferred throughout the study area, between users within and between the different land classes. This treatment is representative of allowing for the sale of quotas between users for use on a specific piece of land. Quotas must be priced in order to provide the incentive for this transferability to occur. The linear programming model optimally allocates among users the available water resulting in a similar allocation as would be provided by pricing and transferability of quotas. Again, the

---

[66] A number of the model assumptions result in pre-determined efficiency levels for each individual cropping activity. This is because yields, costs of production and levels of individual crop water use are all pre-set in the model. Efficient use of available water depends solely on allocation among the different activities. This result is crucial to the understanding of the modelling of transferability, as explained in this section.

right is simulated to be tied to a specific piece of land (or pivot).

Treatment 3 allows additional water to be allocated on permits that do not guarantee water availability every year. Second and third level priority rights are simulated whereby water is made available 15 out of 20 years and ten out of 20 years. Transferability between users within and between land classes is allowed, the same as for Treatment 2. Again, quotas must be priced to provide incentive for such transferability and the right is specific to a particular piece of the right-holder's land.

Finally, Treatment 4 is similar to Treatment 3, allowing for transferability of rights within and between land classes, and in addition, transferability is allowed between an individual's fields. The right is not tied to a specific piece of land year-in, year-out, but can be transferred to another field (pivot) in subsequent years. Since this treatment represents the highest degree of transferability, it is most representative of a market. Quotas must still be priced to encourage rights to be transferred among users, as represented by the model's optimal allocation characteristic.

Table 5.1 illustrates the major features of the benchmark and treatment solutions.

Table 5.1

Comparison of Model Treatments

Treatment	Treatment Characteristics	annual water availability (acre inches)
Benchmark 1	Dryland production, no irrigation	0
Benchmark 2	Irrigated production, unlimited water	unlimited
Treatment 1	Quantity restriction, non-transferability, one priority rights, 20/20 year supply	88,587(20/20)
Treatment 2	Quantity restriction, restricted transferability, one priority rights, 20/20 year supply	88,587(20/20)
Treatment 3	Quantity restrictions, restricted transferability, variable priority rights, 20/20, 15/20, 10/20 year supply	88,587(20/20) 101,615(15/20) 75,973(10/20)
Treatment 4	Quantity restrictions, transferability, variable priority rights, 20/20, 15/20, 10/20 year supply	88,587(20/20) 101,615(15/20) 75,973(10/20)

5.2 NET REVENUE EFFECTS

5.2.1 Aggregate

With no irrigation in the area, gross receipts are determined to total \$39.4 million. This includes revenue from all crop and pasture production (see Table 5.2). Subtracting expenses, including variable costs and investment costs, results in net revenue of \$12.7 million. Under extensive irrigation, with no water restrictions, gross receipts total

$95.4 million, $56 million greater then when no water-use is allowed. Additional capital costs and production costs result in net revenue of $31 million, an increase of $18.4 million over the dryland benchmark. These two benchmark solutions are not representative solutions since some irrigation development has already occurred and water availability is indeed limited.

When water use is restricted to a level assumed to be available every year (Treatment 1) and the supply is distributed among the aquifer area, yet non-transferable between land classes, gross receipts increase to $43.2 million, $3.9 million over the dryland benchmark value. Net revenue is $13.9 million, an increase of $1.25 million over the dryland benchmark. By allowing the rights to be transferred between land classes, Treatment 2 indicates gross receipts are now $44.4 million, $5.1 million greater than the dryland benchmark. Net revenue is increased to $14.0 million, $1.35 million over the dryland benchmark.

In Treatment 3, the varying supply of water is utilized by distributing priority rights. Net revenue is increased by $2.0 million over the dryland benchmark, to $14.7 million, after expenses from a gross income of $48.6 million. Finally, if a "market" featuring readily transferable rights was set up for water (Treatment 4), gross revenue is $47.3 million. Net revenue is $15.1 million, an increase of $2.5 million for the area versus the dryland benchmark.

TABLE 5.2

Net Revenue Effects ($ million)

	Benchmark 1	Benchmark 2	Treatments 1	Treatments 2	Treatments 3	Treatments 4
Gross Revenue	39.4	95.4	43.2	44.4	48.6	47.3
% Change From Benchmark		142	10	13	23	20
Net Revenue	12.7	31.0	13.9	14.0	14.7	15.1
% Change From Benchmark	-	144	9	10	16	19

5.3 LAND USE EFFECTS

5.3.1 Levels of Irrigated and Dryland Acreage

If an unlimited supply of water was available, all irrigable land would be brought into irrigated production. Given the cost and revenue relationships specified in the model, all land, if irrigated, would contribute more to net revenue than dryland production.

The only limiting resource to irrigation development, if water is available, is the amount of land. With no water restriction, dryland crop is reduced from 147,913 acres to 21,975 acres. The difference, 125,938 acres of land, becomes irrigated (see Table 5.3).

When water use is restricted to 20/20 year supply and is apportioned to each land class, irrigated acreage drops to 12,434 and there are 140,710 acres of dryland. If water rights are not apportioned to land classes, but irrigation development is allowed to tend towards C land, total irrigated acreage falls to 11,091 acres because this land requires more water per acre. Because A and B land have no irrigation, dryland production increases to 147,913 acres.

With a system of variable priority rights, the number of acres developed for irrigation (but not necessarily irrigated each year) increases to 35,366; dryland acreage is 126,986. Irrigation development increases slightly with freer transferability of quotas; 36,273 acres. Dryland production falls to 117,823 acres because an extensive amount of irrigation is replacing B land production.

TABLE 5.3

Levels of Dryland and Irrigated Acreage

	Benchmark		Treatment			
	1	2	1	2	3	4
DRYLAND ACRES	147,913	21,975	140,710	147,913	126,986	117,823
IRRIGATED ACRES	0	190,095	12,434	11,091	35,366	36,273

5.3.2 Crop Types

Potatoes contribute the most to the objective of maximization of net revenue for the area under either irrigated or dryland production. If no irrigation is allowed in the area, the acreage of dryland potatoes is at a maximum on both A and B lands, limited only by rotational restrictions and the amount of arable land available. All land fallowed the previous year is cropped to potatoes because the marginal value product is the largest for potatoes. Since summerfallow on A and B land is restricted to 16 per cent of the land in dryland crop, the acres of potatoes grown on fallow equals 16 per cent of the land in dryland crop, for each solution. Grain corn provides the next largest contribution to the objective function on dryland, per unit of the restricting resource, and is the only other crop grown on dryland in any of the solutions. Grain corn, therefore, completes the four year dryland rotation, being grown three years, followed by potatoes in the fourth year.

If irrigation is allowed, irrigated potato acreage is limited only by the availability of water, irrigation land and crop rotational restrictions.[67] Irrigated grain corn completes the rotation on irrigated land. Land unsuitable to irrigation but arable, or irrigable land for which no water remains, is cropped to dryland potatoes and dryland corn, again subject to land and rotational constraints. All fallow land is in potatoes. In each land class, for either irrigated or dryland acres, there are three times as many acres in grain corn as there are acres in potatoes, reflecting the rotational relationship.

Hay and silage corn are the next most attractive crops to grow. That is, under irrigation, after potatoes and grain corn, hay and silage corn contribute the most to the objective function. Model results indicate the "reduced costs" of the activities which do not occur as part of the

---

[67] Crop production is not restricted due to demand constraints. Grain corn has tremendous advantages as a feed ingredient for livestock and poultry. Assuming that Canadian corn can maintain price competitiveness with American corn, the demand is such that potential production should find a market. Even with maximum development, the Carberry area is significantly small to be only a fraction of Manitoba's production.

As for potatoes, buyers have a high appreciation for Manitoba production, which have characteristics desirable to food processors. Currently the processing plant at Portage la Prairie has the capacity to double output and therefore double acreage under contract. The demand for Manitoba potatoes is firm. Potato production around Carberry, an area ideal for growing potatoes, is limited due to rotational constraints on cropland. If water restrictions are also taken into account, total possible production should be sold with no decrease in price.

solution. An activity's reduced cost is the amount by which the returns from that particular activity will have to increase before it will enter the solution set of activities (see Table 5.4). For example, irrigated hay has a reduced cost on A land of $4.73 per acre. If the return from growing an acre of irrigated hay on A land increases by this amount, then irrigated hay is as attractive to grow as one of the activities already appearing in the solution, in this case, growing irrigated grain corn. On a per ton basis, the price of hay has to increase by only $.95, based on a yield of 5 tons per acre. Therefore, irrigated hay and silage corn require price increases of only up to 3% and 6%, respectively, before being included in the model solution. (The actual increase is dependent on the land class.) Wheat and barley require price increases of up to 16% and 14%, respectively, to be as economically attractive as activities already in the solution. However, these crops would be replacing the land currently in grain corn and therefore are being compared relative to grain corn, not a high value crop like potatoes. These crops are not subject to rotational constraints. Yet rapeseed and sunflower production are subject to rotational restrictions and will tie up land that could be used for potatoes. Therefore, relative to potatoes, rapeseed and sunflowers provide a much lower contribution to net income under the prices in the model; price increases of 73% and 122% for rapeseed and sunflowers are required before they will enter the solution.

TABLE 5.4

Reduced Costs (dollars)

IRRIGATED CROP	A LAND per acre	A LAND per unit*	B LAND per acre	B LAND per unit	C LAND per acre	C LAND per unit
wheat	37.08	.74	36.07	.72	32.11	.64
barley	23.46	.31	22.62	.30	19.94	.27
rapeseed	187.93	4.18	177.85	3.95	129.51	2.88
sunflower	229.69	.11	220.73	.11	175.01	.09
hay	4.73	.95	5.58	1.12		
silage corn			2.88	.16	15.04	.84

* appropriately, either bushels, pounds or tons

5.3.3 Pricing of Land

If land is the limiting factor to irrigation development, assuming water is unlimited, or there are restricted rights that limit irrigation to a specific total area, a farmer would be willing to pay on an annual basis, for the opportunity to irrigate an additional acre, up to the marginal net revenue of that acre.

Given the assumptions and coefficients of the model, an additional acre of A land available for irrigation would result in an increase to the objective function of \$80.03. If this marginal net revenue could be expected every year, and a real discount rate of five per cent is assumed, then the capitalized value of A land is equal to \$1600, the amount a farmer would be able to pay "extra" for an acre of A land if the water rights were attached to the ownership of the land. The marginal value of an acre of B land available for irrigation is \$98.09; for

C land, \$121.29. Capitalized, water rights attached to the land would mean an increase in the amount the farmer would be willing to pay for B land of \$1962, and for C land , \$2426. When land is the limiting factor of production, or the water right is specific to the land and is transferable with the land, the economic rent falls on the price of land.

5.4 CAPITAL EFFECTS

5.4.1 Operating Capital

In the benchmark solution with no irrigation and complete dryland production, there is a total operating expenditure of \$21.8 million, which represents all variable production costs (see Table 5.5). These expenditures are high relative to existing farm costs because the most profitable crops determined by the solution are potatoes and corn, which have higher input costs. These figures are used for benchmark purposes to determine the additional operating capital requirements of irrigation development that occur as the result of the different treatment assumptions.

Additional variable production costs are not large if the main thrust of irrigation development occurs on land previously in the same dryland crop. This land would receive fertilizer, cultivations and other operations if left in dryland production. The irrigated land is replacing a similar dryland rotation, save the irrigated land which is not required to be in summerfallow.

Treatment 1 forces development throughout the area on all land types. Most of the farms are irrigating land previously in dryland crop and therefore variable cost increases by only \$1.1 million over the dryland benchmark, to \$22.9 million. Therefore operating capital increases by five per cent over the dryland benchmark value.

Treatment 2 allows for all development to occur on C land which previously was not in dryland crop. For the same water utilization as Treatment 1, variable costs now increase by \$1.8 million to \$23.6 million (8%).[68]

Variable costs for Treatment 3 increase by \$7.2 million (12%) over the dryland benchmark because the same level of irrigated corn and potatoes occurs on C land as in Treatment 2, plus there are additional input costs from irrigating additional acres on B land.

Variable costs decrease from Treatment 3 to Treatment 4, to \$23.4 million (7%), because fewer acres of C land are irrigated. In fact, this treatment has the lowest utilization of C land.

TABLE 5.5

Operating Capital (\$ million)

	Benchmark		Treatment			
	1	2	1	2	3	4
Variable Cost	21.8	61.5	22.9	23.6	24.5	23.4
% Change From Benchmark			5	8	12	7

---

68 Throughout the discussion, percentage increases over the dryland benchmark solution are shown in brackets.

5.4.2 Fixed Capital

Capital investment equals $30.9 million if no irrigation takes place, representing the additional investment requirement for following a potato and corn rotation (Table 5.6). This value increases to $40.6 million if water rights are allocated under one priority, among the different land classes (Treatment 1). This is an additional $9.7 million directly attributed to irrigation development. If development is allowed to tend to C land, additional investment requirement is greater due to the addition to land under crop, requiring equipment not presently available (Treatment 2). This additional requirement for C land development is $2 million, resulting in $11.7 million of investment as a direct result of irrigation development, or a total investment requirement of $42.6 million.

When variable priority rights are considered, investment increases substantially due to the large increase in land set up for irrigation, to a total investment of $58.5 million. This is $28 million of investment directly attributed to irrigation development.

Investment requirements decrease from Treatment 3, if transferability of rights is allowed between fields as well, to $55.3 million. This is because less C land is irrigated and therefore less additional machinery investment is required.

TABLE 5.6

Investment Requirements ($ million)

	Benchmark 1	Benchmark 2	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Capital Investment	30.9	174.6	40.6	42.6	58.5	55.3
% Change From Benchmark		465	31	38	89	79

5.5 WATER USE EFFECTS

If water is unlimited, as in Benchmark 2, irrigation develops to the point where irrigable land becomes the limiting factor and 1,311,181 acre inches of water are used per year. This amount is almost fifteen times greater than that which has been estimated in the study to be available each year. In all the solutions, where water is restricted to an estimated availability, it becomes the limiting resource.

5.5.1 Water Pricing

The highest marginal net return to an acre inch of water available every year occurs on C land, $15.19 (Table 5.7). The marginal value of an acre inch on B land is $13.42. These varying marginal values indicate an additional increase to net revenue will be obtained if water rights are allowed to be transferable between all regions within the aquifer area. Then, all water would tend to be used on C land.

The highest marginal net return to an acre inch available 15/20 years, if it is not transferable between fields, is $9.04 on B land. If water is only available 10/20 years, an acre inch contributes $.31 to the objective function.

If a right is made more easily transferable, the marginal value of an acre inch of 15/20 year supply would increase to $10.91 on B land. The 10/20 year supply would have an marginal value per acre inch of $7.48.

TABLE 5.7

Water Prices ($ per acre inch)

	Treatment 1&2,3,4	3		4	
	.... water availability				
	20/20	15/20	10/20	15/20	10/20
A Land					
B Land	13.42	9.04	.31	10.91	7.48
C Land	15.19				

5.6 INSTITUTIONAL IMPLICATIONS OF THE FOUR TREATMENTS

The institutional requirements to actually implement regulation with the characteristics of the four treatments are fairly extensive, particularly because of the model's inherent characteristic of allocating resources to the most efficient activities. The "costs" of the different externally imposed constraints of each treatment are indicated by the difference in the treatment solutions. There is no inefficient allocation, save those costs caused by the constraints imposed in each treatment.

Treatment 1 is the most similar to the present institutional arrangement in Manitoba, although with some major differences. Allocation is based upon quantity restrictions (quotas). Although of varying priority, quotas in Manitoba are treated as if they are a single priority, and will be until water shortages or externality effects develop. Then, priority considerations are assumed to be enforceable.

However, for quota regulation in the province to be effective, there must be enforcement of the requirement to use only the amount allocated, and to be a licensed user in the first place. Such enforcement, possible under existing legislation, is the first step in improving groundwater control in the area. The aggregate quantity restriction in the treatment is intended mainly to minimize externality effects, effects which currently are not a major concern in Manitoba. Then, the monitoring of actual water use will provide information on how the aquifer is affected by the pumping.

Considerations of external effects, which are not represented in the model, will have to be handled by a board set up for the administration of the water rights and the adjudication of such concerns.

Precedence of purpose categories must still be maintained. Since Manitoba water right quotas are non-transferable, therefore unpriced, there is no considerations for ensuring water is allocated to the most beneficial use. However, Treatment 1 has considerations for allocation to the most beneficial use, a characteristic of the maximization nature of the linear programming model. To achieve similar allocation in the province, with non-transferable quotas, a per unit tax on water use could be charged. Although not the objective of the tax, it may be sufficient to cover or offset the cost of water administration in the area.

The tax need not limit development (which can be accomplished by the quotas), but should be sufficient to discourage the wasteful use of water. If water use is monitored to control water right priviledges, then this information can also be used for taxation purposes.

A further comment on the aspect of non-transferability is appropriate here. Since irrigation development requires a large fixed investment, any attempt by an irrigator to sell his irrigated land and equipment would have to include consideration for transfer of the water right to the subsequent owner. Otherwise, the seller will suffer a loss if he is only able to obtain salvage value for the equipment, and if the well becomes useless. Non-transferability hardly seems practical. Currently there is no concern, the new users typically apply for a right and begin pumping whether the application is approved or not. However, when rights are enforced, this aspect of the right will become a major concern.

A local administrative board is suggested to implement these extensive regulatory requirements in the Carberry area. Such extensive regulation will be necessary because of the indicated impending widespread development.

Treatment 2 requires the same need for monitoring and enforcement of the regulations. With transferability, a quota price determined by the buyer and seller, instead of a per unit or per quota tax, will provide the incentive to transfer. An authoritative board would be necessary to facilitate the "auctioning process" and for considerations of externality effects. Allocation could be subject to the requirement that water use be commenced within a time limit, say three years, or the right would be rescinded. Therefore the requirement for actual investment in irrigation would discourage speculators.

The simplest allocation may involve one priority rights, with no one right having privilege over another, yet this will limit the quantity of water allocated to a small portion of the average availability. As the aquifer is monitored in the developmental stages, the obtainment of adequate hydrological data will enable rights with varying priority to be distributed (Treatment 3). Distributing rights with varying priority of use should be considered as the value of water increases and therefore a demand is created for a right which does not guarantee water use every year. Hydrological information will have to be adequate enough to determine the amount of water available each spring. Lower priority right holders must be informed as to the amount of water they will be allowed to pump, before planting decisions are completed.

Treatment 4, no restriction on transferability, is similarly implemented. The water right must have the appropriate conditions of transferability as an element of its specification.

Chapter VI

SUMMARY AND CONCLUSIONS

This final chapter presents a summary and conclusions of the results of the study. Limitations of the study are also offered and areas for further research are suggested.

6.1 SUMMARY AND CONCLUSIONS OF THE RESULTS

6.1.1 Summary of the Study

Parameters determined for this study indicated that the groundwater resource in the Carberry area will become a limiting factor of production and regulation for the allocation of the groundwater will become necessary.

A major objective of the study was to consider the theoretical reasoning for the impending resource allocation problem and the alternative pragmatic solutions. Groundwater is a common property resource. The fact that users have no regard for the future value of the water results in inefficiency of use. As well, there is no incentive to consider external effects, a result of the open accessability of the resource. Both of these conditions lead to a level of use that is greater than is desirable from an economic efficiency standpoint.

Quotas serve to make the water excludable; water is then accessable to permit holders only. Unless the level is restricted to that which keeps externality effects close to zero, or at least minimal, then such effects will have to be taken into account by means other than through the market. As the value of the resource increases, non-transferable quotas fail to provide adequate consideration for efficiency aspects of water allocation.[69]

A price could be charged per unit of water used. This tax would encourage more efficient use of the water but would most likely have to be in conjunction with an upper limit quantity restriction. The determination of an exact tax with the intent of restricting quantity is difficult. The required tax would also fluctuate depending on price/cost relationships and other factors.

A combination of pricing, transferability and quotas could result in the most efficient form of water allocation, being close to a market situation. Consideration of third party effects can be accomplished through the level of quotas imposed as well as by a regulating board that works in conjunction with the quota allocations.

The study investigated four Treatments of water allocation incorporating these different arrangements. Taxation alone was not examined due to the suggested infeasibility of determining the appropriate level of tax.

Treatment 1 represented a system of quotas, with an attempt to simulate the situation where there is no transferability. There was consideration for economic efficiency, subject to the constraints, due to the optimizing nature of the linear program. Therefore, the treatment simulated a price, or tax, whereby the irrigator is encouraged to use the

---

[69] In this study's analysis, when water became a limiting resource, and transferability of use was restricted between land classes, net revenue was constrained by $100,000.

water prudently.

Treatment 2 allowed for greater transferability and simulated having a price on the quotas. This price provided the incentive to transfer a quota to a more efficient user.

Treatment 3 was similar to Treatment 2 but considered priority rights to enable utilization of water which can not be guaranteed every year. Due to the fluctuating nature of the supply, priority rights were necessary to enable greater utilization of the available varying supply. This treatment was representative of transferable quotas between users, subject to incentive provided through pricing.

Treatment 4 allowed for transferability between users and within an individual irrigation enterprise, from one field to another, which enabled a greater on-farm efficiency of use. The quota was most easily transferred under this scenario and therefore more closely approximated a market.

6.1.2 Conclusions of Results

As regulation became more rigorous, net income for the area increased. Between the simplist quota system and the more complex market-type system, net revenue due to irrigation increased by 100%, from $1.25 million to $2.5 million. Of this increase, $100,000 (8%) could be attributed to allowing for transferability between land classes, $650,000 (52%) to the establishment of priority rights, and $500,000 (40%) to allowing rights to be readily transferable, within and between different irrigated fields.

Small gains, therefore, would be achieved by limiting development to the area of the low dryland productivity around Shilo. The quotas would tend towards this area if transferability between users is allowed. Larger gains resulted from distributing rights with varying priority to enable greater utilization of available water. Also, if rights are tied to a specific piece of land, even if still transferable between users, net revenue is significantly constrained.

The model solutions indicated that all irrigable land provided a contribution to the objective function if water can be guaranteed each year. However, when lower priority rights are considered, their highest contribution occurs on the moderately productive land, the Stockton fine sandy loams and the Firdale associations. The required large investment for the low productivity Miniota sand area, and because of the limited dryland alternatives to irrigation, results in irrigation being unattractive if water availability each year is not given a high priority. However, greater gains are to be made by irrigating moderately productive land versus the highly productive Wellwood and Glenboro clay loams because the yield response to additional water is greater.

Therefore, if water rights are allowed to be transferred between areas, high priority rights will tend to the Shilo area of the aquifer in the Miniota sands. Lower priority rights will tend to the moderately productive land around Carberry and the central north eastern area of the aquifer.

Under the assumptions of the study, including 1979 cost/return relationships, the only crops included in the model solutions are potatoes and grain corn. However, the net returns of hay and silage corn were only slightly less than grain corn. Only minimal changes in their prices relative to grain corn could result in their inclusion in the solutions. If any market constraints, climatic limitations or any reluctance by farmers to grow corn were considered, hay and silage corn would replace a portion of the grain corn acreage. Any agronomic limitations to grow grain corn continuously, or even three years out of four, would also encourage other crops to occur in the rotation.

Wheat and barley required price increases of up to 16% and 14% to be as attractive as grain corn in the rotation. Therefore, these crops would be grown in place of grain corn, at least in one or two years of the rotation, when considerations other than economic are taken into account, or if these prices increase relative to grain corn.

Rapeseed and sunflowers were included with potatoes in the rotational constraint. Therefore, they will not be included in the solutions until they become more financially attractive than potatoes, and potatoes are very attractive under irrigation. It is interesting to note, as long as a high value crop such as potatoes is included in the rotation, the type of cereal or other crop in the rotation is not as important. It is a higher value crop, like potatoes, that makes irrigation development appear so financially attractive in this model, not the grain corn.

Capital investment requirements were greatly affected by the amount of low productivity Miniota sands brought under irrigated production. This was because of the assumed additional requirements for a complement of farm machinery and additional storage capacity for the entire crop. Investment also was greatly increased by allowing for priority rights, since this allows for a much larger level of development.

A simple evaluation of the efficiency of use of capital is the Capital Turnover Percentage; gross profit over total capital investment. All percentages, for each treatment, are quite high; 40%, 44%, 32% and 32%, respectively. These percentages are understandable since, under the system of priority rights, some pivots will be sitting idle at various times due to the varying availability of water. Although it may be argued that this simple evaluation provides little additional information, these percentages indicate the most efficient use of capital is when all development occurs in the Miniota sand area and water use is limited to the amount that is available every year. If this is the objective of the management, then development should be restricted to this area, and to this quantity of use.

6.2 LIMITATIONS OF THE STUDY

The limitations of this study are largely a consequence of weaknesses inherent in using linear programming to model a real world problem, or because of the simplifying assumptions intended on making the analysis more manageable.

While the linear programming model is useful for this analysis, a linear program allocates resources strictly on the basis of maximization (or minimization) of the objective function. By using this model, the researcher must assume that maximization of net income is the objective of all producers in the area. Actually, other factors influence a producer's allocation decisions, such as consideration of risk and uncertainty.

All of the decisions and allocations in the model are based upon 1979 cost and price relationships. This assumes these values adequately influence the levels of activities in the model solutions. Because of the static nature of this model, there is no consideration for changes in these relationships over time. For example, with regard to the prices of output, this program is very sensitive.

A number of assumptions with the purpose of simplifying the analysis do so at the expense of model authenticity. For instance, the model has pre-determined efficiency levels for all cropping in each land type and for each crop type, either dryland or irrigated. All crop yields are the same for each acre in a particular land type, as are the costs of production. Moisture is assumed to be the limiting factor to crop production, therefore irrigated yields are the same for all the land types.

As well, the model has no consideration for increased pumping costs as the amount of water pumped is increased. No consequences of externality effects can be assumed.

An irrigator's response to a reduction in water availability is very limited. In fact, water use can be reduced only by changing the cropping, irrigating a different land type or by reducing the acreage under irrigation. Therefore, you either irrigate the total requirement or you do not. A more realistic alternative response would be to reduce the amount applied in a particular crop. Considerations of the affect of such action on yield could be included in the model by incorporating a production function for crop response to water. Other simplifying assumptions also impinge upon the model's ability to give an accurate depiction of the actual problem. The study, therefore, is unable to provide adequate estimates of economic impacts of the various allocative policies under examination. However, the study is useful in providing indications and insight into how different policies will tend to influence the nature of development and the effects upon efficiency of water through more rigorous regulation.

6.3 SUGGESTIONS FOR FURTHER RESEARCH

The suggestions given here provide direction in achieving quantitative research results to this problem which more closely approximate the effects that would take place.

First, minimum and maximum limitations for the acreage of all crops should be included in the model. These should be representative of managerial restrictions and would acknowledge the fact that cropping patterns are not only comprised of crops that contribute the most to net income. These restrictions should reflect the rate of adoption of new technology.

Similarly, a farmer's risk adversion should be taken into account. Some judgement is required concerning a required investment return before development occurs.

Higher water procurement costs because of a lower water table, as a result of increased development, should also be included in a subsequent analysis. Such considerations would result in a possible evaluation of alternative policy implications on external effects.

Inclusion of production functions for crop response to water would enable consideration of applying lesser amounts of water to an acre of irrigated crop, as a realistic reaction to water quantity restrictions.

This may require initial research into the development of adequate production functions for the crops typically grown in the Carberry area and under similar conditions.

Finally, this study addresses only efficiency effects, without any regard for equity effects between the different resource users. Equity aspects must be considered by policy makers as the alternative policies will impinge more or less upon particular individuals or groups in society.

BIBLIOGRAPHY

Bator, F.M., "The Anatomy of Market Failure," Quarterly Journal of Economics, August, 1958.

Bator, F.M., "The Simple Analytics of Welfare Maximization," American Economic Review, March, 1957.

Baumol, William J., "On Taxation and the Control of Externalities," American Economic Review, Vol. 62: June, 1972.

Boadway, R.W., Public Sector Economics, Winthrop Publishers, Inc., Cambridge, 1979.

Bredehoeft, I.D. and R.A. Young, "The Temporal Allocation of Groundwater-A Simulation Approach," Water Resources Research, Vol.6, 1970.

Brewer, M.F., "The Economics of Water Transfer," Natural Resources Journal, January, 1965.

Burt, O.R., "Economic Control of Groundwater Reserves," Journal of Farm Economics, Vol. 38: December, 1956.

Burt, O.R., "Optimal Resource Use Over Time with an Application to Groundwater," Management Science, Vol.11: No.1, September, 1964.

Castle, Emery N., and Herbert H. Stoevener, "Water Resources Allocation, Extra-market Values, and Market Criteria: A Suggested Approach," Natural Resources Journal, Vol 10: July, 1970.

Coase, Ronald, "The Problem of Social Cost," Journal of Law and Economics, No. 3, October, 1960.

Craddock, W.J., "Linear Programming Models for Determining Irrigation Demand for Water," Canadian Journal of Agricultural Economics, Vol.19: No.3, November, 1971.

Dales, J.H., "Pollution, Property, and Prices," Natural Resources Journal, Vol.8: 1968.

Davis, J.R. and J.R. Hulett, "An Analysis of Market Failure," University of Florida Social Sciences, Monograph #61, University Presses of Florida, Gainsville, 1977.

Demsetz, Harold, "Toward a Theory of Property Rights," Vol. 57, American Economic Association Papers and Proceedings, 1967.

Dorfman, Robert, H. Jacoby and H. Thomas, Models for Managing Regional Water Quality, Harvard University Press, Cambridge, 1972.

FAO, FAO Commodity Projections 1985, Cereals: Supply, Demand and Trade Projections 1985, prepared by the Commodities and Trade Division, Economic and Social Policy Department, FAO, Rome.

Finn, G.J., "An Economic Feasibility Study of Irrigating From Groundwater in South-western Manitoba," unpublished M.Sc. thesis, Department of Agricultural Economics, University of Manitoba, 1971.

Geddes, S. and D.F. Kraft, "Water Rights in Manitoba," unpublished research paper, Department of Agricultural Economics, University of Manitoba, 1979.

Gordon, H. Scott, "The Economic Theory of a Common Property Resource: The Fishery," Journal of Political Economy," Vol. 62: April, 1954.

Guise, J.W.B., and J.C. Flinn, "The Allocation and Pricing of Water in a River Basin," American Journal of Agricultural Economics, Vol. 52: August, 1972.

Hartman, L.M. and D. Seastone, Water Transfers: Economic Efficiency and Alternative Institutions, John Hopkins Press, Baltimore, 1970.

Hassenmiller, K.W., "Planning for Irrigation Development in the State of Washington," unpublished Ph.D. thesis, Washington State University, 1972.

Kraft, Daryl F., "Economics of Agricultural Adjustments to Water Quality Standards in an Irrigated River Basin," unpublished Ph.D. thesis, Department of Agricultural Economics, Washington State University, 1975.

Kraft, D.F., R.M. Josephson, et al., "Economic Analysis of Irrigation Investment in Manitoba," Department of Agricultural Economics, University of Manitoba, 1981.

Krier, James E. and W. David Montgomery, "Resource Allocation, Information Cost and the Form of Government Intervention," Natural Resources Journal, Vol.13: January, 1973.

Maas, Arthur, et al, Design of Water Resource Systems, Harvard University Press, Cambridge, 1962.

Manitoba Department of Agriculture, Manitoba Agriculture Yearbook, 1979.

Manitoba Department of Agriculture, "Report of Reconnaissance Soil Survey of Carberry Map Sheet Area," Manitoba Soil Survey, Soil Report No. 7, 1957.

Manitoba Department of Mines, Resources and Environmental Management, Water Resources Branch, "Groundwater Availability in the Carberry Area," Ground-water Availability Studies Report No.2, November, 1970.

Mapp, Harry P. Jr. and Vernon R. Eidman, "A Bioeconomic Simulation Analysis of Regulating Groundwater Irrigation," American Journal of Agricultural Economics, Vol: 58, 1976.

Meade, J.E., "External Economies and Diseconomies in a Competitive Situation," Economic Journal, Vol.62: March, 1952.

Milliman, J.W., "Commonality, the Price System and the Use of Water Supplies," Southern Economic Journal, Vol.22: 1956.

Ministry of Agriculture and Forestry, Outline of the World Food Model and the Projections of Agricultural Products for 1980, 1985, Japan, August, 1974.

Mishan, E.J., "The Postwar Literature on Externalities: An Interpretive Essay," Journal of Economic Literature, Vol.9: March, 1971.

Montgomery, "Markets in Licenses and Efficient Pollution Control Programs," Journal of Economic Theory, 1972.

Province of Manitoba, "An Act Respecting Water Rights," Queen's Printer, Winnipeg, 1970.

Randall, Allan, "Market Solutions to Externality Problems: Theory and Practise," American Journal of Agricultural Economics, Vol.54: May, 1972

Smith, S.C. and E.N. Castle, Economics and Public Policy in Water Resource Development, Iowa State University Press, Ames, 1966.

Timmons, J.F., "Theoretical Considerations of Water Allocation Among Competing Users," Journal of Farm Economics, Vol.38: December, 1956.

United States Department of Agriculture, Alternative Futures for World Food in 1985, Vol. 2, World GOL Model Supply-Distribution and Related Tables, Economics, Statistics, and Cooperative Service, Foreign Agricultural Economic Report No. 149, Washington, D.C., September 1978.

University of Manitoba, Principles and Practices of Commercial Farming in Manitoba, Fifth Edition, Winnipeg, Manitoba, 1977.

Appendix A

MODEL ACTIVITIES AND CONSTRAINTS

TABLE A.1

Description of Activities

Activity Number	Code Name	Description of Activity	Unit
Selling Activities:			
1	WS	wheat, produced and sold	bushels
2	BS	barley, produced and sold	bushels
3	GCS	grain corn, produced and sold	bushels
4	RS	rape, produced and sold	bushels
5	SS	sunflowers, produced and sold	pounds
6	PS	potatoes, produced and sold	cwt.
7	HS	hay, produced and sold	tons
8	SCS	silage corn, produced and sold	tons
9	PCC	pasture yield, produced and sold	A.U.M.
Producing Activities:			
10	IWA20	irrigated wheat, A land, 20/20 year supply	acre
11	IBA20	irrigated barley, A land, 20/20 year supply	acre
12	IGCA20	irrigated grain corn, A land, 20/20 year supply	acre
13	IRA20	irrigated rape, A land, 20/20 year supply	acre
14	ISA20	irrigated sunflowers, A land, 20/20 year supply	acre
15	IPA20	irrigated potatoes, A land, 20/20 year supply	acre
16	IHA20	irrigated hay, A land, 20/20 year supply	acre
17	ISCA20	irrigated silage corn, A land, 20/20 year supply	acre
18	IWA15	irrigated wheat, A land, 15/20 year supply	acre
19	IBA15	irrigated barley, A land, 15/20 year supply	acre
20	IGCA15	irrigated grain corn, a land, 15/20 year supply	acre
21	IRA15	irrigated rape, A land, 15/20 year supply	acre
22	ISA15	irrigated sunflowers, A land, 15/20 year supply	acre
23	IPA15	irrigated potatoes, A land, 15/20 year supply	acre
24	IHA15	irrigated hay, A land, 15/20 year supply	acre
25	ISCA15	irrigated silage corn, A land, 15/20 year supply	acre
26	IWA10	irrigated wheat, A land, 10/20 year supply	acre
27	IBA10	irrigated barley, A land, 10/20 year supply	acre
28	IGCA10	irrigated grain corn, A land, 10/20 year supply	acre
29	IRA10	irrigated rape, A land, 10/20 year supply	acre
30	ISA10	irrigated sunflowers, A land, 10/20 year supply	acre
31	IPA10	irrigated potatoes, A land, 10/20 year supply	acre
32	IHA10	irrigated hay, A land, 10/20 year supply	acre
33	ISCA10	irrigated silage corn, A land, 10/20 year supply	acre
34	IWB20	irrigated wheat, B land, 20/20 year supply	acre
35	IBB20	irrigated barley, B land, 20/20 year supply	acre
36	IGCB20	irrigated grain corn, B land, 20/20 year supply	acre
37	IRB20	irrigated rape, B land, 20/20 year supply	acre
38	ISB20	irrigated sunflowers, B land, 20/20 year supply	acre
39	IPB20	irrigated potatoes, B land, 20/20 year supply	acre
40	IHB20	irrigated hay, B land, 20/20 year supply	acre

TABLE A.1- continued

41	ISCB20	irrigated silage corn, B land, 20/20 year supply	acre
42	IWB15	irrigated wheat, B land, 15/20 year supply	acre
43	IBB15	irrigated barley, B land, 15/20 year supply	acre
44	IGCB15	irrigated grain corn, B land, 15/20 year supply	acre
45	IRB15	irrigated rape, B land, 15/20 year supply	acre
46	ISB15	irrigated sunflowers, B land, 15/20 year supply	acre
47	IPB15	irrigated potatoes, B land, 15/20 year supply	acre
48	IHB15	irrigated hay, B land, 15/20 year supply	acre
49	ISCB15	irrigated silage corn, B land, 15/20 year supply	acre
50	IWB10	irrigated wheat, B land, 10/20 year supply	acre
51	IBB10	irrigated barley, B land, 10/20 year supply	acre
52	IGCB10	irrigated grain corn, B land, 10/20 year supply	acre
53	IRB10	irrigated rape, B land, 10/20 year supply	acre
54	ISB10	irrigated sunflowers, B land, 10/20 year supply	acre
55	IPB10	irrigated potatoes, B land, 10/20 year supply	acre
56	IHB10	irrigated hay, B land, 10/20 year supply	acre
57	ISCB10	irrigated silage corn, B land, 10/20 year supply	acre
58	IWC20	irrigated wheat, C land, 20/20 year supply	acre
59	IBC20	irrigated barley, C land, 20/20 year supply	acre
60	IGCC20	irrigated grain corn, C land, 20/20 year supply	acre
61	IRC20	irrigated rape, C land, 20/20 year supply	acre
62	ISC20	irrigated sunflowers, C land, 20/20 year supply	acre
63	IPC20	irrigated potatoes, C land, 20/20 year supply	acre
64	IHC20	irrigated hay, C land, 20/20 year supply	acre
65	ISCC20	irrigated silage corn, C land, 20/20 year supply	acre
66	IWC15	irrigated wheat, C land, 15/20 year supply	acre
67	IBC15	irrigated barley, C land, 15/20 year supply	acre
68	IGCC15	irrigated grain corn, C land, 15/20 year supply	acre
69	IRC15	irrigated rape, C land, 15/20 year supply	acre
70	ISC15	irrigated sunflowers, C land, 15/20 year supply	acre
71	IPC15	irrigated potatoes, C land, 15/20 year supply	acre
72	IHC15	irrigated hay, C land, 15/20 year supply	acre
73	ISCC15	irrigated silage corn, C land, 15/20 year supply	acre
74	IWC10	irrigated wheat, C land, 10/20 year supply	acre
75	IBC10	irrigated barley, C land, 10/20 year supply	acre
76	IGCC10	irrigated grain corn, C land, 10/20 year supply	acre
77	IRC10	irrigated rape, C land, 10/20 year supply	acre
78	ICB10	irrigated sunflowers, C land, 10/20 year supply	acre
79	IPC10	irrigated potatoes, C land, 10/20 year supply	acre
80	IHC10	irrigated hay, C land, 10/20 year supply	acre
81	ISCC10	irrigated silage corn, C land, 10/20 year supply	acre
82	DWAF	dryland wheat, A land, fallow crop	acre
83	DWAS	dryland wheat, A land, stubble crop	acre
84	DBAF	dryland barley, A land, fallow crop	acre
85	DBAS	dryland barley, A land, stubble crop	acre
86	DGCAF	dryland grain corn, A land, fallow crop	acre
87	DGCAS	dryland grain corn, A land, stubble crop	acre
88	DRAF	dryland rape, A land, fallow crop	acre
89	DRAS	dryland rape, A land, stubble crop	acre
90	DSAF	dryland sunflowers, A land, fallow crop	acre
91	DSAS	dryland sunflowers, A land, stubble crop	acre

TABLE A.1- continued

92	DPAF	dryland potatoes, A land, fallow crop	acre
93	DPAS	dryland potatoes, A land, stubble crop	acre
94	DHA	dryland hay, A land	acre
95	DSCAF	dryland silage corn, A land, fallow crop	acre
96	DSCAS	dryland silage corn, A land, stubble crop	acre
97	DWBF	dryland wheat, B land, fallow crop	acre
98	DWBS	dryland wheat, B land, stubble crop	acre
99	DBBF	dryland barley, B land, fallow crop	acre
100	DBBS	dryland barley, B land, stubble crop	acre
101	DGCBF	dryland grain corn, B land, fallow crop	acre
102	DGCBS	dryland grain corn, B land, stubble crop	acre
103	DRBF	dryland rape, B land, fallow crop	acre
104	DRBS	dryland rape, B land, stubble crop	acre
105	DSBF	dryland sunflowers, B land, fallow crop	acre
106	DSBS	dryland sunflowers, B land, stubble crop	acre
107	DPBF	dryland potatoes, B land, fallow crop	acre
108	DPBS	dryland potatoes, B land, stubble crop	acre
109	DHB	dryland hay, B land	acre
110	DSCBF	dryland silage corn, B land, fallow crop	acre
111	DSCBS	dryland silage corn, B land, stubble crop	acre
112	PASTC	dryland native pasture, C land	acre
113	PASTCIMP	dryland improved pasture, C land	acre
114	SA	summerfallow, A land	acre
115	SB	summerfallow, B land	acre
Resource Purchasing Activities			
116	CAP	capital investment due to irrigation and special crops	dollars
117	AIP	amount of water pumped	acre-inch
118	AIC20	amount of water consumed- 20/20 year supply	acre-inch
119	AIC15	amount of water consumed- 15/20 year supply	acre-inch
120	AIC10	amount of water consumed- 10/20 year supply	acre-inch

TABLE A.2

Description of Constraints

Constraint Number	Description	Type of Constraint	Right-Hand Side	Unit
1	arable A cropland	E	92581	acre
2	arable B cropland	E	78998	acre
3	arable C cropland	E	270972	acre
4	maximum irrigated A land	L	78694	acre
5	maximum irrigated B land	L	60448	acre
6	maximum irrigated C land	L	50952	acre
7	fallow cropped A land	E	14813	acre
8	fallow cropped B land	E	12640	acre
9	summerfallowed A land	E	15197	acre
10	summerfallowed B land	E	23452	acre
11	wheat yield	E	0	bushel
12	barley yield	E	0	bushel
13	grain corn yield	E	0	bushel
14	rape yield	E	0	bushel
15	sunflower yield	E	0	pound
16	potato yield	E	0	bushel
17	hay yield	E	0	bushel
18	silage corn yield	E	0	ton
19	pasture yield	E	0	A.U.M.
20	rotational restriction, irr. A land	L	0	acre
21	rotational restriction, irr. B land	L	0	acre
22	rotational restriction, irr. C land	L	0	acre
23	rotational restriction, dry A land	L	0	acre
24	rotational restriction, dry B land	L	0	acre
25	irrigation water pumped	E	0	ac.-in
26	irrigation water use- 20/20 consump.	L	88587	ac.-in
27	irrigation water use- 15/20 consump.	L	76211	ac.-in
28	irrigation water use- 10/20 consump.	L	37987	ac.-in
29	additional investment due to irrigation and specialty crops	E	0	dollar
30	maximum improved pasture	L	0	acre
OBJFUNC	maximize net revenue	N		dollar

Appendix B

MODEL CO-EFFICIENTS

TABLE B.1

Model Land Inventory (acres)

Association or Associate	Total Acres	Deductions				Gross Arable	Net Arable	Gross Irrigable	Net Irrigable
		Forrest Reserve	Dunes	Marsh	Sole-netzic				
A LAND:									
Wellwood	96573	-	-	32	496	94046	89323	89323	75924
Glenboro	3368	-	-	96	-	3272	3043	3043	2586
Carroll	232	-	-	-	-	232	216	216	184
sub-total	100172					99550	92581	92582	78694
B LAND:									
Stockton Fine S.Loam	93488	21600	1520	1232	-	69136	64296	64296	54651
Firdale Clay Loam	376	-	-	-	-	376	350	350	298
Firdale Loam	2208	-	-	-	-	2208	2053	320	272
Assiniboine	13352	128	-	-	-	13224	12298	6149	5227
sub-total	109424					84944	78998	71115	60448
C LAND:									
Miniota S.	86784	19792	4968	-	-	62024	57682	57682	49030
Marring.	2432	-	-	-	-	2432	2262	2262	1922
Stockton L.Sand	390800	183568	207232	-	-	207232	192726	-	-
Miniota S.	4968	-	4936	-	-	4936	4590	-	-
Stockton Fine S.L.	1520	-	1520	-	-	1520	1414	-	-
Assiniboine	13352	128	-	-	-	13224	12298	-	-
sub-total	499856					291368	270972	59944	50952
NON-AGRICULTURAL:									
Eroded slopes	1192	42							
Marsh	35217	24240							
sub-total	36409	24282							
TOTAL AREA	739374	249530				475862	442551	223640	190094

TABLE B.2

Crop Yields (per acre)

	DRYLAND YIELDS						IRRIGATED YIELDS		
	Stubble			Fallow					
	Land Class								
CROP	A	B	C	A	B	C	A	B	C
wheat (bus.)	27.45	25.32	-	30.20	27.85	-	50	50	50
barley (bus.)	39.20	34.98	-	43.12	38.48	-	75	75	75
grain corn (bus.)	55.41	53.29	-	60.95	58.62	-	100	100	100
rape (bus.)	18.31	16.49	-	20.19	18.14	-	45	45	45
sunflowers (lbs.)	881.84	784.84	-	970.02	863.32	-	2000	2000	2000
potato (cwt.)	150	125	-	165	137.5	-	250	250	250
hay (tons)	2.00	1.75	-	-	-	-	5	5	5
silage corn (tons)	8.00	6.40	-	8.80	7.05	-	18	18	18

improved pasture (AUM): 8.0
native pasture (AUM): 3.5

TABLE B.3

Price Coefficients of Output (dollars)

CROP	PRICE
wheat (bus.)	4.50
barley (bus.)	2.25
grain corn (bus.)	3.15
rape (bus.)	5.75
sunflowers (lb.)	.09
potatoes (cwt.)	3.60
hay (ton)	37.50
silage corn (ton)	15.00
AUM	3.13

TABLE B.4

Variable Cost per Acre (dollars)

	DRYLAND						IRRIGATED		
	Stubble			Fallow					
	......................Land Class......................								
CROP	A	B	C	A	B	C	A	B	C
wheat	61.38	61.10	-	61.74	61.43	-	84.15	84.15	84.15
barley	64.75	64.20	-	65.26	64.65	-	87.40	87.40	87.40
grain corn	99.26	98.99	-	99.98	99.68	-	113.51	113.51	113.51
rape	62.86	62.60	-	63.12	62.83	-	94.21	94.21	94.21
sunflower	66.17	65.87	-	66.44	66.11	-	116.31	116.31	116.31
potatoes	266.97	262.97	-	269.37	264.97	-	284.30	284.30	284.30
hay	43.73	41.48	-	-	-	-	75.57	75.57	75.57
silage corn	125.20	116.40	-	129.60	119.92	-	172.10	172.10	172.10
summerfallow	12.25	12.25							

improved pasture: 24.73
native pasture: 10.02

TABLE B.5

Additional Investment per Acre for Irrigation (dollars)

CROP	....Land Class...... A	B	C	Based on storage investment costs of:
wheat	540	542	669	.76/bus.
barley	550	553	688	.76/bus.
grain corn	593	595	743	.76/bus.
rape	543	545	665	.76/bus.
sunflowers	560	563	696	.76/bus.
potatoes	1500	1563	1983	2.50/cwt.
hay	523	523	631	no storage cost
silage corn	684	704	928	12.50/ton

TABLE B.6

Crop Water Use (inches)

CROP	Evapotrans- piration	G. Season Rainfall	Readily Available Moisture			Irrigation Requirement		
			Land Class					
			A	B	C	A	B	C
wheat	13.5	10.76	2.2	1.3	.9	4.44	5.84	6.76
barley	13.5	10.76	2.2	1.3	.9	4.44	5.84	6.76
grain corn	15.5	10.76	3.3	1.95	1.35	5.49	7.53	8.83
rape	14.0	10.76	2.2	1.3	.9	5.02	6.46	7.43
sunflowers	17.0	12.55	3.3	1.95	1.35	5.78	7.83	9.15
potatoes	18.0	12.55	2.2	1.3	.9	8.25	9.89	11.08
hay	20.5	12.55	4.4	2.6	1.8	8.60	11.39	13.21
silage corn	15.5	10.76	3.3	1.95	1.35	5.49	7.53	8.83

CROP	Water Pumped			Water Consumption			Water Evaporation			Return Flow		
	Land Class											
	A	B	C	A	B	C	A	B	C	A	B	C
wheat	4.44	5.84	6.76	3.77	4.67	5.07	.44	.58	.68	.22	.58	1.01
barley	4.44	5.84	6.76	3.77	4.67	5.07	.44	.58	.68	.22	.58	1.01
grain c.	5.49	7.53	8.83	4.67	6.02	6.62	.55	.75	.88	.27	.75	1.32
rape	5.02	6.46	7.43	4.27	5.17	5.57	.50	.65	.74	.25	.65	1.11
sunflower	5.78	7.83	9.15	4.91	6.26	6.86	.58	.78	.92	.29	.78	1.37
potatoes	8.25	9.89	11.08	7.01	7.91	8.31	.83	.99	1.11	.41	.99	1.66
hay	8.60	11.39	13.21	7.31	9.11	9.91	.86	1.14	1.32	.43	1.14	1.97
silage c.	5.49	7.53	8.83	4.67	6.02	6.62	.55	.75	.88	.27	.75	1.32

TABLE B.7

Incorporating Varying Water Availability

A) YIELDS PER ACRE

CROP	A LAND 20/20*	A LAND 15/20	A LAND 10/20	B LAND 20/20	B LAND 15/20	B LAND 10/20	C LAND 20/20	C LAND 15/20	C LAND 10/20
	......	......	......Water	Availability	......	......	......	......	......
wheat (bu)	50	44.36	38.73	50	43.83	37.66	50	37.50	25.00
barley (bu)	75	66.05	57.10	75	65.00	54.99	75	56.25	37.50
grain c.	100	88.85	77.71	100	88.32	76.65	100	75.00	50.00
rape (bu)	45	38.33	31.66	45	37.87	30.75	45	33.75	22.50
sunflower	2000	1720.46	1440.92	2000	1696.21	1392.42	2000	1500.00	1000.00
potatoes	250	225	200	250	218.75	187.50	250	187.50	125
silage c.	18	15.50	13.00	18	15.10	12.20	18	13.50	9.00

* Weighted dryland and irrigated cropping mix, i.e., 15/20 - crop is irrigated 15 out of 20 years; the remaining 5 years is dryland production. Therefore, the values in this table on weighted averages for 20 years.

B) VARIABLE COSTS PER ACRE (dollars)

CROP	A LAND 20/20	A LAND 15/20	A LAND 10/20	B LAND 20/20	B LAND 15/20	B LAND 10/20	C LAND 20/20	C LAND 15/20	C LAND 10/20
	......	......	......Water	Availability	......	......	......	......	......
wheat	84.15	78.46	72.77	84.15	78.39	72.63	84.15	69.24	48.20
barley	87.40	81.74	76.08	87.40	81.60	75.80	87.40	71.68	49.83
grain c.	113.51	109.94	106.39	113.51	109.88	106.25	113.51	91.26	62.88
rape	94.21	86.37	78.54	94.21	86.31	78.41	94.21	76.78	53.23
sunflowers	116.31	109.95	106.39	113.51	109.88	106.25	113.51	91.26	62.88
potatoes	284.30	279.99	275.64	284.30	278.97	273.64	284.30	219.35	148.28
hay	75.57	67.61	59.65	75.57	67.05	58.53	75.57	65.36	56.65
silage c.	172.10	160.38	148.65	172.10	158.18	144.25	172.10	135.20	92.18

TABLE B.7– continued

C) INVESTMENT PER ACRE (dollars)

CROP	A LAND	B LAND	C LAND
	....................Water Availability....................		
	20/20,15/20,10/20	20/20,15/20,10/20	20/20,15/20,10/20
wheat	540	542	669
barley	550	553	688
grain corn	593	595	743
rape	543	545	665
sunflower	560	563	696
potato	1500	1563	1983
hay	523	523	631
silage corn	684	704	928

D) AVERAGE WATER PUMPED PER ACRE PER YEAR (inches)

	A LAND			B LAND			C LAND		
	....................Water Availability....................								
CROP	20/20	15/20	10/20	20/20	15/20	10/20	20/20	15/20	10/20
wheat	4.44	3.33	2.22	5.84	4.38	2.92	6.76	5.07	3.38
barley	4.44	3.33	2.22	5.84	4.38	2.92	6.76	5.07	3.38
grain c.	5.49	4.12	2.75	7.53	5.65	3.77	8.83	6.62	4.42
rape	5.02	3.77	2.51	6.46	4.85	3.23	7.43	5.57	3.72
sunflower	5.78	4.34	2.89	7.83	5.87	3.92	9.15	6.86	4.58
potato	8.25	6.19	4.13	9.89	7.42	4.95	11.08	8.31	5.54
hay	8.60	6.45	4.30	11.39	8.54	5.70	13.21	9.91	6.61
silage c.	5.49	4.12	2.75	7.53	5.65	3.77	8.83	6.62	4.42

TABLE B.7- continued

E) AVERAGE WATER CONSUMPTION PER ACRE PER YEAR (inches)

	A LAND			B LAND			C LAND		
	....................Water Availability....................								
CROP	20/20	15/20	10/20	20/20	15/20	10/20	20/20	15/20	10/20
wheat	3.77	2.83	1.89	4.67	3.50	2.34	5.07	3.80	2.54
barley	3.77	2.83	1.89	4.67	3.50	2.34	5.07	3.80	2.54
grain c.	4.67	3.50	2.34	6.02	4.52	3.02	6.62	4.97	3.32
rape	4.27	3.20	2.13	5.17	3.88	2.58	5.57	4.18	2.79
sunflower	4.91	3.69	2.46	6.26	4.70	3.14	6.86	5.15	3.44
potato	7.01	5.26	3.57	7.91	5.94	3.96	8.31	6.23	4.16
hay	7.31	5.48	3.66	9.11	6.83	4.56	9.91	7.43	4.96
silage c.	4.67	3.50	2.34	6.02	4.52	3.02	6.62	4.97	3.32

F) AVERAGE WATER EVAPORATION PER ACRE PER YEAR (inches)

	A LAND			B LAND			C LAND		
	....................Water Availability....................								
CROP	20/20	15/20	10/20	20/20	15/20	10/20	20/20	15/20	10/20
wheat	.44	.33	.22	.58	.44	.29	.68	.51	.51
barley	.44	.33	.22	.58	.44	.29	.68	.51	.51
grain c.	.55	.41	.28	.75	.57	.38	.88	.66	.66
rape	.50	.38	.25	.65	.49	.32	.74	.56	.56
sunflower	.58	.43	.29	.78	.59	.39	.92	.69	.69
potato	.83	.62	.41	.99	.74	.50	1.11	.83	.83
hay	.86	.65	.43	1.14	.85	.57	1.32	.99	.99
silage c.	.55	.41	.28	.75	.57	.38	.88	.66	.66

TABLE B.7- continued

G) AVERAGE RETURN FLOW PER ACRE PER YEAR (inches)

	A LAND			B LAND			C LAND		
	....................Water Availability.....................								
CROP	20/20	15/20	10/20	20/20	15/20	10/20	20/20	15/20	10/20
wheat	.22	.17	.11	.58	.44	.29	1.01	.76	.51
barley	.22	.17	.11	.58	.44	.29	1.01	.76	.51
grain c.	.27	.21	.14	.75	.57	.38	1.32	.99	.66
rape	.25	.19	.13	.65	.49	.32	1.11	.84	.56
sunflower	.29	.22	.14	.78	.59	.39	1.37	1.03	.69
potato	.41	.31	.21	.99	.74	.50	1.66	1.25	.83
hay	.43	.32	.22	1.14	.85	.57	1.97	1.49	.99
silage c.	.27	.21	.14	.75	.57	.38	1.32	.99	.66

Appendix C

MODEL SOLUTIONS

Table C.1

Land Use Effects (acres)

			Benchmark 1	Benchmark 2	Treatment 1	Treatment 2	Treatment 3	Treatment 4
DRYLAND:								
A	land	potatoes(s)*	7183	1077	6908	7183	7183	7183
		potatoes(f)**	12770	1915	12282	12770	12770	12770
		grain corn(s)	59858	8979	57570	59858	59858	59858
		grain corn(f)	0	0	0	0	0	0
		summerfallow	12770	1915	12282	12770	12770	12770
B	land	potatoes(s)	6129	1439	5755	6129	4245	3421
		potatoes(f)	10897	2559	10232	10897	7548	6082
		grain corn(s)	51076	11993	47963	51076	35382	28509
		grain corn(f)	0	0	0	0	0	0
		summerfallow	10897	2559	10232	10897	7548	6082
	Total Dryland Crop		147913	21975	140710	147913	126986	117823
IRRIGATED LAND:								
A Land		potatoes(20/20)	-	19674	885	-	0	0
		potatoes(15/20)	-	-	-	-	0	0
		potatoes(10/20)	-	-	-	-	0	0
		corn(20/20)	-	59021	2654	-	0	0
		corn(15/20)	-	-	-	-	0	0
		corn(10/20)	-	-	-	-	0	0
B Land		potatoes(20/20)	-	15112	1204	-	0	8726
		potatoes(15/20)	-	-	-	-	3472	0
		potatoes(10/20)	-	-	-	-	2597	0
		corn(20/20)	-	45336	3611	-	0	0
		corn(15/20)	-	-	-	-	10416	14973
		corn(10/20)	-	-	-	-	7790	11206
C Land		potatoes(20/20)	-	12738	1020	2773	2773	342
		potatoes(15/20)	-	-	-	-	0	0
		potatoes(10/20)	-	-	-	-	0	0
		corn(20/20)	-	38214	3060	8318	8318	1026
		corn(15/20)	-	-	-	-	0	0
		corn(10/20)	-	-	-	-	0	0
	Total Irrigated Crop		0	190095	12434	11091	35366	36273

* s = stubble crop ** f = fallow crop

TABLE C.2

Receipts and Expenses (dollars)

	Benchmark		Treatment			
	1	2	1	2	3	4
RECEIPTS:						
grain corn	19021580	48490095	21037171	21641760	23785829	22427536
potatoes	19615838	46404889	21478420	22111246	24093270	24175292
pasture	735240	486452	715318	681088	681088	728564
Gross receipts	39372658	95381436	43230909	44434094	48560187	47331392
Change From Benchmark	-	56008778	3858251	5061436	9187529	7958734
EXPENSES:						
Variable prod. costs	21755535	59218430	22651641	23439635	24113854	22999096
Irr. water cost	0	2285501	155885	163545	362673	354801
Capital cost	4940282	27935045	6496150	6808843	9360711	8840107
Change From Benchmark	-	22994736	1555868	1868561	4420429	389982
Total Expenses	26695817	64297435	29303676	30412023	33837238	32194004
NET REVENUE:	12676841	31084001	13927233	14022071	14722949	15137388
Change From Benchmark	-	18407160	1250392	1345230	2046108	2460547

TABLE C.3

Resource Use

	Benchmark 1	Benchmark 2	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Water Use (acre inches):						
water use 20/20	0	1311181	88587	88587	88587	88587
15/20	0	-	-	-	76211	76211
10/20	0	-	-	-	37987	37987
water pumped	0	1455733	99290	104169	231002	225988
Capital Use (dollars):						
	30876760	174594036	40600937	42555271	58504444	55250668
Change From Benchmark	-	143717270	9724177	11678511	27627684	24373908