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Economic Value of Groundwater in the Assiniboine Delta Aquifer in Manitoba

S.N. Kulshreshtha

Social Science Series No. 29

Environmental Conservation Service
Ottawa, Ontario 1994

(Disponible en français sur demande)

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Economic Value of Groundwater in the Assiniboine Delta Aquifer in Manitoba

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Abstract

Knowledge of the relative value of a natural resource is useful in making allocative and other policy-related decisions. This study was undertaken to ascertain the economic value of groundwater in the Assiniboine delta aquifer of Manitoba. The aquifer is located in a predominantly agricultural region, as reflected in the fact that almost 69% of all withdrawal use if for agricultural purposes. The valuation procedure followed in the study was limited to the use-related value of water. The valuation procedure followed in the study was limited to the use-related value of water. This valuation was conducted using two different perspectives: economic efficiency and regional development. In the first approach, the value of water was equated to the lesser of the gains in economic benefits to the user and its opportunity cost. In the latter approach, the value of water was the contribution it makes to the economic activity in the region. The total economic worth of the aquifer water was estimated at between $85 million and $460 million using the economic efficiency perspective, and between $795 million and $4000 million using the regional development perspective. The upper level of the value reflects the increase in the economic activity directly related to the availability of the aquifer water. The study recommends the development of a management plan for the aquifer, along with streamlining of the activities that may become a threat to this natural resource in the future.

Résumé

Lorsque des décisions d'allocation et d'autres décisions politiques sont prises au sujet d'une ressource naturelle, il est utile de connaître la valeur relative de cette ressource. Cette étude a été entreprise afin de déterminer la valeur économique des eaux souterraines dans l'aquifère du delta de l'Assiniboine au Manitoba. Cet aquifère est situé dans une région à vocation principalement agricole, de sorte que près de 69% de tous les prélèvements d'eau sont à des fins agricoles. L'évaluation a porté uniquement sur la valeur de l'eau du point de vue de son utilisation et elle a été faite sous deux optiques différentes: l'efficacité économique et le développement régional. Dans l'évaluation sous l'optique de l'efficacité économique, la valeur de l'eau a été prises comme étant la valeur la plus faible entre les gains économique pour l'utilisateur et le coût d'opportunité. Dans l'évaluation sous l'optique du développement régional, la valeur de l'eau était sa contribution à l'activité économique dans la région. On a ainsi estimé que la valeur économique totale de l'eau de l'aquifère était entre 85 millions et 460 millions de dollars sous l'optique de l'efficacité économique et entre 795 millions et 4 000 millions de dollars sous l'optique du développement régional. Le chiffre le plus haut reflète l'augmentation de l'activité économique directement reliée à la disponibilité de l'eau de l'aquifère. L'élaboration d'un plan de gestion de l'aquifère est recommandée, ainsi que l'harmonisation des activités qui pourraient constituer une menace pour cette ressource naturelle.

Executive Summary

BACKGROUND

This study was undertaken with the primary objective of ascertaining the economic values associated with a groundwater aquifer used primarily for agricultural purposes. the Assiniboine delta aquifer of Manitoba, commonly known as the Carberry aquifer, was chosen as the study region. The Assiniboine delta aquifer is located east of the city of Brandon and west of the city of Winnipeg, in the southwest corner of the province. The town of Carberry is located almost in the centre of the aquifer region. The Assiniboine River crosses the aquifer region and draws some water from the aquifer in the process. The aquifer covers an area of 3 885 km^2. The annual recharge capacity of the aquifer is estimated at 60 378 dam^3 of water.

The Carberry aquifer region is a predominantly agricultural one. There are no large urban centres located within the region or dependent on the aquifer water. Most of the agricultural use of groundwater is for irrigation, with the irrigation of potatoes topping the list. Locally grown potatoes are processed into french fries and other potato products in Carberry. The aquifer region has an estimated population of 12 391 people, who are directly dependent on the aquifer water for their domestic needs.

WATER USE IN THE CARBERRY AQUIFER REGION

Only 16.7% of the annual recharge capacity of the aquifer is currently being used for productive purposes. During 1990, an estimated 10 064 dam^3 of water was used, 69% of which was for agricultural purposes. The industrial users accounted for another 11% of the total, and the remaining 20% was used for domestic purposes, including the needs of the Canadian Forces Base at Shilo.

In addition to the above direct withdrawal uses of the aquifer water, 41 185 dam^3 of water is annually discharged into the Assiniboine River. This makes the total groundwater withdrawal from the aquifer an estimated 51 249 dam^3, or 85% of the annual recharge capacity. The water discharged into the river, along with the natural flow of water in the river, passes through the Spruce Woods Provincial Park and is a major attraction for recreational purposes and tourism in the region.

VALUATION APPROACHES

The valuation of groundwater in this study was carried out from two different perspectives: (1) an economic efficiency perspective and (2) a regional equity or regional development perspective. In the first case, the value of water was equated to the lesser of the gains in economic benefits to the user and its economic opportunity cost. The latter concept was defined in terms of the cost of obtaining water from an alternative source to replace the groundwater from the Assiniboine delta aquifer. Lake Manitoba was selected as this alternative.

Initially, a total valuation framework for the groundwater was proposed. This framework, however, requires the estimation of three types of values: (1) the value of water currently in use within the aquifer region; (2) the value of aquifer water used outside the aquifer region; and (3) the estimation of nonuse-related values, such as the option, existence, and bequest values of water. Although such a framework is superior, the estimation of values in this study was limited to the use-related values for water used within the aquifer region, due to time and budget constraints.

VALUE OF WATER FROM THE ECONOMIC EFFICIENCY PERSPECTIVE

The total value of water withdrawn from the Assiniboine delta aquifer was estimated by disaggregating it by type of use. Two major types were identified first: direct use and indirect use. The major direct uses identified in the study included agricultural (subdivided into irrigation and stockwater), domestic, industrial and commercial, and that of the Canadian Forces Base. The only indirect use of water included in the study was that for recreation.

The irrigation water use was valued using a producer surplus approach. The value of water was equated to the additional returns to producers from irrigating a given crop, above that which could be obtained from its dryland production. This method yielded an average value of \$486 per dam^3.

The value of stockwater use was estimated using the opportunity cost principle. Given that the amount of water required is small, and currently available in the Assiniboine River, the cost of obtaining this water from the river was selected as an appropriate opportunity cost to replace this water. The resultant value of this water was \$622 per dam^3.

The value of water for domestic use was estimated separately for the town of Neepawa, rural farms, and nonfarms. The concept of consumer surplus was used as the measure of benefit. The value of this consumer surplus was constrained by the opportunity cost of water. The value of one dam^3 of water for the town of Neepawa was estimated at \$82, and that for farms and nonfarms at \$536 and \$159, respectively.

The value of water for industrial and commercial purposes was estimated using a methodology similar to that for domestic water use. For agricultural processing purposes, the value of water was estimated to be \$28 per dam^3. Other industrial uses and commercial uses of water had a valuation of \$652 and \$281 per dam^3, respectively.

The largest single nonagricultural user in the region was the Canadian Forces Base at Shilo. The value of water here was also based on the use of consumer surplus, constrained by the opportunity cost of water. This resulted in an estimate of \$652 per dam^3 of water used on the base.

The only indirect use of water, for recreation, was valued using secondary data and a contingency valuation method. This resulted in a total benefit of \$26 000 from the use of water.

Taking into account the quantities for various uses and the average value of water as estimated above, the total annual benefit from the Assiniboine delta aquifer for the year 1990 was estimated at \$4.7 million.

THE VALUE OF WATER FROM A REGIONAL DEVELOPMENT PERSPECTIVE

From a regional development perspective, the value of water was measured as the contribution a given use of water makes in generating the level of economic activity in the region or province. The most commonly used measure of such activity is gross domestic product at factor cost. Two activities that had legitimate regional development impacts were irrigation of potatoes and other crops, and agricultural processing. The value of water, using this perspective, for irrigating potatoes was estimated at \$2737 per dam^3 and that for other crops at \$547 per dam^3. The operations of a food-processing company generated a large amount of economic activity in the region. In fact it was the largest employer in the region. This is reflected in the value of water, which was estimated at \$33 956 per dam^3.

Assuming that the uses that did not have any regional development impacts would continue to provide the same level of benefits as estimated using the economic efficiency perspective, the annual total value of water withdrawn from the Assiniboine delta aquifer was estimated to be $43.6 million, some nine times that based on the economic efficiency perspective. The weighted average value of 1 dam^3 of water from the regional development perspective was $4 363, as against only $464 based on the economic efficiency perspective.

THE ECONOMIC WORTH OF THE ASSINIBOINE DELTA AQUIFER

Using a 5% discount rate and a 50-year aquifer lifetime, the total economic worth of the Assiniboine delta aquifer was estimated under two sets of assumptions: (1) that the level of economic activity in the region would remain at the 1990 level for the rest of the life of the aquifer and (2) that the water use in the region would be based on a doubled capacity of the food-processing company, and furthermore, that the potatoes processed would be grown under irrigation.

Under the first set of assumptions, the aquifer is worth $85 million from the economic efficiency perspective and $795 million from the regional development perspective. Under the second set, the projected level of economic activity, the total economic worth of the aquifer increases to $460 million and $4 billion, respectively, from the economic efficiency and the regional development perspectives.

THE IMPLICATIONS OF THE RESULTS

The results of this study have demonstrated that groundwater availability can be very significant regional resource for the Carberry region of Manitoba. Therefore, any changes in the quality of quantity of groundwater in the aquifer would have serious repercussions for the regional economy, whether one uses resource allocation as the major criterion or regional development as the major goal of public policy in the province.

Two major threats to the Assiniboine delta aquifer may be listed as overuse and point or nonpoint pollution. The first would lead to the depletion of the natural resource and thereby to a much shorter economic life, and could not be endorsed, on the basis of sustainable development. The second threat - point and nonpoint pollution of groundwater- would also result in the destruction of the economic benefits from the aquifer. Such pollution could be caused by agricultural practices, livestock activity, or uncontrolled disposal of sewage and other effluents in the region.

Given the value of the aquifer, this study recommends the development of an appropriate management plan for the aquifer, along with streamlining of economic activities in the region that could become a major threat to this natural resource, today or in the future. Provincial water resource managers should give this a fairly high priority.

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In addition, several individuals in the study region helped me obtain a local perspective on the aquifer and its significance. In particular, I thank Murray Frank, Manitoba Agriculture; David McKenzie, Carnation Foods Company, Carberry; and Garnet Shearer, Environment Officer, Canadian Forces Base Shilo - both for their exchange of ideas with me and their provision of valuable data and information.

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Views or opinions expressed in this report do not necessarily represent those of the Ecosystem Sciences and Evaluation Directorate, Environment Canada, or the Government of Canada.

S.N.K.

CHAPTER 1

Introduction

1.1 BACKGROUND TO THE STUDY

Groundwater is an important resource in regions where surface water resources are inadequate. It is essential for drinking, for farming, and for manufacturing. The survival of these regions may very well depend upon the availability of good quality water from underground sources. Western Canada, particularly the prairie region, due to an arid and semiarid climatic regime resulting in inadequate surface water flow, is dependent on groundwater supply. Much of this water is used for domestic and municipal purposes, making it the backbone of the region's existence. For example, in Manitoba, according to Hess (1986), some 266 000 people in rural areas and in small communities depend on groundwater for domestic purposes, and almost four fifths of the total agricultural water used is obtained from groundwater sources. In spite of the obvious importance of groundwater for certain regions of Canada, its significance for water management decisions has not been recognized by public policy-making bodies or by the public at large. According to Environment Canada (1990c), for the majority of Canadians, particularly those who are not dependent on it, groundwater is a hidden resource whose value is not well understood or appreciated. This research project was initiated to fill this void.

1.2 NEED FOR THE STUDY

The value of groundwater resources is critical for several reasons, of which the most important relate to planning, development, and management of such resources. One of the major environment and health issues of the 1990s relates to groundwater contamination. Contamination may occur from both point and nonpoint sources. The most common examples of point source pollution of groundwater are leaky tanks or pipelines, chemical spills in manufacturing plants, industrial wells, municipal waste sites, and livestock-raising activities in the groundwater recharge areas. Many nonpoint pollution sources can also be identified, including fertilizers and pesticides and contaminated snow or rainfall. According to Environment Canada (1990a), it would cost the Canadian economy $2.5 billion to clean up known contaminated sites. Groundwater contamination is a problem that occurs nationwide, although its impact on regional economies would be different. To estimate these impacts, one needs some knowledge of groundwater's value to society. Only when such a value has been established can one proceed to decide if such cleanup actions are desirable.

The development of groundwater as a resource is another area where knowledge of the value of groundwater is essential. To determine whether the development costs for this resource will be repaid through benefits to society, one should be able to determine its economic value. Although it is recognized that the economic value is only a subset of the total value of a resource, it nevertheless constitutes an important and significant component of the total, deserving further study. (This is further discussed in Chap. 4.)

The value of groundwater is also required for managing a region's water resources, both groundwater and surface water. In addition, there is a need for conjunctive management of both surface water and groundwater resources through the regulation of anthropogenic activities, land use, and point and nonpoint source pollution. The conjunctive management of the two water resource systems is based on some not so obvious, but important, interconnections. (1) Groundwater and surface water are interrelated in that today's contaminated groundwater may become tomorrow's contaminated surface water. This is because some of the surface water supply is dependent on groundwater recharge. (2) Some surface water bodies, such as wetlands, are also a source of groundwater recharge. Thus, any economic activity that affects one water supply would eventually lead to impacts on the other. The development of proper management policies would be facilitated through a knowledge of the value of water, as held by society at large.

The recently formulated groundwater strategy (see Environment Canada 1990b) recognizes some of these issues related to the groundwater resource in Canada. It suggests emphasizing the prevention of groundwater contamination and the recognition of the interconnectedness of the hydrologic cycle, and simultaneously encompassing both water quantity and water quality issues. Further acceptance of various measures under this strategy would be facilitated by providing decision makers with a set of values for the groundwater in Canada.

1.3 PROBLEMATIC SITUATION

During the fall of 1990, the Inland Waters Directorate of Environment Canada initiated a study of the value of groundwater in Canada. (A report on Phase One of this study is provided by Wayne B. Trusty and Associates 1991.) This study had several overall objectives, including the following:

1. to develop and refine a conceptual model for estimating groundwater value in various uses and in aggregate for a given site

2. to develop groundwater value estimation factors that can be broadly applied

3. to develop a preliminary estimate of value of groundwater in Canada using the estimation factors

4. to develop value-added factors that can be used to establish priorities and rank "orphan sites" for subsequent more detailed study

This study recommended that a series of pilot studies be carried out in different parts of Canada, perhaps reflecting the importance of groundwater for different situations.

One of the major uses of groundwater is irrigation. Many areas in western Canada, particularly in Manitoba, depend upon groundwater for drinking and other domestic purposes, as well as for irrigating crops, on account of the semiarid climatic conditions. One large body of groundwater in Manitoba is the Assiniboine delta aquifer, located in the southwestern part of the province. This aquifer was selected for valuation on account of its unique use—solely for agricultural and domestic purposes.

The major question to be considered in this study is an appropriate conceptual framework for valuing groundwater for irrigation and domestic purposes. Although the study by Wayne B. Trusty and Associates did recommend a conceptual methodology (reviewed in Chap. 5), empirical considerations may necessitate changes. Furthermore, the estimation factors for valuing the groundwater in a region may be region-specific and therefore deserve further scrutiny.

Valuation of a natural resource can vary depending upon the underlying philosophy. Two major lines of thought that are commonly used are the criteria of economic efficiency, which is a basis of resource allocation in economic problems, and of economic equity, which is sometimes presented in a regional development perspective. How different are the valuation magnitudes produced by the two criteria? These and other related questions need to be answered by a study of groundwater in the Assiniboine delta aquifer in Manitoba.

1.4 OBJECTIVES OF THE STUDY

This study was designed to estimate the economic value of groundwater obtained from the Assiniboine delta aquifer. This primary objective was accomplished by following the secondary objectives of the study:

1. to identify major users of groundwater in the Assiniboine delta aquifer region of Manitoba

2. to develop an empirical method of estimation for valuing groundwater in the aquifer for different uses using the two perspectives: economic efficiency and regional development

3. to estimate the economic worth of the aquifer using the methodology developed above

4. to draw implications for management of groundwater and to make recommendations for further research.

1.5 SCOPE OF THE STUDY

This is a case study of the Assiniboine delta aquifer of Manitoba. Since this aquifer is centred at Carberry, the terms Assiniboine delta aquifer and the Carberry aquifer region are used interchangeably. (The Carberry aquifer region is the physical boundary of the area served by the groundwater contained in the Assiniboine delta aquifer. Although theoretically a simple matter, empirically it poses some problems, as discussed in Chap. 2.) The results of the study are based on current uses, and the projections of uses in the future are based on current knowledge. Since the major focus of the study was on the development of the empirical method for estimating the value of groundwater, forecasting of economic and social activity was done using simple methods. There may exist other, and perhaps better, methods that present a more accurate picture of the future. Although an attempt has been made in this study to generalize on a set of economic factors, their application to other regions should be made with caution.

1.6 ORGANIZATION OF THE REPORT

The following report is divided into three parts. In Part One, the background and methodological details are presented. The description of the aquifer region and major uses of water in the region are presented. The conceptual model, including a review of previous studies, is discussed, followed by the proposed methodology for this study.

In Part Two, the results of estimation for the value of groundwater in various uses are presented. Two types of values are discussed here: annual values and economic worth (lifetime value) of the aquifer. As noted above, the latter set of values are based on the current knowledge of economic and social activity in the region. In this part, special consideration is given to assigning a value to groundwater in the Assiniboine delta aquifer. Two considerations of interest are the cost of water from alternative sources and the value of water from a regional development perspective. Part Three includes a summary of the study as well as areas for further research.

Part One

Background and Methodology

CHAPTER 2

The Carberry Aquifer Region

In this chapter, the study region, the Carberry aquifer region of Manitoba, is described. The description includes a geographical layout of the area, followed by its agricultural profile. Other economic activities in the region are also listed. The primary purpose of this chapter is to provide a background to, and an economic profile of, the region, in the hope that it will be helpful in the interpretation of the study results.

2.1 LOCATION OF THE ASSINIBOINE DELTA AQUIFER

The Assiniboine delta aquifer is located in the southwestern part of Manitoba. The aquifer, centred around the community of Carberry, is east of Brandon and west of Winnipeg (Fig. 1). The Assiniboine River passes through the region. The aquifer itself covers an area of 3 885 km^2 (1 500 sq. mi.). The aquifer is a result of the deposition of sediments by a very large glacial river in a depression in the preglacial shale escarpment that extends back to the present location of Brandon (Render 1987, p. 2). The aquifer thickness averages 18.29 m (60 ft.), varying from less than a metre at the extremities to over 30 m (100 ft.) in the central part of the reservoir. The groundwater level varies from the ground surface in areas adjacent to streams to over 21 m (70 ft.) below ground level under some of the large sand dunes and hills that are between deep erosion scars.

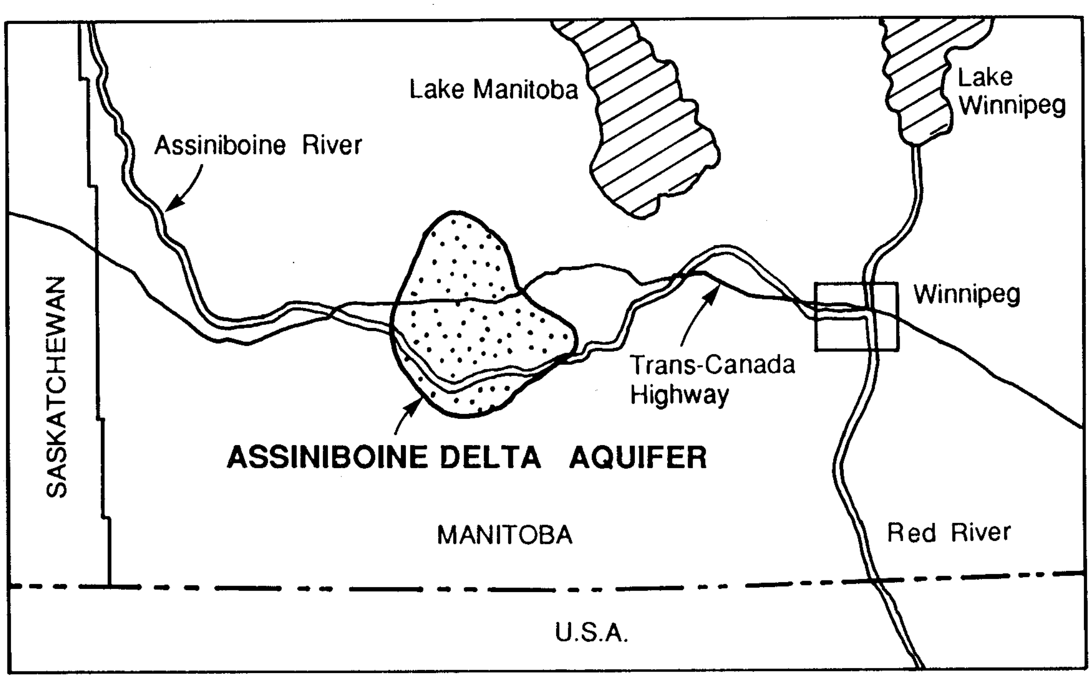

Figure 1. Location of the study aquifer.

2.1.1 Capacity of the Aquifer

According to Render (1987, p. 5), a preliminary estimate of the long-term annual rate of water availability from the aquifer is 60 378 dam^3 (or 74 449 acre-feet). The aquifer can be divided into 13 subbasins, based on various streams in the region. These are shown in Figure 2 , and their respective capacities are given in Table 1 .

Table 1

Capacity of the Assiniboine Delta Aquifer by Subbasin

	Capacity	
Subbasin	dam^3	acre-feet
Whitemud West	3 720	4 588
Upper Whitemud East	2 337	2882
Lower Whitemud East	9 337	11 513
Pine Creek North	5 388	6 644
Pine Creek South	2 925	3 607
Epinette Creek North	7 622	9 699
Epinette Creek South*	-	-
Assiniboine-Souris	1 636	2 017
Assiniboine West	4 712	5 810
Assiniboine South	10 316	12 494
Assiniboine East	5 679	7 003
Squirrel Creek North	1 148	1 416
Squirrel Creek South	3 925	4 840
Total	58 665	72 513

Source: Render, interview, May 1991.
*No information available.

A more recent estimate for the annual rate of water availability is 58 800 dam^3 (or 72 500 a.-ft.). This is based on the recharge area of 2 600 km^2 (1 000 sq. mi.) of irrigable land in the region. According to these estimates, the aquifer consists of two large subregions: Assiniboine South and Lower Whitemud East; six relatively smaller subregions: Whitemud West, Pine Creek North, Epinette Creek North, Assiniboine West, Assiniboine East, and Squirrel Creek South; and five smaller subbasins: Upper Whitemud East, Pine Creek South, Epinette Creek South, Assiniboine-Souris, and Squirrel Creek North. Water use in different subregions varies, partly because of the distribution of the economic activity. Current estimates suggest that in the Assiniboine West subregion allocation is about 101.6% of the annual capacity of the subbasin. In the Squirrel Creek North, Assiniboine East, Squirrel Creek South, and Assiniboine South subregions, water allocation is less than 2% of the subbasin capacity. In Epinette Creek North, water allocation is approaching roughly half of the estimated supply of the subregion. Other subregions with relatively large water use include Upper Whitemud East, Pine Creek North, Lower Whitemud East, and Whitemud West.

2.1.2 Water Cycle Characteristics

The Assiniboine delta aquifer is recharged through the natural precipitation in the region. Surface runoff and infiltration to groundwater are generally high during the snowmelt period and after summer rainstorms. The groundwater flow system in the region is very complex but generally follows the expected pattern, i.e., downward movement in the upland area under the influence of gravity, lateral movement, and upward movement beneath the lowland areas. The aquifer discharges water into the Assiniboine and Whitemud rivers, and the Pine and Squirrel creeks.

The history of groundwater use in the Carberry aquifer region is relatively short. Before the 1960s, the major users were the Canadian Forces Base located at Shilo, Manitoba, and various towns and farms located in the CAR. Other users of groundwater included domestic and agricultural. Significant irrigation in the region was promoted during the late 1960s and became a reality during the early 1970s. At present, agriculture is the largest single water user in the region.

2.2 DELINEATION OF THE STUDY REGION

To study the agricultural profile, the region was defined in terms of an agricultural area combining various rural municipalities located directly above the aquifer (Fig.3). Although there are a total of 12 municipalities, only 6 of these have a major part of their area over the aquifer: North Cypress, South Cypress, Langford, North Norfolk, South Norfolk, and

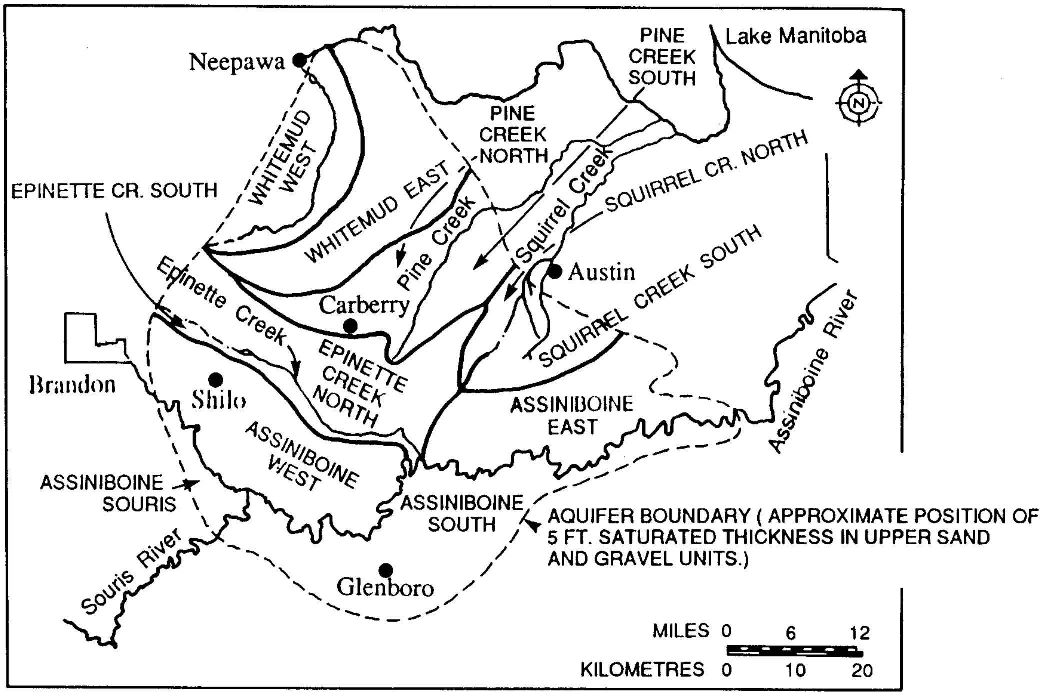

Figure 2. Assiniboine delta aquifer subregions. (From Render 1988, p. 25, with permission.)

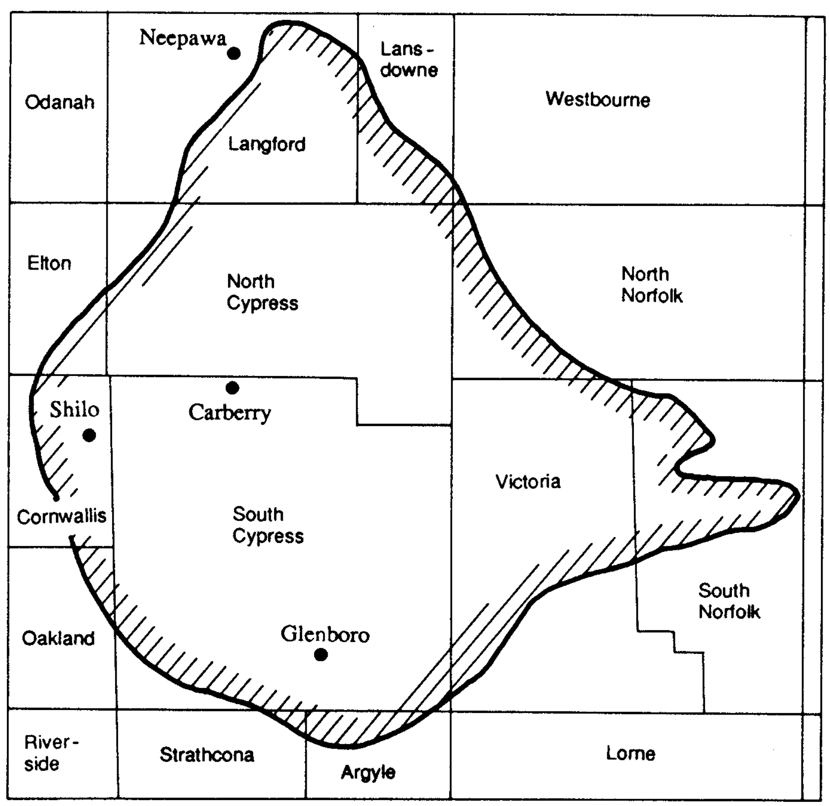

Figure 3. Composition of the Carberry aquifer region by rural municipalities and major communities.

Victoria. Six other municipalities are on the fringe of the aquifer: Argyle, Strathcona, Oakland, Cornwallis, Elton, and Lansdowne. In delineating the aquifer region for agricultural purposes, the first 6 municipalities were included, while the 6 on the fringe of the aquifer were not considered. Even for the municipalities within the confines of the aquifer, only the portion of the total area that lies directly above the aquifer was included. The proportion of the area of each municipality included in the project region is shown in Appendix A. In the subsequent discussion, this study region is referred to as the Carberry aquifer region (CAR). This boundary of the region is used for the study of water use, particularly for agricultural purposes.

2.3 AGRICULTURAL PROFILE OF THE REGION

The elevation of the CAR varies from 400 m above sea level in the north and northwest corner to about 335 m along the eastern margin. The Assiniboine and the Whitemud rivers and their tributaries drain most of the region. The Assiniboine River carries its water from southeast Saskatchewan and southwest Manitoba through the CAR to the Red River, which it joins at the city of Winnipeg. The north central part of the region drains into Lake Manitoba through the Whitemud River and its tributaries.

The precipitation regime of the CAR is characterized by winter snowfall; high-intensity, short-period thunderstorms during the summer months; and low intensity rains during the fall. As a result, evapotranspiration during the agricultural growing season is high, and for some crops irrigation is a necessity.

2.3.1 Farm Size and Ownership

The CAR was estimated to include about 791 farms in 1986, down by almost half from 1 384 farms in 1951 (Table 2). The average size of a farm in the region increased during the 1951-1981 period from 184.8 ha to 350.3 ha. Almost two thirds of the area in the region is owned by farm operators. During the 1980s, the proportion of farm operator-owned land to the total declined slightly to about 60%, most probably due to the deteriorating financial situation caused by lower farm prices for major grains and oilseeds.

Table 2

Selected Farm Characteristics of the Carberry Aquifer Region, 1951-1986

Year	Total number of farms	Average size of farm (ha)	% of total area owned
1951	1 384	184.8	67.2
1956	1 252	207.3	67.4
1961	1 142	234.0	68.3
1966	1 079	252.3	72.2
1971	967	280.3	71.8
1976	909	302.8	68.8
1981	859	308.3	67.2
1986	791	350.3	60.2

Source: Computations using special tabulation data, Statistics Canada.

A majority of farms in the CAR are small, 226.2 ha or less (559 acres or less). Very large farms (647 ha or more) constitute less than 6% of the total number of farms in the region (Table 3). The relatively large concentration of small farms in the region perhaps reflects the

Table 3

Distribution of Farms in the Carberry Aquifer Region by Size, 1986

Size (ha)	Number of farms	% of total
< 28.3	108	13.6
28.4 - 96.7	128	16.2
96.8 - 226.2	254	32.1
226.3 - 307.6	105	13.2
307.7 - 452.9	99	12.6
453.0 - 647.1	51	6.4
> 647.1	46	5.9
Total	791	100.0

Source: Computations using special tabulation data, Statistics Canada.

quality of the land resources and their income-generating capacity. The general topography and landscape of the region also constrain expansion of the total land base. As new arable land in the region is not available, any expansion in farm size depends on other farmers leaving the region.

2.3.2 Land Use Pattern

Over time there has been a trend towards increasing the cropped area in the CAR, through land clearing. In 1951, there was about 157 000 ha of improved land, which by 1986 had increased to almost 187 000 ha (Table 4). Apart from the absolute increase in the cropped area, there was also a steady increase in the area under crops as a percentage of the total area.

A large share of the region's cropped area is devoted to cereal grains and oilseeds, as shown in Table 5 . Wheat is still the single most important crop in the region, and its importance did not diminish during the 1951-81 period; in fact, it increased somewhat. For example, in 1951, wheat constituted roughly 31% of the total cropped area; by 1986, this proportion had increased to 41.8%. This may, to a certain extent, reflect the lack of economically feasible alternative options but more likely reflects the high returns experienced in the 1970s and expected by the farming industry to continue.

Table 4

Comparison of Cropped Area to Improved Area on Farms in the Carberry Aquifer Region, 1951-1986

Year	Total improved area (ha)	Total cropped area (ha)	Cropped area (% of total improved)
1951	156 944	102 024	65.0
1956	158 073	103 724	65.6
1961	166 639	107 323	64.4
1966	176 219	119 749	67.9
1971	172 366	126 326	73.3
1976	172 933	147 596	85.4
1981	185 864	157 986	85.0
1986	186 676	164 072	87.9

Source: Computations using special tabulation data, Statistics Canada.

Table 5

Comparison of Various Crop Areas to the Total Cropped Area (%) in the Carberry Aquifer Region, 1951-1986

Year	Wheat	Other grains	Oilseeds	Other field crops	Hay and fodder	Total cropped area
1951	30.8	52.5	8.8	0.6	7.3	100.0
1956	30.6	47.6	6.1	1.5	14.2	100.0
1961	37.5	34.3	7.0	0.4	20.8	100.0
1966	36.4	37.4	8.7	0.9	16.6	100.0
1971	23.7	45.5	13.0	1.9	15.9	100.0
1976	29.0	36.8	9.3	10.4	14.5	100.0
1981	26.9	39.5	16.6	6.3	10.7	100.0
1986	41.8	21.2	18.3	7.6	11.1	100.0

Source: Computations using special tabulation data, Statistics Canada.

The relative area under special crops included under the category of "other field crops" is of particular interest to this study. Although these crops constitute a small portion of the total (less than 10%), they include potatoes, the major irrigated crop in the region and therefore of special significance to the study of valuation of groundwater in the Assiniboine delta aquifer.

2.3.3 Irrigated Area

According to the 1986 Census of Agriculture, 14 farmers reported using irrigation on their farms. The total reported irrigated area was 2 375 ha. Most of this area was located in the rural municipalities (RM) of North Cypress, South Cypress, and South Norfolk. The areas irrigated in these RMs were 1 859 ha in North Cypress, 371 ha in South Cypress, and 145 ha in South Norfolk. According to Statistics Canada, most of this area was irrigated with the use of pivots. Of the total area in the North Cypress RM, 80% was irrigated by this method. The only other method reported to be in use was that of the travelling gun.

Information on the irrigated area is not available on a historical basis. Inclusion of the question of irrigation started with the 1981 Census of Agriculture. In 1981, the irrigated area in the CAR was reported to be 1 021 ha by some 16 farmers. Thus, between 1981 and 1986, the total irrigated area in the region increased by 133%. Whether this approximates the long-run trend in the irrigated area in the region cannot be said with any degree of confidence. Most of the irrigated area is located in the southwestern part of the CAR and in the Upper Pine Creek Basin around Carberry, as shown in Figure 4 .

2.3.4 Livestock Population on Farms

The regional trends in livestock and poultry farming are similar to the provincial and Prairie trends. Generally speaking, the number of cattle and calves and poultry have shown some

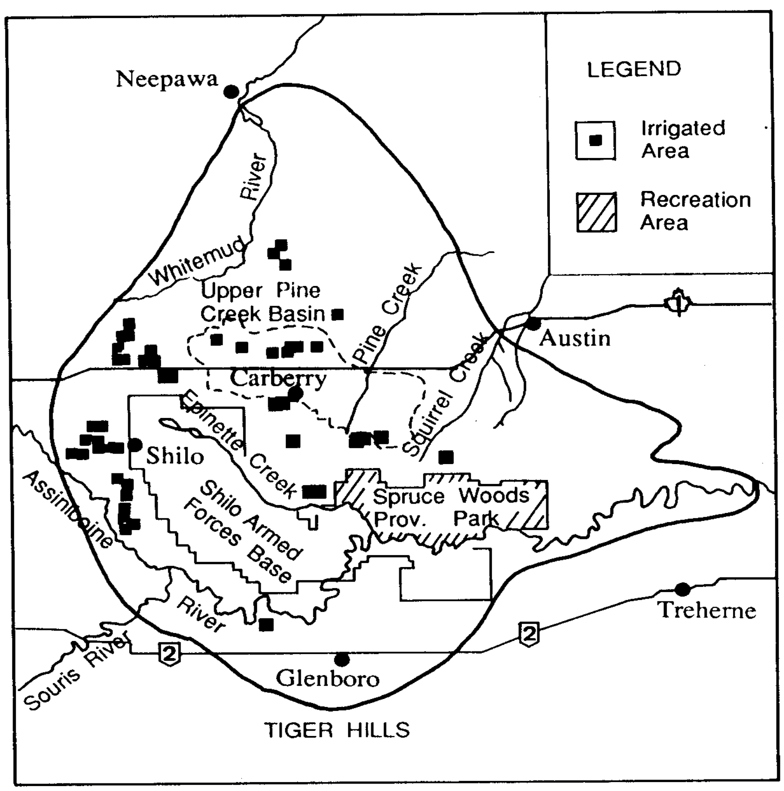

Figure 4. Map of the Carberry aquifer region showing location of economic activities.

Table 6

Livestock and Poultry Population in the Carberry Aquifer Region, 1951-1986

Year	Cattle and calves	Pigs	Sheep and lambs	Horses	Poultry
1951	24 506	10 154	1 882	4 042	166 811
1956	34 315	8 816	2 018	1 782	162 173
1961	41 387	12 882	2 146	1 800	183 567
1966	44 506	14 189	1 842	1 628	144 200
1971	44 248	34 867	2 593	1 541	173 852
1976	54 855	31 536	567	1 487	255 488
1981	45 403	41 789	837	1 897	166 236
1986	39 603	50 407	386	2 543	165 795

Source: Computations using special tabulation data, Statistics Canada.

fluctuations but no discernible trend. There is an increase in the number of pigs in the region, whereas the number of sheep is on the decline (Table 6). The number of horses showed a general decline until 1976, but since then there has been a resurgence in their number.

2.4 MAJOR COMMUNITIES IN THE STUDY REGION

The Carberry aquifer region is predominantly a rural area. There are no large urban centres within the region, although the city of Brandon is located just outside the western edge of the aquifer. However, this city does not draw water from the Assiniboine delta aquifer. The largest community within the study region is the town of Carberry, with a population of slightly over 1 500 in 1991. The other large (relatively speaking) centre of population is the Canadian Forces Base near Shilo; its population varies between 1 000 and 5 000. The total population of the study area is estimated at 12 391 people (Table 7). Of the total population, rural inhabitants make up slightly less than half. The town of Neepawa is included in this estimate since it depends partially on the seepage of water from the Assiniboine delta aquifer into the Upper Whitemud River and then through Lake Irwin.

2.5 INDUSTRIAL ACTIVITY IN THE STUDY REGION

The Carberry aquifer region is predominantly an agricultural area. The main occupation of the majority of the people is agriculture, both crop production and livestock raising. The only manufacturing type of activity in the region is carried out by a food-processing company located at Carberry. The plant processes over 145 million kg (some 320 million lb.) of raw potatoes annually into almost 73 million kg (160 million lb.) of french fries, dehydrated potatoes, and other consumer potato products. During 1989, it was estimated that the plant spent some $58 million, of which $46 million was spent within the province of Manitoba. The local impact of the plant was to be seen in the employment of 300 to 500 workers, depending upon the production output. Most of the raw potato supply was from local sources, although during drought periods, when local supply fell short, potatoes were imported from the United States, Alberta, and Prince Edward Island.

Table 7

Population of the Carberry Aquifer Region by Type, 1991

Type of population	Estimated population	% of the total population
Nonrural		
Glenboro	741	6
Carberry	1 510	12
Neepawa	3 425	28
CFB Shilo*	1 200	10
Total nonrural	6 876	56
Rural municipality		
N. Cypress†	2 004	15
S. Cypress†	855	7
N. Norfolk†	1 219	10
S. Norfolk†	257	2
Victoria†	716	6
Langford†	464	4
Total rural†	5 515	44
Total region†	12 391	100

Source: Statistics Canada (1991).
* Estimated.
† Represents only the part of the total population that is within the CAR.

2.6 RECREATIONAL SITES IN THE STUDY REGION

The only defined recreational site within the Carberry aquifer region is the Spruce Woods Provincial Park, with an area of 248.6 km^2. The park is located about 10 km southeast of the Carberry (Fig. 4). It derives its name from the white spruce trees which, along with other trees and shrubs and the rolling topography, provide a very attractive landscape. It also offers to visitors creeping sand dunes, oxbow lakes, and the Assiniboine River and its valley. The park represents one of Manitoba's twelve major natural regions. It offers camping, swimming, canoeing, hiking, cross-country skiing, bicycling, and nature interpretation programs. A part of the area in the park makes an excellent wildlife habitat. As a result, a large population of white-tailed deer is found there, providing the local residents and other visitors a valuable source of meat, and hunting and viewing experience.

CHAPTER 3

Water Use in the Carberry Aquifer Region

In this chapter, an assessment is made of the present water use pattern, and the factors that may affect trends in water use in the Carberry aquifer region are considered. Water users are disaggregated into major standard categories. For each category, water use is estimated using different sources of data.

3.1 IDENTIFICATION OF WATER USES

Users of water drawn from the Assiniboine delta aquifer can be grouped into two major types, according to whether they are within or outside the CAR. Within the CAR, the following categories of water use can be identified:

1. agricultural, which may include farm-related water use, primarily for three purposes: irrigation, stockwater, and other farm activities

2. domestic or household, which may include farm domestic and nonfarm domestic water use, but not urban domestic or municipal, as there is no large urban centre in the region

3. industrial and commercial, which may include the water used for agricultural processing, nonagricultural manufacturing, and that used by other commercial establishments

4. in situ, which may include recreational, wildlife, and other uses

5. defence establishment

In addition to water used within the CAR, water is discharged from the aquifer into the Assiniboine River, the Whitemud River, Pine Creek, and Squirrel Creek. Those who use it outside the CAR, further downstream, constitute the second type of user. The categories of water use listed for within the CAR could also be used for outside the CAR, although that area was not included in this report.

3.2 REGIONAL WATER USE ESTIMATES USING WATER RIGHTS DATA

Most of the water use in the Carberry aquifer region is associated with developments taking place over the past 15 to 20 years. Before the 1960s, groundwater from the aquifer went primarily for CFB Shilo use, as well as for domestic and stockwater use. Since the mid-1970s, there has been a significant increase in its use for irrigation, mostly for potatoes, which are grown in the vicinity of Carberry.

3.2.1 Agricultural Water Use

Actual water use in the CAR cannot be obtained since no measurements are made of actual use by any of the major users. Lacking direct measurements, estimates must be made from sources such as the Manitoba Natural Resources' water rights data. The Province of Manitoba issues a permit to all major users for the withdrawal of groundwater from the aquifer. This permit authorizes the user to secure a maximum quantity of water. However, a major limitation of this data source is that without monitoring the water use, it is virtually impossible to estimate actual water use from the licensed water right. Actual level of water use may be higher or lower than the permitted quantity. In the CAR, licenses have been issued for agricultural, municipal, and commercial purposes. In 1990 (from April to August), farmers in the region held licenses to withdraw a total of 14 412 dam^3 (or 17 771 acre-feet) of groundwater from the aquifer (Table 8). The period of rapid increase in irrigation appears to be in the late 1980s (particularly in 1987, during which the largest quantity of water was licensed for withdrawal). The year the license was issued should be interpreted with caution, because for earlier years, the numbers of licenses do not necessarily reflect the actual number of licenses that were held by farmers. Some of these licenses may have expired since and may have been reapplied. The reapplications are listed under the year of reissue.

Table 8

Estimated Water Use for Irrigation in the Carberry Aquifer Region, 1961-1990

	Withdrawal license		Cumulative withdrawal	
Year	a.-ft.	dam^3	a.-ft.	dam^3
1961	20	16.2	20	16
1962	45	36.5	65	53
1973	30	24.3	95	77
1976	15	12.2	110	89
1977	480	389.3	590	478
1978	420	340.6	1 010	819
1979	200	162.2	1 210	981
1980	300	243.3	1510	1225
1981	300	243.3	1810	1468
1982	305	247.4	2 115	1 715
1983	1 129	915.6	3 244	2 631
1984	310	251.4	3 554	2 882
1985	400	324.4	3 954	3 207
1986	1205	977.2	5159	4184
1987	5 430	4 403.7	10 589	8 588
1988	246	199.5	10 835	8 787
1989	2 470	2 003.2	13 305	10 790
1990	4466	3 621.9	17 771	14 412

Source: Dan Sie, Water Rights Data, Manitoba Water Resources, May 1991.

3.2.2 Nonagricultural Water Users

Two types of user other than farmers have been granted a license to remove water from the Assiniboine delta aquifer. One is municipal, for the town of Neepawa, allowing withdrawal of water from Lake Irwin on the Upper Whitemud River, and the other is the rural municipality of North Norfolk. These two licenses allow the total withdrawal of about 1 245 dam^3 (or 1 535 a.-ft.) of water per year. The other type of user identified in the water rights data is commercial, for a license of 24 dam^3 (or 29 a.-ft.) of water annually.

3.2.3 Total Water Use

The total water withdrawn under the above three types of license is 15 681 dam^3 (or 19 335 a.-ft.) on an annual basis (Table 9). Four major limitations of the above data must be kept in mind. (1) As mentioned above, the license for water may not be equated with water use. (2) There are a number of small users that do not require licenses under the present regulations and are not included in the above data. (3) Two large users—the potato processing plant at Carberry and the Canadian Forces Base at Shilo—are not included in these estimates. Both of these are heavy users of groundwater. (4) The town of Neepawa depends partially on the aquifer water. The seepage of water from the aquifer into the Upper Whitemud River, which further forms Lake Irwin, constitutes only a portion of the contents of the reservoir. The exact proportion of this water used by Neepawa is not available.

3.3 ESTIMATION OF WATER USE FOR THE STUDY

Since the above approach to the estimation of the level of water use has obvious limitations,

Table 9

Level of Water Use in the Carberry Aquifer Region, 1990, Using the Manitoba Water Rights Data

Type of use	Licensed quantity (dam^3)	% of the total licensed quantity
Irrigation	14 412	90
Domestic	1 245	8
Commercial	24	2
Total	15 681	100

an alternative approach was also used in this study. This approach estimates water use by assessing the water needs or requirements of various users. This estimation was based on the methodology developed by Kulshreshtha and Spriggs (1982) and by the Prairie Provinces Water Board (1982).

3.3.1 Agricultural Water Use

Two major types of agricultural water use are irrigation and stockwatering. No accurate information of the area under irrigation is available, and its further breakdown by crop is even more difficult to obtain. Consultations with the personnel of the local agricultural representative's office suggested that potato was the major crop irrigated in the region; however, some other crops in the Shilo district were also irrigated. Information obtained from the food-processing company in Carberry indicated that the irrigated area in the region for potatoes was 3 238 ha (or 8 000 a.). In the absence of any better data, the above information was accepted as the best estimate of the irrigated area. It was further assumed that on average, a water application rate of 1 to 1.5 dam^3/ha was standard in the region.[1] In addition, the area under irrigated cereals and oilseeds was estimated at between 1 175 and 1 750 ha. Using this information, the total water use for irrigation was estimated at 5 494 dam^3.

The stockwater use in the region was estimated using the "water requirements" approach, using the daily water intake of various types of livestock, as suggested by the Prairie Provinces Water Board (PPWB) (1982). Using the data on livestock and poultry in Table 6, the total stockwater use in the CAR was estimated at 957.1 dam^3.

In addition to the above two uses, farm operations such as the cleaning of machinery and the use of herbicides require water. No precise measure of this use of water has been developed in the previous studies. This water use has therefore been excluded in this study.

[1] No precise study of actual application of water by farmers in the region has been carried out. This figure is based on the Survey of Irrigators in South Saskatchewan River Irrigation District No. 1, as reported in Schuetz, Kulshrestha, and Brown (1990).

3.3.2 Domestic Water Use

Domestic water use was also estimated for the CAR by using the water requirements approach. Three types of population were identified for this purpose: rural population on farms, population in small villages and hamlets, and population in towns with a water system for which municipal data were also available.

Rural population on farms: Rural farm population in the CAR was assumed to be associated with the number of farms in the region. In 1986, as shown in Chapter 2, there were 791 farms. Assuming an average of 3.16 people for every farm[2]. The total number of rural farm people is estimated at 2 500 people. Adding other families in the open rural areas, as shown in Table 7 , an estimated total of 5 515 people is reached. Assuming a daily average of 381 L of water per capita, a total water use of 767 dam^3/yr is estimated for this type of domestic use.

Rural nonfarm population in smaller centres: Smaller centres in the region include Carberry and Glenboro. Communities located on the edge of the aquifer boundary include Austin and Treherne. The communities of Macgregor and Gladstone are located outside the aquifer region. In this study, it was assumed that the communities located within the CAR or in close proximity to it drew their water from the Assiniboine delta aquifer, whereas those outside did not. This resulted in a total population of 2 251 served by the aquifer. With an average use of 381 L/day, the total water use was estimated at 246.5 dam^3/yr.

Rural nonfarm population in municipal centres: The only community in the region with a municipal water system is Neepawa. The community draws water from Lake Irwin, an artificial reservoir on the Upper Whitemud River, which in turn derives some of its water from the aquifer itself. The 1986 population of the town was estimated at 3 425 inhabitants, and has shown a slight decrease (Table 10). The average per capita pumpage for the community is estimated at 146 m^3/yr. The 1991 level of municipal water use is estimated at 481.8 dam^3, using this average and the 1991 level of population.

[2] This is based on an average figure for Manitoba, calculated from Statistics Canada (1986). There were 86 505 people on 27 336 farms censused during that year.

Table 10

Water Use and Population Size for the Town of Neepawa, Selected Years

Year	Population	Total pumpage (dam^3)
1951	2 900	
1971		485
1976	3 500	540
1977		507
1978	3 600	510
1986	3 425	
1991		482*

Source: PPWB (1982) and Statistics Canada (1951, 1976, 1978, 1986).
* Estimated.

The per capita domestic water use in the town for the 1970s was reported at 50 286 L/yr. Assuming that this level of consumption was still applicable, the total domestic water use of the community was estimated at 172 dam^3 for 1991.

3.3.3 Industrial and Commercial Water Use

Major industrial and commercial water usersare located in the towns of Neepawa and Carberry. Their water use in 1991 was estimated using data from PPWB and from the Environment Canada municipal water use data base (MUD). For the Town of Neepawa, the PPWB study has reported the following estimates of industrial and other uses for the year 1976: 64 dam^3 for industrial use and 134 dam^3 for other commercial uses. For this study, these uses were assumed to apply for the Town of Neepawa in 1991.

For the Town of Carberry, the water used by the food-processing company was obtained from the Environment Canada data base. This estimate was an intake of 905 dam^3/yr. The other uses of water in Carberry, including commercial water use for the town, were estimated by prorating quantities used for Neepawa, on a per capita basis. The 1976 per capita amount of water for other uses was 38.3 m^3/yr. Using this procedure for the Town of Carberry resulted in an estimate of 57.5 dam^3/yr.

The total industrial and commercial water use for the CAR was estimated at 1 160.8 dam^3/yr.

3.3.4 Water Use for the Canadian Forces Base

The Canadian Forces Base located at Shilo was one of the earliest water users in the region and appears to be one of the major users of groundwater from the aquifer. Estimates of water use on the base were received from the office of the base commander and are shown in Table 11 . According to these estimates, the annual use of water is 775.3 dam^3/yr. In Table 11 , a monthly distribution of this water use is also shown. Water use is the heaviest in the summer months and in October.

3.3.5 Water Used for Recreational Purposes

As noted above, the CAR houses a major recreational site, the Spruce Woods Provincial

Table 11

Water Use at Canadian Forces Base Shilo, April 1990 to March 1991

Year	Month	Total pumpage (dam^3)
1990	April	56.1
1990	May	80.8
1990	June	77.1
1990	July	91.3
1990	Aug.	70.4
1990	Sept.	67.7
1990	Oct.	80.3
1990	Nov.	48.7
1990	Dec.	35.7
1991	Jan.	44.2
1991	Feb.	60.4
1991	March	62.6
Total		775.3

Source: CFB Shilo, pers, com., base commander, June 1991.

Park. Since water use for recreational purposes is an in situ use, no precise estimates of it can be made. However, the volume of flow may be a major factor for recreationists, particularly those engaged in boating and other direct-contact activity with water. According to Render (1988), the discharge of water from the aquifer to the Assiniboine River is estimated at 1.274 m^3/s (45 cu.ft./s). This would result in a total discharge of 40 185 dam^3 of water, unavailable otherwise, into the river.

3.4 WATER USE OUTSIDE THE AQUIFER REGION

Use of aquifer water outside the CAR would come through discharge into the Assiniboine River, the Whitemud River, Pine Creek, and Squirrel Creek. This water may be used for stockwatering, wildlife habitat, and domestic and agricultural purposes. Other than for the Assiniboine River, no estimates of discharge of water from the aquifer are available. Furthermore, the discharge from the aquifer is not distinguishable from the other natural flow of these streams. For these reasons, estimates of this water use were not made in this study.

Table 12

Estimated Water Use in the Carberry Aquifer Region, 1990

Type of use	Quantity (dam')	Subtotal (dam^3)	% of total use
Agricultural			
Irrigation	5 494		54.6
Stockwater and other farm	1 448		14.4
Total agricultural		6 942	69.0
Domestic			
Rural farm	767		
Rural nonfarm	247		
Municipal	172		
Total domestic		1 186	1.8
Industrial/ comm.		1 161	11.5
CFB Shilo	775	775	7.7
Total withdrawal use		10 064	100.0
Discharge into rivers	41 185		
Total		51 249	

3.5 SUMMARY OF WATER USE

A summary of estimated water use is presented in Table 12 . Total water use could amount to as much as 10 069 dam^3/yr. About 55% of this is for irrigation purposes. This total refers to anthropogenic use of water and excludes any discharges into a river stream.

Regardless of the methodology used to estimate the water use level in the aquifer region, one conclusion is inescapable: irrigation is the largest use of groundwater in the region. Estimates indicate that during 1990 about 5 494 dam^3 of water was being used for this purpose, although the farmers held licenses to withdraw up to 14 412 dam^3/yr.

CHAPTER 4

The Economic Value of Water — Conceptual Framework

The primary purpose of this chapter is to present a concise description of various concepts that will be used in the valuation of groundwater in this study. The concept of economic value is discussed first, then alternative approaches to the valuation of water. Although this study deals primarily with the use-related values, nonuse values are also discussed. The chapter is divided into three major sections. First, the concept and taxonomy of values associated with groundwater are discussed. Here, the two groups of values—use and nonuse—are discussed. In the next section, alternative approaches to valuation of water are discussed. Procedures to estimate use-related values under two alternative perspectives are discussed in the last section of the chapter.

4.1 CONCEPT OF THE VALUE OF GROUNDWATER

4.1.1 Value Defined

What is the value of water to a water user? If the water is used in the production of goods sold in the marketplace, its value can be measured through the bids that buyers offer. These bids are a function of individual preferences, constrained by the distribution of wealth, which in turn is a function of human endowments and property ownership (Schmid 1989, p. 59). These bids express some willingness to pay (WTP). Money is generally used as the measuring rod for these preferences, since in everyday life we express our preferences in monetary form: when buying goods we exchange money for the goods. In reality, each individual's willingness to pay will differ. Thus, we could arrange all our consumers of water in order of their preferences and the quantities they would be willing to purchase. If this concept is drawn as a relationship between the monetary value of their preferences and the quantity purchased, this concept becomes analogous to a market offer curve, or demand curve, for that good. A hypothetical demand curve for water is shown in Figure 5 . The entire area under the demand curve is commonly referred to as the "gross benefit" or gross value, and can be distinguished into two parts: total expenditures and consumer surplus. Consumer surplus is the maximum amount of money a consumer would be willing to pay rather than go without that quantity of water. The size of the consumer surplus in cost-benefit analysis is a measure of the benefits to society from the production of a certain good. Given the nature of the relationship between quantity and price of water, three types of value measure can be estimated: (1) gross value, which is the area ACDO divided by the OD quantity of water, (2) net average value, which is the level of consumer surplus, area ABC, divided by the quantity of water OD, and (3) net marginal value, which is the value of the last unit of water demanded, or OB. Each of these values has a role to play in determining the allocation of water resources. Marginal values are better than average values in making the allocative decisions. Gross values should be used with caution, since there is a duplication with expenditures by consumers.

4.1.2 Taxonomy of Values

Managing groundwater sustainably depends upon correctly identifying and estimating various values of groundwater. The most commonly conceived value of water is through the genera-

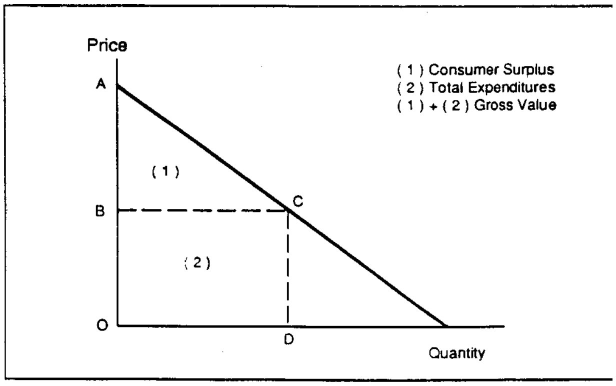

Figure 5. A hypothetical demand curve for groundwater.

tion of economic activity. Included among these values are the uses of groundwater that lead to activities that would not take place if that quantity of water did not exist. Such uses include irrigation, domestic water use, industrial water use, and commercial water use. However, there is a value of groundwater associated with its conserved state. There may be ecological functions of groundwater, such as the maintenance of flora and fauna, wildlife habitats, and other parts of the ecosystem. There may be indirect values associated with recreation and tourism in the region. Some individuals may wish to hold groundwater for use at some future time, whereas others may like to conserve that water body for future generations.

Based on the above discussion, the total value of groundwater can be divided into two major types: use and nonuse. (Fig. 6). The stock of groundwater resources is multifunctional with very significant economic values. The structural values provided by the water are presently being exploited to support human livelihoods.

The direct-use value is one component of the use-related value of the groundwater, which is a subset of the total economic value of groundwater. Major economic activities in the Carberry aquifer region involving the use of groundwater include agricultural, domestic, industrial, and commercial. Major benefits arising out of this use of water include the production of commercial commodities or services as well as the sustenance of human life.

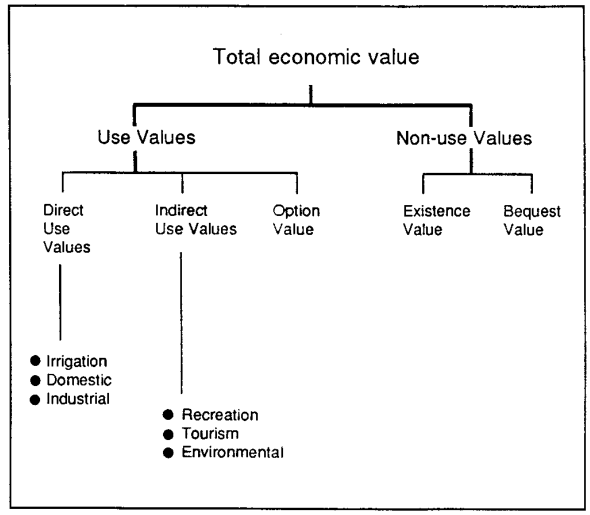

Figure 6. Valuation of groundwater benefits.

The second component of the use value of groundwater is derived from indirect uses of water. This includes its indirect support of the ecosystem, as well as its support of some regional economic activities, such as recreation and tourism. Support of wetlands in the region could also be classified under this category of values. Wetlands have similar types of values associated with them (Turner 1991). Some of the values may be direct-use related, while others may include indirect-use values, as well as nonuse values.

Since all use-related values are associated with the current use of water, they do not include values associated with their future use. Some of the individuals who are currently nonusers of groundwater from the aquifer have the potential to be users at some future date and may be willing to pay for such a use. This type of value is captured through the estimation of option values. Users wishing to secure the use of groundwater at some future time may be willing to contribute a positive value over and above the benefits foreseen from the use of water at some future date. This premium is called the option value of groundwater use in the region.

A second category of values pertains to pure nonuse of groundwater. People may be deriving some value from the fact that the Assiniboine delta aquifer does exist. This value is not derived from any current or future planned use of groundwater. This type of value is called the existence value of groundwater. In addition to pure existence value, people may affix a certain value to the groundwater because of their desire to maintain the option to pass on such a resource to future generations. Such a value is called the bequest value.

Thus, the total value of a resource, such as the groundwater in an aquifer, would be the sum of two types of values: use-related and nonuse-related. The use-related ones can be further broken down into three types: direct use, indirect use, and option values. Similarly, the nonuse-related values are basically of two types: existence and bequest. Thus, the total valuation of groundwater necessitates exploration and valuation of all of these values.

4.2 ALTERNATIVE APPROACHES TO VALUATION OF WATER

4.2.1 General Approaches

The theoretical concept of consumer surplus, as discussed in the previous section, has become the focus of estimation for the valuation of water from an economic efficiency perspective. In theory, one can use three categories of methods in the valuation of water:

- conventional market information
- implicit markets
- artificial markets

Information from conventional markets is used in situations where such markets exist and can be trusted. Situations where market analysis is used include changes in production and its valuation, replacement cost of an asset, preventive expenditures (such as the cost of cleaning up the environment), and substitution of products. Use of water, say in irrigation, may change the level of production and therefore have a value. This gross value can be estimated with the help of market prices. However, one must be cognizant of market distortions, which if present would render market prices untrustworthy. Significant distortions in market prices can be brought about by subsidies or transfer payments, or the presence of monopoly or monopsony. Under these conditions, market prices cannot be used unless corrected for these distortions.

Implicit markets are used in the valuation of nonmarket goods, such as recreational activities and environmental improvement or degradation. The basic idea behind this technique is that there are links between the consumption of market goods and of nonmarket goods, which are not traded through the marketplace. Examples of such techniques include the travel cost method, and land and property value approaches using hedonic price models.

Use of artificial markets is intended for the situations where the above valuation techniques fail to apply. Here one measures the consumer surplus in hypothetical situations by creating artificial markets. Such an approach is often called the contingent valuation method (CVM). The major strength of this approach is that it can be applied to a variety of situations where data are not available, or are difficult to get (Bojo et al. 1990, p. 78). Artificial markets have been used to value recreation goods, water quality, aesthetic quality, and environmental degradation.

4.2.2 Estimation of Use-Related Value

Direct use-related value of groundwater can be estimated using one of two criteria: economic efficiency or economic equity. The economic efficiency criterion bases the value of the resource on he true magnitude of benefits derived from its use. In this context, the estimation of benefits is analogous to that in the cost-benefit analysis methodology. In the estimation of value of water using the economic equity criterion, the value of water is generally equated to the regional welfare of a specific region. The contribution is measured in terms of level of economic activity. Alternatively, the criterion is called the regional development criterion.

In this study, the value of groundwater was estimated using both of these criteria. More details on the methodology based on the economic efficiency perspective are provided in Section 4.3.1, and on that for the regional development perspective in Section 4.3.2.

4.2.3 Estimation of Option Value

In the estimation of the option value, one is dealing with expectations, since the user is reserving the use of the groundwater for some future date. The relevant measure of the utility derived from the use of that water at present is the expected value of the consumer surplus (E[CS]). The relationship between the willingness to pay by future users and their intended use of water can be expressed in the following way:

$$\text{Option price} = \text{expected consumer surplus} + \text{option value} \quad (1)$$

In other words, the option value is the difference between the individual's bid for the WTP for the future use of water and the expected level of consumer surplus from the use of that water. The individual's bid for the willingness to pay for future use can be estimated using the contingent valuation method.

4.2.4 Estimation of Nonuse-Related Value

Estimation of existence and bequest values for a natural resource, such as the Assiniboine delta aquifer, can be done using the contingent valuation technique. This technique can be used to elicit people's preferences, as revealed by their willingness to pay for keeping the aquifer in its natural (undisturbed) state or for leaving it for use by the next generation of users. The formulation of appropriate questions to elicit such bids is an important step of this analysis. The most commonly used method is the iteratively bidding technique, where respondents are asked to offer their bid for the hypothetical situation described in the question. The level of bid is increased by small amounts until the maximum bid is reached.

4.3 ESTIMATION PROCEDURES FOR USE-RELATED VALUES

4.3.1 Estimation Procedures Using the Economic Efficiency Perspective

Benefits from the use of aquifer water can accrue to various users directly where water is withdrawn, and indirectly where water is only a part of the mechanism that benefits the user. The latter is called indirect use of water. Each of these benefits can be estimated using the economic efficiency perspective.

Estimation of Direct Use Value of Water The use-related value of groundwater can be one of three types: direct use, indirect use, and option. A variety of techniques can be applied to estimating a value for the groundwater in the aquifer. For the direct-use related values, market methods are the most commonly used. Among these, five methods that could be used as a proxy for this value of water are noteworthy (Fig. 7): the market analogy method, the intermediate goods method, the cost-savings method, the cost of alternative supply method, and the alternative technology method.

Direct use value:	• Market Methods o Market Analogy o Intermediate Good o Cost Savings o Cost of Alternative Supply o Alternative Technology
Indirect use value:	• Implicit Market Method o Travel Cost o Hedonic Price o Artificial Market o Contingency Valuation
Option value:	• Artificial Market Method o Contingency Valuaiton
Non-use values:	• Artificial Market Method o Contingency Valuation

Figure 7. Alternative methods for estimating groundwater value.

- *Use of market analogy (substitute products) method* — This technique refers to a situation where groundwater is traded in an explicit market. In this case, the market price (if not distorted) for the value of groundwater in the aquifer could be used as a measure of value. Such an approach cannot be applied in the CAR, since water is not traded as a market good. Although some trading of water rights is being carried out in the western and southern United States, its appropriateness to the Manitoba situation can be questioned due to institutional and geographic differences.

- *Intermediate good method* — In this method, the value of water is inferred from the value of those goods for which water is an input. Thus, water is an intermediate input, and its use contributes to the production of the final goods. The value of final goods produced, say in the case of irrigation the value of irrigated output, would be the source of valuation of groundwater in the aquifer.

- *Cost-savings method* — When the use of water is a perfect substitute for some other market good, through reduction in the cost of production, the savings in the cost of production through the use of water is equivalent to the value of groundwater. This method is also called the producer surplus approach to the valuation of an intermediate input, such as water. This type of valuation methodology is applicable to the use of water for irrigation. In this case, one may identify two methods of producing the same good, say potatoes. Potatoes can be produced under dryland or irrigated conditions. Let S(1) be the supply curve for potatoes under dryland conditions and S(2) the supply curve under irrigation (Fig. 8). Given a demand curve DD', reflecting the region to be a price taker, the area EBCA represents the gain to the producers from irrigation. In this case, irrigation reduces the cost of production to the producers and results in a gain. This producer surplus is a measure of the value of water and represents the maximum willingness to pay for water.

- Cost of alternative supply method — In this method, the value of water is the difference between the cost of obtaining water from the aquifer and that from the next higher cost source. If S(1) (Fig. 9) is the cost of supplying groundwater from the Assiniboine delta aquifer and S(2) the cost of supplying water from another source, then the value of the aquifer water is the area ABCE, given a demand for water represented by the curve DD'.

- Alternative technology method — This method of valuing water can be applied when alternative technologies could be applied to the production of certain goods that require water. One of these technologies could increase the efficiency of water use. The value of the water is based on the savings in the quantity of water relative to the additional cost of the more water-conserving technology. Implicit in this valuation is the assumption that water could not be substituted for by any nonwater input, except through the introduction of new water-conserving technologies. This type of

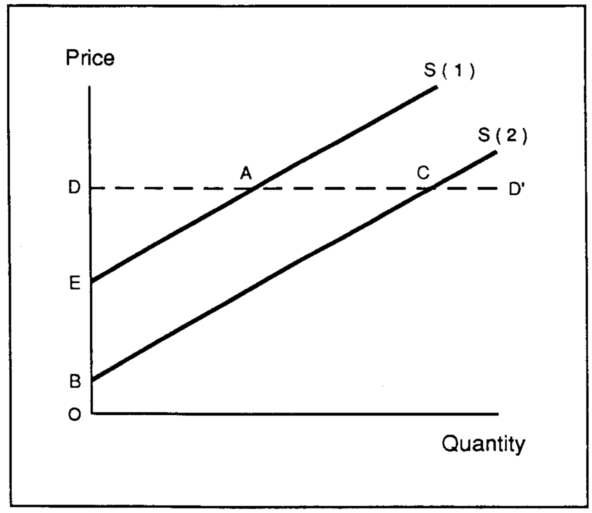

Figure 8. Concept of producer surplus in dryland and irrigated potato production.

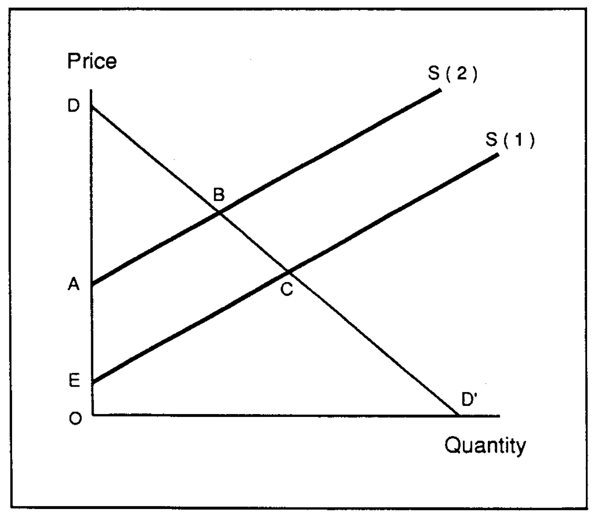

Figure 9. Value of water using the cost of alternative supply source method.

methodology can be applied to value water for domestic purposes, as well as for industrial and commercial water use.

Estimation of Indirect-Use Value of Water

Among the indirect uses of groundwater, those for recreation and for wetland preservation are the most important. Estimation of these values cannot be done using the market analysis approach, since these goods are not traded in the marketplace. However, two techniques commonly used for the estimation of the value of water in recreation are the travel cost method and the contingent valuation method.

In the travel cost method, the number of visits to a recreation site are assumed to be functionally related to the cost of that trip. As trip cost increases, the number of visits to that site decrease. This information can be used to generate a demand curve for visitation rates to the site. This demand curve can be interpreted in a manner similar to the market demand curve for a market good. The consumer surplus can then be estimated as a measure of the net value of recreation. If one subtracts from the net value of recreation the cost of nonwater inputs at the recreation site, the remaining value can be attributed to water. The value of water can be estimated for the recreation site or for some average unit of water.

In the contingent valuation method, a proxy to the demand curve is sought. This is called a bid curve and represents the maximum willingness to pay for recreational activity at a particular site. The relationship between the WTP and the number of visitors can then be taken as a proxy for the demand for recreation. The consumer surplus measure can be obtained and can subsequently be used for the estimation of the value of water in a manner similar to that discussed above.

4.3.2 Estimation of Value Using the Regional Development Perspective

Estimation of this type of value requires the estimation of the contribution of the water resource for a certain use to the regional economic activities. The typical measurement of these activities is the gross domestic product at factor cost. The analytical framework is marginal in that only incremental economic activities are included.

CHAPTER 5

Analytical Framework

In this chapter, the empirical methodology adopted for the study is described. The chapter begins with a discussion of the criteria of valuation of water, based on the techniques listed in Chapter 4. This discussion constitutes the study framework. Since the life of an aquifer if water use level is at or below the annual recharge rate is infinite, the total value of aquifer water is the lifetime value of that water. Therefore, an important consideration in the estimation is the methodology for estimation of net present worth of the aquifer. Methodological considerations with respect to this estimation are presented in the second section. The third section describes the estimation approach for each of the uses of groundwater in the region. As mentioned in Chapter 4, use-related valuation is one approach to estimation. Here, one could employ two alternative criteria—economic efficiency or regional development. A discussion of the latter approach is provided in Chapter 8.

5.1 FRAMEWORK FOR THE ESTIMATION OF THE VALUE OF WATER

The starting point for the methodology followed in this study was that suggested by the Trusty report (Wayne B. Trusty 1991). This methodology is briefly outlined in Section 5.1.1 and is followed by a description of the modifications deemed necessary to adapt the Trusty methodology for the Assiniboine delta aquifer. In the next two subsections, the framework for the valuation of groundwater as used in this study is described.

5.1.1 Methodology Suggested by the Trusty Report

The Trusty methodology called for a disaggregation of the total water use by its major types. This was because a single methodology was not considered to be appropriate for different water uses. Therefore, in this section, the Trusty methodology is described for each water use relevant to the present study.

For municipal water use, the recommendation was to use the method of alternative supply source. The price of water to municipal users under this alternative was to be estimated using a cost-of-service principle. The concept of consumer surplus was suggested as the measure of benefits from the use of groundwater.

It was suggested that the value of groundwater to rural residential water users be estimated in a manner identical to municipal water use, with one exception: that the selected municipality should represent a small area. The suggested procedure for the estimation of value for agricultural water use was complicated. The study recommended an analysis of production alternatives, particularly under the condition that groundwater was not available. A supra-marginal method of valuation was suggested. In other words, the benefit of using ground-water would come both from the increased production (over and above dryland) and from the change in the price of that product. The value of water would then be equated to the change in net income from the use of the water.

Although the Trusty report also outlined the methodologies to be followed for the estimation of value of water for the self-supplied industrial users and for environmental uses, these are not reviewed here, since their relevance to this study is limited.

5.1.2 Modifications in the Trusty Methodology

Every attempt was made in this study to follow the Trusty methodology as closely as possible. However, some modifications were necessitated on account of location-specific considerations or the lack of data. Both of these aspects of this study's methodology are briefly reviewed here. Following the Trusty recommendation, the value of water use in the CAR was carried out in a disaggregated manner (Sect. 5.1.4).

The value of municipal water use was estimated using the concept of consumer surplus, while the maximum price of water charged was established using the cost of obtaining water from an alternative source. Thus, in this respect the methodology was identical to that in the Trusty report. However, this study modified the Trusty methodology through disaggregation of the total municipal water use into residential, industrial, commercial, and other. Thus, instead of estimating the value of a single municipal water use, values were estimated separately for domestic and nondomestic water uses. The domestic use of water was further subdivided into major types of users.

The value of water for agricultural uses was estimated using the concept of "net income change" from irrigation, compared with income from dryland production. Although the use of a supramarginal basis for valuation was suggested by the Trusty report, it was not used in this study. The reason for this decision was that the Carberry region is a small area and thus the producers in the region are price takers. The prices of their products are either based on world markets or on North American ones. Their share of production in the world and the North American context is not large enough to influence the price level, and given that the producers in the CAR compete with producers in other regions, a long-term disparity between the local price and the international price is not very likely.

Since the Trusty report did not suggest any methodology for the indirect uses of water, such as those for recreation, a methodology was developed in this study.

5.1.3 Valuation Framework for the Present Study

In this study, the methodology for estimation of the value of groundwater has the following features:

1. It is based on combined criteria of use value and opportunity cost of that water.

2. It uses a disaggregated approach to valuation of various use-related values.

3. Estimation of nonuse values and of option values has not been done in this study but has been left for future studies in this area.

The last aspect of the study methodology was motivated by time and budget limitations. Since such values cannot be estimated without some primary data collection, and given that no previous study in the region has attempted to estimate such values for the aquifer water or for other natural resources, such estimates could not be incorporated within the resources available for the study. This is not to suggest that such values are less important: in fact, for natural resources quite often such values are equally or more important.

If water is used for a certain purpose, and there are other sources, what is the value of water from one of the sources? This type of question is very relevant for the estimation of groundwater in the Assiniboine delta aquifer. If an unlimited quantity of water could be obtained from another source, the value of the groundwater might be different in various uses. To illustrate this point, let us assume that there are two sources of water—a groundwater aquifer and a surface water source. Let us further assume that the cost of obtaining this water is borne by the users; in other words, there are no public subsidies for obtaining water from either. Let S(G) be the marginal cost function for obtaining the groundwater and let S(R) be the marginal cost function for obtaining the surface water. As mentioned above, there are no particular capacity restrictions for obtaining water from either of these two sources. Let the demand for water be represented by a linear demand function. Two situations may be envisioned. For the first, the value in use for a given quantity of water is lower than the cost of obtaining water from the alternative surface source (Part A of Fig. 10). The value of groundwater is then the minimum of either the value in use or the cost of obtaining water from the surface source. In this case, since the marginal cost curve for the surface water is situated to the right of the demand curve (BD), the value of groundwater is measured as the total area of the consumer surplus, or BCF.

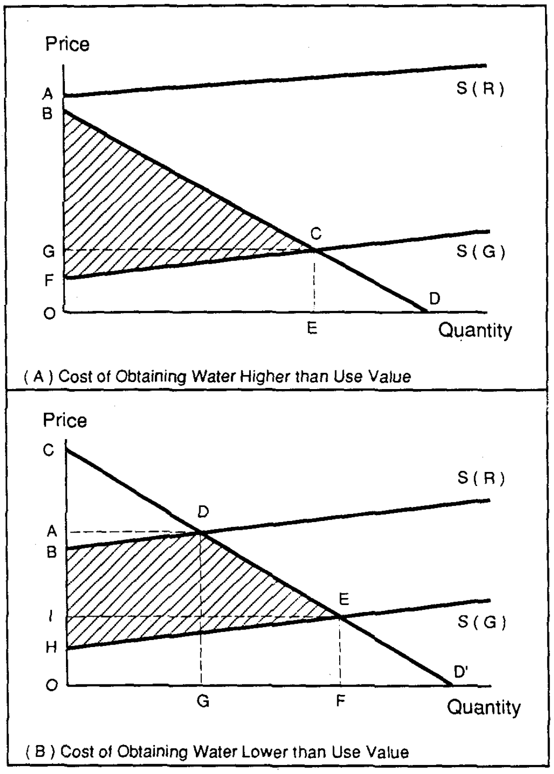

Figure 10. Value of water under alternative sources of supply.

Now, let us visualize another type of situation. Let the value of water in use be very high, and let it be higher, for some users, than the marginal cost of obtaining water from surface sources. This demand curve is shown as DD' in Part (B) of Figure 10 . In this type of situation, the value of groundwater is not simply the value in use but a slight modification of it. In this case the value is represented by the minimum of either the marginal cost of obtaining water from the surface sources or the value of water in that use. This is depicted by the area ADEI in Figure 10 (B).

This type of analytical framework is more accurate than either the alternative supply source method or any of the other methods for estimating the value of water in any given use.

5.1.4 Disaggregation of Total Value

The total value of groundwater in the Assiniboine delta aquifer was estimated in a disaggregated manner. Some of the values, particularly the use-related values, were estimated, while others, notably the nonuse-related ones, were not. A framework for a complete valuation process is shown in Figure 11 . Conceptually the total value of groundwater can be shown to be a total of use and nonuse values (Equation 2).

$$\text{Total Value} = \text{Use Value} + \text{Nonuse Value} \qquad (2)$$

As indicated above, the nonuse values were not estimated in this study, and to this extent, the values reported here may be considered to be an underestimate.

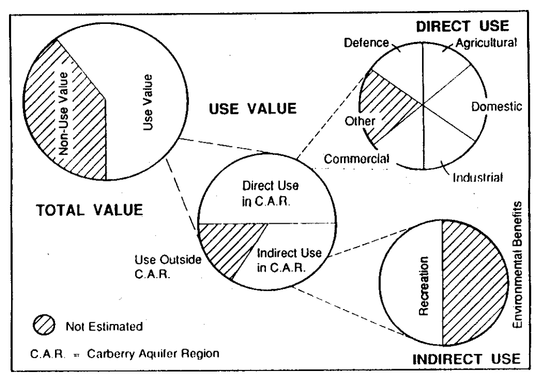

Figure 11. Estimation framework for the valuation of groundwater in the Assiniboine delta aquifer.

The use-related value of groundwater can further be disaggregated into two types: the value of the water used in the aquifer region and that used outside the aquifer region (Fig. 11). Again, the water used outside the CAR was not estimated due to lack of available information.

The water use within the CAR can then be broadly divided into two types, direct and indirect. The total direct water use in this study was subdivided. For each use, the value of water was estimated by using the most appropriate method for estimating the consumer surplus.

The following uses of water were included in the estimation:

1. Agricultural

- irrigation
- stockwater

2. Domestic

- rural farm
- rural nonfarm
- municipal

3. Industrial

4. Commercial

5. Defence (CFB Shilo)

There may be other unidentified uses of water in the aquifer region. Examples of this use may include farm-related water use other than stockwater and irrigation. To the extent these were not identified in the above list, an "other" water use category is shown in Figure 11 .

The indirect use of water includes that for recreational purposes, preservation of wetlands, and other environmental purposes. In this study, only the recreational water use was identified and its value estimated. The other environmental uses of water and their respective values were not included, partly due to lack of data.

One should keep in mind the scope of estimation for this study while interpreting the value estimates of this study.

5.2 ESTIMATION OF THE DIRECT-USE RELATED VALUE (ECONOMIC EFFICIENCY PERSPECTIVE)

It was noted in Chapter 4 that the value of water in any given use in this study was hypothesized to be equal to some average willingness to pay by the users. This WTP was approximated by the measure of consumer or producer surplus. The method of estimation for this surplus for a given use is described in this chapter, while most of the computational details and data sources are provided in Chapter 6.

5.2.1 Agricultural Water Use

The two types of agricultural water uses included in this study were irrigation and stockwater use. For each of these uses, the measure of producer surplus was used as a proxy to their willingness to pay. For irrigation, this measure was presented in Chapter 4 (Fig. 8). Estimation of this measure requires information on the cost of production of irrigated crops and their respective dryland cost of production. Assuming that the region is small, macro or market level effects from irrigation were assumed not to be present. Thus, the measure of producer surplus was estimated as follows:

$$PS = \frac{ATC_r - ATC_d}{Q_w} \qquad (3)$$

where

PS = producer surplus per unit of water use

ATC_r = average total cost of production for a given commodity under irrigation per unit of land

ATC_d = average total cost of production for a given commodity under dryland conditions per unit of land

Q_w = quantity of water used per unit of land

Assuming that there are no significant economies of size, the average producer surplus in equation (3) would be a close enough approximation of the willingness to pay for water from the aquifer.

Stockwater use is a demand for water derived from the demand for livestock products. Thus, the demand for water for livestock is functionally related to the level of livestock prices, the cost of obtaining water, and the cost of nonwater inputs. Such estimates of derived demand are not available for the region.

Therefore, a direct estimation of a demand function and its subsequent use for estimation of consumer surplus was not possible. Instead, the approach taken in this study was that of the "substitute product." In other words, the cost of obtaining water from the next cheaper source to the aquifer was used as the farmers' willingness to pay for water for its use as stockwater.

5.2.2 Domestic Water Use

Estimation of the value of domestic water use was done with the help of a synthesized demand curve, along with information on current water use and zero cost of water to the user. Estimates of the price elasticity of demand were obtained from the literature. Values were estimated per unit of water. More details on the methodology are presented in Chapter 6.

5.2.3 Industrial Water Use

Estimation of the value of industrial water use was based on a methodology similar to that for domestic water use. Elasticity of demand for water used for agricultural processing was obtained from other Canadian studies. A demand curve was simulated using this information and the present level of consumption and cost to the user.

5.2.4 Commercial Water Use

Information on the demand characteristics for commercial water use is scarce. Given that most of this water use is associated with hygienic and other personal uses, it was assumed to be similar in nature to domestic water use. Its value was estimated in a manner similar to that for domestic water use.

5.2.5 Water Use for the Canadian Forces Base

The demand characteristics for this type of water use are also not very well documented in the literature. A major part of this water use is for hygienic and personal purposes and should be similar to domestic water use in terms of demand characteristics. However, there may also be other uses of the water, details on which are very scanty. Given the lack of information on this type of water use, it was assumed that the demand elasticity for this type of water use would be smaller in absolute value than that for private domestic demand. The rest of the methodology was similar to that presented for domestic water use.

5.3 ESTIMATION OF THE INDIRECT-USE RELATED VALUE

The indirect water use for which a value was estimated in this study was that for recreational purposes. The methodology for this value can be presented as follows. First, the total value of recreational activity associated with the aquifer water is estimated. This value is generally expressed on a per visitor basis. Estimation is based on the technique of contingent valuation, as applicable to nonmarket goods. This value is denoted as VP_{rc} in equation (4). Multiplying it by the number of visitors (NV) provides us with the total value of recreation activity for a given site (TV_{rc}).

$$TV_{rc} = VP_{rc} \times NV \qquad (4)$$

$$VW_{rc} = \frac{TV_{rc} - C_f}{QW_{rc}} \qquad (5)$$

where

TV_{rc} = total value of recreational experience associated with the aquifer water

VP_{rc} = value of recreational experience per person-trip

NV = number of person-trips to the recreation site

VW_{rc} = net value of water for recreational purposes

C_f = cost of nonwater inputs associated with the recreational experience

QW_{rc} = quantity of water associated with the recreational site

The total value of this recreational experience is used in the estimation of value for water, using equation (5). The cost of all nonwater inputs (C_f) is deducted. The remaining value is the net value of water for recreational purposes. Dividing it by the quantity of water used for recreational purposes gives us the average value of water. Further details on this methodology can be found in Kulshreshtha (1991).

5.4 VALUE OF THE AQUIFER FROM A REGIONAL DEVELOPMENT PERSPECTIVE

The water drawn from the aquifer is of some regional significance. It sustains economic activity in the region, some of which is captured in the use-related value of water. However, the creation of economic activity such as irrigation has far broader impacts on the region than is captured in the direct value of irrigation water. This broader context is provided by the regional development perspective. In this study, the regional development significance of the aquifer is estimated in terms of economic activity generated in the region through direct-use related activities. The forward and backward linkages of the water use are captured by applying the concept of multiplier activity. An estimation of the level of the multiplier for the region although desirable could not be accomplished due to time and budget limitations. Multipliers were obtained from the input-output model of Manitoba for relevant economic activities. More details on this are provided in Chapter 9 of this report.

5.5 ESTIMATION OF THE ECONOMIC WORTH OF AN AQUIFER

Since water in the aquifer is renewable, its use could continue almost indefinitely, provided that level of water use was below the recharge rate of the aquifer. Thus, the value of water would be generated over a long period of time. One could translate the annualized values into the net present worth of the aquifer. In this study this worth was estimated as follows:

$$NPW_w = \sum_{i=1}^{s} NPVW_i \qquad (6)$$

$$NPVW_i = \sum_{t=1}^{L} \frac{VW_{it}}{(1+r)^t} \qquad (7)$$

where

NPW_w = net present worth of the aquifer

$NPVW_i$ = net present value of water in i^{th} use ($i = 1 \ldots s$)

VW_{it} = total value of water in the i^{th} use for the year t ($t = 1 \ldots L$)

r = rate of discount

The total value was a discounted value of the water values in various uses, aggregated at a given point in time. The current value of water in various uses were as estimated in the section above. The choice of the discount is a critical step in this analysis. More details on this estimation procedure are provided in Chapter 9.

Part Two

Results of Estimation

CHAPTER 6

Value of Groundwater for Different Uses

In this chapter, the value of groundwater is estimated using the analytical framework presented in Chapter 5. The estimation of each of the values in use was made individually, partly out of the consideration that a single methodology might not be appropriate. Major uses for which estimation of the value was carried out included irrigation, stockwater, domestic (rural farm, rural nonfarm, and municipal), industrial, commercial, and defence purposes. In addition, the estimation of the value of water in recreation, which is an indirect use of water, was carried out. In this chapter, all values are based on the concept of willingness to pay regardless of the opportunity cost of water. The latter consideration is taken into account in the next chapter.

6.1 VALUE OF GROUNDWATER FOR AGRICULTURAL USE

The two major agricultural uses of groundwater noted in Chapter 2 were irrigation and stockwater. The estimation of the value of water in these two uses was made separately. The results are presented in this section.

6.1.1 Value for Irrigation

The value of groundwater in irrigation was estimated by using the producer surplus as a proxy for farmers' willingness to pay for water in the CAR. The measure of producer surplus was the imputed marginal rent for water on irrigation farms. This rent was calculated as the difference between the long-term profits from farming under dryland vs. the same under irrigated conditions. In other words, it was equated to

$$PS = NP_i - NP_d \qquad (8)$$

where

PS = producer surplus

NP_i (or $_d$) = net profit from irrigation (or dryland)

Since net profit under any type of cultivation is the difference between gross revenue and the cost of production, and the latter term can be further divided into two parts—fixed costs and variable costs—equation (8) can be rewritten as follows:

$$PS = [(P * YD_i) - (FC_i + VC_i)] - [(P * YD_d) - (FC_d + VC_d)] \qquad (9)$$

which can be further modified as shown in equation (10):

$$PS = P\,(YD_i - YD_d) - [(Fc_i - FC_d) + (Vc_i - VC_d)] \qquad (10)$$

where

P = price per tonne of the product (under irrigation or dryland)

YD = yield per hectare (I = irrigation and d = dryland) in tonnes

FC = fixed cost per hectare in dollars

VC = variable cost per hectare in dollars

Equation (10) above should represent a long-term perspective, since all the relevant costs are being recovered. If one takes a short-term perspective where the fixed costs are sunk and therefore not relevant, the value of groundwater is approximated by the producer surplus in the short run (PS[S]) and can be calculated as shown in equation (11).

$$PS(S) = P\,(YD_i - YD_d) - (VC_i - VC_d) \qquad (11)$$

In other words, in the short run the value of water can be approximated by the short-term profit level under irrigation and dryland farming.

To estimate either the short-term or the long-term value of groundwater in the CAR, one needs information on the cost of production of crops grown under irrigation and the cost under dryland conditions.

Irrigated Crop Mix

According to published information, and information based on personal communications with local government officials and other residents in the region, potatoes are the major crop that is irrigated. Over the past several years, not only has the area under irrigated potatoes increased, but the proportion of dryland production of potatoes to total production has declined. About eight years ago, the proportion of dryland produced potatoes was about 90% of the total; today this share has decreased to 40% (based on information from Mr. Murray Frank, agricultural repreentative, Manitoba Agriculture, Carberry, June 1991). Two reasons may be cited for this change: (1) irrigated potatoes may be more profitable, particularly during the drier years; and (2) the local processor has shown a consistent preference for the irrigated potatoes, due primarily to their quality and their relatively stable production over time.

In addition to potatoes, at Shilo Farms (located near Shilo, Manitoba), cereals, sunflower, and other grains are produced under irrigation. According to the Water Rights Branch of Manitoba Natural Resources (Water Resources), farmers in this area (Range 17, Townships 9 and 10), hold a license to withdraw 4 350 acre-feet of water from the aquifer. Assuming an average water requirement of from 1 to 1.5 dam^3/ha, this would translate into 1 175 to 1 750 ha irrigated under these crops.

According to the information presented in Chapter 2, in 1989 there were an estimated 3 238 ha (or 8 000 a.) of irrigated potatoes. Thus, in total there is an estimated irrigated area of 4 413 to 5 000 ha in the CAR. For the estimation of the 1990 value of irrigation water, a mid-value estimate of the irrigated area was taken. Thus, it was assumed that some 4 700 ha were irrigated in the CAR, of which 3 238 ha were under potatoes and 1 462 ha under cereal grains and oilseeds.

Cost of Production of Potatoes

The costs of production per hectare of potatoes under irrigated and dryland conditions are shown in Table 13 . The 1989 cost of production was based on the information provided by the WESTARC Group (1990), whereas the 1990 cost information was based on a survey of 11 farms in Manitoba conducted by Manitoba Agriculture (1991) during the winter of 1990/91. The information obtained from the two sources is not wholly comparable. One major difference between the two sets of data is the definition of costs. The 1989 data set included selected items of variable costs and no fixed costs. Even within the variable costs, it is more than likely that the information was not taken from actual records or survey. The 1990 information was, in contrast, obtained from actual operations for dryland and irrigated production of potatoes and was also more comprehensive in terms of coverage. In addition, the definition of costs in this survey was based on the economic concept behind resource valuation.[1] For these reasons, the Manitoba Agriculture data was preferred for the valuation of groundwater.

This information was converted into net profits per hectare and per tonne, as shown in Table 14 . The net profit for growing potatoes under irrigation during 1990 was estimated at $937.20 per hectare, which translates into $39.26 per tonne of potatoes marketed. This compares to $218.20 per ha and $15.21 per tonne (marketed) for potatoes grown under dryland conditions. Thus, in the long term, the return for irrigated over dryland production is estimated at $719.00 per ha or $24.05 per tonne of potatoes marketed.

Net Willingness to Pay for Irrigation Water by Potato Producers

The returns to those using irrigation, over the returns to those using dryland to produce

[1] This is reflected in the fact that resources were priced at their market value or their opportunity cost. For example, the labour and investment costs included both the out-of-pocket expenses and the charge for owned resources.

Table 13

Costs of Potato Production, Manitoba, 1989 and 1990

Item	1990 costs in $/ha		1989 costs in $/ha	
	Irrigated	Dryland	Irrigated	Dryland
Seed	330.12	235.73	222.39	197.68
Fertilizer	134.17	94.95	210.03	148.26
Chemicals	144.63	116.95	128.49	128.49
Fuel and mach.	106.25	81.37	212.50	123.55
Custom work and rental	129.23	78.58	-	-
Repairs	254.43	211.34	148.26	148.26
Insurance and utilities	157.13	137.26	-	-
Land	172.97	172.97	111.19	111.19
Labour	528.05	370.82	195.21	116.13
Misc. incl. interest	174.43	146.97	27.18	27.18
Total variable costs	2 131.41	1 646.63	1 262.66	1 013.09
Depreciation	342.11	218.68		
Investment	535.95	289.01		
Total fixed costs	878.06	507.78		
Total cost of production	3 009.47	2 154.41		

Source: 1990 data from Manitoba Agriculture (1991) and 1989 data from the WESTARC Group(1990.

Table 14

Comparison of Unit Cost of Production and Returns from Irrigating Potatoes, Manitoba, 1990

Particulars	Unit	Irrigated	Dryland	Difference
Yield per hectare	(t)	23.87	14.35	9.52
Price in 1989	($/t)	165.34	165.34	-
Gross revenue	($/ha)	3 946.67	2 372.63	1 574.04
Returns over var. costs	($/ha)	1 815.26	726.00	1 089.26
Returns over total costs	$/ha)	937.20	218.20	719.00
Variable costs	($/t)	89.29	114.75	-
Total cost of production	($/t)	126.08	150.13	-
Returns over var. costs	($/t)	76.05	50.59	25.46
Returns over total costs	($/t)	39.26	15.21	24.05

Source: Calculated from data in Table 13 and information from Manitoba Agriculture (1991).

potatoes, can be equated to their willingness to pay for groundwater. Thus, on average, the maximum willingness to pay by the irrigation farmers for the groundwater obtained from the Assiniboine delta aquifer would be $719 per hectare. Assuming an average annual input of water at 1.169 dam^3 per hectare (or seven inches per acre), this would result in a value of $615.07 per dam^3. Similarly, in the short term, the value of water for irrigating potatoes is estimated at $931.79 per dam^3.

These WTP estimates should be taken as approximations of the average WTP and not those of the marginal WTP, since different producers would have different levels of cost of production and therefore different levels of WTP for groundwater. However, without further study of the supply response of the producers under irrigated and dryland conditions, it is impossible to estimate the supply functions for potatoes under those conditions and to estimate the marginal WTP for groundwater.

Net Willingness to Pay for Water by Producers of Other Crops

Systematically collected data on the costs and returns of irrigated and dryland production are not available for other grain, forage, and oilseed crops. Some cursory data on a comparative study of irrigated and dryland farms is reported by Kraft et al. (1981). However, these data are somewhat dated, since they pertain to the year 1979. For lack of a better alternative, the following procedure was followed: The information contained in the above publication for the average difference in the cost of production per acre of wheat, tame hay, and corn silage was taken. These cost differences were inflated to 1990 levels by using the farm input price index for western Canada, assuming that these three crops were grown in equal proportion. The 1989 prices for these products were obtained from Manitoba Agriculture (1989). These prices were multiplied by the average irrigated and dryland yields to obtain an estimate of returns over variable costs. This estimate was taken as an approximation for the producers' WTP for water. This estimate was $198.29 per dam^3 or $231.80 per hectare. Caveats similar to those noted above should apply for this estimate.

Estimated Total Value of Groundwater for Irrigation

The total value of water used for irrigating various crops in the CAR was estimated by multiplying the average willingness to pay for different crops by their respective water use. For this calculation, the irrigated area in the CAR was taken to be 4 700 ha, of which 3 238 ha were under potatoes and the rest under other crops. Using the net WTP estimates, the total value of water in 1990 was estimated at $2.667 million per annum. This results in a weighted average value of water for irrigation of $485.42 per dam^3. If one accepts the commitment for irrigation water use at 14 412 dam^3, as estimated on the basis of water rights data, the total value of groundwater in the region for irrigation would increase to $7 million annually. This value reflects the long-term value, since farmers are recovering all their costs—actual or imputed.

6.1.2 Value for Stockwatering and Other Farm Uses

In Chapter 2, it was estimated that in the Carberry aquifer region, 957 dam^3 of groundwater is required for stockwatering and another 491 dam^3 of water for other farm uses. Thus, a total of 1 448 dam^3 of groundwater may be withdrawn for these agricultural purposes. The value of this water was estimated using the method of replacement cost. In other words, this criterion was, what would it cost the farmers to replace this water had there been no groundwater available locally? Given that the water used for these purposes is small and indispensable, it is assumed that its demand is very inelastic. In areas where water is not available locally, farmers haul water from the neighbouring communities. For shorter distances, this approach is feasible. However, if there were no groundwater, none of the neighbouring communities would have any water available either. Therefore, the cost-of-hauling approach was not applied in this study.

An alternative to groundwater in the region would be water diverted from the Assiniboine River. The Manitoba Regional Division of the Prairie Farm Rehabilitation Administration has developed cost estimates for various diversion schemes (PFRA 1986). In one scheme selected for this purpose, a pipeline with a flow of 1.4 m^3/s (50 cfs) is designed to carry water to the vicinity of Pine Creek and then farther by a canal (Fig. 12). The water is pumped from the Assiniboine River, as necessitated by the topography of the region. The total capacity of the scheme is 1 672 dam^3 of water.

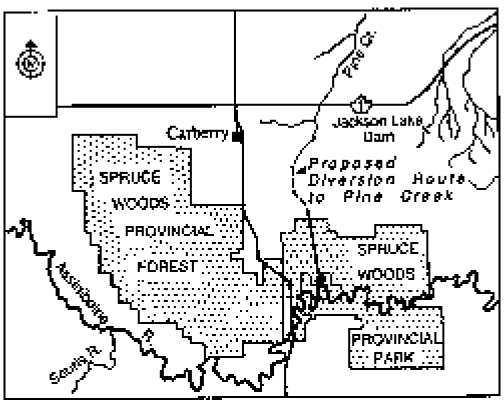

Figure 12. Map of the Carberry aquifer region showing diversion of water from the Assiniboine River into Pine Creek.

The total cost of the project, including that of pipelines, pumping station, canal, and electrical works required, was estimated at $8.4 million in 1985 dollars. Inflating this amount by 4% per annum, in 1990 the cost would increase to $10.2 million. Annual costs were estimated under the assumption that the project life would be 50 years and that an 8% interest rate would be appropriate. This cost was estimated to be $835 000. The operation and maintenance costs were assumed to be 2% of the capital cost. The total cost of delivering the 1 672 dam^3 of water was estimated at $1.04 million. This amounts to a value of $621.86 per dam^3, delivered at the Pine Creek site.

The cost to the users of hauling this water to their own farm is even more difficult to estimate, since no recent study of water hauling costs are available. For the sake of simplicity, it was assumed for this estimation that this cost is not high and therefore can be ignored. Using the above methodology, the total cost of replacing groundwater for stockwatering use was estimated at $900 450 dollars.

6.2 VALUE OF GROUNDWATER FOR DOMESTIC USE

In Chapter 3, it was noted that the regional domestic water use comprised three types: rural farm, rural nonfarm, and municipal (Neepawa). The value of water methodology involved the estimation of the consumer surplus. One key parameter of this estimation is the nature and magnitude of price elasticity of water for a given demand. However, no study has been carried out that has reported this type of information for Manitoba as a whole, or for the local region. A fresh study of the consumers in the region would be equally futile, since residents do not pay any water-associated costs, except in Neepawa. For this reason, a survey of water demand elasticities was carried out using the available studies in the literature. The value of water was approximated as the average willingness to pay (rather go without), which was estimated as the value of consumer surplus, using the following formula, as suggested by Muller (1985):

$$CS = P_0 Q_0 \frac{[P_a / P_0]^{n+1} - 1}{n + 1} \qquad (12)$$

where

P_0 = base price of water in \$ per dam^3

P_a = new price of water in \$ per dam^3

Q_0 = original quantity of water consumed, in dam^3

n = elasticity of demand for water in the region

The average value of water was estimated simply as the ratio of total consumer surplus to the original quantity of water intake.

Based on a survey of available studies, a range of price elasticity of domestic demand for water is noted (summarized in Table 15). The nature of the elasticity depends upon two major factors: the type of data used, i.e., time series data or cross section data; and the nature of functional specification, i.e., linear or logarithmic functional form. The estimates varied between -0.15 and -0.81. There is no apparent explanation of this variability,

Table 15

A Summary of Price Elasticity of Demand for Water

Authors	Type of data	Price elasticity: Linear specification	Log specification
Gibbs (1978)	CS	-0.62	
Danielson (1979)	TS	-0.27	
Hanke and de Mare (1982)	PL	-0.15	
Attanasi et al. (1975)	PL	-0.81	
Gardner (1977)	CS	-0.24	-0.15
Foster and Beattie (1981)	CS	-0.27	
Jones and Morris (1984)	CS	-0.18	-0.34

CS = cross-section data.
TS = time series data.
PL = pooled data set.

other than the fact that the data are obtained from different data points, for different time periods, and for different locations. Furthermore, many of these studies are for urban areas. Here the availability of an adequate size sample is almost guaranteed, and therefore collection of data is relatively easy. In addition, large urban centres have shown interest in water demand management, where a knowledge of price elasticity is crucial.

One major limitation of these estimates is that no relationship is shown with respect to the size of the community and the magnitude of demand elasticity. Furthermore, as all the studies are for the United States, direct comparability with the study region is of dubious value. Among Canadian studies, one by Brockman et al. (1987) has estimated the size of price elasticity for various-sized communities. In this study, the selection of the price elasticity of demand for domestic water use was based on the study by Brockman et al. (1987). It was felt that the comparability between this study and that of Brockman et al. was less suspect than that with the American studies, carried out for a large metropolitan area.

Based on the results of the study by Brockman et al. (1987), the following price elasticity estimates were accepted for this study: -0.23 for small communities and open areas, -0.42 for medium-sized nonfarm communities (500 to 1500 people), and -0.53 for large rural nonfarm communities (1500 to 5000 people). Using the present level of consumption and a very small nonzero price of water (assumed at $\$1/dam^3$), average WTPs were estimated for alternative levels of prices (Table 16). The value of groundwater, using this approach, was estimated to be $\$451$ per dam^3 for rural farm households. For the households in small nonfarm communities, the value was slightly lower, at $\$140$ per dam^3, and even lower for the residents in Neepawa, at $\$74$ per dam^3 Of course, this value is directly proportional to the magnitude of their elasticity: the higher the elasticity, the lower the consumers' willingness to pay for water.

Table 16

Value of Groundwater for Domestic Use in the Carberry Aquifer Region, 1990 ($\$/dam^3$)

Value based on maximum prices of water	Rural farm	Rural nonfarm	Town of Neepawa
500	154.20	61.66	37.36
1500	361.03	118.14	64.04
2000	450.87	139.91	73.62
4000	769.77	260.00	102.80

The estimates in Table 16 were used to derive the total value of water for domestic use (Table 17). Here the lower value refers to the value of water established under the maximum price of water at $500 per dam^3, whereas the upper value uses the value of water established under the assumption that the maximum price of water is $4000 per dam^3. The weighted average value of water for domestic use was estimated to be between $119.8 and $556.46 per dam^3. The total value of this water was similarly estimated to be between $139 927 and $659 966 per annum. The relatively lower (or higher) value of water reflects both the quantity used and the elasticity of demand for water for different types of users. Again, these estimates should be taken as the average willingness to pay for water used for domestic purposes and not marginal willingness to pay for water in the CAR. Furthermore, one should also note that although the aquifer supplies only a portion of the total water needs of the town of Neepawa, in this estimation it was assumed that all the needs are met through the Assiniboine delta aquifer. This may have overestimated the total value of groundwater.

Table 17

Total Values of Water for Domestic Use

Type of use	Lower value	Upper value
Rural farm	$118 271	$ 590 414
Rural nonfarm	15 230	51 870
Neepawa	6 426	17 682

6.3 VALUE OF GROUNDWATER FOR INDUSTRIAL AND COMMERICAL USES

6.3.1 Value for Industrial Use

The major industrial water user in the CAR is a food-processing company located near the town of Carberry. The total annual water used by this plant is around 905.3 dam^3, a major part for the processing of potatoes (Table 18). The above quantity of water reflects the water intake. The annual discharge of the water from the plant is 850 dam^3, making a net consumption of only 55.3 dam^3 per annum.

Table 18

Breakdown of Total Annual Water Used by the Food-Processing Company

Purpose	Amount (dam^3)
Process	634.5
Cooling	118.8
Sanitary	151.6
Other	0.4

The economic value of industrial water use was estimated using the method of consumer surplus as a proxy for the willingness to pay for water. Renzetti (1987) has reported the price elasticity for water demand by the food processing plants in Manitoba at -0.72. This elasticity estimate was assumed to apply to the water demand by the food-processing company. Using equation (12), the value of this water was estimated using different levels of maximum price for water (Table 19).

Thus, if we take the lower value of water, the total value of groundwater for use at the food-processing company is estimated at $15 910, whereas at the highest level of price, the total value may be about $29 738 per annum.

In addition to the above, 64 dam^3 of water is used by other industries in Neepawa. A figure of -0.2 was selected from the available price elasticity estimates to represent manufacturing use (Renzetti 1987). Using this estimate, the average willingness to pay for these industrial uses was estimated at $179.09 (at a maximum price of $500) to $950.58 (at a maximum price of $4 000) per dam^3. The total value of this

Table 19

Values of Water Used by the Food-Processing Company ($/dam^3)

Maximum price	Value of water
500	16.78
1 500	24.11
2 000	26.43
4 000	32.86

Table 20

Values of Water for Commercial Use ($/dam^3)

Maximum price	Value
500	94.50
1 500	198.91
2 000	241.51
4 000	385.15

water is estimated to range from $11 462 to $60 857 per annum.

Combining the two estimates, the total value of water for industrial uses in the CAR is estimated to range from $26 653 to $90 595 per annum.

6.3.2 Value for Commercial Use

Commercial water in the CAR is a very small portion of the total use. As estimated in Chapter 3, the total water use for this purpose is only 192.5 dam^3 annually. One of the most difficult problems in the estimation of an economic value of this type of water use is that relatively little is known in terms of its demand characteristics. In this study, it was assumed that this demand is similar in character to the domestic demand, except that it is more price inelastic. An elasticity estimate of -0.33 was assumed to apply in this type of water use. The method of valuation was that of consumer surplus as a proxy for the willingness to pay for water. Four levels of maximum prices were used for this estimation (Table 20). These values were used to obtain the total value of water used for commercial purposes. This value ranged from $18 191 to $74 141 per annum.

6.4 VALUE OF GROUNDWATER FOR THE CANADIAN FORCES BASE

The Canadian Forces Base near Shilo is one of the largest single water users in the region. Water use here was reported to be 775 dam^3 per annum during the year 1990-91. More details on this water use, including the nature of the use and demand characteristics, are not known at this time. The approach used in the estimation of the value of water for this use was that of consumer surplus. However, since no price demand elasticity estimates for this type of demand were available, the following assumptions were made:

1. This demand for water is primarily for hygienic and other domestic purposes.

2. The price elasticity for this type of demand is lower than that for the local domestic demand for water since defence is an important function.

3. 3. The willingness to pay by the federal government is likely to be higher than that of local residents, making this demand more price inelastic.

Using the above assumptions, the price elasticity of demand for this type of water use was assumed to be -0.2. Using this estimate and the four levels of maximum price of water used in the above cases, the average value of water and the total willingness to pay were estimated (Table 21).

Thus, depending upon the upper limit of the estimation of the willingness to pay, the value of water for defence purposes could range from $179 to $951 per dam^3. The total value of the quantity of water used in 1990 would range between $138 793 and $736 700 per annum.

Table 21

Values of Water for Canadian Forces Base Shilo ($/dam^3)

Maximum price	Value	Total willingness to pay
500	179.09	138 793
1 500	433.04	335 608
2 000	545.43	422 709
4 000	950.58	736 700

6.5 TOTAL USE-RELATED VALUE OF GROUNDWATER IN THE REGION

The above uses of water and their respective values, along with the total value of groundwater in use, are summarized in Table 22 . The average value of water in different uses ranged from a low of $16.78 per dam^3 in industrial use to a high of $951 per dam^3 in stockwater and other farm type uses of groundwater.

6.6 VALUE OF WATER FOR INDIRECT USE—RECREATIONAL

Recreation is a major indirect use of the groundwater in the Carberry aquifer region. There is a discharge of water from the aquifer into the Assiniboine River, which travels through the Spruce Woods Provincial Park. The park is a major recreational site for the local people, as well as an attraction for visitors from other parts of Manitoba and North America. The aquifer is also directly or indirectly related to some of the vegetative and other physical features that attract visitors to the park. There is unique vegetation in the park, some of which may be related to the presence of groundwater in the area.

As mentioned in Chapter 5, the value of water for recreational purposes was estimated indirectly, through the value of recreational activities. This requires information on visitation rates, economic and demographic characteristics of the visitors, as well as on their willingness to pay for the unique recreational experience offered by the park. Unfortunately, much of this information is lacking, including the number of visitors. Discussions with the local officials indicate that at least 10% of the total visitors are of nonlocal origin. The Manitoba Department of Parks and Renewable Resources has estimated the number of visitor-days to be between 4500 and 6000. Taking the mid-value of this range, we have assumed the number of visitor-days to be 5250 per annum. Since no survey of the willingness to pay of these visitors has been carried out, data were borrowed from neighbouring Saskatchewan. Using the information provided in O'Grady et al. (1987) for three regional and provincial parks (Clearwater Lake, Duck Mountain Provincial Park, and Lac Pelletier Regional Park), the average willingness to pay for a visitor-day of

Table 22

Summary of Relative and Total Values of Groundwater in Different Uses in the Carberry Aquifer Region, 1990

Type of use	Average value of water ($/dam^3)	Total value of water (thousands of dollars)
Irrigation	485.82	2667
Stockwater and other farm use	621.86	900
Domestic	119.8 - 556.46	138 - 660
Industrial	16.78 - 32.86	27 - 91
Commercial	94.50 - 385.15	18 - 74
Defence	179.10 - 950.58	139 - 737
Total		3889 - 5129

recreational experience was estimated to be $4.46 in 1986 dollars. Adjusting this figure to the increase in the cost of living, one arrives at a value of $5.17 per person per day. Multiplying it by the estimated number of visitor-days, the total value of the recreational experience is estimated at $26 161 per annum.

CHAPTER 7

Value of Groundwater Using the Opportunity Cost of Water

The true value of groundwater, as discussed in Chapter 5, is somewhere between its use value and the value established through the cost of obtaining water of comparable quality and in equal quantity from some alternative source. In the case of the Assiniboine delta aquifer, this alternative cost must be estimated to ensure that the use-related values are a correct reflection of the true value of the groundwater in the Carberry aquifer region. In this chapter, the value of water is estimated using secondary information available to the author at the time of writing.

7.1 SELECTION OF ALTERNATIVE SITES

In selecting alternative sites for water to replace the groundwater in the Assiniboine delta aquifer, one must be cognizant of three major considerations:

1. The quality of water from the aquifer is very high. In fact, the groundwater can be used without any treatment. It has no major problems such as harshness or odor. In selecting an alternative source of supply, the quality of water must be an important consideration.
2. The quantity of water to be replaced must also be taken into account. There may exist some sources for replacing smaller quantities of water, but to replace the entire recharge capacity of the aquifer, which is presently estimated at 60 378 dam^3, would require a major source of water.
3. The groundwater from the aquifer is highly reliable. Although there may be occasional lowering of the water table in the fringe subbasins, the major part of the aquifer is a reliable source of water for the users.

Based on various investigations by the Prairie Farm Rehabilitation Administration in connection with devising alternatives for supplying water to the Westlake area and for increasing irrigation near the Assiniboine River, a number of alternative sources of water have been considered. Some of these may be very appropriate for replacing the water from the Assiniboine delta aquifer.

One of the major sources of water in the region is the Assiniboine River, along with its major tributaries, the Shell River and Little Saskatchewan Creek. Before the construction of the Shellmouth dam, the natural historical flows had been extremely variable, both from year to year and within a year. The Shellmouth dam regulates the minimum flow of water through the river, provides flood protection, and maintains the minimum flow required to preserve the regional ecosystem. Under the present regulations to operate the dam, the minimum assured flow at Portage la Prairie is 8.5 m^3/s. Of this, about 75% is already allocated (PFRA 1989, p.7). Thus, if any of this water were to be used within the Carberry aquifer region, either the Shellmouth dam would have to be built for a larger capacity and operated so as to release a larger flow of water into the Assiniboine River or the downstream use of water would have to be curtailed. The option of building a larger capacity dam was not considered appropriate for this study without a thorough review of the water flow regime in the upstream region, and such an investigation was considered outside the scope of this study. Furthermore, estimation of the effect of a major water diversion near the Carberry aquifer region on the downstream users was also considered beyond the scope of this study. For these reasons, this alternative was not used.

A second possible alternative source of water to replace groundwater in the region is Lake Manitoba. This alternative could provide an almost unlimited quantity of water to the region, enough to satisfy current as well as future water use. This alternative has been investigated by the Manitoba Water Services Board. Accor-ding to the PFRA report (1988, p. 13), the alternative would involve a raw water intake near Lynch Point, located approximately 3 km offshore. This would be necessary, particularly during low lake levels and winter ice cover, on account of the shallow nature of the lake. This would be complemented by a dugout in which to store some water in the event of lake intake problems or severe water quality fluctuations. The water would have to be piped to the CAR, perhaps to some central point near a major use centre. The town of Neepawa was selected to be such a centre. An extra pumping station would be needed to lift the water over the escarpment. Since the quality of water from the lake is lower than that from the aquifer, the water would have to be treated for domestic use. Untreated water could be distributed to farm users using a distribution pipeline system. An approximate concept of this system is shown in Figure 13 .

One area of concern regarding this source is the quality of the water. Up to the present there has been no investigation as to its acceptability by the local residents. Studies have shown that the Lake Manitoba water is relatively hard, has higher chloride concentration than recommended for treated municipal water, and is relatively high in sodium concentrations, which may be a concern for some residents of the CAR. However, lacking this information, one must assume that this water would be acceptable locally after being properly treated. This issue needs further investigation, however.

7.2 ECONOMIC COST OF WITHDRAWING WATER FROM LAKE MANITOBA

The economic costs of diverting 1 700 dam^3 of water annually have been estimated by PFRA in an exercise to develop alternatives to satisfy

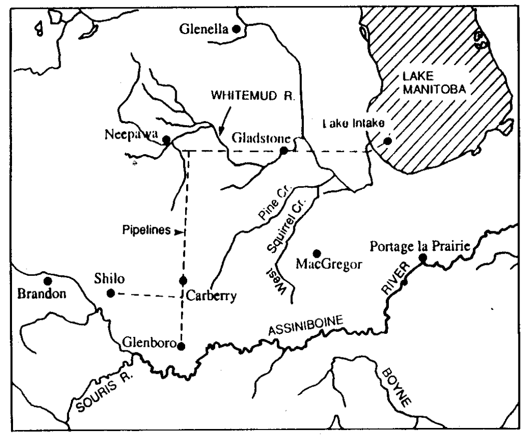

Figure 13. Rough design of a water supply system from Lake Manitoba.

the water needs of the Westlake region. These costs were used as a guide in developing the costs of the system outlined above. The costs of the system were estimated for the year 1990 through inflating the PFRA estimates, which referred to 1988.

The cost of obtaining water from Lake Manitoba and treating it for domestic use was estimated at $2 573 per dam^3, including both the capital cost and operating costs. (In this calculation, the project was assumed to have a life of 50 years; a discount rate of 8% was used.) For untreated water, this cost was slightly lower, $2 318 per dam^3. Details on these calculations are given in Appendix B.

7.3 REVISED VALUE OF GROUNDWATER

In Chapter 6, the value of groundwater was estimated using the criterion of value in use for a specific user. In Chapter 5, the argument was presented that the upper limit on this value in use would be the opportunity cost of this water; in other words, the value in use could not exceed the price (or cost) of obtaining that water from an alternative source. In Section 7.2, this cost was estimated. Since these estimates are somewhat crude, we have accepted the cost of treated water at $2 500 per dam^3 and that of untreated water at $2 300 per dam^3. These values are used as upper limits to the price of water for various users, in a revised calculation of the value of groundwater for various uses.

Using the above estimates, the value of groundwater needed to be revised in only a few uses. Since the value of water for irrigation was lower than the opportunity cost of water, there was no need for revision. Similarly, for stockwater use, the value of groundwater was based on an opportunity cost of obtaining water from the Assiniboine River, and since this cost was less than that of obtaining water from Lake Manitoba, there was no need for revision. However, the value of groundwater for domestic, industrial, commercial, and defence establishments in the region would be constrained by the above cost of obtaining water. Thus, there was a need to revise these values.

A revision of the value of groundwater for domestic, industrial, commercial, and defence establishments was done in a manner similar to that in Chapter 6, except that Pa (alternative price of water) in Equation (12) was restricted to \$2 500 per dam^3. The revised value of groundwater and the total value of the consumer surplus for these uses is shown in Table 23 . The value of water using this method of calculation is estimated to range between \$28.36 per dam^3 for the food-processing company and \$652.27 per dam^3 for other industrial uses and CFB Shilo. The total value of the water used for all these purposes was estimated at \$1.091 million annually. If we were to add the value of water for irrigation and stockwater from Table 22 , the total value of water currently being used from the Assiniboine delta aquifer would be an estimated \$4.658 million annually. This estimate is some \$471 000 lower than the higher estimate of the total value of water in Table 22 and represents a correction for the opportunity cost of water, as shown in Table 24 . Adding the indirect-use related value of water (obtained from the aquifer) brings the total annual value of the groundwater from the Assiniboine delta aquifer to \$4.68 million. This value reflects the contribution of the aquifer to the economic welfare of Canadians living in the Carberry aquifer region. In other words, if the aquifer were not present, the economic welfare of Canadian society would diminish by this amount, on an annual basis, for the remaining productive life of the aquifer.

Table 23

Revised Value of Groundwater and of Total Consumer Surplus, 1990, for Selected Uses, in the Carberry Aquifer Region

Type of use	Value of water (\$/dam^3)	Total consumer surplus (in thousands of \$)
Domestic		
Rural farm	535.64	410.8
Nonfarm	159.48	33.5
Neepawa	82.00	14.1
Agric. processing	28.36	25.7
Other industrial	652.27	41.7
Commercial	280.70	54.0
CFB Shilo	652.27	505.5

Table 24

Revised Value of Assiniboine Delta Aquifer Water Based on Use-Related and Economic Efficiency Perspective, 1990

Type of use	Value (in millions of dollars)
Agricultural	
Irrigation	2 667
Stockwater	900
Domestic	464
Industrial and commercial	121
CFB Shilo	506
Subtotal	4 658
Indirect use: recreation	26
Total value	4 684

CHAPTER 8

Economic Value of Groundwater From a Regional Development Perspective

So far in this study, the value of groundwater has been perceived from an economic efficiency perspective. In this way, the value of water was defined as the contribution made by the body of groundwater towards the welfare of its users. This contribution was measured as the willingness to pay and was estimated using methods suitable for different users. However, economic efficiency, although an important objective, is not the sole objective of either society at large or its policymakers. An equitable distribution of income and creation of employment opportunities in selected regions is an equally (if not more) important objective of Canadian regional development policies. From an equity perspective, evaluation of the Assiniboine delta aquifer may present a different picture of its value than that held by its users. This value arises through the fact that the use of this water produces employment and income opportunities for the local residents that would be lost if the aquifer water was not present.

In this chapter, the estimation of the value of groundwater is carried out from a regional development perspective. In other words, contributions made through the use of aquifer water to the local and provincial economy are estimated using secondary information available to the author.

8.1 CONCEPT OF VALUE

In a regional development context, the value of a resource is equated to the additional economic activity generated by its use in the regional economy of reference. In the context of the Assiniboine delta aquifer, two regional economies could be of interest to the policymakers: those of the Carberry aquifer region itself and of the province of Manitoba. The value of the groundwater can be conceived as its contribution to the net economic output of the region (of the CAR or the province). This contribution to the net regional product (NRP) is a result of the multiplier effect that exists in any regional economy. In other words, the capital and current expenditures of the water users add to the NRP of the region, which would not be present without the groundwater from the aquifer. This argument is based on the assumption that these economic activities would not be pursued at all in the absence of the groundwater from the Assiniboine delta aquifer.

Contributions of an economic activity can be divided into two major categories: direct and indirect. The indirect contributions can be further subdivided into two types, one resulting from the backward linkages of an economic sector with the rest of the economy and the other resulting from the forward linkages of an economic sector with other production sectors. Let us take the case of irrigated agriculture to illustrate these linkages and their impacts. If farmers did not have access to groundwater from the Assiniboine delta aquifer, there would be no irrigation and they would have to revert to dryland farming. Thus, the direct contribution of the groundwater for irrigation is the farmers' increased income earned from using the water for irrigation (assuming that there are positive returns from irrigation). In addition, the irrigated potato farming requires a higher level of inputs on a per hectare basis. Thus, the conversion of the dryland into irrigated production means a need for more inputs, such as fertilizer, pesticides, and labour. The increased outlay translates into more economic activities by the local or provincial businesses. These contribute to the local or provincial NRP. These contributions are called backward linkages of the irrigated agriculture sector. In addition to the backward linkages, an industry can have forward linkages. In the case of irrigated agriculture, these linkages result from the use of products of irrigated agriculture in generating additional economic activities. The processing of potatoes by the company at Carberry into french fries is an example of this type of linkage. The processing activity itself can have two types of impact: (1) the industry requires inputs, purchased locally or within the province, or imported from other Canadian provinces or other countries; and (2) the wages and salaries paid to workers as remuneration are further spent in the local area and thus create a multiplier effect.

The above types of direct and indirect effect of groundwater use can be associated with each of the uses of water. The estimation of the direct contributions of a sector is relatively simple and has already been demonstrated for some uses (see Chap. 6). The indirect contribution of a certain expenditure is usually done with the help of an input-output model. In order to accurately estimate the local area (the CAR) impacts, one needs an input-output model of that area. Such a model is, however, unavailable. To the best of the author's knowledge, a recent, disaggregated input-output model of Manitoba is not readily available. Therefore, a neighbouring region's (in this case, Saskatchewan's) input-output model, as reported by Kulshreshtha et al. (1991), and the PRARIE model of the PFRA (for details see Kulshreshtha and Yap 1985) have been used. Readers must be cautioned that these multipliers are, at best, approximations of the actual situation in the CAR.

A typical measurement of the net regional product is the gross domestic product at factor prices. This value includes returns to all factors of production and excludes the charges for capital consumption allowance. The value of water from the regional development perspective can be measured as follows:

$$RDVW = \sum_{i=1}^{j} direct\ GDP(i) + \sum_{i=1}^{j} indirect\ GDP(i) - DC \qquad (13)$$

where

RDVW = total value of water from a regional development perspective

j = number of water user categories

direct GDP(i) = direct contribution of water user category (i) to the gross domestic product at factor cost

indirect GDP(i) = indirect contributions of the water user category (i) to the gross domestic product at factor cost

DC = correction for double counting if present in the indirect contributions of various water user categories

The correction for double counting may be necessary for some situations and not for others.

If one divides the estimated value of RDVW by the quantity of water used, one can obtain an average value of water. The calculation of the value, as noted above, can be done either for the local region or for the province as a whole. In this study this value is estimated only at the provincial level.

8.2 METHODOLOGY OF ESTIMATION

To estimate the total (direct and indirect) contribution of an economic activity to the provincial gross domestic product (at factor cost), one needs two sets of information: (1) the level of direct contributions of the activity and (2) an appropriate multiplier estimate for the generation of the indirect economic activity by the direct-water-use economic activity. In this study, the uses of groundwater from the Assiniboine delta aquifer for the following were assumed to have an economic impact on the region and/or the provincial economy:

- irrigation of potatoes
- raising of livestock
- agricultural processing

- other industrial activities in the region
- defence (CFB Shilo)
- recreational activities at the Spruce Woods Provincial Park

To attribute the indirect activity generated by any of these water users to the aquifer, one must ask whether these activities would exist without the aquifer. Only the activities that are strongly linked with the availability of water from the aquifer should be included in this estimation. Let us discuss the water users in the order listed above.

The irrigation water users would not exist in the region without the water from the aquifer. Thus, all the economic activities associated with irrigated potato production and its indirect contribution through the backward linkages can be attributed to the availability of groundwater. The livestock activity, although dependent upon the availability of good quality and the required quantity of water, could not be considered to be directly dependent on the presence of groundwater from the aquifer. If the aquifer were not present, the livestock raising would move to areas in the vicinity of the Assiniboine River, or failing that, livestock farms would develop their own source of water through farm dugouts. For this reason, the indirect effects of the livestock sector were not included in this valuation of water.

The presence of agricultural processing, that is, the processing of potatoes into french fries, is a forward linkage of irrigated potato production. It is safe to assert that if there were only dryland potato production in the region, the potato processing firm might have moved to a region where there would be an assured supply of good quality potatoes. For this reason, the backward linkages of this operation were included in the valuation of the regional development value of groundwater.

The other manufacturing industries in Neepawa and CFB Shilo were assumed not to be directly linked to the availability of water from the aquifer. The primary motivation for this was the fact that water is a very small component of the total operations of these economic activities. Therefore, the availability of water was not regarded as a crucial factor in their location decisions, and thus one could not justify that their activities were based on the availability of groundwater from the aquifer.

The recreational activities associated with the Spruce Woods Provincial Park could be partially associated with the availability of groundwater in the region. The vegetation and the wildlife in the region could have some linkages with the groundwater. However, the park is located on the banks of the Assiniboine River, and some of the recreational activities at the park may also be on account of the water released from the Shellmouth dam. Thus, at best the association between the groundwater in the region and the recreational activities is weak. Furthermore, no surveys have been conducted for estimating the expenditures of recreationists in the park. Such expenditure data would become the basis of the direct contribution of this type of water use. For these two reasons, this contribution of the aquifer was not included in this study.

Thus, the two uses of groundwater for which total (direct and indirect) contributions were estimated were irrigation and potato processing.

8.2.1 Methodology for Irrigated Production

As noted earlier in this report, the major crop grown under irrigation is potato, with a relatively small area devoted to some cereals and oilseeds. For potato, the direct contribution of groundwater to the level of provincial output (as measured in terms of gross domestic product at factor cost) was estimated as the marginal contribution of irrigated potato production over and above the dryland production. This contribution was estimated from the data presented in Chapter 6.

The second set of information, the appropriate multiplier, was based on the PRARIE model and some judgment on the author's part. The multiplier used to estimate the indirect contributions was a ratio-form type II multiplier.[1] Its value was assumed to be 3.2.

1 The type II multiplier refers to the changes in the economic output resulting from (1) the purchase of inputs (excluding wages and salaries) and (2) the re-spending of the wages and salaries paid by the sector in question. The first type of linkage would create GDP through increasing

For the other irrigated crops, information on the direct GDP contributions was based on the data provided by Kraft et al.(1981) and other studies for the South Saskatchewan River Irrigation District. The ratio-form multiplier selected for these crops was 2.8. The slightly smaller value was based on the fact that these crops are not so input-intensive as potato.

8.2.2 Methodology for Agricultural Processing

The economic impact of the Carberry food-processing company on the provincial economy was based on the information obtained from the WESTARC Group (1990) report. These data pertain to the year 1989 and were considered to be a good approximation of the situation that existed during 1990. Primary data collection for the year 1990 was not considered feasible on account of confidentiality problems and time and budget constraints of the study. The multiplier value was selected from a review of various input-output models for Manitoba and Saskat-chewan. A pseudo-output multiplier of 1.6 and a pseudo value-added multiplier of 0.78 were used in the study. Adjustments were also made for the fact that the plant uses potatoes grown under irrigation as well as those grown under dryland conditions. The contribution made by groundwater was based on an apportionment of the total, using the quantity of raw potatoes as a basis for this apportionment.

8.3 ESTIMATED VALUE OF WATER

In this section, the economic value of groundwater is estimated from a regional development perspective. The two water-using activities that were considered to have very strong regional development connotations were irrigation of potatoes and cereals and oilseeds, and the processing of potatoes into french fries.

the demand for various input-producing sectors and thereby increasing their level of output. The second type of linkage would generate GDP through increasing the demand for consumer products and the output of the producers of these goods. The first type of impact is called indirect impact and the second one, induced impact. The two combined are commonly referred to as the type II impacts and the corresponding multiplier as the type II multiplier.

8.3.1 Value for Irrigation

The direct contributions of irrigated potato production to the gross domestic product (at factor cost) consist of three major items: wages and salaries paid by farmers, income of the farm operators, and investment income. Each of these was estimated in an incremental manner, that is, the contribution of irrigated potatoes over and above that under dryland conditions (Table 25).

Table 25

Marginal Contribution of Irrigated Potatoes to Gross Domestic Product (at factor cost), Manitoba, 1990

Items	Value* ($/ha)
Labour wages and salaries	157.23
Operators' income	719.00
Investment income†	123.47
Total	999.70

* Irrigated minus dryland.
† 50% of the investment cost.

The total contribution of potato production under irrigation is estimated to be almost $1 000 per hectare (ha). The total contribution of this water use is estimated at $3 199.04 per ha (3.2 * $999.70). Using a water use coefficient of 1.169 dam^3 per ha, the value of this water is estimated at $2 736.56 per dam^3.

For the irrigation of other crops—cereals and oilseed—we estimated a direct GDP contribution of approximately $228.50 per ha. Using a multiplier of 2.8 and the water use coefficient of 1.169 dam^3 per ha, the value of water is estimated at $547.30 per dam^3.

8.3.2 Value for Agricultural Processing

During 1989, the food-processing company near Carberry had gross sales of $74.9 million and expenditures of $57.9 million. According to the WESTARC (1990) report, about $46.22 million of the total expenditure was on purchases from Manitoba industries, some

Table 26

Annual Value of the Assiniboine Delta Aquifer from a Regional Development Perspective, 1990

Type of water use	Quantity of water used (dam)	Value ($/dam)	Total value (millions of dollars)
Irrigation			
Potato	3 785	2736.56	10.358
Other crops	1 709	547.30	0.935
Agric. processing	905	33 956.00	30.730
Domestic	1 187		0'
Subtotal	7 548		42.023
Stockwater	1 448		0.900
Other industrial	64		0.042
Commercial	192		0.054
CPB Shilo	775		0.506
Recreation	0		0.026
Subtotal	2 479		1.528
Total value	10 064		43.551

* Included with the backward linkages of the agricultural processing sector.

of which are in the Carberry aquifer region. The GDP contribution of the firm was estimated by using the gross output of the firm at $74.9 million and a pseudo-GDP multiplier of 0.78.[2] . This yielded a figure of $58.42 million as the total (direct and indirect) contribution of the firm to the provincial economy. Given that the firm used 905 dam^3 of water annually, the value per dam^3 for this water use is estimated at $33 956.

8.4 TOTAL ECONOMIC VALUE OF THE AQUIFER

The total economic value of the aquifer was estimated by multiplying the average value (value per unit of water) by the quantity of water used. However, to make the value of the aquifer water comparable to the total use-based value, the water uses that were not included in the computation of the regional development contributions were included here. The value per unit of water for the latter uses was the same as that estimated under the economic efficiency perspective. The results are shown in Table 26 . According to these estimates, the value of the aquifer was estimated to be $42 million annually. If we add to this estimate the use-based value of water for other uses, the total value of the aquifer is $43.55 million annually. If we divide the total value by the quantity of water used, the weighted average value of water using this approach is $4 343.4 per dam^3.

[2] This multiplier level reflects the exclusion of the agricultural industry's scale to the processor.

CHAPTER 9

Estimation of the Economic Worth of the Assiniboine Delta Aquifer

The value of groundwater in this report so far has been calculated on an annual basis. An obvious question is, what is the net economic worth of this natural resource to the users and to society at large? The question is addressed in this chapter. The net economic worth is estimated using the sets of values based on both the economic efficiency and the regional development perspectives.

9.1 METHODOLOGY OF ESTIMATION

A natural resource such as the Assiniboine delta aquifer used below its recharge level would generate economic activity for an indefinite time. In other words, if the use level is below the recharge level, the use of the groundwater is sustainable. Under these conditions, we can estimate the total economic worth as simply the net present value (NPV) of the stream of benefits generated from the use of water for the entire life of the aquifer. The estimation involves the use of equations (6) and (7), given in Section 5.5.

These equations can be used for estimating the use-related values based on either the economic efficiency criterion or the regional development (or equity) criterion. In this study, since both sets of value were estimated, the lifetime value of the aquifer was used for both of them.

To estimate future benefits is a formidable task. Forecasts have to be made for the use of water (level of use), as well as for the value in use. This task is further complicated by the fact that the level of water use and its value in various uses are interdependent. This estimation could not be performed satisfactorily within the scope of the study and therefore was not attempted. In its place, a modified methodology was adopted. The future value of the aquifer was estimated under two sets of assumptions:

1. The value of groundwater as well as the level of use of the groundwater for the foreseeable future would continue at the 1990 level.

2. The value of water either in use or for regional development would be the same as the level estimated for 1990. However, the level of use would increase to its maximum potential and remain at that level for the rest of the life of the aquifer.

Both of these assumptions are approximations of reality and therefore provide a range of possible values of the resource. The first assumption provides a minimum value and the second a possible maximum value of the aquifer. Furthermore, as noted above, the level of use under the second assumption must be lower than the recharge capacity of the aquifer.

The second set of data needed for the above estimation is the rate of discount. To preserve intergenerational equity, the choice of an appropriate rate of discount is critical. However, the literature does not offer any solid guidelines for the selection of this value. Therefore, in this study three alternative levels of rates of discount were chosen: 3%, 5%, and 8%. The value of the aquifer is presented as a range obtained from these rates.

The third set of assumptions relates to the life of the aquifer. Although under certain conditions the aquifer could have an infinite productive life, in this study a life of 50 years was selected. This choice, although somewhat arbitrary, does not unduly bias the results, since at the 8% rate of discount, the present value of benefits for beyond 50 years approaches a very small number.

9.2 TOTAL ECONOMIC WORTH BASED ON CURRENT USE LEVELS

In this section, the economic worth of the Assiniboine delta aquifer was estimated under the assumption that the average future value of water either in use or from a regional development perspective is accurately reflected in the estimates provided in chapters 6, 7, and 8. The level of groundwater use in the Carberry aquifer region was also assumed to continue at the 1990 level of use.

9.2.1 Economic Efficiency Perspective

The total annual value of the water withdrawn from the aquifer in 1990 was estimated to be $4.684 million, for a water use of 10 064 dam3. This produces an average value of $465.42 per dam3. Using this annual value of water, and assuming that the future level of use of groundwater in the CAR would not deviate from this level, at least on average, the lifetime value of the aquifer was estimated using equations (6) and (7). The results are shown in Table 27 .

Thus, if we were to take an economic efficiency perspective in estimating the value of water in its various uses, the total economic worth of the aquifer would lie between $57 million and $121 million, in 1990 dollars. These estimates must be used as a lower limit to the present economic worth of the aquifer, since over time one would expect the level of use to increase.

Table 27

Total Economic Worth of the Assiniboine Delta Aquifer Using the Economic Efficiency Perspective, Current Water Use Levels, and Alternative Rates of Discount, 1990

Rate of discount (%)	Total economic worth (in millions, 1990 dollars)
3	120.51
5	85.51
8	57.30

9.2.2 Regional Development Perspective

From a regional development perspective, the annual value of water supplemented with the value in use (for the uses that were assumed to create no regional development benefits) was estimated in Chapter 8 at $43.55 million in 1990 dollars. This averages out to a value of water of $4 243.64 per dam3. Using this annual value of water, the total economic worth of the Assiniboine delta aquifer was estimated using equations (6) and (7) (shown in Table 28).

Table 28

Total Economic Worth of the Assiniboine Delta Aquifer Using the Regional Development Perspective, Current Water Use Levels, and Alternative Rates of Discount, 1990

Rate of discount (%)	Total economic worth (in millions, 1990 dollars)
3	1 120.55
5	795.06
8	532.78

Using the regional development criterion, the net economic worth of the Assiniboine delta aquifer would range from $533 million to $1 121 million, depending upon the selected rate of discount.

9.3 TOTAL ECONOMIC WORTH BASED ON THE PROJECTED LEVEL OF ECONOMIC ACTIVITY

The assumption that future economic activity in the Carberry aquifer region would remain at the same level as in 1990 may be considered too restrictive. Therefore, this assumption was relaxed. The alternative assumption made for these calculations was that the future economic activity in the CAR would be governed by using the productive capacity of the infrastructure in the region already in place to the fullest extent possible. This involved a projection of the regional economic activity, which is discussed in the next section.

9.3.1 Projection of Economic Activity

In projecting the economic activity of the region, the capacity of the food-processing company near Carberry was used as a guide. It was assumed that in the future this capacity would be fully utilized. In addition, the following assumptions were made:

1. The company would process only locally grown potatoes.
2. All potatoes processed by the firm would be produced under irrigation.
3. The total capacity of the firm would be twice the present volume (based on the information provided by WESTARC 1990).
4. The commercial services in the region would double their level of activities. However, there would be no effect on other manufacturing sectors in the region. The latter types of economic activities were not considered to be linked with the potato processing.
5. The livestock production activity and the size of CFB Shilo would not undergo any appreciable increases from their respective 1990 levels.
6. The recreational value of the aquifer would also remain unchanged from the 1990 level.

The current capacity of the food-processing company plant is around 363 000 tonnes of potatoes annually. It was assumed that this level would increase to 726 000 tonnes. Assuming an average yield of 23.87 t/ha, this would imply that the region would have 30 428 ha under irrigated potatoes, with an annual water use of 35 571 dam3. The area of other crops under irrigation was assumed to be saturated at 5 000 ha, with a total annual water use of 5 845 dam^3.

The farm population was assumed to be the same as the 1990 level. This assumption is realistic, since in the above projection we are assuming that farmers would be replacing their dryland potato production by that under irrigation. However, the nonfarm population and the population of Neepawa were assumed to double in response to the employment generated by the food-processing company and its spinoff effect on the region.

9.3.2 Economic Efficiency Perspective

Using the above listed assumptions and the average value of water as estimated in chapters 6 and 7, the water use in the aquifer was estimated at 47 692 dam^3 (Table 29). Most (75%) of this water is for irrigating potatoes. Furthermore, since recreation is a nonconsumptive use of

Table 29

Projected Level of Water Use and Annual Value of Water, Assiniboine Delta Aquifer, Based on 1990 Average Value of Water, by Type of Use, 1990

Type of use	Level of use (dam^3)	Total value (in millions, 1990 dollars)
Irrigation		
Potatoes	35 571	21.88
Other crops	5 845	1.16
Stockwater	1 448	0.90
Agric. processing	1 810	0.05
Other industrial	128	0.08
Commercial	384	0.11
Domestic		
Farm	767	0.41
Nonfarm	420	0.08
Neepawa*	344	0.03
CFB Shilo	775	0.51
Recreation	-	0.03
Total	47 692	25.23

*Assuming all water needs are met by the aquifer.

water, it was not included in the estimation of this total. One should note that the future level of use is below the annual recharge capacity of the aquifer. Thus, the total productive life of the aquifer should be almost infinite. Assuming the average value of water in various uses at the 1990 level, the total value of the aquifer is $25.22 million annually. This amounts to a weighted average of $528.77 per dam^3. Equations (6) and (7) were applied to this annual value using three different rates of discount (Table 30). Depending upon the discount rate chosen, the present worth of the Assiniboine delta aquifer, using the future (projected) level of economic activity, is estimated at between $309 million and $649 million, in 1990 dollars.

Table 30

Economic Worth of the Assiniboine Delta Aquifer, Using the Economic Efficiency Perspective, Projected Level of Water Use, and Alternative Rates of Discount, 1990

Rate of discount (%)	Economic worth (in millions, 1990 dollars)
3	649.16
5	460.59
8	308.66

These estimates of the present worth of the aquifer must be interpreted with caution. They are based on very simple assumptions. One of these is that the food-processing company at Carberry can expand its processing operation successfully and maintain it at that level for the future time period. This would imply that processed potato market demand has reached a point where no retaliatory action would be forthcoming from other Canadian or North American plants. The accuracy of this assumption cannot be determined without further analysis of the market demand for North American processed potatoes.

Similar caution must be exercised with respect to expansion of irrigated potato production. For this to happen, the economic conditions for irrigated potato must be favorable, relative to those for dryland potato.

9.3.3 Regional Development Perspective

The estimation of the regional development based economic worth of the Assiniboine delta aquifer was made using a methodology similar to that shown above. The results are shown in Table 31 .

The economic worth of the aquifer can range between $2.7 billion and $5.6 billion, depending upon the rate of discount used. The set of caveats in Section 9.3.2 apply equally to the estimates of value from a regional development perspective.

Table 31

Total Economic Worth of the Assiniboine Delta Aquifer, Using the Regional Development Perspective, Projected Level of Water Use, and Alternative Rates of Discount, 1990

Rate of discount (%)	Economic worth (in millions, 1990 dollars)
3	5 640.18
5	4 001.86
8	2 681.69

Part Three

Summary

CHAPTER 10

Estimated Value of the Assiniboine Delta Aquifer

The economic value of a natural resource such as a groundwater reservoir can be conceptually approached in several ways. Two of these are more commonly in use: (1) the water contributes to the economic welfare of the people through its use in various economic activities, and (2) it generates economic activities and provides a source of employment and income that would not be possible otherwise. In this study, both of these approaches were used to estimate the economic value of an aquifer. The Assiniboine delta aquifer was selected as a case study.

The aquifer is located in the southwestern part of the province of Manitoba, centred around the community of Carberry. The Assiniboine River passes through the region where the aquifer is located. The area of the aquifer is about 3 885 km^2, with an annual recharge capacity of 60 378 dam^3. The aquifer region is predominantly an agricultural one, and most of the water is used for irrigating potatoes. The irrigated potatoes, along with those produced under dryland conditions, are sold to a food-processing company located at Carberry. The potatoes are processed into french fries and then shipped to various outlets in western Canada.

The population of the aquifer region is estimated to be 12 391 inhabitants, of which 6 876 live in nonfarm communities and the remaining 5 515 on farms. Thus, in terms of population the region is also predominantly agricultural. The only major manufacturing activity in the region is the food-processing company, although several small industrial concerns are located in the town of Neepawa. Carberry, along with Neepawa, provides commercial services for various agricultural and manufacturing concerns and the people living in the region.

10.1 WATER USE IN THE REGION

Although the aquifer has an annual recharge capacity of slightly over 60 000 dam^3, only a small portion of this total is being used at present. Two methods of estimation were employed in this study, the water rights data approach and the water needs or requirements approach. The estimated level of water use using these two approaches is shown in Table 32 . Depending on the source of data, the estimated total water use in the aquifer region in 1990 may range from 10 064 to 15 681 dam^3. However, since not all withdrawal uses of water from the aquifer are licensed, the second estimate has obvious limitations. In this study the estimate based on the water needs or requirements was selected for further estimation purposes.

Based on this information, the agricultural use of the groundwater is the predominant one in the region. About 69% of the total withdrawal use of the water is for this purpose. The other major use of water is for domestic purposes, including Canadian Forces Base Shilo, and accounts for about 20% of the total. The remaining 11% is for industrial and commercial uses. Thus, the groundwater produces the agricultural activity, which provides the stimulus for other economic activities in the region. In this sense, the Assiniboine delta aquifer is an agricultural water body.

10.2 ECONOMIC VALUATION OF GROUNDWATER

The total value of a natural resource can be divided into two major types: use-related and nonuse-related. In the case of the Assiniboine delta aquifer, this leads to the following major categories of values:

Table 32

Water Use Level in the Carberry Aquifer Region
by Type of Use, 1990

Type of use	Quantity based on water rights data(dam^3)	Use based on requirements Quantity (dam^3)	% of total
Agricultural			
Irrigation	14 412	5 494	55
Stockwater and other		1 448	14
Total agricultural		6 942	69
Domestic			
Rural farm		767	
Rural nonfarm		247	
Municipal		1 245	172
Total domestic		1 186	12
Industrial/ comm.	24	1 161	11
CFB Shilo		775	8
Total withdrawal	15 681	10 064	100
Discharge into the river		41 185	
Total		51 249	

1. use-related values

- within the CAR
- outside the CAR

2. nonuse-related values

- option value

  - within the CAR
  - outside the CAR

- existence value

  - within the CAR
  - outside the CAR

- bequest value

  - within the CAR
  - outside the CAR

The estimation of use-related values is straightforward, as discussed below. The nonuse-related values are more complicated to estimate and often require the use of artificial market data. In this study the estimation of value of water in the aquifer was restricted to use-related values and values held by the users within the Carberry aquifer region.

The economic valuation of a natural resource can be carried out using one of two criteria for evaluation. One can take the approach that water is a resource, like any other, to be used solely for the purposes of improving human welfare. This approach is commonly called the economic efficiency perspective and is equivalent to the cost-benefit analysis type of evaluation. More recently, however, some economists have suggested that economic efficiency is not the only objective of governments and public policy and that the regional development aspect deserves some attention. This argument is based on an economic equity perspective, in which regional equity is an important criterion. A choice between these approaches is difficult, and often replete with problems. In this study, both were used in the evaluation of groundwater in order to provide a range of values for the Assiniboine delta aquifer.

The economic efficiency perspective in evaluating natural resources is embodied in the concept of a consumer or producer surplus. The surpluses are approximated by the use of a proxy, willingness to pay. The willingness to pay can be estimated for market goods or nonmarket goods. Since groundwater can be used for the production of either type of goods, both market and nonmarket methods are appropriate.

The estimation of use-related value of the groundwater was complicated by the fact that from an economic efficiency point of view, the contribution made by an existing source of water cannot exceed the cost at which water can be obtained from an alternative source. In this study, this approach was chosen for valuing water use for stockwatering. Furthermore, in the event that there was no groundwater, regional water needs were also assumed to be met through importing water from Lake Manitoba. The cost of this water became the upper limit to the value of water in various uses.

From a regional development perspective, the value of water is equal to the gain in the level of economic output in some reference region. A reference region may be the local area where the aquifer is located or may be extended to a provincial boundary. One should note that if the boundary of the region is extended to the national boundaries, the results obtained would be closer to those using the economic efficiency perspective.

10.3 VALUE OF WATER IN DIFFERENT USES

The average value of groundwater obtained from the Assiniboine delta aquifer was estimated using the "with and without" principle. The contributions of a certain water use activity were compared to the situations when the water was and was not used. The difference between the two situations was taken to be the marginal contribution of water and was equated to its use-related value.

The estimates of these values for the economic efficiency and for the regional development criteria are shown in Table 33 . The value of groundwater was the highest for the commercial establishments and CFB Shilo. This value was followed by that in other domestic water uses. Again these results are plausible and consistent with the allocation priorities of various water management authorities.

The value of irrigation water use was equally high (at about \$615 per dam^3) for potatoes. This again is plausible since potatoes are a cash crop and very sensitive to the availability of water. Not only are irrigated potato yields higher but also the quality of the potato is better and the size of the tuber more uniform.

The weighted average value for water used for various purposes was estimated at \$464 per dam^3. This estimate is much lower than that estimated using the regional development perspective, where the value was over \$4 343 per dam^3. The latter estimate reflects the fact that without the aquifer much of the economic activity in the region would be lost, and therefore the groundwater has a significantly high value for the development of the Carberry aquifer region.

10.4 ECONOMIC WORTH OF THE AQUIFER

Given the value of water in various uses and from a regional development perspective, what is the economic value of the aquifer to

Table 33

Average Value of Water in the Assiniboine Delta Aquifer by Type of Use, 1990

Type of use	Value per dam^3 Economic efficiency	Regional development
Irrigation		
Potato	615.07	2 736.56
Other crops	198.29	547.30
Stockwatering	621.86	
Agric. processing	28.36	33 956.00
Other manufacturing	652.27	
Commercial	280.70	
Domestic		
Farm	535.64	
Nonfarm	159.48	
Neepawa	82.00	
CFB Shilo	652.27	
Recreation	*	
Weighted average value	463.90	4 343.40†

* Not estimated since the use of water is in situ.
† Includes other uses not directly linked to regional development activities.

Manitoba society? The answer was obtained under a set of assumptions, some of which are very restrictive. The values in Table 33 were converted into the annualized value of water for the quantity of water used in 1990 (Table 34). From an economic efficiency perspective, the net benefits of the Assiniboine delta aquifer are estimated at $4.65 million annually. These values must be taken as a lower limit to the total value of the aquifer. This is the total contribution made by the aquifer to the economic welfare of Canadian society. If one changes the accounting perspective to a regional development one, the contributions of the aquifer are estimated at $43.55 million annually. Since the economic activities included in the above estimation would be sustained over an almost infinite period of time, and since some of these activities could increase in the future, a second set of estimates was generated using a water use level based on a futuristic vision of the economic activity in the region.

The projection of the economic activity in the region was based on the simple assumption that the economic activity of the sole potato-processing firm would expand to its capacity. The firm had estimated this capacity at twice the present level of operations. No new investment in capacity was planned by the firm, and so

Table 34

Annualized Total Use-Related Value of the Assiniboine Delta Aquifer, 1990

Perspective	Total value (in millions, 1990 dollars) 1990 level of water use	Future level of water use
Economic efficiency	4.65	25.22
Regional development	43.55	219.00

it was assumed not to take place. Furthermore, no new firms were assumed to be attracted to the region, an assumption based on a lack of abnormal profits being made by the existing processor. Using this level of operations for the food-processing company, those of other sectors were projected. Those economic activities neither directly nor indirectly linked with the agricultural processing activities were assumed to remain at their 1990 level of operations.

Using the above-mentioned methodology of projection, annual benefits from the aquifer-supported economic activity to Canadian society were estimated at $25.22 million annually. In terms of the development of the region, as measured through the contributions to the Manitoba gross domestic product (at factor cost), the value of water was estimated at $219 million annually, in 1990 dollars.

The annualized total value of the aquifer groundwater was used to estimate total net present worth of the aquifer over its life, under three alternative rates of discount (Table 35). Depending upon the rate of discount, the aquifer would be worth from $57 million to $120 million, under the strict assumption that the current level of economic activity would continue in the future. If a projected level of economic activity is used as a guide to its valuation, the economic worth of the aquifer increases to a range extending from $309 million to $649 million. Both of these estimates are based on the economic efficiency perspective. In other words, these estimates show the present worth of the lifetime benefits generated through the use of the aquifer water.

If we change our accounting perspective and use the criterion of regional development, the present worth of the aquifer is significantly higher. Under this condition, the aquifer's worth is estimated at between $533 million and $1 121 million if the present level of economic activity were to continue into the future, or between $2.7 billion and $5.6 billion if the economic activity were to expand to the projected level. Under either level of economic activity, the conclusion that the Assiniboine delta aquifer is a very important natural resource is almost inescapable. Its importance as a contributor to the regional economic activity is even more than its contribution, on average, to the economic welfare of Canadians. As a regional resource, the aquifer is almost irreplaceable and should be treated as such for all regional planning and management decisions.

10.5 IMPLICATIONS OF THE RESULTS

The results of this study have demonstrated that groundwater availability is a very significant regional resource for the Carberry region of Manitoba. Therefore, any changes in

Table 35

Present Worth of the Assiniboine Delta Aquifer, Using Alternative Evaluation Perspectives, Levels of Economic Activity, and Rates of Discount, 1990 Dollars

	Total value (in millions, 1990 dollars)			
	Present level of water use		Projected level of water use	
Rate of discount	Economic efficiency perspective	Regional development perspective	Economic efficiency perspective	Regional development perspective
3	120	1 121	649	5 640
5	85	795	460	4 003
8	57	533	309	2 682

the quality or quantity of groundwater in the aquifer would have serious repercussions on the regional economy, whether we use resource allocation as the major criterion or regional development as the major goal of public policymaking in the province.

The two major threats to the Assiniboine delta aquifer may be listed as overuse and point or nonpoint pollution. The first threat would lead to depletion of the natural resource and thereby to a much shorter economic life. This is not a measure that could be endorsed on the basis of sustainable development. However, there have been similar tendencies in other parts of North America (and the Middle East), to draw down the water level and significantly reduce the productive life of an aquifer. The second threat—point and nonpoint pollution—would also result in a reduction of the economic benefits of the aquifer. Such pollution could be caused by regional agricultural practices, livestock activity, or uncontrolled disposal of sewage and other effluents. Thus, given the value of the aquifer, development of an appropriate management plan for the aquifer, along with the streamlining of economic activities that might become a major threat to this natural resource, should be given high priority.

10.6 LIMITATIONS OF THE STUDY AND AREAS FOR FURTHER RESEARCH

10.6.1 Limitations of the Study

This study was carried out using secondary information for the Assiniboine delta aquifer and for the associated water-use region. Due to time and budget constraints, a number of methodological assumptions were made, which may have simplified the task somewhat but may also have affected the validity of the conclusions drawn. The limitations of the study are described below.

1. The scope of valuation adopted for this study excluded two major values: the value of water outside the Carberry aquifer region and the nonuse-related value of groundwater both inside and outside the region. Since some of the water released from the aquifer into the Assiniboine River could be used outside the CAR, the magnitude of use-related values in this study may have been underestimated. Furthermore, the study did not estimate the option value, existence value, or bequest value for the aquifer, which would further suggest that the total value and the economic worth of the aquifer are much higher than those estimated in this study.

2. Water use for irrigation was based on the "expert opinion" method. Estimates were not based on any direct observation or measurement of water use in the region. These may have over- or underestimated the total water use for the aquifer and thereby affected the average value of water.

3. The opportunity cost of water in the region was based on secondary information generated for other purposes. It was not based on an exact representation of the regional configuration, topography, and water use levels. To the extent that the true opportunity cost of water for the CAR is different than that assumed in this study, the results presented here are biased.

4. The population estimate for the CAR was based on a very simplistic assumption: that the population density in any of the rural municipalities is uniform in its entire geographical space. If the population density is different in different subregions within a municipality, this estimate is biased. A detailed land survey map and personal investigation should be used to arrive at a more precise estimate of the region's population.

5. The values of water for domestic, industrial, and commercial purposes, as well as for CFB Shilo, were estimated using an assumed level of elasticity of demand. Since no primary survey of water demand patterns had been carried out for the region, there was no choice but to make such an assumption. However, such elasticity estimates may not be realistic for the region and thus may have biased the results of this study somewhat.

6. The value of water for recreation was based on four sets of assumptions: The estimates took the value of recreation in the region to

be similar to that in the neighbouring parks, particularly in Saskatchewan. To the extent that these estimates are only a proxy of the real situation in Manitoba parks, the estimates should be used with caution.

- The estimates of the number of visitor used in this study were guesstimates based on an "expert opinion." Again, the actual situation may be different than that portrayed here.

- The projection of economic activity related to the Spruce Woods Provincial Park was assumed to remain at its 1990 level for the future. At present, the government of Manitoba has plans to improve the facilities and carry out a market promotion of the park. This effort may lead to a higher level of visitation to the park and possibly to a higher level of benefits from recreational activities in the CAR.

- The recreational activity was assumed not to have generated any indirect impacts on the region. In reality, however, such activities do have backward linkages with the regional and provincial economies, particularly when such activities are linked to tourism.

10.6.2 Areas for Further Research

The above-noted limitations of the study lead us to list various areas where future research activities may be concentrated to improve the knowledge of economic values of the Assiniboine delta aquifer of Manitoba. These areas are listed in no particular order of importance.

- *A study of water use in the Carberry aquifer region and in the surrounding area*—A study of actual water use patterns particularly for agriculture, should be carried out for the region. Observations of actual water use for potatoes and other crops should be made through a primary survey of producers. This survey should include an examination of the crops being irrigated and the timing and method of irrigation used by various producers. This information would be very useful in developing a water management plan for irrigation in the region.

  Information on the use of water discharged from the aquifer into the Assiniboine River and various creeks should be collected to obtain an accurate picture of the total amount of water used from the aquifer.

- *Economic analysis of water allocation for irrigatio*n—A study of economic benefits from the irrigation of other crops in the region should be carried out, with the help of a programming model of the regional agriculture. In this study, the irrigation water value was estimated using the producer surplus approach. However, in reality, the amount of water allocated for irrigating potatoes may also be affected by relative returns from irrigating other crops.

- *A survey of recreationists at the Spruce Woods Provincial Park*—Given the current lack of information on the visitation of the Spruce Woods Provincial Park, there is a need for a study of this site to estimate (1) the visitation rate and origin of visitors and (2) the value of the recreational experience at the park, using the travel cost method as well as the contingent valuation method.

  Results from this type of survey would be helpful in obtaining the relative value of water in recreation and would be useful in making resource allocation decisions in the region.

- *A survey of domestic, commercial, and industrial water users*— A survey of non-agricultural water users is needed to ascertain the nature of their demand for water. This survey would lead to a more realistic estimate of the price elasticity that was used to estimate the benefit from these water uses in the region.

- *Estimation of opportunity cost of obtaining water*—An engineering study of the cost of diverting water from Lake Manitoba should be carried out to ascertain the value of water for various uses. This cost estimate should be based on a realistic design of the proposed water collection system, as well as its distribution network. In addition, the cost of cleaning water to an acceptable quality should be included in this study.

- Estimation of an input-output model for the study region — The estimation of indirect impacts of the direct water-use activities was made in this study using borrowed multipliers. To check the validity of these multipliers, it is proposed that an economic transaction table for the input-output model of the region be created. This table should become the basis for the multipliers and for the estimation of all indirect impacts of the water use activities.

- *Projection of economic activity in the region* — A study to project the economic activity for the region should be carried out, using information from the regional development plans of the provincial government (including various departments) and checking similar plans of the local and municipal governments, and investment plans of the agricultural processing and other industrial firms. This would provide a more realistic estimate of the future and might result in a better estimate of the economic worth of the Assiniboine delta aquifer.

- *Estimation of nonuse value of groundwater in he region* — The study of the total valuation of the Assiniboine delta aquifer is incomplete unless the nonuse-related values are estimated and added to the use-related values. The three nonuse-related values are option, existence, and bequest. It is suggested that primary surveys of local residents be planned to estimate these values. Since the use of artificial market data is the most appropriate for these purposes, surveys should be carried out using the personal interview method.

- *An estimation of the environmental benefits of aquifer water* — In this study only a partial subset of the economic benefits of the aquifer were estimated. In addition to the economic values, the water body may have some beneficial effects on the environment. A study of the physical and biological environment should be carried out to estimate these values. The benefits of the aquifer to the ecosystem, to wetlands, and to wildlife in the region should be estimated.

- *A study of possible sources of contamination of groundwater in the region* — A survey of present agricultural and land use patterns in the region should be carried out to provide water managers with sufficient information to prevent water quality degradation. This study should include livestock activity, as well as the disposal of livestock and municipal effluence, directly above the aquifer.

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Appendix A

Table A-1

Percentage of Municipal Areas
Included in the Carberry Aquifer
Region

Municipality	% of total area included in the CAR
North Cypress	100
South Cypress	100
Langford	60
Victoria	50
North Norfolk	40
South Norfold	20

Appendix B

Table B-1

Estimated Cost of Delivering Water to the Carberry Aquifer Region from Lake Manitoba, 1990

Cost categories	Cost (in thousands of dollars)
Intake and pump	247
Dugout	449
Delivery pipeline	17 119
Distribution pipelines	20 723
Additional pumping station	200
Subtotal	38 738
Water treatment	4 247
Total cost	42 985

Source: Each of these costs was estimated through extrapolation from the existing PFRA studies or those of the Manitoba Water Resources Commission.

The annualized cost of the system for treated water, assuming a project life of 50 years and an 8% interest rate, was estimated at \$3.513 million. The operation and maintenance cost were estimated at 2% of the total capital costs, at \$859 700 per annum. The total capacity of the system was 1 700 dam^3, bringing the total cost of treated water to \$2 573 per dam^3. Using similar calculations, the cost of untreated water was estimated at \$2 318 per dam^3.

The above cost estimates would be realistic as long as the system was designed in a linear fashion, in other words, that for greater capacity, the number of similar capacity pipelines was increased proportionally. This would assume that there would be no significant economies of size in pipelines or in terms of treatment plants. Both of these assumptions may be considered somewhat restrictive.