Final Report

"Agricultural Beneficial Management Practices for Lake Winnipeg – Cost-benefit analysis using an ecological goods and services approach"

Project No. K1A12-09-0180

– to –

Environment Canada

Gatineau, Quebec

– by –

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Summary

The objective of the research and analysis reported herein was to "Assess the costs and benefits of agricultural beneficial management practices (BMPs) for Lake Winnipeg in physical and economic terms, with an emphasis on the co-benefits in terms of ecological goods and services." Lake Winnipeg is a large and key natural asset, whose watershed drains a major portion of the Canadian Prairies and part of the U.S. Great Plains. This includes almost all of the agricultural area of the Canadian Prairies. Due to a variety of factors, including increases in nutrient loading, Lake Winnipeg is experiencing increasing eutrophication.

The assessment and estimation methods used were necessarily simple and straightforward. To estimate phosphorus (P) reduction potential of selected BMPs, observed levels of P exported from selected sub-regional watersheds were multiplied with measures of the performance of the BMPs relative to conventional practice. The selected study area includes the major sub-watersheds of the Manitoba portion of the Lake Winnipeg drainage basin, and comprises about 23 percent of Manitoba crop land area. (In conventional Census of Agriculture terms, the study area and surrounding regions include about 60 percent of Manitoba cropland and livestock). BMPs and their ecological goods and services (EGS) impacts and values were identified and estimated on the basis of evidence and information specific to Manitoba, Canadian Prairie, and other similar dryland agriculture, soil, and agroclimatic conditions. Economic and EGS impacts were evaluated using best available evidence from the literature and current Manitoba market prices and costs.

Valuation and related methods were refined over several steps of the project. Several iterations of research revealed a significant lack of evidence as well as the data and information necessary to meet the valuation objectives of the project. Put simply, whereas the level of public awareness and concern for the current condition of Lake Winnipeg is high; and the available evidence solidly indicates that Lake Winnipeg is highly eutrophic, little to no quantitative evidence of the economic and EGS impact of the Lake's condition was found.

Main estimates are that the selected BMPs have the potential to reduce the annual export of P from Manitoba agriculture by approximately 10 percent, or just under 100 tonnes of the 1,200 tonnes of the P load to Lake Winnipeg that Manitoba agriculture is understood to currently account for. Cost-benefit ratios including EGS values or indicators for these BMPs range from 0.8 to 6.3. In other terms, relative to the estimated cost of treating outflow to the Red River by the City of Winnipeg of \$164,697 per tonne of P removed, the cost of reducing P exports from agricultural sources in Manitoba using the BMPs ranges from \$0 (net benefit) to \$765,125 per tonne of P.

Variability and uncertainty of the biophysical potential to reduce P exports to Lake Winnipeg from Manitoba agricultural sources is the greatest determinant of the viability of the BMPs from a cost benefit and EGS perspective. Best estimates of the physical capacity or potential of agricultural BMPs have a wide range, extending nearly an order of magnitude - from a reduction to an increase in P export. Unit costs and prices including EGS values are relatively small factors in comparison to the range of biophysical uncertainty and variability.

Given the large size and key role of Lake Winnipeg and the Lake Winnipeg drainage area, a full and direct economic and EGS accounting and estimate of the value of the lake is warranted and strongly recommended. Amongst other things, it is recommended that this entail a coordinated effort with Manitoba government and related agencies and stakeholders. Information and data with which to do so is currently widely distributed amongst several different public and private agencies in Manitoba and other jurisdictions. Despite the key importance of Lake Winnipeg, research conducted for this project was not able to identify any initiative to draw the necessary quantitative information and data together in coordinated and systematic fashion.

Cost-benefit analysis using an EGS approach could be improved by further investigation and development of quantitative evidence and supporting data of EGS associated with agricultural BMPs.

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1. Introduction

As specified by Environment Canada's Request for Proposal (RFP), the objective of the assessment reported herein was to "Assess the costs and benefits of agricultural beneficial management practices for Lake Winnipeg in physical and economic terms, with an emphasis on the co-benefits in terms of ecological goods and services." Lake Winnipeg is a large and key natural asset. Lake Winnipeg's watershed provides a drain for a major portion of the Canadian Prairies and northern portion of the U.S. Great Plains, including almost all of the agricultural area of the Canadian Prairies. Due to a variety of factors, including increases in nutrient loading, Lake Winnipeg is experiencing increasing eutrophication. This chapter introduces Lake Winnipeg and provides some background to its key role and current condition.

1.1 Lake Winnipeg

Lake Winnipeg (the "Lake") is the 10th largest body of freshwater in the world, and the second largest watershed in Canada next only to the MacKenzie River Basin. At an estimated 953,000 km^2, it has the largest land to drainage surface ratio of all the great lakes in the world, (Lake Winnipeg Stewardship Board (LWSB, 2006)). The Lake's drainage area encompasses four Canadian provinces – Ontario, Manitoba, Saskatchewan, and Alberta, and four American states – Montana, North Dakota, South Dakota, and Minnesota, (Figure 1.1). The watershed is home to six million people and 17 million livestock, and comprises 55 million hectares of agricultural land (LWIC, 2005/2006).

The Lake receives its water from three major rivers and their tributaries: the Winnipeg River which originates in Lake of the Woods in Ontario, Red River which originates in the USA, and the Saskatchewan River which originates in the foothills of the Rockies in Alberta, (Figure 1.1). In addition to these three major rivers, a number of smaller rivers and creeks also drain into the Lake. The Saskatchewan River drains into the northwest of the Lake, and the Red River and the Winnipeg River drain into the south end of the Lake. Average monthly water flow into the Lake is estimated at 2,218 m^3 per second, of which 45 percent is from the Winnipeg River and its tributaries (Table 1.1). The Saskatchewan River is the next largest contributor at 26 percent, followed by the Red River at 11 percent of inflow.

The Nelson is the only river to flow out of the Lake. It flows northeast and discharges into Hudson Bay. Lake water is also lost through evapotranspiration, estimates of which are not readily available.

The hydrology of Lake Winnipeg rivers has changed over time. Average water flows in the Red River and Winnipeg River have been increasing. In contrast, Saskatchewan River flow decreased during the 1910 to 2000 period (LWSB, 2007).

In spite of its large size, the period of residence of water in the Lake is relatively short. Based on hydrological and morphological conditions in 1969-1974 (a period of exceptionally high inflows and lake levels), Brunskill et al (1980) estimated a theoretical water renewal time of 0.4 – 0.8 years for the South basin and 2.9 – 4.3 years for the whole Lake.

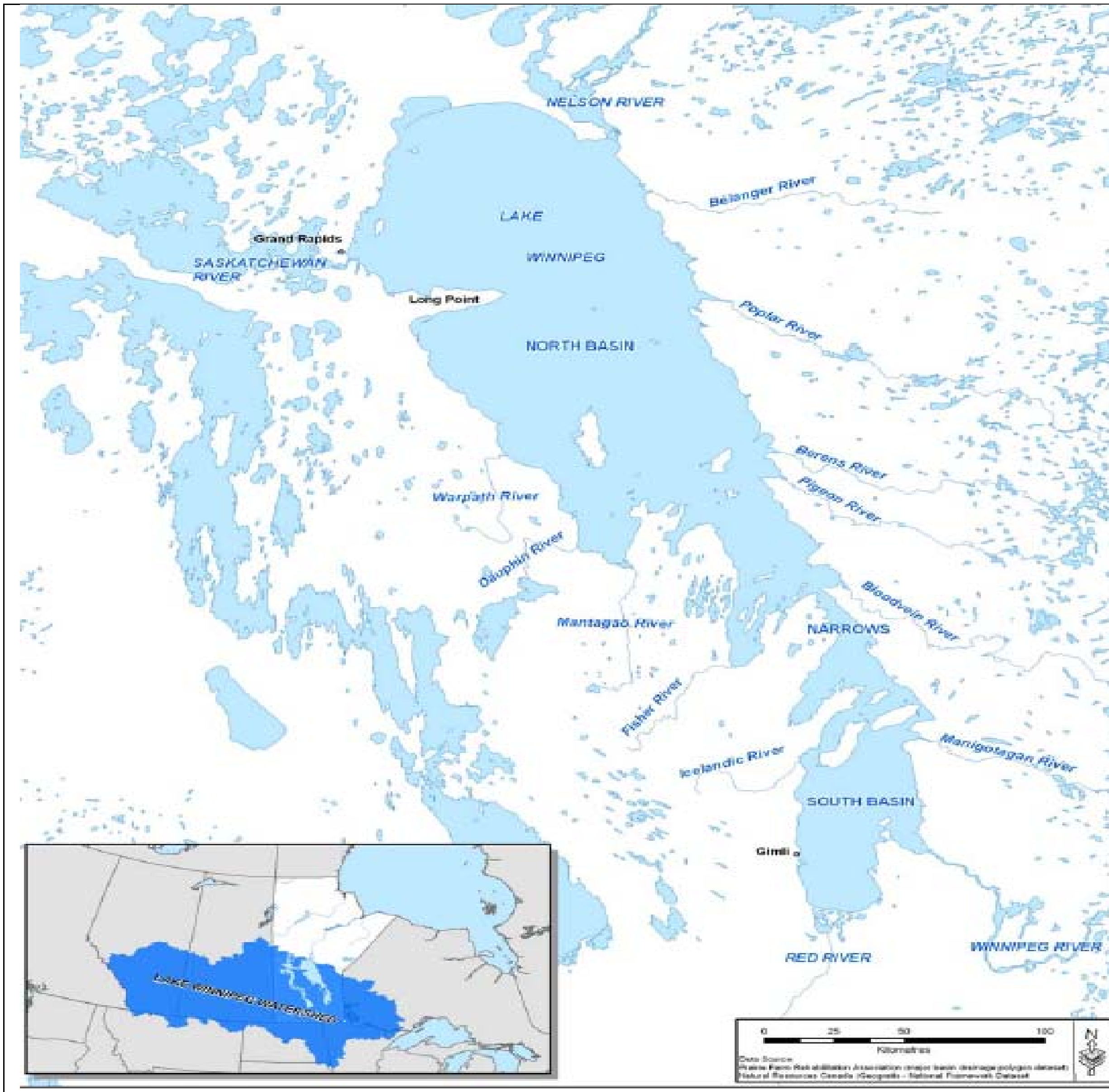

Figure 1.1. Lake Winnipeg and Surrounding Region

Source: (North/South Consultants Inc., 2006)

Table 1.1 Mean Monthly Flows into Lake Winnipeg, Average 1964-2005

Source River	Mean monthly flow in m^3/second	Percent of the Total Flow
Winnipeg River	999	45
Saskatchewan River	567	26
Red River	252	11
Other flows*	400	18
Total	2,218	100

* Other flows include those from many smaller rivers, but do not include precipitation and evaporation.
Source: LWSB (2006)

1.2 Water Quality Attributes

The LWSB (2006) concluded that water quality in Lake Winnipeg has deteriorated over time, and in particular, over the past three decades. Enrichment from nitrogen (N) and phosphorous (P) is the leading cause of this problem of eutrophication.

Much of the nutrient is contributed by economic activity in the watershed, although a portion is also created through natural processes. Tables 1.2 and 1.3 report estimates of average annual loads of P and N from major sources. Manitoba sources contribute 41 percent of the total P and 19 percent of total N to the Lake, with the remaining 59 and 81 percent respectively contributed by upstream jurisdictions. From 1994 to 2001, the Red River contributed the largest portion, or 54 percent of the Lake's total P-load; the Winnipeg River is the next highest contributor (11 percent); and the Assiniboine and Saskatchewan rivers contribute about eight and four percent respectively of the Lake's total P-load (LWSB, 2006).

A major portion of the Manitoba P-load is contributed by agricultural activities, and from natural and undefined sources. These two sources make up almost two-thirds of the total P-load in the Lake on an annual basis. Note that Manitoba agriculture's share of the total Lake P-load is only 15 percent.

Since the 1970s, P-concentrations in most of the rivers within Lake Winnipeg's watershed have been increasing, resulting in increasingly high loading of P into the lake (Figure 1.1, Jones and Armstrong, 2001).

Table 1.2 Summary of Estimated Annual Phosphorus and Nitrogen Loading to Lake Winnipeg, 1994-2001

Source	Average Total Phosphorus		Average Total Nitrogen	
	Quantity in t/yr	Percent of Total	Quantity in t/yr	Percent of Total
Upstream Jurisdictions	4,200	53	48,900	51
Manitoba Anthropogenic Sources and Natural and Undefined Sources	3,200	41	28,300	19
Atmospheric Deposition and/or Internal Lake Processes in Manitoba	500	6	18,800	40
Total	7,900	100	96,000	100
Numbers are rounded to the nearest 100 tonnes. Source: (LWSB, 2006)				

Table 1.3 Distribution of Annual Phosphorus Loading to Lake Winnipeg, 1994-2001, by Upstream and Manitoba Sources

Water Body	Source and Load			
	Jurisdiction	Average Total P Loading* in tonnes/year	Percent of Lake Total	Percent of Manitoba Sources
Upstream Jurisdictions				
Red River	US source	2,500	32	-
Souris River	US source	200	3	-
Assiniboine and Saskatchewan Rivers	Alberta and Saskatchewan source	400	5	-
Winnipeg River	Ontario source	800	10	-
Other Rivers	Ontario source	300	3	-
Total Upstream Jurisdictions		**4,200**	**53**	**-**
Manitoba Sources				
Wastewater	City of Winnipeg	400	5	11
Other wastewater	Other towns and municipalities	300	4	8
Agriculture	Non-point	1,200	15	32
Natural background and undefined[1] sources	Non-point and point source	1,300	17	35
Total Manitoba Anthropogenic Sources		**3,200**	**47**	**100**
Atmospheric Deposition	Manitoba	500	6	14
Total Lake Winnipeg Watershed		**7,900**	**100**	

Numbers are rounded to the nearest 100 tonnes.
[1] These may include contributions from sources such as forests, wildlife, and septic fields.
Source: (LWSB, 2006)

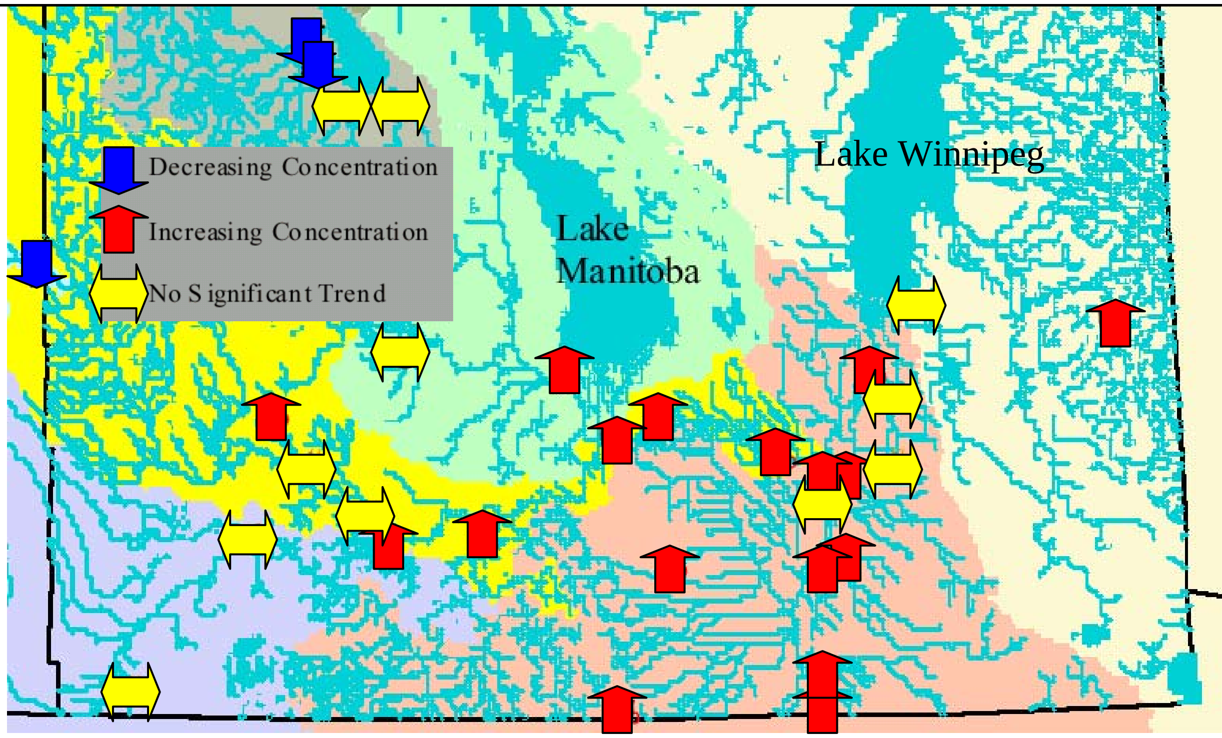

Figure 1.2 Historical Trend in Phosphorus Concentration of Rivers in Lake Winnipeg's Watershed (mid 1970s to mid 1990s)

Source: adapted from Jones and Armstrong (2001).

1.2.1 Eutrophication[1]

Excessive nutrient in lakes causes eutrophication, characterized by the development of algal scum (including blooms of toxic algae), changes in the abundance and composition of aquatic animals including an increase in the numbers of coarse fish, declines in oxygen in the lake water, and taste and odour problems of drinking water supplies.

Nutrient supply affects the growth of aquatic plants in lakes, particularly algae. In many northern temperate lakes, algal growth and biomass is limited by the availability of P. In many lakes, algal growth is a function of P concentration. In some lakes, primary production is dominated by macrophytes, which tend to suppress algae, resulting in clear water even at high nutrient loads (Chambers et al., 2001).

Lakes can be classified according to their nutrient or "trophic" status. Oligotrophic lakes have very low nutrient concentrations (typically less than 5 µg/L average total P). In these sys-

[1] The definition and specification of eutrophication in this section is per Environment Canada's "Nutrients and Their Impact on the Canadian Environment," (Chambers et al., 2001). Chambers et al. define eutrophication as the process of over fertilization of a body of water by nutrients that produce more organic matter than the self-purification reactions can overcome. Eutrophication can be a natural process or it can be accelerated by an increase of nutrient loading to a water body by human activity.

tems, algae are nutrient-limited and low in abundance, and the water is typically clear. Oligotrophic water can be highly coloured by humic matter. Moderately productive lakes (about 10-30 µg/L total P) are said to be mesotrophic. Eutrophic lakes are very rich in nutrients such that the water is green with algae throughout most of the growing season. At very high nutrient concentrations (about 100 µg/L total P), algal growth is independent of P concentration and becomes limited by other factors such as N, micronutrients (e.g., iron) or light (due to self-shading by high algal densities). Lakes with extremely high nutrient concentrations and excessive algal growth are termed hyper-eutrophic (Chambers et al., 2001).

1.2.2 Eutrophication and Lake Winnipeg

Table 1.4 sets out six categories of eutrophication based on P loading as recommended by The Canadian Council of Ministers of Environment (CCME Canadian Council of Ministers of the Environment, 2004).

Table 1.4 CCME Categories of Eutrophication based on Phosphorus Loading

Trophic Status	Phosphorus Concentration, µg/L
Ultra-oligotrophic	<4
Oligotrophic	4-10
Mesotrophic	10-20
Meso-eutrotrophic	20-35
Eutrophic	35-100
Hyper-eutrophic	>100
Source: CCME (2004)	

The most commonly reported effect of nutrient enrichment on aquatic ecosystems is an increase in algal biomass, which is often expressed as chlorophyll *a* concentration. Typically, there is a positive correlation between TP (and often TN) and phytoplankton biomass or chlorophyll in lakes and reservoirs, although the precise relationship may vary between lakes. In general, it is the algal response to nutrient enrichment that is typically associated with eutrophication and the focus of concern and management. Algal blooms can also significantly reduce oxygen levels and prevent life from functioning at lower depths creating dead zones beneath the surface.

Chlorophyll *a*, the major photosynthetic pigment, is the most widely used indicator of algal abundance. However, a major disadvantage of this indicator is that cellular chlorophyll *a* content varies with growing conditions and among groups of algae, so that the biomass of some groups (e.g., diatoms) is consistently underrepresented. Data on chlorophyll *a* for the North and South basins of the Lake Winnipeg are presented in Table 1.5. There appears to be no consistent trend in the concentration of chlorophyll in either of the two basins, but the concentrations in the North Basin are higher as of 2005 than during the early 1990s.

Algae bloom growth increases fish habitat in the lake, but also results in some not so desirable changes for the fishing industry. One visual impact of these blooms is that they can wash up on beaches, as shown in the right panel of Figure 1.3.

Table 1.5 Mean Chlorophyll *a* Concentration in Lake Winnipeg, 1992-2005		
Year	South Basin	North Basin
	(µg/L)	
1992	3.92	2.56
1993	4.27	3.26
1994	14.84	6.25
1995	4.50	--
1996	8.00	7.50
1997	--	--
1998	4.16	--
1999	4.22	11.70
2000	4.46	6.19
2001	6.61	5.20
2002	7.13	7.45
2003	10.92	9.01
2004	3.90	11.51
2005	5.94	21.75
Source: North/South Consultants Inc. (2006)		

Satellite Image of Lake Winnipeg | Blue-green algal bloom at Grand Beach

Figure 1.3 Algae Bloom in Lake Winnipeg and Wash-up on Grand Beach, Lake Winnipeg

Source: LWSB (2006)

1.3 Problematic Situation

As described above, Lake Winnipeg is experiencing worsening eutrophication. With blue-green algae covering more than half the surface of the Lake at times, water quality for many human uses is affected. Change in water quality may affect many stakeholders in the Lake Winnipeg watershed, but more directly those who live in close vicinity to the Lake. Since water is connected to several ecological goods and services (EGS), a decrease in water quality may have significant impact on the human welfare of Lake stakeholders.

Since a major source of eutrophication is P, measures to reduce P-loading of the Lake are required. Manitoba agriculture contributes an estimated 15 percent of the current P-load of the Lake (32 percent of all Manitoba sources). Therefore, adjustments and changes in agricultural practices that can reduce P exports from the agricultural landscape to the watershed may hold some potential in this regard.

1.4 Objectives of the Study

The objective as specified by the project's Request for Proposal (RFP), is to "Assess the costs and benefits of agricultural beneficial management practices (BMPs) for Lake Winnipeg in physical and economic terms, with an emphasis on the co-benefits in terms of ecological goods and services (EGS). This project will focus on the non-market benefits to nutrient reduction, but the market benefits also need to be included, and both types of benefits will be compared against the costs of each beneficial management practice."

1.5 Organization of this Report

This report is presented in seven chapters, and three appendices. Chapter 1 introduces Lake Winnipeg and its watershed, key role, and current condition. Chapter 2 discusses major methodological and data considerations. Chapter 3 discusses the BMPs investigated and selected for assessment, and EGS potentially associated with them. Chapter 4 reports estimates of the physical quantity of P export reduction potential of the BMPs selected for analysis. Chapter 5 reviews EGS values. Chapter 6 reports estimates of P export reduction potential, and economic and EGS costs and benefits. Chapter 7 is a summary and analysis of results. Appendix A includes an outline for more comprehensive EGS methodology, and Appendices B and C include greater detail concerning some of the BMPs examined.

2. Methodology

The general methods and their sequencing as set out by the Request for Proposal (RFP) were refined by the findings of project research and assessment. In broad terms, the approach and general methods suggested by the RFP were refined in two major and interrelated ways: 1) BMPs were identified and developed on the basis of biophysical and agricultural evidence; and 2) several iterations of research and assessment revealed a significant lack of knowledge, or relevant understanding and evidence as well as the data and information necessary to meet the valuation objectives set out by the RFP. Accordingly, methods were refined to work within the bounds of biophysical and valuation evidence. Further, to the fullest extent possible, BMPs and their EGS impacts and values were identified and estimated on the basis of evidence and information specific to Manitoba, Canadian Prairie, and other similar dryland agriculture, soil, and agroclimatic conditions.

In this chapter, these considerations and their methodological implications are briefly elaborated. The next chapters, notably Chapter 4 and Appendices A and B, also discuss some methodology, data, and allied considerations.

2.1 Starting Points - Comprehensive and System-Wide Framework

As specified by Environment Canada, this project is concerned with the physical and economic impact of agricultural BMPs with potential for reducing the flow of nutrients into Lake Winnipeg from agricultural sources.

As outlined in Chapter 1, agriculture is one of several sources of nutrients in the Lake Winnipeg watershed. A change in nutrient load or flow from any one source (such as agriculture) has potential to impact all points in the watershed or system. Accordingly, a system-wide approach recommends itself as a general method for comprehensive assessment.

For practical purposes, the Lake and watershed can be broken down into major components so that the various individual components and their interaction can be systematically assessed. In the context of agricultural BMPs, one such breakdown is to consider that the system is comprised of the following three major components:

Agriculture (farm and rural landscape) ⟶ **River System** ⟶ **Lake Winnipeg**
1 **2** **3**

Using a systems approach, the impact of a change in any one or combination of components is measured as the overall net impact on the system. For example, a change at the agricultural level 1 includes the individual and combined net interaction of impacts at all points 1, 2, and 3.

Given that the focus of this project is Lake Winnipeg (specifically the Lake's nutrient load and ongoing health and viability), project research began at the Lake (3). A major amount of project time and resources expended over several iterations of research were used to investigate this aspect. This investigation included the following two major types of related research, consultations and literature review (A and B, below).

A. Consultation with government and public agency officials and experts and local (Lake and Lake community) representatives.

Interviews and meetings were held with two distinct groups of experts and stakeholders: 1) a full range of officials and experts notably Manitoba government and agency officials including former LWSB officers and officers currently responsible for Lake and related matters; and 2) local representatives of Lake communities including municipal government officers, business and property owners and developers, commercial fishers, and locally recognized experts.

Government officials and local representatives were queried concerning Lake conditions generally, and specifically for existing studies, data, and information concerning the current state of the Lake, its associated economic, and eutrophic condition. All were consulted individually by in-person interviews conducted between April and June 2010. This process resulted in the following summarized observations and findings:

1. Manitoba government officials and other experts are not aware of any Manitoba-specific or other studies and assessments of the economic impact of the Lake's current nutrient load and eutrophic condition, nor of any attempts to <u>quantitatively</u> link or establish cause-and-effect between Lake nutrient load, and economic and EGS impacts.

2. Information and data that could be used to assess and estimate the economic value of the Lake including EGS and associated impacts exists. However, this data is widely distributed amongst several different public and private agencies, and no attempt has been made to draw this information together in a coordinated and systematic fashion.

   For example, beach and beach-tourism data is maintained by a private agency; detailed property value and taxation data is held and maintained by a combination of Manitoba Finance and local municipalities; fishery data is under the purview of the Freshwater Fish Marketing Corporation (FFMC); sport fishing data is administered by Conservation Manitoba and Manitoba Tourism; and water and sewage treatment and information are the responsibility of local municipalities and communities.

3. The available evidence is often mixed, or contradictory.

   For example, Appendix A outlines how the current commercial fish catch from the Lake is at a record high. While the current catch is dominated by Walleye, other species continue to be caught in notable numbers. Reasons or causes are unclear. Anecdotal evidence is that the Lake's fish and especially its Walleye population is high because of the food/nutrition provided by the Lake's nutrient load. Commercial fishers interviewed for this project are also split. On one hand, fishers are acutely aware and deeply concerned about the nutrient load, pollution, and algal bloom conditions of the Lake. On the other hand, at current catch levels, revenue and profit levels are also very high – if not at record highs.

Similarly, anecdotal information from municipal government officials and property developers and owners interviewed for background to this project indicate the Lake's condition has not had an immediately identifiable impact.

B. Literature Review

In addition to expert review of biophysical, agricultural and related literature, an extensive review of valuation literature was conducted. This spanned 1) literature provided by Environment Canada including a review of the Environmental Valuation Reference Inventory (EVRI); 2) references provided by expert and government representatives consulted per A above; as well as 3) other environmental, economic, and agricultural literature. The literature includes numerous assessments and reports of the biophysical aspects of nutrient loading from agricultural and other sources on freshwater bodies including eutrophication. The literature also includes studies, impact assessments, and estimates of the value of water, lakes, and related activities. However, the literature reviewed does not include evidence and data that can be used to address the fundamental issue of this project – namely, quantitative evidence of the linkage or cause-and-effect between nutrient loading, eutrophication, and a change in the value of Lake economic activity and/or associated EGS values. The literature covers many of these aspects of valuation, but none provides evidence that can be applied quantitatively and with confidence to Lake Winnipeg.

2.1.1 Implications

While project research found that much of the data with which to assess and estimate Lake economic and EGS values and impacts is understood to exist, the authority, time and resources required to draw it together is beyond the resources and status assigned to the current project. Consequently, the comprehensive system approach introduced above was replaced with two practical measures:

1. The assessment was limited to the agricultural sector or component of the system approach outlined in section 2.1. This includes an alternative method for estimating the value of reduced nutrient loading of the Lake, introduced in section 2.2.5.2.

2. Appendix A provides an outline of methodology that could be used for a comprehensive, system-wide valuation of Lake and watershed EGS assuming the data and other information required is available and can be collected; and that there are no budget and resource constraints to the associated research.

2.2 Major Methods

Several methods were employed in the analysis reported herein. The major methods and the approximate sequential order in which they were implemented are summarized below.

2.2.1 Identification and Selection of Beneficial Management Practices (BMPs)

The BMPs examined were identified and selected on the basis of two major considerations including 1) BMPs of interest to and suggested by Environment Canada, and 2) BMPs with the greatest nutrient export reduction potential based on Manitoba specific and relevant practical experience, evidence, and data available from the South Tobacco Creek (STC) project and relevant literature. The STC project, located in the upper reaches of the Morris River watershed of Manitoba (Figure 2.1), is part of ongoing assessment by Agriculture and Agri-Food Canada's Watershed Evaluation of BMPs (WEBs).

The following five BMPs were selected for further assessment based on the foregoing and their potential to reduce nutrient, notably P export from agricultural land to surface waters and, ultimately, to Lake Winnipeg. The BMPs are 1) nutrient management; 2) crop selection; 3) conservation tillage; 4) vegetated filter strips; and 5) surface water control structures.[2] These BMPs are described in detail beginning in Chapter 3 and subsequent chapters.

2.2.2 BMPs Compared to the Status Quo

The general approach taken to quantitatively estimate the physical potential of BMPs to reduce nutrient export into the Lake and its watershed as well as the associated costs and EGS benefits, can be described as one of "adoption versus the status quo (or current situation)". In other words, physical and monetary estimates were derived assuming BMPs are adopted and used into the future, relative to the current situation where they are not used or used to a more limited extent. Physical and dollar value estimates were predicated on the use of BMPs relative to the current or base case situation.

For biophysical estimates, observed levels of P exported from sub-regional watersheds were multiplied with measures of the relative performance of agricultural BMPs and conventional practices, and these products were interpreted in the context of the Lake Winnipeg watershed. Similarly, EGS and economic values were estimated for the situation where the BMPs are being used relative to a base case where they are not used.

2.2.3 Manitoba Study Area

Estimates of the quantity of nutrient that is exported from Manitoba's agricultural landscape to Lake Winnipeg were derived using an agricultural management database specifically developed[3] to represent the major Red, Assiniboine, and Dauphin river watersheds. This database was developed as a special compilation of the Census of Agriculture. The cropland of the study area (the area included in the database) represents about 23 percent of all Manitoba cropland. In conventional Census geographic terms, the Consolidated Census Subdivisions that include and surround the study area contain approximately 60 percent of Manitoba crop land and major livestock.

Economic and EGS values were predicated as possible on the study area using region-specific and representative or average provincial data for Manitoba.

[2] The BMPs suggested by Environment Canada include riparian buffers, no-till, manure storage, and cover crops. Riparian covers are consistent with BMP 4; no-till with BMP 3; manure storage is included in manure aspects of BMP 1; and cover crops are BMP 2.
[3] The database was originally developed by some of the authors of this report for other related purposes.

2.2.4 BMP Adoption and Time Frame

The current or existing use of the selected BMPs in the study area and the province of Manitoba were factored into estimates. Adoption was estimated for two major patterns: 1) simple linear adoption (equal annual increases); and 2) a more typical gradual pattern.

A combination of BMP and adoption characteristics was considered in specifying a 30 year time frame for analysis. Experience in Manitoba and related jurisdictions suggest that from a practical perspective, full adoption by the province's farmers will take 30 years or more (with some BMPs adopted more quickly, and others less so). Further, the biophysical nature of several of the BMPs is such that a period of 30 years or more is required before their impact might be fully, if not completely, realized. Full adoption is referred to as "maturity."

2.2.5 EGS and Economic Valuation and Estimation Methods

2.2.5.1 Net Present Value Over 30 Years

All economic and EGS costs, benefits, and impacts were estimated in Net Present Value (NPV) terms over the 30 year horizon selected for the assessment. NPV estimates were generated for 3 and 7 percent discount rates.

2.2.5.2 Avoided Cost

As outlined in section 2.1, research conducted at the outset of the project found that a comprehensive system approach to estimating the full economic and EGS value of Lake Winnipeg was not feasible given the resources available. As an alternative, avoided cost methods were used to estimate nutrient reduction impacts and values. Specifically, estimates of the cost borne by the City of Winnipeg to treat or clean P and N and other contaminants from water discharged into the Red and Assiniboine rivers were used to estimate EGS values and as benchmarks to the analysis.

2.2.5.3 Benefit Transfer

Benefit transfer is recognized as a method to estimate economic and other monetary values in the absence of more direct data or market prices and costs. Benefit transfer was used to derive unit values notably for the estimation of EGS costs and benefits. (Environment Canada regularly uses benefit transfer methods).

2.2.5.4 Market and Opportunity Costs

Manitoba market prices and costs were used to estimate private and other values as fully as possible. Market prices were used to estimate opportunity costs incurred in situations where the adoption and use of BMPs may have private impacts including foregone economic opportunities.

2.2.5.5 Sensitivity Analysis

Sensitivity analysis was used to assess all major biophysical quantity and economic and EGS monetary value estimates. “Main” economic, EGS, and physical estimates are based on and generated from mean, average, and representative data. Main estimates are in turn presented within lower and upper bounds.

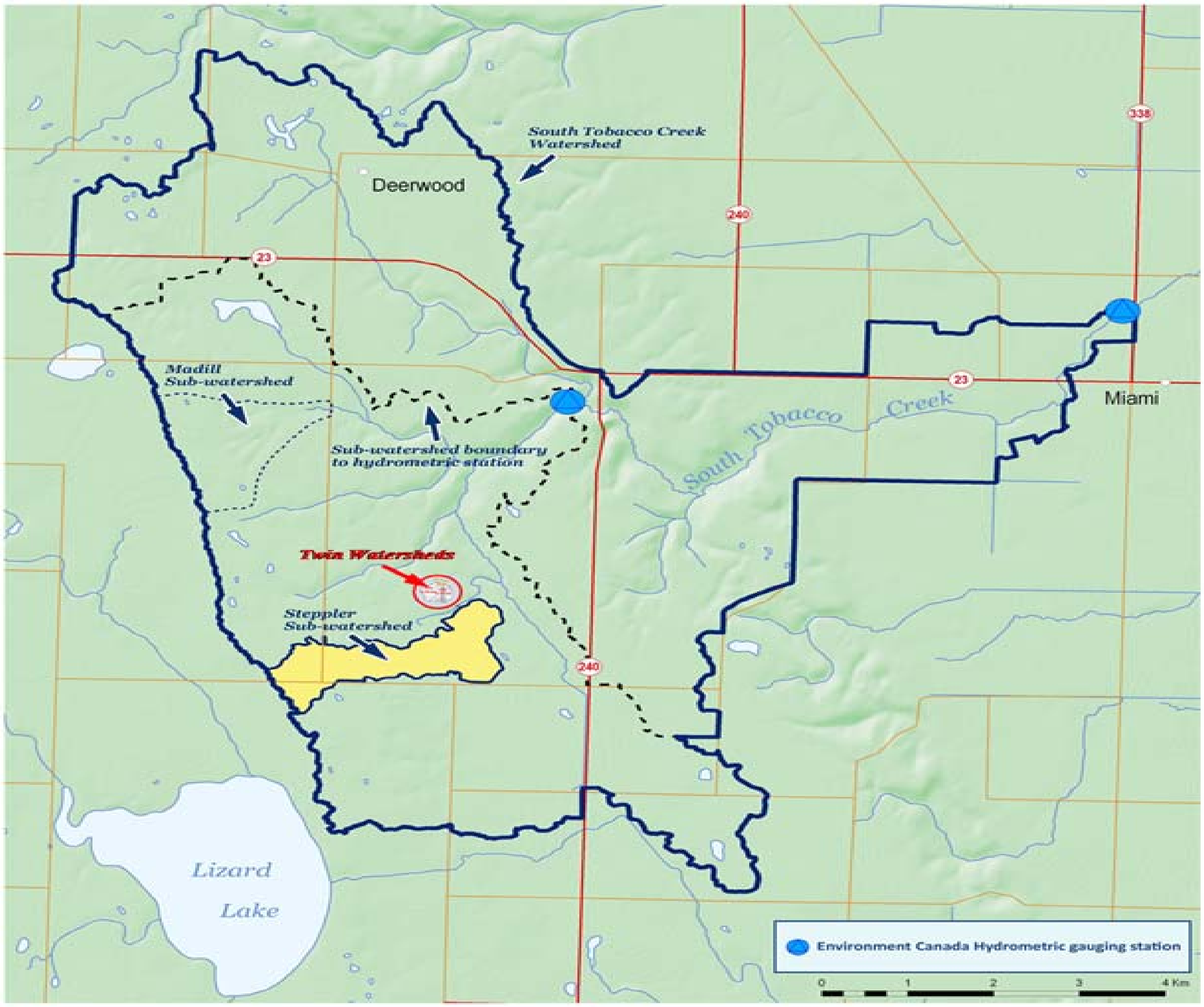

Figure 2.1 South Tobacco Creek Watershed Showing the Steppler Sub-watershed and the Twin Watersheds Study Sites.

Source: Agriculture and Agri-Food Canada (2005)

3. BMPs and EGS

This chapter briefly introduces the BMPs, and provides a summary of literature concerning the EGS that may be associated with them. The discussion is presented in terms of an Environment Canada (undated) EGS framework based on the Millennium Ecosystem Assessment.

3.1 The BMPs

The process of selecting the BMPs for further assessment began with a list of those of interest to and suggested by Environment Canada. This was augmented by expert review of literature and available field and practical results, evidence, and supporting data with emphasis on those BMPs for which quantitative evidence and supporting data relevant to Manitoba conditions are available. The following five sets of BMPs were examined.

1) nutrient management;
2) crop selection;
3) conservation tillage;
4) vegetated filter strips; and
5) surface water control structures.

3.2 Classification of EGS

Table 3.1 presents an Environment Canada classification of EGS. It includes four major categories, and 23 individual EGS within the categories. This chapter is presented according to the four major categories, with elaboration of individual EGS. Emphasis is on those BMPs with potential to reduce the export of nutrient from Manitoba agriculture to the Lake Winnipeg watershed.

Table 3.1 Environment Canada's Classification of Ecological Goods and Services

Major Category	Detailed Items	
Goods	• wood and fibre • food • fuel • genetic resources	• pharmaceuticals • drinking water • minerals
Regulating services	• climate regulation • water purification • pest and disease control	• erosion control • waste treatment
Supporting services	• soil formation • nutrient cycling • pollination	• photosynthesis • primary production
Cultural services	• aesthetic • recreation • education	• psychological health • heritage • spiritual
Source: (Environment Canada, undated)		

3.3 Goods

Also referred to as Provisioning services, Goods include the products obtained from ecosystems. By definition, BMPs are practices that can be used in managing the production of goods – in this case, agricultural goods including plants, animals, and associated products. Accordingly, with some exception, the BMPs do not directly result in goods but are indirectly involved in the management of the production of economic goods. The majority, if not all agricultural production associated with the BMPs result in goods that are traded in the market place.

While the BMPs do not directly result in the production of goods (with some possible exceptions discussed below), they can impact the level of production as well as the mix or combination of agricultural goods produced. The following briefly discusses the major ways by which each BMP can affect the level and mix of agricultural production.

- BMP 1. Nutrient Management involves management of the type and amount of nutrient applied to agricultural crops. Nutrients are applied to maintain and/or improve natural soil fertility. Nutrients are typically applied with the expectation of increasing crop yields. Accordingly, a reduction in applied nutrient can result in lower crop yields.

- BMP 2. Crop Selection entails changing the mix of crop production – specifically an increase in the area of forage and perennial grass grown as part of crop rotation. When forage or grass area is increased in replacement of other crops, the area and quantity of other crops produced decreases (assuming no or small yield impacts). Forages grown may be harvested and used as an intermediate product or input to the production of livestock. Forages have also been considered as a potential feedstock for the production of biofuel, however this remains largely undeveloped.

- BMP 3. Conservation Tillage can affect the mix of crops grown. On the Canadian Prairies, conservation tillage typically encompasses a wide range of management techniques including specific rotations of cereals, oilseeds, and legumes.

- BMP 4. Vegetated Filter Strips can also affect the types and area of crops grown. For example, if filter strips are established on crop land, they reduce the area available for crop production.

- BMP 5. Surface water control structures may affect the type of crops grown, but are more likely to affect the area of crop production. Similar to the other BMPs considered here, if water control structures are established on crop land, the area of land available for crop production is reduced. Conversely, more land area may become available if structures reduce downstream flooding.

As touched on above, several of the BMPs could entail production of non-conventional crops. For example, crop rotations, filter strips and water holding and diversion areas could include plants for energy biomass e.g. wood, fibre, pharmaceutical and similar and related applications (McConkey et al., 2008). However, these require further biophysical, technical, infrastructure and market development.

3.4 Regulating Services

3.4.1 Reduction of Nutrient Export to the Watershed

As noted, the emphasis of this assessment and report is on BMPs with potential to reduce the export of nutrients, particularly P from agriculture into the Lake Winnipeg watershed. The following begins with a discussion of the evidence concerning N and P nutrients. It then characterizes BMPs according to whether they are source or transport BMPs, and goes on to discuss each BMP and its ability to reduce nutrients. The distinction between source and transport BMPs is an important one as source BMPs are designed to fundamentally and permanently align nutrient balance over the long term, while transport BMPs are more short term or temporary as they lose their effectiveness over time.

Excessive loading of P is generally the most common cause of eutrophication of freshwater lakes in the world (Carpenter, 2008; Schindler et al., 2008). Even though losses of nitrate-N are a significant threat to the suitability of groundwater for human consumption, the main threat to surface water quality is ammonium-N. Almost all fertilizer that is applied in the form of ammoniacal-N (e.g., anhydrous ammonia and urea) rapidly converts to ammonium-N in soil. However, ammonium forms of N are generally attracted to soil particles, relatively immobile in soil and present little threat of loss to surface water unless applied in very late-fall or during winter (Maule and Elliott, 2006a; Maule and Elliott, 2006b), situations that rarely occur in Manitoba. For example, the majority of N from inorganic fertilizer or pig manure measured in snowmelt and post-snowmelt runoff measured in Quebec by Gangbazo et al (1997) was as nitrate (43 kg N ha^{-1}), followed by total Kjeldahl N (8.0 kg N ha^{-1}) and ammonium (1.8 kg N ha^{-1}). For these reasons, it is unlikely that fertilizer N losses could be reduced in a way that would provide meaningful improvements to Lake Winnipeg's water quality.

Although N surpluses are a matter of concern for nitrate accumulation and leaching to groundwater (Drury, 2007; Yang et al., 2007), the low rates of loss of ammonium N in runoff from agricultural fields and the small role of N in eutrophication (Schindler et al., 2008; Carpenter, 2008) imply that adjustments to the rate of N applied will have little impact on water quality in Lake Winnipeg. Accordingly, the assessment of BMPs for this report is limited to P exported from agricultural sources within Manitoba into Lake Winnipeg. It does not include P from other sources or other regions of the Lake Winnipeg watershed, nor does it include N.

3.4.1.1 Source and Transport BMPs

Nutrient management and crop selection (study BMPs 1 and 2) are practices that affect the source of P, as they determine how much P is applied to the soil, how much is removed through crop harvest, and, therefore, the levels of P found in the soil and crop. They also affect the position of P relative to overland flow which transports P to surface waters. Conservation tillage, vegetated filter strips and surface water control structures (BMPs 3, 4, and 5) are practices that affect the transport of P, as they determine how much runoff is generated, the erosivity of the runoff, and the retention of P on its course downstream.

Source BMPs are designed to reduce the risk of N and P loss at a particular site, before the nutrients begin to move off that site. Some nutrient management BMPs, such as balancing nutrient application with removal or decreasing soil supplies of nutrients are fundamentally effective and essential over the long term. However, some source BMPs may require many years to show their effectiveness due to the buffering effect from large reserves of nutrients (sometimes referred to as "legacy" nutrients) already present in the soil. In contrast, transport BMPs are designed to reduce movement of nutrients off the site and/or intercept nutrient and thereby reduce nutrient transfer into surface water bodies. Transport BMPs are effective in the short term, but generally lose their effectiveness over time because their capacity to intercept nutrients (especially P) declines as their retention capacity becomes saturated.

Source BMPs reflect basic good agronomic practice. The fundamental, internationally-recognized principles of agronomically and environmentally sustainable nutrient management require using the proper placements to apply the correct forms of nutrients, at the proper rates and time (International Plant Nutrition Institute, 2010).

3.4.1.2 Nutrient Management

Nutrient management is a key source BMP, and includes a large number of practices entailing the form, rate, timing and placement of nutrients to optimize their use by crops. Appendix B includes a detailed discussion of nutrient management. Both synthetic fertilizers and livestock manure are considered, and manure storage, as it affects the timing of manure applications is also considered. Appendix B includes additional nutrient management detail.

3.4.1.3 Crop Selection

A wide variety of crops can be grown within a cropping system and those that are selected reflect the requirements and opportunities associated with the individual farm operation; the presence of livestock, as an example. Crops differ in the amount of fertilizer that is applied and the amount of nutrients that are removed through harvest, and they differ in how the fertilizer is applied and how the crop is managed; all of which have the potential to affect the P in the soil and crop residues and, therefore, affect the export of P. Assuming that recommended practices for nutrient management are followed for all crops included within a cropping system, a change in crops grown is not expected to result in a large change in soil P. Crops that provide greater cover for longer periods, such as forages, are expected to have lower rates of runoff and water erosion and, therefore, lower levels of P export. However, it is necessary to have diversity in the crops grown on an individual farm and within a region -- a major shift in the distribution of crops grown in Manitoba is not possible.

3.4.1.4 Conservation Tillage

Conservation tillage practices are currently being assessed as part of the ongoing WEBs study in the STC watershed. Published data (Tiessen et al., 2010a) indicates that conservation tillage results in greater export of P from crop land. The majority of this P is transported in a dissolved form rather than in a particulate form. Although there is little soil erosion under conservation tillage, the stratification of nutrients in the soil and increased concentration of nutrients near the soil surface and the presence of nutrient-rich crop residues on the soil surface results in greater concentration of dissolved P in the runoff.

Although conservation tillage is generally well-documented as an effective BMP for reducing sediment and particulate P losses, there is a consistent body of research demonstrating that losses of dissolved P, in particular, from conservation tillage are greater than those from conventional tillage (summarized in Table C.1 of Appendix C). This results in increases in total P losses from conservation tillage compared to conventional tillage in situations where dissolved P forms the majority of P loss. For example, this is observed in a long term twin watershed study in the STC model watershed in Manitoba, (Tiessen et al., 2010a).

The STC study is the only study in the Canadian Prairies to quantify the effect of conservation tillage vs. conventional tillage on runoff losses of P. However, the results in the STC study are similar to those observed in other equivalent regions. For example, researchers in Finland observed increases of 20 to 300 percent in total P losses from two conservation tillage systems tested on flat landscapes (Uusitalo et al., 2007).

The reason why conservation tillage in Manitoba affects total runoff P losses differently than in some other regions of North America is the result of the distinctive landscape and climate of this region of the Northern Great Plains. The relatively level landscapes and semi-arid climate throughout most of the Great Plains result in relatively small amounts of soil erosion by water. The cold, continental, semi-arid climate also results in an average of 85-90 percent of runoff occurring during the early spring snowmelt period (Little et al., 2007; Nicholaichuk, 1967), when most of the soil is still frozen. More than 2/3 of total runoff P and N losses in the STC model watershed also during snowmelt (Glozier et al., 2006). Further, throughout the northern agricultural regions of North America, the majority of P losses during snowmelt occur as dissolved, rather than particulate P (Glozier et al., 2006; Tiessen et al., 2010a; Little et al., 2006; Little et al., 2007; Ontkean et al., 2005; Gaynor and Findlay, 1995; Hansen et al., 2000a). The net result is that erosion is not the main cause of P losses in Manitoba and erosion control measures such as conservation tillage are therefore unlikely to be very effective for reducing P losses in Manitoba and Great Plain watersheds.

The two most likely reasons for greater losses of dissolved nutrient losses from conservation tillage, compared to conventional tillage in Prairie watersheds are:

1. Release of nutrients from plant residues that remain on the soil surface (Baker and Laflen, 1983; Bundy et al., 2001; Daverede et al., 2003; Langdale et al., 1985; Puustinen et al., 2005; Sharpley and Smith, 1994; Ulen, 1997; Uusitalo et al., 2007; Zhao et al., 2001), especially after freezing and thawing (Bechmann et al., 2005; Roberson et al., 2007)

2. Stratification or stranding of nutrients at the soil surface due to reduced mixing of fertilizers or manures by tillage (Selles et al., 1999).

One of the issues often raised during the discussion of increased P losses from conservation tillage systems is how these losses compare to runoff losses of P from native prairie, given the rich layer of vegetation on the soil surface that also occur in these natural ecosystems.

In fact, runoff from natural prairie is also rich in P. For example, total P concentrations in spring and summer runoff from native Prairie near Stavely, Alberta ranged from 0.10 to 0.52 mg/L (Little et al., 2007), 5-26 times greater than the 0.02 mg/L threshold for eutrophication. In a study of runoff from native Prairie in west central Minnesota, total P concentrations were also high, averaging 0.50 mg/L (Timmons et al., 1970). However, due to the semi-arid to sub-humid climate in the Prairies, runoff volumes and exports of P on a mass per unit area basis are usually small. For example, in the Minnesota study by Timmons et al. (1970), total exports of runoff P were only 0.09, 0.01, and 0.1 kg/ha in snowmelt runoff, rainfall and annual total runoff, respectively, with snowmelt runoff accounting for 82 percent of total P losses. This trend for Prairie runoff to produce high concentrations of nutrients, but low exports has also been observed in studies with unfertilized cereal stubble in southern Saskatchewan, where Nicholaichuk and Read (1978) measured large concentrations of N and P in runoff (1.4 and 0.8 mg/L, respectively), but small exports (0.4 and 0.4 kg/ha, respectively). The relatively low rates of overall nutrient loss enable the land in these watersheds to remain relatively fertile and productive although the concentration of P in runoff from natural and agricultural watersheds in the Prairie region is high enough to contribute to eutrophication in water bodies.

Appendix C includes additional detail concerning conservation tillage.

3.4.1.5 Vegetated Filter Strips

Vegetation can be used to filter sediments and nutrients from surface water flowing over the land. Grassed strips established along ephemeral waterways within fields are referred to as grassed waterways. The primary function of grassed waterways is not to filter sediments or nutrients, but to convey runoff from the field without rilling and gullying of the soil (OMAFRA, 2009). The vegetation along the boundary of fields where these waterways exit fields and pass through riparian zones to stream channels can serve to filter sediments and nutrients from surface runoff (only a very small portion of a riparian zones' length actually serves as a filter for runoff). Vegetated filter strips require careful design and maintenance to be effective in removing sediments and nutrients (OMAFRA, 2008).

Riparian zones are being evaluated for their ability to filter nutrients as part of the ongoing WEBs study in the STC watershed, but the data are not yet published. Sheppard et al. (2006) measured the effectiveness of established vegetated strips at decreasing P in runoff from agricultural fields on flat landscapes in the eastern side of the Red River Valley. In some cases P concentration in the runoff water decreased, but it was equally likely to remain the same or increase. Sheppard et al. (2006) provide an excellent review of other relevant studies. More recent studies and reviews are found in Uusi-Kamppa and Jauhiainen (2010), and Raty et al. (2010).

3.4.1.6 Surface Water Control Structures

Structures can be used to control surface water, reducing the flow by storing water, and reducing the erosivity and sediment transport capacity of the flow by slowing it. These structures can be located within fields or within riparian areas in the upper reaches of a watershed. The structures within fields are normally referred to WASCoBs, water and sediment control basins. They are small earthen dams situated across ephemeral waterways, and they are designed to detain surface water and sediment (OMAFRA, 2009; MDA, 2010; NRCS-MN, 2007; NRCS-MN, 2009). WASCoBs normally have drop inlets to divert excess surface water to subsurface drainage tiles which convey the water to stream channels. In doing so, they can greatly reduce downslope surface runoff and the formation of gullies by water erosion. Larger dams that cross streams in the upper reaches of watersheds are referred to as headwater dams (NRCS-MN, 2003), and they are also designed to detain surface water and sediment, thereby reducing downstream flood damage.

Headwater dams are also being evaluated as part of the ongoing WEBs study in the STC watershed, (Tiessen et al., 2010b). These structures can significantly reduce P export at the scale in which they operate. WASCoBs could be applied in landscapes which are undulating or rolling (about 30 percent of the land area in the agricultural regions of Manitoba, based on the Soil Landscapes of Canada data in the National Soil Data Base), but would have limited value in other landscapes. Consequently, their ability to reduce P export at the sub-region and regional watershed scale is limited. Headwater dams are even more limited in extent of application since the landscapes that are suitable for this practice are deeply incised valleys, areas such as the Manitoba Escarpment and the valley walls of the Pembina and Assiniboine Spillways. Although headwater dams have considerable potential to reduce P export in local watersheds situated along the escarpment, at sub-regional and regional watershed scales these local watersheds account for relatively small portions of the total land area (about 3-5 percent, based on the Shuttle Radar Topographic Mission data) and, therefore, have little potential to reduce P export.

3.4.2 Carbon Sequestration

BMPs 2, 3, and 4 (crop selection; conservation tillage; and vegetated filter strips respectively), to the extent that they involve the establishment and growth of forages and perennial grasses, have potential to sequester carbon in the soil. Perennial forages grow for a longer period of the year than annual crops which allows them to trap more carbon dioxide. Their root system allows them to store carbon deep underground such that perennial forages in crop rotations result in higher levels of soil carbon. Perennial forages can slow decay rates by creating conditions that are less favourable for soil microbes (Janzen et al., 1998b).

According to Janzen (2004), restoring degraded lands to grassland can increase the carbon stored in plants and soil because ecosystems that have lost notable amounts of soil carbon have the potential to take up atmospheric carbon dioxide. Areas where carbon stores have been replenished experience restored soil fertility and often enhanced biodiversity. Returning marginal lands to grassland has the potential to return soil carbon to levels comparable to what would have existed before the land was cultivated (Janzen et al., 1998a).

3.4.3 Energy Use and Greenhouse Gases

Khakbazan et al. (2007) showed that in the Black soil zones of Manitoba, low input zero tillage has the potential to reduce energy use and improve energy use efficiency. Relative to conventional tillage, zero tillage provided significant energy savings in farm fuel use and in machine operation and manufacture.

3.4.4 Water Regulation

Forages and grasses can help reduce the risk of flooding by storing water and reducing the rate of water flow, and by reducing erosion thereby allowing water time to soak into the ground (ARHMS, Undated). Riparian areas formed by forages help reduce flooding by storing water during high water events (Coote and Gregorich, 2000). Perennial forages and grasses in riparian areas help to filter water, decrease the number of potential pollutants, and improve overall water quality, (Fitch & Adams, 1998; ARHMS, Undated). Forages in riparian areas can improve water quality and reduce the cost of removing sediments from reservoirs and transportation channels.

3.4.5 Soil Erosion

Perennial forages in riparian areas help to slow water down, thereby reducing erosion, (Beschta & Platts, 1986; ARHMS, Undated; Elmore, 1992; Olewiler, 2004; Platts, 1981). The deep roots of the forages provide a physical barrier to the effects of high water velocity and help to create bank stability. These deep roots act to trap sediments and build up the soil (ARHMS, Undated; Ohmart, 1996; Platts, 1990). Sediment erosion can be reduced from six tonnes to less than one tonne/hectare/year by using farming practices that enhance vegetation (Olewiler, 2004).

3.4.6 Soil Nitrogen

According to Entz et al. (2002), forages' deep root systems allow them to reach nutrients that most annual plants are not able to. Manitoba research by Kelner et al. (1997) demonstrated increased soil N as a result of including alfalfa in crop rotation. The increase was attributed to fixed atmospheric N being added to the soil, and the ability of forages to reach nitrate from more than one meter below the soil surface. Soil N was higher even after factoring removals by the alfalfa crop. Such additions to soil N can reduce the need or use of synthetic fertilizer in succeeding crops, and thereby reduce input costs.

3.4.7 Pollination

Grass and forage cover can provide habitat, nesting and forage for pollinators. Pollination is very important to agriculture. For example, according to Wilson (2008), approximately 30 per cent of the world's food is from crops that depend on pollinators like bees, insects, bats, and birds.

3.5 Cultural Services

Potential cultural services, primarily including recreational and aesthetic services, are principally associated with the grass and forage cover of BMPs 2 and 4, and possibly with BMP 5 (crop selection; vegetated filter strips; and surface water control structures respectively). For example, in riparian areas, forage and grass cover can improve water quality and stream productivity and thereby increase use of the area for human recreation and enjoyment of the aesthetics and activities such as fishing, camping, swimming, and boating. Healthy grasslands can assist in meeting human expectations of the recreational and aesthetic value of rural areas (ALUS, Undated).

Rural open spaces are of value to both landowners and passersby, (Rosenberger and Walsh, 1997). Open spaces are aesthetically pleasing to humans, and may provide recreational opportunities. Human health can be improved by green spaces, and any improvements in air and water quality (LEAD International, 2009).

Native American culture is closely tied to grassland. Farmers' heritage is also closely tied to the land including grasslands (Crosson, 1985).

3.6 Support Services

Grassland including grass and forage cover have potential to provide refugium and nursery functions and support wildlife habitat. For example, open and green spaces can provide corridors between habitats and area for wildlife reproduction and refuge (Reháčková and Pauditšová, 2004). Animals such as migratory birds, notably ducks, need large areas for nesting. For example, Nelson (2004) reports that ducks need 40 percent of the landscape as grass in order to realize the nesting success necessary to maintain their population.

4. Estimating the Nutrient Export Reduction Potential of the BMPs

This chapter discusses the basis, methods and data used to estimate the P reduction potential of the BMPs examined.

4.1 Scope

The scope of this biophysical assessment of BMPs is limited to P exported from agricultural sources within Manitoba into Lake Winnipeg. It does not include P from other sources or other regions of the Lake Winnipeg watershed, nor does it include N. For reasons outlined in the previous chapter, it is unlikely that fertilizer N losses could be reduced in a way that would provide meaningful improvements to Lake Winnipeg's water quality.

4.1.1 Spatial Context

A range of scales was considered, from individual fields to the Manitoba portion of the Lake Winnipeg watershed. The field scale is the smallest and corresponds to the P that leaves fields, not the distribution that occurs within fields. As such, the field scale is also referred to as “edge-of-field”. Once P leaves the field, it is transported through watersheds of increasing size, and for the purposes of this study, these are referred to as the local watershed scale (e.g. STC), the sub-regional watershed scale (e.g. Red River watershed) and the regional watershed including the Lake Winnipeg watershed, with Lake Winnipeg being the receiving water body.

4.1.2 Temporal Context

Two time scales are considered in assessing the effect of BMPs: 1) short-term, three to five years, which reflects a normal farm planning cycle (as well as the five year census of agriculture cycle); and 2) long-term, 30-50 years, which reflects the generational cycle of farm management. It is expected that BMPs which relate to the transport of P, such as vegetative filter strips, will generate a response within the short-term. Other BMPs, such as nutrient management practices, which relate to the source of P on agricultural land, will generate a response over the long-term rather than the short-term. The response of BMPs, such as surface water control structures, may diminish over time and have little added response in the long-term. These two time scales are used to frame scenarios for P reduction in response to the selected BMPs.

4.1.3 Climate, Landscapes and Hydrology

The environmental conditions of the Lake Winnipeg watershed greatly affect the contamination of its surface waters. As noted in Chapter 1, the watershed is very large extending to Alberta in the west, Ontario in the east and South Dakota in the south – a large portion of the Northern Great Plains. The climate is semi-arid to sub-humid with relatively little runoff and water erosion in comparison to other regions of North America. The climate is cold with snowmelt-dominated surface hydrology. The landscape of the watershed is unusual in that large portions have closed hydrologic networks and do not normally contribute overland flow to the creeks and rivers within the watershed. Consequently, the runoff entering Lake Winnipeg is relatively small given its large area, and the majority of this runoff occurs over a relatively short period of time. The concentration of P in this runoff can be relatively high, and the P in this runoff is mostly in the dissolved form. These conditions make it very difficult to relate research on P BMPs from other regions to the Lake Winnipeg watershed.

4.2 Assessment of Phosphorus Reduction Potential

The approach taken to assess the potential reduction in P export from agricultural land to surface waters through the use of agricultural BMPs is necessarily simple. Observed levels of P exported from sub-regional watersheds are multiplied with measures of the relative performance of agricultural BMPs and conventional practices, and these products are interpreted in the context of the Lake Winnipeg watershed.

4.2.1 Export of Phosphorus

Manitoba studies that quantify the amount of P exported have been conducted for various watersheds ranging in size from small, first order drainage basins to large, regional watersheds. This section reviews Manitoba and related studies beginning with a data summary in Table 4.1. The data are reported as intensity levels of P exported (kg P ha^{-1} yr^{-1}). The discussion following Table 4.1 provides additional detail.

Table 4.1 Export of Phosphorus[a] from Agricultural Land to Surface Waters in Manitoba

Scale	Watershed	Phosphorus Export Intensity		No. Water sheds	Total Area of Watershed	Portion of Watershed in Crop Land[c]	Portion of Manitoba's Agricultural Land[d]
		(kg P ha^{-1} yr^{-1})		No.	ha	percent	
Field Scale (edge-of-field)	Twin Watersheds of STC	Mean[b]	0.450	1	9.3	100	0.0001
		Lower[b]	0.180				
		Upper[b]	0.650				
Local Watershed Scale	STC (South Tobacco Creek)	Mean[b]	0.600	1	7,638	71	0.10
		Lower[b]	0.390				
		Upper[b]	0.790				
Sub-Regional Watershed Scale	Tributaries to the Red River[d]	Mean[b]	0.101	7	1,242,112	52	11.7
		Lower[b]	0.011				
		Upper[b]	0.258				
Sub-Regional Watershed Scale	Tributaries to the Assiniboine River[e]	Mean[b]	0.040	1	414,551	37	3.2
		Lower[b]	0.007				
		Upper[b]	0.102				
Regional Watershed Scale	Various Watersheds in Manitoba[f]	Mean[b]	0.057	14	2,605,570	43	21.2
		Lower[b]	0.006				
		Upper[b]	0.156				

[a] Total phosphorus, expressed as kilograms of P.
[b] Mean annual P transport from the watershed via the surface water expressed as an intensity (per hec-

Table 4.1 Export of Phosphorus[a] from Agricultural Land to Surface Waters in Manitoba

tare per year) over a period of about 10 years. Lower is the lowest and Upper is the highest reported annual export for that period. Values are area-weighted means of the means for the selected watersheds, and the area-weighted means of the lowest intensity levels for the selected watersheds; and the area-weighted means of the highest intensity levels for the selected watersheds.

[c] Crop Land includes land in annual crops, forage and summer fallow in 2001, assuming that this land receives P on a regular basis.

[d] The agricultural land area reported in the watershed in 2001 relative to Manitoba's total agricultural land.

[e] LaSalle, Seine, Rat-Marsh, Boyne, Cooks, Roseau and Cypress river watersheds.

[f] Little Saskatchewan River watershed.

[g] The Red River and Assiniboine River tributaries plus the Brokenhead, Valley, Wilson, Ochre, Vermillion and Turtle River watersheds.

Field scale export data are based on the Twin Watersheds study within the STC watershed (Figure 2.1). These first order drainage basins are paired, side-by-side fields with edge-of-field monitoring of P levels from 1993 to present. The data are reported in Tiessen et al. (2010a). Additional data continues to be collected from the Twin Watersheds study and from other field scale basins within the STC watershed under the WEBs program, but they have not yet been published. Similar field scale data from elsewhere in the Lake Winnipeg watershed, if they exist, have not been published.

Local watershed scale data are based on the STC watershed study. Monitoring of P concentrations in the surface water of this watershed also extends from 1993 to present. The data are reported in Hope et al. (2002)[4]. Additional data continues to be collected from the STC watershed study under the WEBs program, but they have not yet been published.

Studies by Bourne (2002), Salvano and Flaten (2006), and Salvano et al. (2009) report on P levels in many larger scale watersheds in Manitoba. The data from these studies have been organized into sub-regional and regional watershed scales. The water quality data reported spans 1974 to 2001. The water quality monitoring program, led by Manitoba Water Stewardship, is ongoing, but more current data are not yet published. For the purposes of this study, only the data from 1988 to 1999 were used to assess P export characteristics.

The Red River and Assiniboine River watersheds are given greater attention since they are considered to be the major contributing areas of P to Lake Winnipeg. The progression of drainage from the Twin Watersheds to the STC watershed to the Boyne-Morris River watershed to the Red River watershed provides a linear, downstream view of P transport within watershed systems.

The studies noted above each consist of about ten years of data which are used to calculate mean annual export intensity levels, and the upper and lower annual export intensity levels for each scale of watershed. Upper and lower levels are reported for each watershed scale

[4] Reviewers of this report observe that alternative data is available. For example, Glozier et al. (2006) report slightly higher and more variable P export intensity - a mean of 0.70 within a lower and upper bound of 0.11 and 1.41 respectively (compared to 0.6 within 0.39 and 0.79, Table 4.1). As noted, additional data continues to be collected from the STC site.

to illustrate the variability that can exist within these systems. This variability is largely due to normal variations in weather. Coefficients of variation are reported to illustrate the variability that exists across watersheds due to biophysical conditions, and land use and management practices. The data found in these studies span 1988 to 2007, but include many years in common.

4.2.2 Performance of BMPs

The potential of the selected BMPs to reduce P export from agricultural land to downstream surface waters is expressed as relative export coefficients (REC) which, when multiplied with a value of P export intensity (PEI, kg P ha^{-1} yr^{-1}), provides a measure of potential P reduction (PPR, kg P ha^{-1} yr^{-1}).

$$PPR_{(BMPi)} = PEI \times REC_{(BMPi)}$$

These coefficients are based on a comparison of P export under a given BMP to P export under the corresponding conventional practice; as such, they are RECs. The RECs for selected BMPs are presented in Table 4.2.

The areal extent of potential application of the selected BMPs was taken into consideration in determining REC values over the range of scales. The practice of conservation tillage is applied at the field scale and can be applied to all fields within the local, sub-regional and regional watershed scale. Consequently, REC values for conservation tillage are constant across all scales. In contrast, headwater dams as a surface water control structure are applied at a local watershed scale, not at a field scale. Consequently, REC values for surface water control structures vary across scales.

It is recognized that scale can affect the fate of P exported from farm fields and delivered to Lake Winnipeg. This is observed in the transformation between dissolved and particulate P in the STC watershed where P leaves fields largely in a dissolved form and is exported from the watershed largely in particulate form. Scale effects are well documented for sediments in other regions, and delivery ratios have been developed to reflect the changes in the nature of sediments moving from the field scale to the regional watershed scale. Such delivery ratios do not exist for P for the Lake Winnipeg watershed and there is insufficient data to develop them. Consequently, it is necessary to assume that once P is exported from the field and enters the stream, the total amount of P is delivered to Lake Winnipeg.

4.2.3 Magnitude of Phosphorus Reduction

The magnitude of the potential P reduction in Lake Winnipeg (kg P yr^{-1}) is calculated as the cumulative potential of selected BMPs to reduce P (PPR) multiplied by the combined area of the sub-regional watersheds where these BMPs could be implemented within the Lake Winnipeg watershed.

$$\text{Phosphorus Reduction} = \Sigma(PPR_{(BMPi)}) \times Area$$

Two approaches were considered to scaling up BMP performance from the field and local watershed scale to sub-regional watershed scale for the purpose of assessing the magnitude of potential P reduction in the Lake Winnipeg watershed. One approach was to use the Soil Landscapes of Canada database. The other approach was to use the watershed database for the Lake Winnipeg watershed. The Census of Agriculture was used as the source of agricultural management data for the province of Manitoba. This census data has been spatially reconfigured from the census reporting areas to the Soil Landscape (SLC) polygon areas for census years 1981 to 2006 and to the sub-regional watershed areas for 2001 alone. With the SLC database it is possible to aggregate land management practices and associated REC values based on soil and landform data, and it is also possible to apply Agriculture and Agri-Food Canada's Indicator of Risk of Water Contamination by Phosphorus (IROWC-P) model to estimate P export from farm fields. For the purposes of this study, the watershed database which has measurements of P export at the watershed scale as well as on land management practices was used.

4.3 Study Area

Table 4.3 presents the study area – the area of land and associated coefficients and factors on which the P export potential and EGS costs and benefits are estimated. The study area, which as outlined above, consists of Census of Agriculture data at the SLC level compiled specially for the listed watersheds comprises approximately 23 percent of the cropland area in Manitoba. When measured in terms of the encompassing and surrounding Census Consolidated Subdivisions (CCS), the study or watershed area and surrounding CCS represent approximately 56 percent of the area under crop in Manitoba.

Table 4.2 Relative Export Coefficients for Phosphorus[a, b] from Agricultural Land To Surface Waters in Manitoba

Beneficial Management Practice (BMP)	Field Scale (edge-of-field)			Local Watershed Scale			Sub-Regional Watershed Scale			Regional Watershed Scale		
	Twin Watersheds of STCW			South Tobacco Creek Watershed			Red River Watershed			Lake Winnipeg Watershed		
	EC[c]	L[d]	H[d]	EC[c]	L[d]	H[d]	EC[c]	L[d]	H[d]	EC[c]	L[d]	H[d]
Source BMPs: *Those that affect the amount of P found in the soil and vegetation of fields*												
A) Nutrient Management	0.94	0.84	0.95	0.94	0.84	0.95	0.94	0.84	0.95	0.94	0.84	0.95
Practices (form, rate, timing and placement) to optimize nutrient use by crops compared to conventional nutrient management practices												
(i) Synthetic Fertilizer												
(ii) Livestock Manure												
(iii) Manure Storage												
B) Crop Selection	0.95	0.90	1.00	0.95	0.90	1.00	0.95	0.90	1.00	0.95	0.90	1.00
Annual crops with forages in rotation compared to annual crops without forages in rotation												
Transport BMPs: *Those that affect the transport of P from fields and through watersheds*												
C) Conservation Tillage	1.12	0.50	3.00	1.12	0.30	3.00	1.12	0.30	3.00	1.12	0.30	3.00
Conservation tillage practices (reduced-till, minimum-till, zero-till and no-till) compared to conventional tillage practices												
D) Vegetated Filter Strips	0.95	0.90	1.00	0.90	0.80	1.10	0.90	0.80	1.10	0.90	0.80	1.10
In-field and edge-of-field waterways with managed vegetative cover compared to those without												
(i) In-Field Grassed Waterways	0.95	0.90	1.00									
(ii) Edge-of-Field Vegetative Filter Strips (Riparian)				0.90	0.80	1.10	0.90	0.80	1.10	0.90	0.80	1.10

Table 4.2 Relative Export Coefficients for Phosphorus[a, b] from Agricultural Land To Surface Waters in Manitoba												
Beneficial Management Practice (BMP)	**Field Scale (edge-of-field)**			**Local Watershed Scale**			**Sub-Regional Watershed Scale**			**Regional Watershed Scale**		
	Twin Watersheds of STCW			**South Tobacco Creek Watershed**			**Red River Watershed**			**Lake Winnipeg Watershed**		
	EC[c]	**L[d]**	**H[d]**	**EC[c]**	**L[d]**	**H[d]**	**EC[c]**	**L[d]**	**H[d]**	**EC[c]**	**L[d]**	**H[d]**
E) Surface Water Control Structures	0.95	0.85	1.00	0.90	0.88	0.91	0.98	0.95	1.00	0.98	0.95	1.00
Use of structures to retain runoff within the field and within the upper reaches of a watershed compared to the use of no such structures												
(i) In-field Structures (WASCoBs)	0.95	0.85	1.00									
(ii) Headwater Dams				0.90	0.88	1.00	0.99	0.98	1.00	0.99	0.98	1.00

[a] Values greater than 1.0 indicate an increase in P export for the BMP relative to the practice of comparison, the conventional management practice.
[b] Export of total P, the sum of particulate and dissolved P. Although no distinction is made between dissolved and particulate, the ecosystems in Manitoba are normally dominated by dissolved P during snowmelt.
[c] Export Coefficient (BMP/no-BMP)
[d] The **L** low and **H** high (or upper) values reflect information found in the literature, and the relevance of that literature based on its climate, cropping and tillage systems under consideration, the scale of observation, the duration of study, and the time frame over which an impact is considered (short-term to long-term).

Table 4.3 Study Area. Selected Manitoba Watersheds (1988-1999). Land Area, Use and Cover. P Export Intensity										
Watershed	**Total Land Area**	**Cultivated Land Area**		**Annual Crop Land Area**		**Pasture**		**Average Intensity**	**Lower Intensity**	**Upper Intensity**
	ha	**ha**	**% Water-shed**	**ha**	**% Water-shed**	**ha**	**% Water-shed**	**kg P ha-1**		
Tributaries of Red River			54		52					
La Salle River	240,624	188,706	78	185,182	77	20,489	9	0.1353	0.0142	0.3649
Seine River	210,748	108,096	51	101,346	48	22,620	11	0.0516	0.0085	0.1320
Rat-Marsh River	201,132	74,434	37	70,526	35	29,203	15	0.1105	0.0186	0.3152
Boyne-Morris River										
Boyne River	174,529	138,448	79	134,794	77	17,742	10	0.0398	0.0088	0.2052
Morris River[1]										
Lower Red River										
Cooks Creek	74,680	34,883	47	31,487	42	5,187	7	0.0478	0.0097	0.1597
Upper Red River										
Roseau River	259,082	64,975	25	60,960	24	42,461	16	0.1594	0.0105	0.2681
Cypress River	81,317	60,923	75	59,866	74	13,302	16	0.1004	0.0030	0.2996
Tributaries of Assiniboine River										
Upper Assiniboine River[1]										
Middle Assiniboine[1]										
Lower Assiniboine										
Little Saskatchewan River	414,551	165,902	40	151,885	37	42,743	10	0.0402	0.0065	0.1022
Tributaries of Lake Winnipeg										
Brokenhead River	263,688	69,114	26	64,108	24	9,774	4	0.0404	0.0041	0.0700
Tributaries of Dauphin Lake										
West Dauphin Lake										
Valley River	296,128	103,369	35	97,837	33	27,505	9	0.0361	0.0024	0.1255
Wilson River	99,619	46,311	46	44,424	45	10,328	10	0.0658	0.0068	0.1748
Vermillion River	75,673	29,692	39	28,989	38	5,230	7	0.1491	0.0095	0.8773
South Dauphin Lake										
Ochre River	37,115	7,499	20	7,273	20	5,796	16	0.0677	0.0132	0.1288
Turtle River	176,684	71,622	41	69,031	39	56,447	32	0.0173	0.0025	0.0409
Source: Salvano and Flaten (2006). Land and area data from 2001 Census of Agriculture. [1] Data not available.										

4.4 Current Level of Adoption of BMPs

This section sets out a selection of best available information concerning the current and possible adoption of the five BMPs by Manitoba farmers. It includes indicators of adoption of nutrient management, crop selection, conservation tillage, and vegetated filter strips at the field site scale or level and local watershed, subregional watersheds, and the regional watershed and province. This and additional related information are used to qualify and quantify current and potential farm adoption of each of the BMPs, which in turn become a determining factor of how much P is exported to the watershed.

Tables 4.4 and 4.8 are for the province of Manitoba and are from the Farm Environmental Management Survey (FEMS) of Statistics Canada. Table 4.6 is for the province based on the 2001 and 2006 Census of Agriculture. Tables 4.5, 4.7, and 4.9 report on study watersheds.

4.4.1 Summary Observations by BMP

- **Nutrient management**. Table 4.4 suggests that as of the 2001 FEMS, nutrient management plans (BMPs typically recommended for livestock producers)[5] were not widely adopted in Manitoba. Approximately 13 percent of farmer respondents to the FEMS indicated having a nutrient management plan, of which 91 percent had been implemented. About 53 percent do not test manure nutrient content before land applying, but 37 percent report reducing the amount of fertilizer applied to offset nutrient content of manure.
- **Crop selection**. Table 4.5 suggests some physical room for expansion of forage in rotation with less than about 5-6 percent of the total area of the 14 subregional watersheds in 2001. However, the poor profitability of Manitoba's cattle industry since 2003 limits the opportunities for increased forage production.
- **Conservation tillage**. Table 4.6 indicates the provincial trend is to increased conservation and no-till. In 2001 and 2006 Manitoba farmers used no-till and conservation tillage on 55.5 and 56.5 percent of seeded crop area respectively. Table 4.7 indicates the STC watershed is similar in that about 55 percent of its area is conservation tilled. Table 4.9 indicates conservation and zero tillage in the subregional watersheds ranges from 25 to 56 percent of seeded area.
- **Vegetated filter strips**. Table 4.8 indicates that as of the 2001 FEMS, 79 percent of Manitoba farmers reported a related BMP, notably vegetation in areas adjacent to natural sources of water. Table 4.9 indicates grassed waterways are generally reported by fewer than 5 to 7 percent of farmers in the majority of subregional watersheds, with some watersheds reporting 15-30 percent of farmers with some grassed waterways.

[5] Nutrient management planning is a phrase that has traditionally been used for manure management on livestock farms. It is not a common term for crop producers in Manitoba. Therefore, this observation should be interpreted in the context of the proportion of farms with livestock manure to manage. Nutrient management in the broader sense also includes soil testing, which is a common practice among crop producers.

Table 4.4 Fertilizer and Pesticide Management by Manitoba Producers, 2001

BMP - Survey Question	Response Qualifier	No. of Responses	Percent		
			Yes	No	Total
Have a nutrient management plan		13,885	13.1	86.9	100.0
Have implemented the nutrient management plan	No	2,185	90.8	7.5	100.0
	N.A.	35		1.6	
Test manure nutrient content before applying	No	14,040		53.2	100.0
	Liquid	480	3.4		
	Solid or liquid	335	2.4		
	No manure	5,755		41.0	
Reduce amount of fertilizer applied to offset nutrient content of manure	No	10,795	36.9	14.6	100.0
	N.A.	10,795	36.9	48.5	100.0
Source: Statistics Canada (2004)					

Table 4.5 Manitoba Watersheds Report (2001 LandSat Data)

Watershed	Total Land Area	Agricultural Land Area	Annual Crop Land Area	Forages
	hectares		Percent of Watershed	
Tributaries of Red River			51.9	3.7
La Salle River	240625	90.4	75.3	4.1
Seine River	210746	67.2	37.7	5.0
Rat-Marsh River	201333	57.4	29.3	2.7
Boyne-Morris River	407844	90.5	76.6	2.8
Boyne River				
Morris River				
Lower Red River	419542		44.7	4.2
Cooks Creek				
Upper Red River	168325		69.7	2.7
Roseau River	259007	46.8	17.2	3.2
Cypress River	81790	96.6	61.8	6.5
Tributaries of Assiniboine River				
Upper Assiniboine River				
Middle Assiniboine				
Lower Assiniboine				
Little Saskatchewan River	414530	58.2	33.3	2.3
Tributaries of Lake Winnipeg				
Brokenhead River	263691	5.2	20.0	2.1
Total Area Captured in Study	2403742	1285126		
Average, Area-weighted		13.8		
Manitoba`s Agricultural Land Area		3.2		
Percent of Manitoba Ag Land Area		16.9	48.7	
Source: AAFC-PFRA (2005)				

Table 4.6 Tillage Systems and Soil and Water Conservation Practices in Manitoba, 2001 and 2006 Census of Agriculture

Year	Conventional Tillage	Conservation Tillage	No Tillage
	Percent of Seeded Land		
2001	54.5	32.6	12.9
2006	43.4	35.2	21.3

Source: 2001 and 2006 Census of Agriculture, Statistics Canada

Table 4.7 Tillage Practices in the South Tobacco Creek Watershed

Twin Watersheds of South Tobacco Creek Watershed Tributary of Morris River, Tributary of Red River[1]	**Hectares**	**Percent**
Conventional Till (2004-2007)	4.2	45.2
Conservation Till (2004-2007)	5.1	54.8
Cultivated Land	9.3	100.0
Annual Crops	9.3	100.0
South Tobacco Creek Watershed (1991-1999) Tributary of Morris River, Tributary of Red River[2]	**Hectares**	**Percent**
Total Area Captured in Study	7,638	
Manitoba`s Agricultural Land Area	7,585,266	
Percent of Manitoba`s Agricultural Land Area		0.1

[1]Source: Tiessen et al. (2010a) [2]Source: Hope et al. (2002)

Table 4.8 Water Management by Manitoba Producers, 2001

BMP - Survey Question	Response Qualifier	No. of Responses		Percent Yes	Percent No	Percent Total
Vegetation in areas adjacent to natural sources of water			8,745	78.7	21.3	100
Grazing livestock access to surface water bodies			8,290	45.7	54.3	100
Implementation of BMPs for water management	Full	2,815	15,200	18.5		100
	Partial	1,860				
	N.A.	240			12.2	
	Unfamiliar	5,875			42.7	
	Not relevant	4,410			29.0	

Source: Grimard (2007)

Table 4.9 Tillage Systems and Soil and Water Conservation Practices in Tributaries of the Red and Assiniboine Rivers

Tributary	Conventional Tillage			Conservation Tillage			No Tillage			Grassed Waterways	
	ha	Percent		ha	Percent		ha	Percent		Farms no.	Per-cent of Farms
		Seed -ed	Water shed		Seed -ed	Water-shed		Seed -ed	Water shed		
Tributaries of Red River											
La Salle River (13)	129907	75.2	54.0	37622	21.8	15.6	5222	3.0	2.2	644	7.3
Seine River (10)	54190	66.2	25.7	21705	26.5	10.3	5729	7.0	2.7	895	3.2
Rat-Marsh River (8)	41051	70.9	20.4	14947	25.8	7.4	1918	3.3	1.0	477	3.6
Rat-Marsh River (8)	41051	70.9	20.4	14947	25.8	7.4	1918	3.3	1.0	477	3.6
Boyne-Morris River (14)	201518	69.0	49.4	77114	26.4	18.9	13310	4.6	3.3	1225	15.0
Boyne River											
Morris River											
Lower Red River (11)	114489	66.2	27.3	51981	30.0	12.4	6551	3.8	1.6	1450	3.7
Cooks Creek											
Upper Red River (6)	99920	79.3	59.4	23634	18.8	14.0	2491	2.0	1.5	605	5.0
Roseau River (7)	25924	67.4	10.0	10368	27.0	4.0	2157	5.6	0.8	418	5.7
Cypress River (4)	29396	55.1	35.9	18970	35.6	23.2	4940	9.3	6.0	260	31.0
Tributaries of Assiniboine River											
Upper Assiniboine River (15)											
Middle Assiniboine (14)											
Lower Assiniboine (12)											
Little Saskatchewan River (17)	56979	44.1	13.7	41591	32.2	10.0	30644	23.7	7.4	407	21.0
Tributaries of Lake Winnipeg											
Brokenhead River (9)	32473	61.0	12.3	16886	31.7	6.4	3915	7.3	1.5	350	2.6
2001, portion of seeded land area in study area		67.0	31.3		26.5	12.4		6.5	3.0	19054	
Source: AAFC-PFRA (2005)											

5. EGS Valuation

This chapter reports sources and data used to estimate physical and monetary values for the EGS potentially associated with the BMPs examined. Three major types and sources of values and estimation methods are used consisting of 1) benefit transfer where values are transferred from other studies and estimates and applied to the Lake Winnipeg and Manitoba situation; 2) including estimates derived using avoided cost methodology; and 3) Manitoba market prices and costs. Values are estimated for eight EGS including individual and combinations of the 23 EGS set out by Environment Canada's framework (Table 3.1). Note that particularly for BMPs involving grass and forage cover, the following draws extensively from Gschaid et al. (2010), which is a recent and comparable EGS valuation of grassland in Manitoba.

5.1 Value of Nutrient Reduction

As discussed in Chapter 2, the preferred method for deriving the value of reduced nutrient loading of Lake Winnipeg is a comprehensive approach that factors all components, agents, and stakeholders in the entire watershed from upstream origins through to the Lake. Given that the time, resources and authority required to assemble the information necessary for such a comprehensive approach are well beyond those of this project, an alternative using avoided cost methodology is used.

The International Institute for Sustainable Development (IISD, 2008) completed an assessment of EGS for the STC project including valuation of the nutrient and P reduction potential of a selection of BMPs. IISD (2008) valued P reduction potential on the basis of actual and planned City of Winnipeg expenditures to reduce nutrient outflow. Specifically, (Shkolny, 2008) reported that Winnipeg plans to spend $670M on facilities to reduce P loading to the Red River by 300 tonnes per year. Based on a 20-year amortization, IISD (2008) estimated this as equal to $112 per kg of P per year.

Shkolny[6] indicates that the IISD (2008) estimate is based on upgrading three City of Winnipeg treatment plants. One of these upgrades has already been made, and two are in the proposed and planning stage as outlined in the top three rows of Table 5.1. Whereas the City of Winnipeg's base and current capacity is for removal of P to a level of 3-4 mg per litre of discharge, the proposed upgrades would provide the ability to reduce the P concentration of waters exiting City treatment to 1 mg P per litre. The combined total capacity of the proposed improvement would enable the City to remove up to 300 tonnes of P annually from the three plants. Note that proposed capital costs include capability to remove P and N, as well as other treatment.

Szoke[7] indicates that an alternative for the North end plant has also been looked at. The alternative would remove P primarily, and would potentially entail lower capital and operating costs of $50 million and $9.2 million/year respectively (compared to $400 million and $17.5 million/year for the main proposal).

[6] Mike Shkolny, City of Winnipeg, Personal communication, October 2010.
[7] Nicholas Szoke, City of Winnipeg, Personal communication, October and November 2010.

The rightmost column of Table 5.1, under the heading "Unit Cost of P Removal" is an estimate of the unit cost of removing one tonne of P from water discharged by the City of Winnipeg into the Lake Winnipeg system (Red and Assiniboine rivers). The unit cost estimates assume the capital and operating costs and time schedule of Table 5.1, reinvestment over a 30 year period, an average life of 35.6 years for plant and equipment[8], straight line depreciation, and salvage equal to acquisition cost less cumulative depreciation. Estimates in NPV for 30 years are presented for 3 and 7 percent discount rate (the discount rate is reported in parentheses to the right of the $/tonne estimate). At 3 percent discount rate, the cost of removing a tonne of P from discharge waters by the City of Winnipeg is $164,092/tonne for the main plan, and $114,523/tonne if the alternative for the North plant is used. At 7 percent discount, the cost is $96,750/tonne for the main plan, and $71,814/tonne using the North alternative.

<table>
<tr><th colspan="5">Table 5.1 City of Winnipeg Nutrient Treatment Plants, Current and Proposed Capacity</th></tr>
<tr><th rowspan="2">Plant</th><th rowspan="2">Capacity</th><th>Capital Cost and Status[1]</th><th>Operating Cost[1]</th><th>Unit Cost of P Removal[2]</th></tr>
<tr><th>2008 $million. Year completed</th><th>2008 $million/year</th><th>NPV $2010 / tonne of P</th></tr>
<tr><td>West</td><td rowspan="3">417 t/year @3-4 mg P/L
118 t/year @1 mg P/L
300 tonnes P / year[3]</td><td>$32 m. 2008</td><td>2.0</td><td rowspan="3">164,697 (3%)
96,750 (7%)</td></tr>
<tr><td>South</td><td>$200 m. 2012</td><td>7.0</td></tr>
<tr><td>North[3]</td><td>$35 m. 2010
$400 m. 2014</td><td>17.5</td></tr>
<tr><td colspan="5">P Only[4]</td></tr>
<tr><td>North[4]</td><td>to 1 mg P/L</td><td>$50 m.</td><td>9.2</td><td>114,523 (3%)
71,814 (7%)</td></tr>
<tr><td colspan="5">1 City of Winnipeg planning estimates, in $2008.
2 Estimated NPV $/tonne of P removed by the City of Winnipeg assuming reinvestment over a 30 year period, average 35.6 year life for plant and equipment, straight line depreciation, and salvage equal to acquisition cost less depreciation; NPV for (3%) and (7%) discount rate.
3 Capacity to reduce to 1 mg/L total P and 15 mg/L total N in discharge.
4 Capacity to reduce to 1 mg/L total P in discharge. All other capacity and cost remains the same.
Source: Mike Shkolny and Nicholas Szoke, City of Winnipeg, Personal communication, October and November 2010.</td></tr>
</table>

5.2 Greenhouse Gases and Carbon

5.2.1 Soil Sequestration of Carbon

Gschaid et al. (2010) estimated the rate of soil carbon uptake for naturalized and tame or seed grassland in Manitoba to be 0.47 tonnes of carbon (C) per ha and 0.56 tonnes C per ha per year respectively.

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8 Average life of 35.6 years assuming the following percent distribution of capital cost and life by major component: plant 43% 60 years; major mechanical 35% 23 years; building mechanical and HVAC 4% 20 years; and electronics 18% 5 years.

5.2.2 Energy Use in Forage and Crop Production

In a comparison of the energy use and efficiency and environmental impacts of low input mixed crop and grazing systems in Manitoba, Khakbazan et al. (2007) showed that in the Black soil zones of Manitoba, low input zero tillage has the potential to reduce energy use and improve energy use efficiency. Khakbazan et al. (2007) report that forage crops use less energy and N fertilizer equivalent to an average 144 kg C per ha than conventional wheat, canola, flax, and pea rotations.

5.2.3 Fertilizer

Mono-ammonium phosphate (MAP 11-52-0) is the most common and widely used P fertilizer in Manitoba. The International Fertilizer Association, (IFA, 2009) estimates that the energy and resources consumed in the manufacture and use of MAP is equivalent to 6.6 tonnes CO_{2e} per tonne of MAP (or 1.8 tonnes C per tonne of MAP).

5.2.4 Value of Carbon

EGS benefits including lower direct energy use and greenhouse gas (GHG) emissions and increased carbon storage are valued at 2009-2010 Chicago exchange prices of CAD $2.38 per tonne of C; and at a suggested social cost of CAD $15.00 per tonne of C.

5.3 Water Regulation

Based on a review of studies and using benefit transfer methods, Gschaid et al. (2010) estimated that the value of water regulation provided by Manitoba grasslands is an average $0.85 per hectare within a low and high range of $0.25 and $1.18 per ha respectively.

5.4 Erosion Control

In their valuation for Manitoba, Gschaid et al. (2010) estimate that erosion control provided by grasslands is an average $0.49 per hectare within a range of $0.25 and $2.21 per ha.

5.5 Pollination

Based on pollination and related studies in Ontario and other parts of the world, Gschaid et al. (2010) estimated the value of pollination services by Manitoba grasslands. Consistent with other estimates, Gschaid et al. (2010) assume that pollination services are equivalent to 30 percent of the commercial value of established grass and forage, or $127.06 per hectare annually. Pollination services were also considered within an arbitrary range of $63.53 (one half of the main estimate) to $139.76 per hectare (10 percent greater than the Gschaid et al. estimate).

5.6 Wildlife Habitat

Based on their review of literature and benefit transfer analysis, Gschaid et al. (2010) estimated that the combination of refugium and nursery services provided by Manitoba grassland is $4.73 per hectare and lies within a range of $2.83 and $6.65 per ha (2010$). Gshaid et al. (2010) base their calculation, in part, on Atakelty et al. (2000) WTP estimate for prairie grassland conversation for burrowing owl (considered a minimum value); and on a Costanza et al. (2006) estimate of the welfare loss associated with loss of prairie grassland habitat for wildlife and hunting.

5.7 Manitoba Market Values and Estimates

The following describes the major sources and methods used to develop the principal Manitoba market values, prices and costs used in assessing the BMPs.

5.7.1 Crop Production

The opportunity cost of conventional crop production is represented by estimates of the net proceeds or income from wheat and canola production. Manitoba generally and particularly the study area produces a wide range of crops. However, cost and revenue data on a detailed geographic basis is not readily available. Wheat and canola are two major Manitoba crops, and their range of profitability over the most recent 10 years (2000-2009) is used to represent and measure the opportunity cost of crop production that may be impacted by the BMPs examined by this study.

According to Manitoba Agriculture, Food and Rural Initiatives (MAFRI, 2010), using provincial average yield, price and cost data, the average pretax income (revenue less all costs) of wheat and canola production in the province for the most recent 10 years 2000-2009 for which data is available was $15.38 per hectare (and within a range of $-166.72 and $370.50 per hectare). Assuming a 40 percent rate of income tax, on an after tax or net income basis this is equivalent to $9.23 per hectare (and a range of $-100.23 and $222.30 per hectare).

5.7.2 Grass and Forage Establishment

MAFRI (2008) estimates the cost of establishing alfalfa/hay is $41.16/hectare/year (2010 $) when spread over a ten year life. Assuming a five year life for the grass or alfalfa stand, establishment costs are double or $82.32/hectare/year.

5.7.3 Livestock Manure Treatment and Transport

Mann and Grant (2006) estimated that the annual cost for Manitoba's pig industry to adapt to manure P balance would be approximately $28 million per year (2005 $). Pigs produce approximately 50 percent of the mechanically applied manure in Manitoba (Halket et al., 2003); and according to the 2006 Census of Agriculture, approximately 60 percent of all Manitoba cattle, pigs, poultry, and sheep are located in the Census Consolidated Subdivisions that include and surround the Red, Assiniboine, and Dauphin river watersheds of the study area. Based on this information, and updating Mann and Grant's estimate to 2010 using the Consumer Price Index, the cost for storing, treating and transporting all major livestock manure in the study area such that all manure is land applied at a rate no higher than crop use or uptake is a conservative $36.34 million in 2010 dollars.

5.8 Summary

Table 5.2 is a summary of the values reviewed in this chapter. The table relates the main EGS categories and items of Environment Canada's framework (column 1) to the EGS and other items included in this valuation (column 2). Column 3 indicates the BMPs to which each EGS applies. The Main, Low, and High values of the columns numbered 4 are the actual unit and other values on which valuation and the cost benefit analysis reported in Chapter 6 are based. Column 5 indicates the unit of the values in column 4. Column 6 is the general method by which the values were obtained and otherwise derived. Note that calculated and amortized values reported in the table (e.g., P reduction) were estimated assuming a three percent discount rate, and that this discount rate is varied in the sensitivity analysis reported in Chapter 6.

Table 5.2 Ecological Goods and Services Included in BMP Assessment, Values, and Valuation Method							
1	2	3	4			5	6
EGS per EC Framework[1]	**EGS Included**[2]	**BMP**[3]	**Value**[4]			**Unit**[5]	**Valuation Method**[6]
			Main	**Low**	**High**		
Regulating Services							
Phosphorus reduction		all	164,697[7]	114,523[7]		$/tonne P	Avoided cost
climate regulation	soil carbon sequestration	2, 3	2.38		15.00	$/tonne C	Market and social cost
	lower energy use	2					
water purification	water regulation	2, 3	0.85	0.25	1.18	$/ha/year	Benefit transfer
erosion control	soil erosion	2, 3	0.49	0.25	2.21	$/ha/year	Benefit transfer
All Other Regulating Services: pest & disease control, waste treatment							
Supporting Services							
soil formation	soil nitrogen	2, 3, 4	799.42	528.56	1,500.55	$/tonne N	Market
pollination	pollination	2, 3, 4	127.06	63.53	139.76	$/ha/year	Benefit transfer
All Other Supporting Services: nutrient cycling, photosynthesis, primary production							
Cultural Services							
aesthetic, recreation, & heritage	wildlife habitat	2, 4, 5	4.73	2.83	6.65	$/ha/year	Benefit transfer
All Other Cultural Services: education, psychological health, spiritual							
Provisioning Services; and Market Costs and Prices[8]							
• food • wood and fibre	crop production	1, 2, 3, 5	9.23	-100.23	222.30	$/ha/year	Market opportunity cost
	grass & forage establishment	2, 3	41.16		82.32	$/ha/year	Market
	manure handling	1	36.34	32.71	54.51	$million/year	Market, transfer
	MAP fertilizer	1	606.18	364.93	1,349.19	$/tonne MAP	Market
All Other Goods and Provisioning Services: fuel, genetic resources, pharmaceuticals, drinking water, minerals							

[1] Major categories and Ecological Goods and Services per Environment Canada framework. See Table 3.1. P reduction is included as a separate regulating service.
[2] EGS included in this valuation and report. EGS not included are listed in the last row of each category as "All Other."
[3] BMPs to which the EGS in column 2 are associated, where 1) nutrient management; 2) crop selection; 3) conservation tillage; 4) vegetated filter strips; and 5) surface water control structures.
[4] Unit and other values used in this valuation including main or average value, and low and high limits of possible range in $2010; and [5] Unit of value.
[6] General method by which value calculated, estimated or otherwise obtained.
[7] Assuming three (3) percent discount rate. See Chapter 7 for sensitivity analysis of discount rate.
[8] Includes EGS provisioning services as well as major market costs and prices used in cost benefit analysis, Chapter 6.

6. Estimates of Potential Phosphorus Export Reduction, and Costs and Benefits of BMPs

This chapter presents estimates of the P reduction potential, and associated costs and EGS benefits of the BMPs selected for assessment. Estimates are presented in two sections. Section 6.1 reports physical estimates of P export reduction potential by BMP. Section 6.2 reports estimated costs and EGS benefits.

6.1 Estimated Phosphorus Export Reduction Potential of BMPs

Table 6.1 reports physical estimates of P export reduction potential by BMP. Estimates are annual reduction potential measured in P per tonne per year. P export reduction potential is measured at maturity, or for full potential adoption of each BMP. As discussed in previous chapters, transport BMPs are generally considered temporary and short term BMPs. As such, they can be implemented or realized in relatively shorter time horizons (5+/- years), but are not permanent and have to be repaired and replaced in order to provide sustained benefits. The estimates reported in this chapter assume reinvestment in transport BMPs is made every 10 years. Source BMPs, specifically nutrient management BMPs, are longer term and more permanent BMPs. They require a longer period to be fully implemented or adopted (20-30 years). Once in place, nutrient management that balances manure and synthetic fertilizer application with crop uptake offers more permanent solutions.

Table 6.1 reports a main export reduction estimate within bounds of lower and upper limits, where the limits are defined as the lower and upper estimate of the potential for the BMP to reduce P export (export coefficients of Tables 4.1 and 4.2). All BMPs with the exception of conservation tillage are estimated to reduce P export, with nutrient management offering the largest reduction potential. Based on studies and field results in Manitoba and locations with similar conditions, conservation tillage, although beneficial in other agronomic and environmental respects, is estimated to increase and not reduce P export to the Lake Winnipeg drainage area.

Table 6.1 Main Estimates of BMP Phosphorus Reduction Potential

BMP[1]	Change in Phosphorus Export, tonnes P / year[2]		
	Main[3]	Lower[3]	Upper[3]
1. Nutrient Management	-96.9	-10.7	-254.6
2. Crop Selection	-3.9	-0.4	-11.4
5. Surface Water Control Structures	-2.4	-0.3	-6.5
4. Vegetated Filter Strips	-1.0	-0.1	-3.0
Sum of above[4]	**-104.2**	**-11.5**	**-275.5**
3. Conservation Tillage	18.3	2.1	53.6

[1] BMPs are presented in order of descending order of P export reduction potential, but are numbered as presented in Chapter 3. A negative number indicates potential to reduce P exports to Lake Winnipeg watershed, and a positive number indicates potential to increase P exports to the watershed.
[2] Change in P Export, tonnes/year at full adoption/maturity.
[3] Main estimate within lower and upper bounds of the P export impact of the BMP relative to the situation without the BMP, see Table 4.2.
[4] Sum of BMPs 1, 2, 4, and 5 not including BMP 3 Conservation Tillage. BMPs are not necessarily cumulative or additive.

The main estimates of Table 6.1 are based on average P export intensity. Table 6.2 reports the main, lower, and upper estimates within the range of average, low, and high P export intensity. See Tables 4.1 and 4.2 for P export intensity coefficients.

Table 6.2 Main Estimates of BMP Phosphorus Reduction Potential Within Lower and Upper Bounds of Export Intensity

BMP[1]	Change in P Export, tonnes/year[2]								
	Main[3]			Low[3]			High[3]		
	Main[4]	Low[4]	High[4]	Main[4]	Low[4]	High[4]	Main[4]	Low[4]	High[4]
1. Nutrient Management	-96.9	-104.1	-96.2	-10.7	-11.5	-10.6	-254.6	-275.7	-252.5
2. Crop Selection	-3.9	-3.7	-4.1	-0.4	-0.4	-0.5	-11.4	-10.8	-12.0
5. S. Water Ctrl. Structures	-2.4	-2.3	-2.5	-0.3	-0.2	-0.3	-6.5	-5.7	-7.9
4. Veg. Filter Strips	-1.0	-0.9	-1.2	-0.1	-0.1	-0.1	-3.0	-2.6	-3.6
Sum of above[5]	**-104.2**	**-111.0**	**-104.0**	**-11.5**	**-12.3**	**-11.5**	**-275.4**	**-294.9**	**-276.0**
3. Conservation Tillage	18.3	-4.9	49.1	2.1	-0.6	5.7	53.6	-14.4	143.6

1 BMPs are presented in order of descending order of P export reduction potential, but are numbered as presented in Chapter 3. A negative number indicates potential to reduce P exports to Lake Winnipeg watershed, and a positive number indicates potential to increase P exports to the watershed.
2 Change in P Export, tonnes/year at full adoption/maturity.
3 Main estimate within lower and upper bounds (Low and High respectively) of the P export impact of the BMP relative to the situation without the BMP.
4 Main or average, low and upper estimates of export intensity, see Table 4.2.
5 Sum of BMPs 1, 2, 4, and 5 not including BMP 3 Conservation Tillage. BMPs are not necessarily cumulative or additive.

6.2 Costs and Benefits by BMP

The balance of this chapter reports estimates of the costs and EGS benefits of each of the four BMPs with P export reduction potential. Estimates are presented in standard fashion, beginning with a tabular summary of the main cost and benefit estimates. This is followed by a discussion of the major cost and benefit components. P export reduction benefits are estimated and reported for all BMPs. However, other EGS benefits are only estimated for those EGS for which physical evidence and data is available. As such, estimates can be considered conservative.

Costs and benefits reported in Tables 6.3 to 6.6 are NPVs expressed in 2010$ discounted at 3 percent over 30 years. All values other than P reduction and C carbon related items reported in Tables 6.3 to 6.6 are expressed as a main or average estimate within low and high bounds. P reduction, C and greenhouse gas (GHG) items, and the NPV discount rate are constant at average value ($164,697 per tonne of P; $2.83 per tonne of C; and 3 percent respectively) in the estimates and tables of this Chapter 6, but are varied in the sensitivity analysis reported in Chapter 7.

6.2.1 Nutrient Management

Table 6.3 reports a summary of estimated costs and benefits of nutrient management BMPs assuming the BMPs are adopted / implemented at full or maximum potential, where maximum potential includes all crop land in the study area watersheds (Table 4.3).

Table 6.3 Costs and Benefits, NPV[1] $million. Nutrient Management			
P Reduction Potential. Main estimate (Table 6.1): -96.9 tonnes P/year at maximum potential			
Summary	**Main**	**Low**	**High**
Costs			
Manure treatment and transport	320.08	288.07	480.12
Lower crop yield and foregone income	287.08	172.26	514.99
Total Costs	607.16	460.33	995.11
Benefits			
Lower P exports	162.59	162.59	162.59
Fertilizer expense saving	29.18	17.57	64.94
Lower GHG emission	1.46	1.46	1.46
Total Benefits	193.22	181.61	228.99
C/B Cost/Benefit Ratio	3.1	2.5	4.3
Net cost $/tonne P	244,361	164,537	452,267
[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.			

Costs

Major and representative costs are private and include:

Manure treatment and transport. Estimates are derived from Mann & Grant (2006). The Low scenario of Table 6.3 assumes costs are 10 percent lower than Mann and Grant's (2006) base estimate, and the High scenario assumes that these costs are as much as 50 percent higher.

Lower crop yield and foregone income. Chapter 3 and Appendix B outlined how matching of fertilizer and manure P to crop uptake of P may result in yield losses in some regions and for some farmers. The main estimate of Table 6.3 assumes a 10 percent yield[9] loss on 50 percent of the cropland in the study area based on the average net income from wheat and canola production in Manitoba in the most recent 10 years for which data is available (2000-2009). The Low estimate is based on the lowest net income observed in Manitoba over the period; while the High estimate is based on the highest average provincial wheat and canola profitability observed over the period.

[9] Ten percent is the average response of crop yield to additions of P.

Benefits

Major EGS benefits include a **reduction in P exports to the watershed** and **lower GHG emissions** as a result of reduced fertilizer use and more widely distributed land spreading of livestock manure. The impact of increased energy and fuel costs associated with greater manure treatment and transport are not included.

Fertilizer expense saving. Previous chapters set out how nutrient management BMPs, at their fullest, would involve spreading manure over a wider land area, and reducing fertilizer P application by about 20 percent in order to bring P application and crop uptake into balance. Assuming a provincial average rate of P fertilizer application (24.24 kg/ha, Appendix B), fertilizer savings are estimated as a 20 percent reduction in application of the main P fertilizer used in Manitoba (mono-ammonium phosphate MAP 11-52-0) valued at the average, low and high prices over the last 10 years (Table 5.2; Thomsen, 2009).

6.2.2 Crop Selection

Table 6.4 is a summary of estimated costs and benefits of the crop selection BMP assuming the BMP is adopted / implemented at its full or maximum potential. As outlined in Chapter 3, there is limited opportunity to introduce cover crops (e.g. alfalfa) into existing crop rotations. Further, expansion of cover crop area as part of a shift to livestock production presents another set of environmental issues. Specifically, if cover crop area is expanded to produce forage for increased livestock production, livestock production and manure present increased environmental and P management challenges that can exceed and further complicate the current situation[10]. Therefore, the maximum potential adoption of this BMP was assumed equivalent to five percent of the crop land of the study area (Table 4.3).

Costs

Major and representative costs are private and include:

Foregone income. Expansion of cover crop area decreases the area available to produce cash or revenue generating crops. In other words, expansion of cover crops can incur some loss of potential income. The opportunity cost of foregone income is based on the average, low and high income ($/ha) from crop production in Manitoba in the most recent 10 years 2000-2009, ($15.38, $-166.72, and $370.50 respectively). The main and high estimate of Table 6.4 assume these per hectare amounts on the five percent of study area sown to cover crops.

[10] A comparable BMP and scenario with potential for greater overall environmental benefit involves a shift to greater legume production (edible beans, peas, lentils etc.), and away from current levels of livestock production and consumption. For example, using a Greenhouse Gas Emissions and Economic Model for Ontario (GEEMO), Thomsen et al. (1999) showed that the largest positive total environmental and climate change impact involved the replacement of animal protein with vegetable (legume) protein in human diets. However, edible legumes also require P such that this scenario requires further development to be considered as an option for reducing agricultural P exports to Lake Winnipeg.

Seeding: Seeding is the cost of establishing cover crops. MAFRI (2008) estimates the cost of establishing alfalfa/hay is $41.16/hectare/year when spread over a 10 year life. The main and low estimate assumes $41.16/ha/year seeding and establishment costs. The high estimate assumes a five year life of cover crops, or $82.32/ha/year.

Benefits

Major EGS benefits include a reduction in P exports to the watershed, and reduced GHG emissions as a result of lower energy use on cover crops including a reduction/no nitrogen fertilizer use. Other EGS benefits potentially stem from the grass and/or forage cover crop and include carbon sequestration and increased soil N; pollination; water regulation; erosion control and wildlife habitat. EGS benefits are estimated at the average, low and high unit values reported in Table 5.2. Soil N is valued at the average, low and high price of nitrogen fertilizer in Manitoba over the last 10 years (Thomsen, 2009).

Table 6.4 Costs and Benefits, NPV[1] $million. Crop Selection

P Reduction Potential. Main estimate (Table 6.1): -3.9 tonnes P/year at maximum potential

Summary	Main	Low	High
Costs			
Foregone income	29.03	17.42	52.07
Seeding	29.24	29.24	68.93
Total Costs	58.27	46.66	120.99
Benefits			
Lower P exports	$5.80	$5.80	$5.80
Carbon sequestration	$0.40	$0.40	$0.40
Lower energy use	$0.63	$0.63	$0.63
N, soil	$3.68	$2.44	$6.92
Pollination	$63.77	$31.89	$70.15
Water regulation	$0.43	$0.12	$0.59
Erosion control	$0.25	$0.12	$1.11
Wildlife habitat	$2.38	$1.42	$3.34
Total Benefits	$77.34	$42.82	$88.94
C/B Cost/Benefit Ratio	0.8	1.1	1.4
Net cost $/tonne P	-307,015	61,765	515,996

[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.

6.2.3 Surface Water Control Structures

Table 6.5 is a summary of the estimated costs and benefits of the surface water control structure BMP assuming it is adopted / implemented at a maximum estimated potential. As outlined in Chapter 3, the area to which this BMP might apply is limited. Analysis of its impact, costs, and benefits are further complicated by a lack of evidence. For example, this BMP continues to be investigated and has not yet been reported on by the STC project. Further, geographic detail with which to identify potential installation is not available in consolidated form. Therefore, the maximum potential adoption of this BMP was estimated / assumed as follows. Structures were assumed to apply to a potential total area equivalent to three percent of the study area. If one structure or dam were installed per section (640 acres) of the three percent of potential area, a total of 128 dams would be required in the study area. The estimates of Table 6.5 assume 128 structures.

Table 6.5 Costs and Benefits, NPV[1] $million. Surface Water Control Structures			
P Reduction Potential. Main estimate (Table 6.1): -2.4 tonnes P/year at maximum potential			
Summary	**Main**	**Low**	**High**
Costs			
Foregone income	17.42	10.45	31.24
Installation	17.58	15.83	19.34
Total Costs	35.00	26.28	50.58
Benefits			
Lower P exports	3.59	3.59	3.59
Lower energy use	0.56	0.56	0.56
Wildlife Habitat	1.43	0.85	2.00
Total Benefits	5.58	5.01	6.16
C/B Cost/Benefit Ratio	6.3	5.2	8.2
Net cost $/tonne P	765,125	553,176	1,155,413
[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.			

Costs

Major and representative costs are private and include:

Installation: IISD (2008) assumed an install cost of $12,500 per structure. Updating using the Consumer Price Index, this is equivalent to $12,587 in 2010 dollars. The main estimate assumes 128 structures installed at a cost of $12,587 per unit. Low and high cost scenarios arbitrarily assume this unit cost is 10 percent lower and higher respectively. Maintenance costs are not included.

Foregone income. If water control structures are installed on land that would otherwise be cropped, this BMP entails a potential opportunity cost measured as foregone crop income. The opportunity cost of foregone income is estimated based on the average, low and high income ($/ha) from crop production in Manitoba in the most recent 10 years 2000-2009.

Benefits

Major EGS benefits include reduced P exports to the watershed, potentially lower GHG emissions, and wildlife habitat. Lower GHG emissions are possible if the land area on which structures are installed was previously cropped. In this situation, lower GHG emissions result from energy and fertilizer that would otherwise be used in cropping the land area. Land area surrounding the structures have potential to create improved wildlife habitat. EGS benefits are estimated at the average, low and high unit values of Table 5.2.

6.2.4 Vegetated Filter Strips

Table 6.6 is a summary of estimated costs and benefits of the vegetated filter strips BMP, assuming it is adopted / implemented at maximum estimated potential. Similar to surface water control structures, the evidence available is that this BMP has limited potential to affect total P exports. Detailed geographic detail with which to identify adoption potential is also limited. Therefore, a maximum potential adoption of this BMP was estimated as follows. The BMP was assumed to apply to all crop land in the study area. The installation of a 10 foot wide vegetated filter strip around every quarter section (160 acres) area amounts to 1.5 percent of all crop land in the study area. It is important to emphasize that this is a theoretical maximum estimated in the absence of detailed geographic and land information. The practical maximum is expected to be substantially less than the theoretical maximum.

Costs

Major and representative costs are private and include:

Foregone income. Filter strips decrease the area available to produce income generating crops. The opportunity cost of foregone income is based on the average, low and high income ($/ha) from crop production in Manitoba in the most recent 10 years 2000-2009.

Seeding: Filter strips are assumed installed by seeding alfalfa/hay in ten foot wide strips around each quarter section in the study area. The main and low estimate assumes $41.16/ha/year seeding and establishment costs (MAFRI, 2008). The high estimate assumes a five year life of cover crops, or $82.32/ha/year.

Benefits

Major EGS benefits include **lower GHG emissions** as a result of **lower energy use** on filter strip area including no fertilizer use and a **reduction in P exports to the watershed**.

Energy savings reported in Table 4.6 are based on Khakbazan et al.'s (2007) estimate of annual energy savings equivalent to 144 kg C/ha for grass and forage relative to conventional revenue generating crops.

Major EGS benefits include a reduction in P exports to the watershed and reduced GHG emissions as a result of **lower energy use** on filter strip area and no fertilizer use. Other EGS benefits potentially stem from the grass and/or forage cover filter strip area, and include carbon sequestration and increased soil N; pollination; water regulation; erosion control and wildlife habitat. EGS benefits are estimated at the average, low and high unit values reported in Table 5.2. Soil N is valued at the average, low and high price of nitrogen fertilizer in Manitoba over the last 10 years (Table 5.2; Thomsen, 2009).

Table 6.6 Costs and Benefits, NPV[1] $million. Vegetated Filter Strips

P Reduction Potential. Main estimate (Table 6.1): -1.0 tonnes P/year at maximum potential			
Summary	**Main**	**Low**	**High**
Costs			
Foregone income	8.53	5.12	15.30
Seeding	8.69	8.69	20.39
Total Costs	17.22	13.81	35.68
Benefits			
Lower P exports	1.61	1.61	1.61
Carbon sequestration	0.12	0.12	0.12
N, soil	1.08	0.72	2.03
Pollination	18.74	9.37	20.61
Water regulation	0.13	0.04	0.17
Erosion control	0.07	0.04	0.33
Wildlife habitat	0.70	0.42	0.98
Total Benefits	22.45	12.31	25.86
C/B Cost/Benefit Ratio	0.8	1.1	1.4
Net cost $/tonne P	-306,798	88,357	576,965

[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.

6.2.5 Conservation Tillage

As discussed in previous chapters (with supporting material in Appendix C), although many agronomic and environmental benefits of conservation tillage are well documented, there is a consistent body of research (including Manitoba research) demonstrating that losses of dissolved P from conservation tillage are greater than those from conventional tillage. As a consequence, conservation tillage is estimated to result in increased P exports to the watershed. This is reflected in the estimates reported in Table 6.1. Specifically, the main estimate is that conservation tillage will increase P exports to the watershed. Therefore, cost and benefit estimates are not reported.

7. Summary and Analysis

This chapter is a summary and analysis including sensitivity analysis of the P export reduction potential and selected cost and benefit values of the BMPs reported individually in Chapter 6.

Table 7.1 is a summary of P reduction potential, costs, and benefits for individual BMPs including cost benefit ratios (CB) and net estimated cost per tonne of annual P export reduction, where net cost = (costs – benefits) / tonne of P reduction. Crop selection (cover crops) and filter strips indicate the lowest CB and net cost. However, the P reduction potential of nutrient management is the greatest (and most permanent) of all BMPs examined.

Table 7.1 Phosphorus Reduction Potential, Costs and Benefits by BMP, 2010$

BMP	P Reduction Potential	Costs	Benefits	CB Cost Benefit Ratio	Net Cost
	tonnes P/year[1]	NPV[2] $million			NPV $/tonne P/year
Vegetated Filter Strips	-1.0	17.22	22.45	0.8	-306,798
Surface Water Control Structures	-2.4	35.00	5.58	6.3	765,125
Crop Selection	-3.9	58.27	77.34	0.8	-307,015
Nutrient Management	-96.9	607.16	193.22	3.1	244,361

[1] At maturity.
[2] Net Present Value (NPV) over 30 years and 3 percent discount rate.

7.1 Sensitivity Analysis

Table 7.2 presents estimates of the unit or net cost per tonne for the main estimate of P reduction potential, within the bounds of the lower and upper estimate for each BMP. The bounds are the lower and upper estimate of the physical potential for the BMP to reduce P exports (see Table 6.1). Vegetated filter strips and crop selection exhibit a negative net cost per tonne indicating that they are less costly than the benchmark cost of removing P by the City of Winnipeg on a per tonne basis (the avoided cost). If the BMPs are able to realize the upper end of their estimated physical capacity, Table 7.2 indicates that the net cost of all BMPs except surface water control structures is lower than the cost of removing P by the City of Winnipeg.

Table 7.2 Sensitivity Analysis. Quantity of Phosphorus Reduction, 2010$

BMP	NPV[1] $ / tonne P / year		
	Main	Lower	Upper
Vegetated Filter Strips	-306,798	-1,930,154	-167,254
Surface Water Control Structures	765,125	7,999,395	226,136
Crop Selection	-307,015	-1,942,845	-166,399
Nutrient Management	244,361	2,996,764	33,564

[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.

Table 7.3 reports sensitivity analysis of the avoided cost of P reduction. Section 5.1 reported the main estimate of an avoided cost benchmark is $164,697 per tonne of P assuming the City of Winnipeg actual and planned treatment plant capital expenditures over 30 years. The "Low" estimate of Table 7.3 assumes only P removal capability is installed in the North Winnipeg plant (Table 5.1). Table 7.3 indicates that, under a scenario of "Low" avoided cost, the CB ratio for vegetated filter strip and crop selection BMPs are relatively unchanged from the main estimate; and surface water control structures and nutrient management remain relatively more expensive than the City of Winnipeg treatment – or avoided costs benchmark value.

Table 7.3 Sensitivity Analysis. Value of Phosphorus Reduction, 2010$

BMP	NPV[1] $ / tonne P / year		Cost Benefit Ratio	
	Main[2]	Low[2]	Main[2]	Low[2]
Vegetated Filter Strips	-306,798	-277,920	0.8	0.8
Surface Water Control Structures	765,125	793,573	6.3	7.8
Crop Selection	-307,015	-278,567	0.8	0.8
Nutrient Management	244,361	273,602	3.1	4.2

[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.
[2] Avoided cost main estimate $164,697 per tonne of P, and Low estimate $114,523 per tonne, Table 5.1.

Table 7.4 reports sensitivity analysis of the cost of carbon used in calculating potential GHG benefits of the BMPs. The main estimates (Chapter 6) assume a market or "private" price of C of $2.38/tonne based on 2009-2010 Chicago market activity. Table 7.4 includes estimates based on a "social" cost of carbon (SCC) of $15.00/tonne as well. Table 7.4 indicates that, assuming a SCC, CB ratios for all BMPs except surface water control structures are relatively unchanged from the main estimate; and that surface water control structures and nutrient management BMPs remain relatively more expensive than the City of Winnipeg benchmark cost on a per tonne P basis.

Table 7.4 Sensitivity Analysis. Private and Social Cost of Carbon, 2010$

BMP	NPV[1] $ / tonne P / year		Cost Benefit Ratio	
	Private[2]	Social[2]	Private[2]	Social[2]
Vegetated Filter Strips	-306,798	-343,574	0.8	0.7
Surface Water Control Structures	765,125	687,382	6.3	4.1
Crop Selection	-307,015	-395,236	0.8	0.7
Nutrient Management	244,361	239,811	3.1	3.0

[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.
[2] Private cost of carbon C is $2.38/tonne, and Social cost is $15/tonne of C.

Table 7.5 presents sensitivity analysis of the discount rate used to calculate the NPV of the costs and benefits of the BMPs. At seven (7) percent discount rate, CB ratios are relatively unchanged relative to the main estimate, and the unit cost of nutrient management is lower than the City of Winnipeg benchmark.

Table 7.5 Sensitivity Analysis. Discount Rate, 2010$				
BMP	NPV $ / tonne P / year		Cost Benefit Ratio	
	3%[1]	7%[2]	3%[1]	7%[2]
Vegetated Filter Strips	-306,798	-157,011	0.8	0.8
Surface Water Control Structures	765,125	410,601	6.3	8.4
Crop Selection	-307,015	-151,893	0.8	0.8
Nutrient Management	244,361	148,689	3.1	4.7

[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.
[2] Net Present Value (NPV) over 30 years and 7 percent discount rate.

Table 7.6 presents a distribution of EGS benefits by type for all BMPs combined. Given that the BMPs examined were selected for their P export reduction potential, it is intuitive that lower P exports comprise the majority of benefits. The majority of all other potential EGS benefits are primarily associated with the grass and forage cover involved in the BMPs. Pollination benefits are also potentially substantial.

Table 7.6 Distribution of EGS Benefits by Type, Main Estimate NPV 2010$		
EGS	NPV[1] $million	Percent Distribution
Lower P exports	189.37	66.4
Pollination	82.51	28.9
N, soil	4.77	1.7
Wildlife habitat	4.50	1.6
GHG fertilizer	1.46	0.5
GHG, energy	1.20	0.4
Water regulation	0.55	0.2
Carbon sequestration	0.52	0.2
Erosion Control	0.32	0.1
Total	285.19	100.0

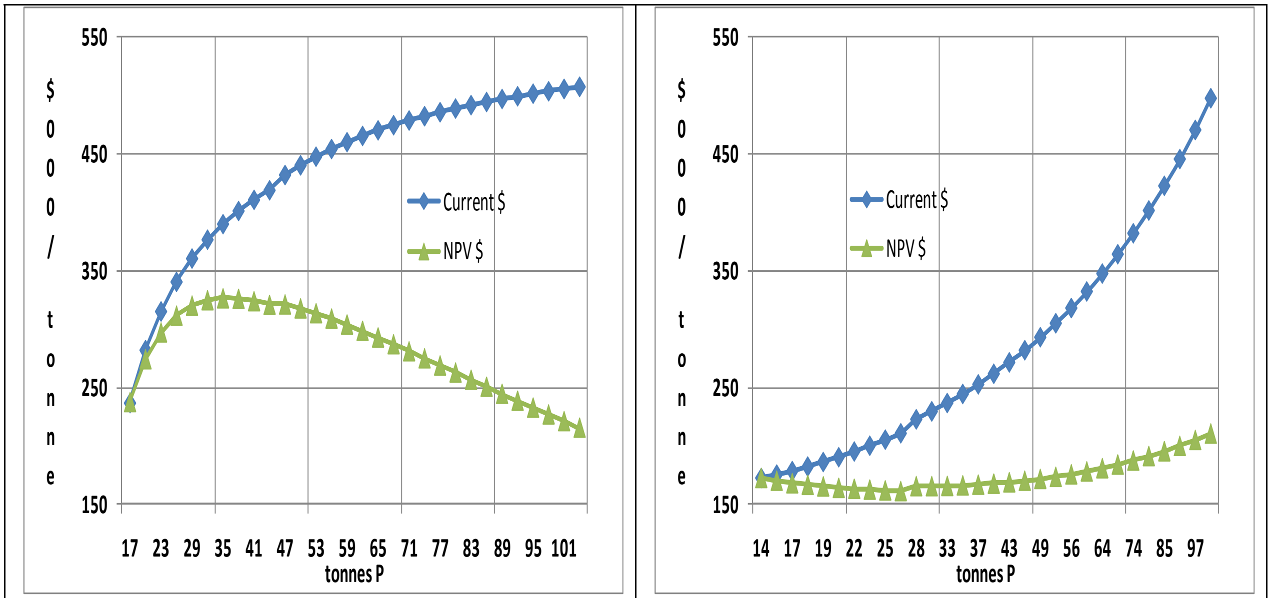
[1] Net Present Value (NPV) over 30 years and 3 percent discount rate.

7.2 Possible Supply Curve

Figure 7.1 presents possible supply curves for P reduction. The horizontal axis is the quantity of P exports from Manitoba agriculture – in other words, the quantity of P entering the Lake Winnipeg watershed that could be reduced or eliminated from Manitoba agriculture sources if all the BMPs examined were adopted by the Manitoba farming industry over 30 years. The vertical axis is the unit net cost (costs minus benefits) in $/tonne of reducing agriculture P exports. The "Current $" curve is net unit cost in current dollars; and the "NPV $" curve is net unit cost in NPV terms (assuming a three percent discount rate).

Note that Figure 7.1 presents the combined total of all BMPs examined, however the BMPs are not necessarily additive (cumulative).

The horizontal axis of Figure 7.1 is reported in tonnes of P. Given that P reduction and EGS costs and benefits are estimated over time as adoption progresses, the horizontal axis is also equivalent to time, or years 1 to 30. The left chart A of Figure 7.1 assumes linear adoption of the BMPs by Manitoba agriculture, in other words, adoption in approximately equal annual increments. The right chart B assumes a more typical or gradual adoption pattern.



A. Linear BMP Adoption | **B. Gradual BMP Adoption**

Figure 7.1. Potential Phosphorus Reduction Supply Curve

Horizontal axis measures quantity of P reduction over time, and is equivalent to time years = 1 to 30
NPV at three (3) percent discount rate.

7.3 Summary Observations

The following is observed:

1. The high variability or uncertainty of the potential of the BMPs examined to reduce P exports, evidenced by the large range or bounds about the main estimate, is the greatest determinant of their viability when measured using a CB of EGS approach.

2. Cost and benefit unit values have a smaller impact on CB indicators relative to physical estimates of P reduction capability. Per observation 1 above, the uncertainty (or potential variability) of the amount of P that can be physically reduced is the greatest determinant of the viability of the BMPs and associated indicators. Relative to this physical uncertainty, the variation of units costs and benefits has a small impact on CB indicators.

3. Other than P reduction and possibly pollination benefits, EGS values are very modest factors in the viability of the BMPs examined.

4. The value of P reduction is also a relatively more important determinant of BMP viability when measured using a CB of EGS approach. Given the large size and key role of Lake Winnipeg and the Lake Winnipeg drainage area, a full and direct economic and EGS accounting and estimate of the value of the Lake is warranted and recommended (see section

2.1 Comprehensive and System-Wide Framework, and Appendix A). Amongst other things, it is recommended that this entail a coordinated effort with Manitoba government and related agencies and stakeholders.

5. The CB EGS approach could be improved by further investigation and development of quantitative evidence and supporting data of EGS associated with the selected and other BMPs. As documented herein, EGS information and values that is based on and drawn directly from Manitoba experience is limited.

See Chapters 3 and 4, and Appendices B and C for background to the following recommendations.

Recommendation 1: Future work should consider P distribution within individual fields, and the fate of P within Lake Winnipeg. Management practices that affect the spatial variability of either the application and/or the redistribution of P within a field will affect the P exported from a field. The response of Lake Winnipeg to changes in agricultural management practices and resulting P would benefit greatly from improved understanding of the fate of P that enters the lake.

Recommendation 2: More research needs to be carried out in the Lake Winnipeg watershed on the performance of BMPs in reducing P contamination of surface waters.

Recommendation 3: The monitoring of contaminants should be continued for as long as there are water quality concerns in Lake Winnipeg. Monitoring should be intensified spatially and temporally to provide better understanding and management of contaminants in the surface waters of the watershed.

Recommendation 4: Reconfigure the Census of Agriculture data to the sub-regional watershed areas for the period beginning in 1981. (The most recent Census data that is geographically matched or configured to watersheds such as those of the study area of this report is 2001).

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Appendix A. Valuation of Environmental Goods and Services for the Lake Winnipeg Watershed

In this appendix, methodology that could be adopted for the valuation of Environmental Goods and Services (EGS) is presented. It is designed under two assumptions: 1) the data and other information required can be collected, and 2) there are no budget constraints faced by researchers.

A.1 Rationale for Valuation of EG&S for Lake Winnipeg

The role played by nature, and its functions relevant to society, has been recognized by most governments of the world since the report of the World Commission on Environment and Development (WECD, 1987). The WECD concept integrates economic, social and environmental aspects such that present needs do not compromise the needs of future generations. The Government of Canada's 1990 Green Plan defined a commitment for, among other things, clean air, water and land, and protection of special spaces and species. The connection between natural ecosystem services and human well-being is also recognized by the United Nations through undertaking the Millennium Ecosystem Assessment (MEA). Through case studies conducted throughout the world, the MEA has attempted to show the importance of such services to human well-being.

Precise cost and benefits to society of implementing policies and programs to improve social well-being are required in order to make a rational decision. Such programs may include producers adopting beneficial management practices (BMPs) on farms to improve the state of environment and thereby social well-being of Canadians. Although cost of adoption has been studied in some contexts, the assessment of benefits is a relatively unstudied subject. While some of the benefits may accrue to producers, a major beneficiary from the adoption of these measures is society-at-large.

Agriculture, perhaps more than other economic activities, is intimately linked to the natural environment. This culminates in a dual role – agriculture providing certain EGS to society and at the same time affecting other EGS availability. To undertake analysis of policies and programs, decision makers require information on benefits and costs of undertaking such activities. Potential costs include those borne by adopters and users of BMPs to bring forth the desired change in the environment, as well as those of society as a whole that is affected by the change in environmental attributes. Improvement in the environment reduces such costs to the society, thereby benefitting it.

A.2 Ecosystems and Society: Some Issues

<u>Identification of EGS</u>: Valuation of EGS requires an understanding of ecosystems and their connection with the human system. The services ecosystems provide to society are shown in Table A.1. According to the Millennium Ecosystem Assessment, these can be divided into four categories.

<table>
<tr><th colspan="4">Table A.1: List of Ecosystem Functions, Goods and Services</th></tr>
<tr><th>Functions</th><th>Ecosystem Processes and Components</th><th>Environmental Goods and Services</th><th>Relevance to Manitoba Society through Lake Winnipeg Watershed</th></tr>
<tr><td colspan="4">Regulation Functions - Maintenance of essential ecological processes and life support systems</td></tr>
<tr><td>Gas regulation</td><td>Role of ecosystems in biogeochemical cycles</td><td>Ultraviolet-B protection
Maintaining air quality
Influence on climate</td><td rowspan="2">Relevant from GHG emissions and climate regulation</td></tr>
<tr><td>Climate regulation</td><td>Influence of land cover and biologically mediated processes</td><td>Maintaining temperature and precipitation</td></tr>
<tr><td>Disturbance prevention</td><td>Influence of system structure on dampening environmental disturbance</td><td>Storm protection
Flood dampening</td><td>Somewhat relevant</td></tr>
<tr><td>Water regulation</td><td>Role of land cover in regulating runoff and river discharge</td><td>Drainage and natural irrigation
Medium for transport</td><td>Relevance to be established</td></tr>
<tr><td>Water supply</td><td>Filtering, retention, and storage of freshwater (e.g., in aquifers)</td><td>Providing water for consumption</td><td>Potentially relevant</td></tr>
<tr><td>Soil retention</td><td>Role of vegetation root matrix and soil biota in soil retention</td><td>Maintaining arable land
Preventing erosion and siltation</td><td rowspan="2">Relevant for Producers</td></tr>
<tr><td>Soil formation</td><td>Weathering of rock, accumulation of organic matter</td><td>Maintaining productivity on arable land</td></tr>
<tr><td>Nutrient regulation</td><td>Role of biota in storage and recycling of nutrients</td><td>Maintaining productive ecosystems</td><td>Relevance to be established</td></tr>
<tr><td>Waste treatment</td><td>Role of vegetation and biota in removal or breakdown of xenic nutrients and compounds</td><td>Pollution control and detoxification</td><td>Potentially relevant</td></tr>
<tr><td>Pollination</td><td>Role of biota in movement of floral gametes</td><td>Pollinating wild plant species</td><td>Relevance to be established</td></tr>
<tr><td>Biological control</td><td>Population control through trophic-dynamic relations</td><td>Control of pests and diseases</td><td>Relevance to be established</td></tr>
<tr><td colspan="4">Habitat Functions - Providing habitat (suitable living space) for wild plant and animal species</td></tr>
<tr><td>Refugium</td><td>Suitable living spaces for wild plants and animals</td><td>Maintaining biological and genetic biodiversity; Maintaining commer-</td><td>Relevance to be established</td></tr>
</table>

Table A.1: List of Ecosystem Functions, Goods and Services

		cially harvested species	
Functions	**Ecosystem Processes and Components**	**Environmental Goods and Services**	**Relevance to Manitoba Society through Lake Winnipeg Watershed**
Nursery	Suitable reproductive habitat	Hunting Gathering of fish and game Gathering of fruits & other products	Potentially relevant
Production Functions - Provision of natural resources			
Food	Conversion of solar energy into edible plants and animals	Building and manufacturing Fuel and energy Fodder and fertilizer	Commercial and subsistent fishing
Raw materials	Conversion of solar energy into biomass for human construction and other uses	Improve crop resistance to pathogens and pests	Relevance to be established
Genetic resources	Genetic material and evolution in wild plants and animals	Drugs and pharmaceuticals Chemical models and tools Test and assay organisms	Relevance to be established
Medicinal resources	Variety of (bio)chemical substance in, and other medicinal uses of, natural biota		Relevance to be established
Ornamental resources	Variety of biota in natural ecosystems with (potential) ornamental use	Resources for fashion, handicraft, worship, decoration, etc.	Relevance to be established
Information Functions - Providing opportunities for cognitive development			
Aesthetics	Attractive landscape features	Enjoyment of scenery	Highly relevant
Recreation	Variety in landscape features	Ecotourism	Highly relevant
Cultural and artistic	Variety in natural features with cultural and artistic value	Inspiration for creative activities	Highly relevant
Spiritual and historical	Variety in natural features with spiritual and historical value	Use of nature for religious or historic purposes	Relevance to be established
Science and education	Variety in nature with scientific and educational value	Use of nature for education and research	Potentially relevant

Table A.1: List of Ecosystem Functions, Goods and Services
Source: (De Groot et al., 2002) **Regulation Functions, or Regulating Services:** Services received from the regulation of ecosystem processes. Includes services that improve well-being by regulating the environment in which people live. In the context of Lake Winnipeg, these services include flood protection, human disease regulation, water purification, air quality maintenance, and climate control. These services are generally not marketed but many have clear value to society. **Habitat, or Supporting Services**: Services that maintain basic ecosystem processes and functions such as soil formation, primary productivity, biogeochemistry, and habitat. They affect human well-being indirectly by maintaining processes necessary for provisioning, regulating, and cultural services. Many are included as co-benefits of adoption of BMPs. **Production Functions or Provisioning Services:** Services from products obtained from ecosystems. These products include food, fuel, fibre, biochemicals, genetic resources, and fresh water. Many of these products are traded in markets. In the context of the Lake, they include fish production. **Information Functions, or Cultural Services**: Services that contribute to the cultural, spiritual, and aesthetic dimensions. They include recreational opportunities, aesthetics provided by the Lake, and cultural functions associated with First Nations people.

The Lake Winnipeg ecosystem is expected to provide some of these functions and generate various EGS that are valued by society. Many of the EGS are relevant for the study as many stakeholders value them. (Identification of stakeholders and the services they value is presented in Table A.3). However, these EGS are generated through adoption of some BMPs. Identification of which BMP results in a given improvement in the EGS is the first step for their valuation.

Environmental Goods and Services Stocks vs. Flows: Values of ecosystems can be perceived in two ways: total ecosystem, or stock or the flow of ecosystem services. In the valuation of EGS, one is interested in the flow of services and not the total stocks. The latter is more pertinent in the estimation of Green national accounts involving natural capital.

Applicability of Total Economic Value: Ecosystem services have two types of values to the society: Use values and Non-use values. A sum of these values is called the Total Economic Value (TEV) of an ecosystem, change in which reflects the total well-being change due to a policy or program. However, this concept is more applicable to the stock aspect of ecosystems, such as wetlands, rivers, natural lakes, and other natural ecosystems, and not to the flow. The only components of TEV relevant to the valuation of EGS are Use and Non-use values.

Definition of Society: In the context of social values, it is important to define the scope of the society in terms of stakeholders that are individuals or institutions affected by the change in the EGS and therefore have vested interests in activities and their impact on the Lake Winnipeg basin. For agricultural programs, such as adoption of BMPs by producers, these stakeholders are typically located off-farm. However, a grey area remains about the distribution of inter-farm impacts of cultural practices. For example, lack of soil cover may transport some of the soil from one field to other fields on another farm. This may have beneficial or adverse impacts on the other producers. However, such estimation is more complex and for macro-economic analysis, this aspect of EGS is typically ignored.

Identification of constituents of human well-being. A definition of human well-being is not commonly found in the literature. However, the Millennium Ecosystem Assessment has developed a list of various constituents of human well-being that includes ways a change in the level of ecosystem services affects human well-being (MEA, 2005):

- *Security*: Through change in the level of provisioning services, and cultural services; conflicts over declining resources, among others.
- *Access to basic material for a good life:* This is strongly linked to provisioning services, such as food and water availability.
- *Health:* Strongly linked to provisioning services and regulating services from ecosystems.
- *Social relations:* These are affected by changes in cultural services.

- *Freedom and choice:* These aspects of human well-being are largely predicated on the existence of other components of well-being and thus, are affected by changes in provisioning, regulating, or cultural services from ecosystems.

The connection between the value of EGS and human well-being would need to be addressed by keeping the above aspects of human well-being in mind.

Valuation of EGS: Most ecosystem services are not normally traded in the marketplace. For this reason, they are labelled non-market goods. Over the last quarter century, major strides have been made in the development of methodologies for estimation of these values. These methods have now been accepted for policy evaluation in Canada as well as in the international arena[11]. Attempts have also been made to value world ecosystem services by (Costanza, et al., 1997). This study estimated the value of such services in the range of US$ 16 - 54 trillion per year. A Canadian study has suggested that the net value of conserving or restoring natural areas ranges between $65 to $195 per ha/yr. (Olewiler, 2004)

Methods of non-market valuation have now become a text book topic, e.g., Hanley and Splash (1993). There are many applications of these methods the world-over using a variety of methodologies for different ecosystems, typically classified into one of the following three types of methods.

(1) Revealed Preference Methods. Further divided into Direct and Indirect methods. Direct revealed preference methods include Market Method, and Simulated Market Method. Indirect revealed preference methods include Travel Cost Method, Hedonic Price Model, and Hedonic Travel Cost Model.

(2) Stated Preference Methods. Include Contingent Valuation Method, and the Choice Modelling Method.

(3) Benefit Transfer or Value Transfer Method. Based on the above review, it is concluded that theoretically one has tools to value EGS, but little guidance can be obtained from Canadian studies. Table A.2 lists valuation techniques applied in the literature.

[11] In the USA, the National Oceanographic and Atmospheric Administration appointed a panel of economists, including two Nobel Prize winners, to make recommendations on the use of contingent valuation and other non-market valuation methods (Arrow et al., 1993). The recommendation of the Panel was that a well-conducted contingent valuation study provides an adequately reliable benchmark. It contains information that judges and juries will wish to use, in combination with other evidence.

Table A.2. Sample Methods for Valuation for Select Components of Social Well-being

Environmental Goods and Services	Method of Estimation
Water quality	Contingent valuation Choice modeling Avoided cost method Defensive or averting behaviour model Health costs
Air quality	Contingent valuation Choice modeling Avoided cost method Defensive or averting behaviour model Health costs
Recreation – Consumptive uses	Travel cost method Contingent valuation method
Recreation – Non-consumptive uses	Travel cost method Contingent valuation method Hedonic travel cost method
Climate change	Contingent valuation method Choice Modeling Avoided costs
Aesthetics	Hedonic price model
Commercial enterprises	Market methods Simulated market methods

Additive Property for Aggregation of Human Well-being: Human well-being and ecosystem services may be related such that the same aspect of human well-being may be affected by more than one EGS. For example, a change in human health may be affected by air quality as well as by water quality. The question of whether these changes are additive or not requires further attention. A caution is advised against double counting in the above type of analysis. For example, air quality may be affected by a change in other indicators. A methodology needs to be developed for marginalizing the impact of a change in a given indicator on the social pathway.

Average vs. Marginal Valuation: A second consideration is that some indicators may be directly related to other indicators. For example, soil cover may reduce the level of soil erosion. It will be difficult to distinguish between the benefits from increased soil cover and decreased soil erosion. Such properties may exist for other EGS, and need to be determined at an early stage.

In a conceptual methodology to be developed for the valuation of EGS for the Lake Winnipeg basin, the above set of issues would need to be addressed further.

A.3 Interrelationships between Nutrient Loading, Adoption of BMPs and EGS

Given the high nutrient loading of the Lake Winnipeg, specifically phosphorus (P) loadings, BMPs are needed. Five BMPs were selected in this study. This section describes methodology for the valuation of EGS resulting from adoption of BMPs. Assessment of the social desirability (concentrating on economic desirability) of adopting an agricultural BMP is complex. It involves two major sources of benefits to society: 1) reduced nutrients in the lake and surrounding areas; and, 2) changes, other than nutrient loading, in other ecosystem functions resulting from adoption of BMPs.

These result in changes in the Lake and the agricultural landscape, thereby extending these benefits to virtually all members of Manitoba society. These impacts are called the 'co-benefits' of adopting BMPs. An overview of these interrelationships is shown in Figure A.1. The 'Green Boxes' in this diagram reflect the EGS which lead to benefits and change in the TEV of the Lake. To implement the methodology depicted in Figure A.1, several steps, described below, are needed.

(1) Identify Impact Region: To assess the value of direct and co-benefits of P-loading reduction, one must identify the society of concern and the impact regions. For the Lake Winnipeg watershed, this is shown in Figure A.2. Analysis of the value of EGS generated can be identified for six regions:
Region 1. A sub-watershed where adoption of BMPs takes place.
Region 2. Aggregation of small watersheds into a larger watershed.
Region 3. Aggregation of watershed into major rivers – Red River and Assiniboine River.
Region 4. Between the City of Winnipeg and the point where Red River joins Lake Winnipeg.
Region 5. Lower Basin of Lake Winnipeg.
Region 6. Upper Basin of Lake Winnipeg.

(2) Identify Stakeholders in Impact Regions: This task involves identifying members of the society that would benefit from a reduction in nutrient loading in Lake Winnipeg through adoption of BMPs. These members are called 'stakeholders'. A stakeholder is defined as an economic agent in the region affected by the change in the level of EGS. Since the make-up of the society and EGS is not the same in all six impact regions, a list should be compiled for each impact region. Since the stakeholders in Regions 2 to 4 and Regions 5 and 6 would be almost identical, only three regions are described in Table A.3.

A tentative list of stakeholders might include: local producers, non-farm residents, municipal water treatment plants, recreationalists (including sports-fishermen), cottage owners (affected through aesthetics), commercial fisherman, communities, and others (to be identified). This list would be revised after a reconnaissance survey of the region is completed.

(3) Estimate Direct Bio-Physical Impacts of Adoption of a BMP: This estimation needs to be done first and requires some experimentation in field conditions.

4) Connect Bio-Physical with Human Well-being: This can be done in different ways. One approach is the Impact Pathway Approach (Ribaudo and Young, 1989), and involves several steps (Figure A.3). These define how the on-farm effects of a practice translate into off-farm costs and benefits (externalities), which can be valued in terms of human well-being.

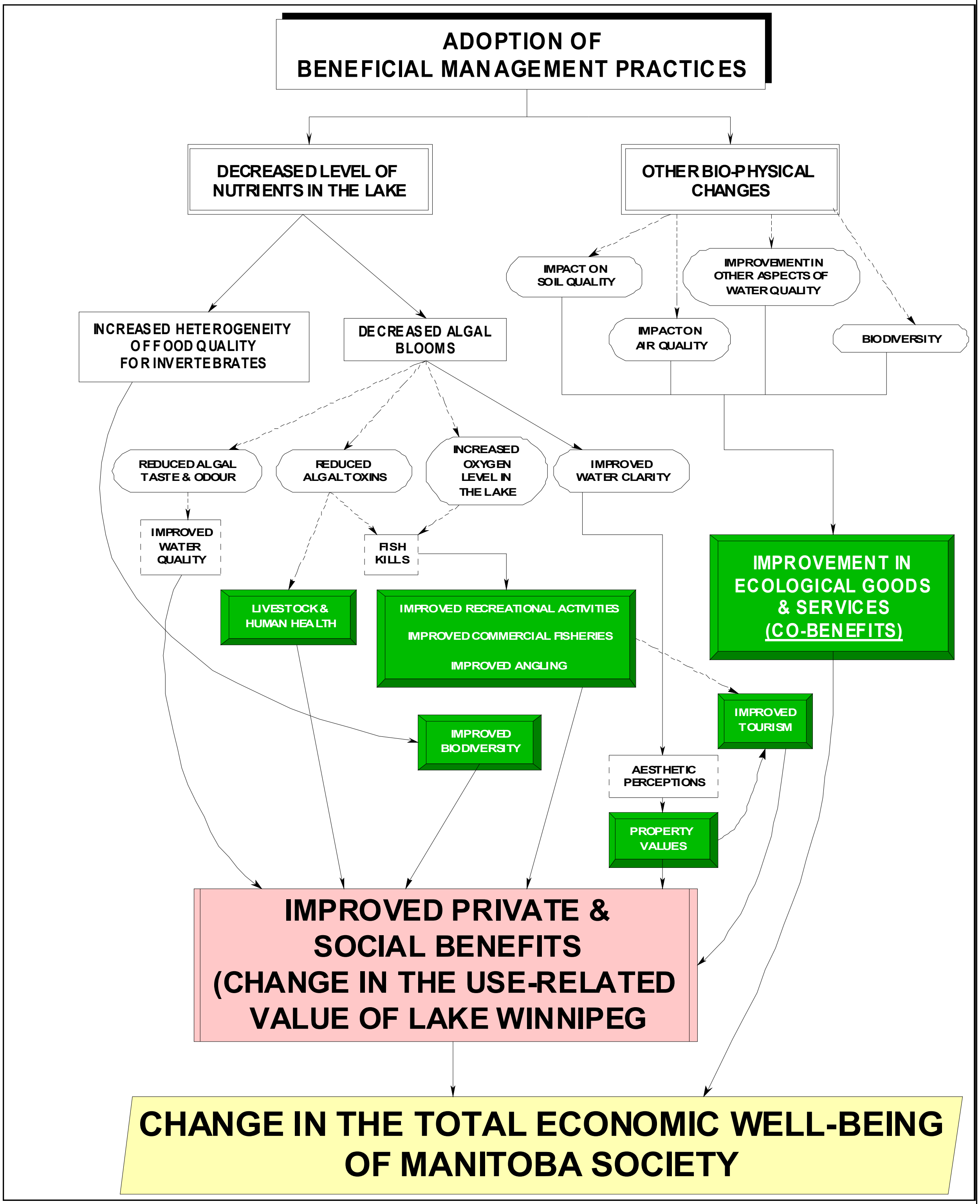


Figure A.1. Interrelationship of BMP Adoption and Creation of Benefits to Society through Reduced Nutrient Loading

Source. Adapted from Dodds et al. (2009)

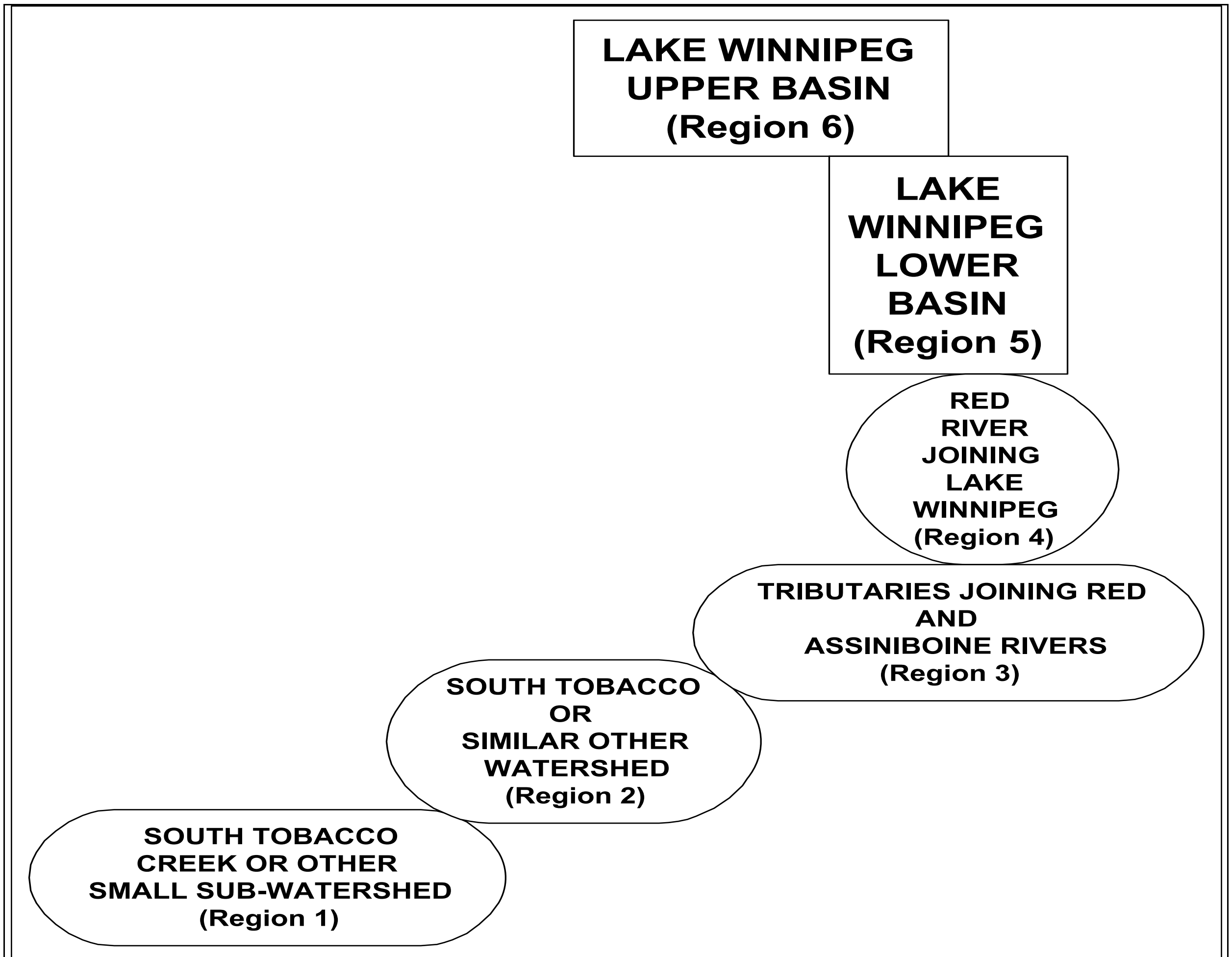
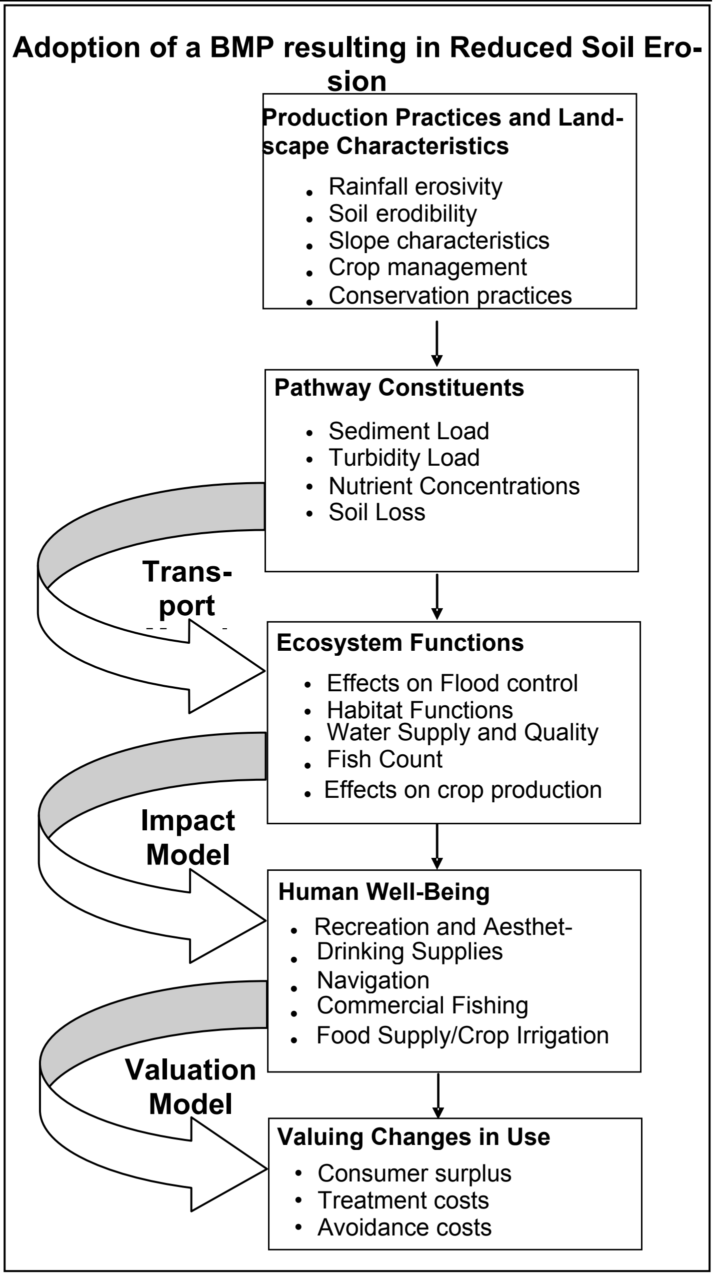


Figure A.2: Approximation of Social Impact Region of Small Sub-Watershed Leading to Lake Winnipeg

Table A.3. Various EGS Associated with Change in Water Quality			
Stakeholder	**Region of BMP Adoption**	**Adjoining Regions**	**Lake Winnipeg**
Local Producers	Farm Net Income Drinking water Health of Livestock Aesthetics	Producers Income through crop and livestock enterprises Drinking water Aesthetics Human health	
Non-Farm Residents		Human health Aesthetics	Human health Aesthetics
Water Treatment Plants		Cost of water treatment Cost of Municipal wastewater treatment	Cost of water treatment Cost of Municipal wastewater treatment
Recreationalists (Including sports-fishermen)		In-stream water-based recreation; Aesthetics	Lake based water-based recreation; Aesthetics Beach-based recreation
Cottage Owners			Aesthetics Property values
Commercial fishery			Income of fishermen
Communities			Economic Development
First Nation Communities			Income from fishing Sustenance Aesthetics Recreation
Ducks Unlimited	Wetlands benefits		Biodiversity Lake aesthetic value
Other users – flora and fauna and other in-stream water requirements			Loss of nature

Figure A.3. Impact pathway approach for the change in soil erosion indicator (Ribaudo, 1989)



Let us assume for purposes of illustrating this methodology that the direct impact of adopting a BMP is reduced soil erosion. Initial steps in this methodology are determination of the pathway constituents and transport model. The determination of pathway constituents refers to identifying how a direct bio-physical change relates to changes in the immediate surrounding environment. Identification of these changes can be done using available literature, unless experimental data are available.

The direct changes of soil erosion may include four different impact pathways: 1) the transport of soil solids to waterways (turbidity and sediment); 2) the transport of P to waterways; 3) the transport of N to waterways; and 4) the loss of productive soil. The next model to be developed will be a transport model, which assesses the pathway by which a constituent disperses from the immediate vicinity to the location of impact of a given ecosystem function. The nature and size of N loading in a nearby waterway, for example, will have a much greater effect on the water supply of surrounding communities than users that are further downstream. The third exercise would involve determining the impact model. This methodology provides the essential link between the impact of pathway constituents on the state of the ecosystem and the resulting changes in ecosystem functions/services and human well-being. It relates the effects of physical changes in the environment (derived from the transport model) to impacts on human well-being.

The focus of the impact model is to undertake a threshold analysis. Individual EGS are affected differently by changes in water quality and/or quantity. In other words, a unit change in an indicator of water quality does not affect all EGS uniformly or in a linear manner. For example, algae bloom in the Lake may only occur after a certain concentration of P in the water; and the cost of water treatment may rise exponentially as sediment load increases. Each of the production functions need to be estimated to predict change in socio-economic activity levels. Parameters for this analysis could be based on literature review. Table A.4 sets out a possible relationship between nutrient loading and its impact in terms of damages to activities.

Table A.4 Potential Thresholds in State Valuation Relationship

Ecosystem Service	Potential Threshold
Biodiversity	Algal blooms restrict sunlight and impact on viability of existing ecosystem.
Fisheries	Certain types of algal blooms are harmful and may lead to fishing activity being banned. In addition algal blooms may have an impact on the quantity and quality of fish stocks, given that fish stocks are related to water quality.
Swimming	Algal blooms may discourage swimming. Toxic algal blooms may also lead to banning of swimming in certain areas.
Walking	The perception of algal blooms may fall at a certain level of algal bloom coverage or at a certain distance from the bloom/sea. Odour may also arise from greater densities of algal bloom.
Amenity	Changes in perception of algal bloom may affect house prices.

Source: Longo et al. (Undated)

The last to be developed is the valuation model. As noted earlier, changes in the natural environment can be represented by separate changes in various attributes that provide value to the human well-being (e.g. health benefits from cleaner air or water, or preservation of the natural habitat and the beauty of the landscape). The valuation model uses economic tools to determine the value associated with a change in the delivery of an environmental attribute that impacts human well-being (i.e. the results of the impact model). Since a single relevant ecosystem service is often associated with multiple impacts on human well-being, the valuation process may require more than one study. Once again taking the simpler example of P loading, each of the effects on human health, recreational value, and wetlands or aquatic habitat might apply separate valuation studies. An overview of linkages between physical change associated with a BMP and its impact on human well-being is shown in Figure A.4.

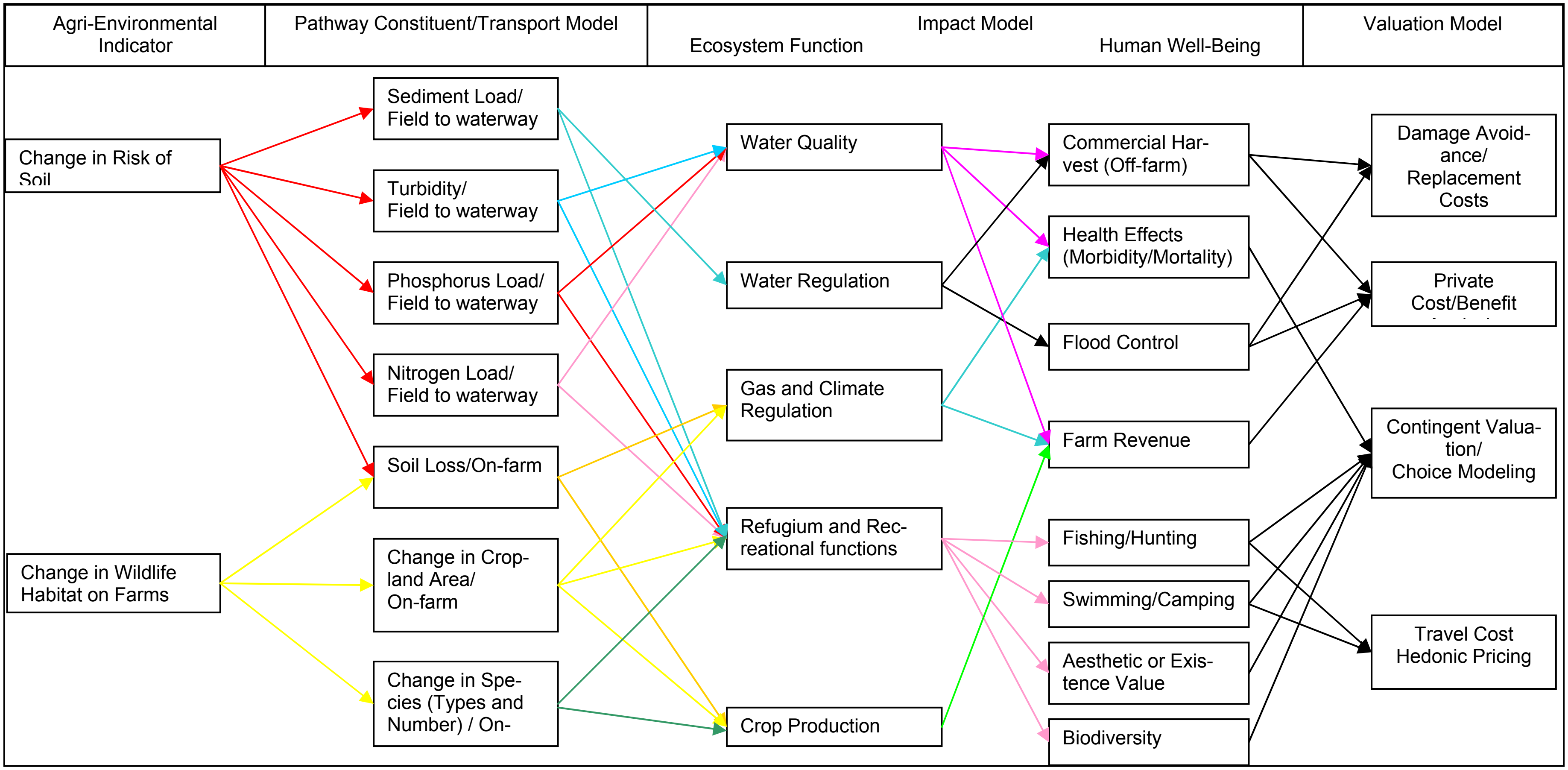


Figure A.4: Linking Change in Bio-Physical Change resulting from Adoption of BMP to Human Well-being

A.4 Estimation of Value of EGS for Adoption of BMPs to Reduce P-Loadings

(1) Revisit to Stakeholders – Non-farmers around the Lake: A major Lake economic activity is fishing. The settlement of people around the Lake was, at least in part, based on the fishery. Several communities depend to a large extent on this activity. Between 2001 and 2005, there was an average 904 commercial fishing licensees plus a similar number of helpers employed in the Lake fishing industry. Income is determined by the size of the catch, value of the fish caught, and the costs of operation. The Lake fishery is regulated by a quota system where each fisher has to obtain a quota to sell to the Freshwater Fish Marketing Corporation (FFMC). A change in the Lake's water quality can affect fisher income and the value of quota.

Associated with the fishing industry are two other types of stakeholders including the FFMC and processors. All fish caught in the Lake is sold through the FFMC. A change in the quantity and value of fish caught affects FFMC operations, income, and employment. There is a packing plant at McBeth Point owned and operated by the Fisher River Fishermen Association. However, in the Lake region there are currently no fish processing plants. A change in the fishery would affect any processing and marketing operations. Other major stakeholders around the Lake are the communities. Although the Lake region is primarily rural, there are a few urban centres. The total population of the region surrounding the Lake is estimated at 71,355 in 2006 (Table A.5). Several towns, villages, rural municipalities, and unorganized districts surround the Lake. Most of the organized regions are around the South basin, whereas the unorganized districts are located around the North basin. In total, there are four towns with a combined population of 12,454 people, and two villages with a population of 1,229 people located right on the Lake front. With a decline in water quality, these properties including commercial, residential, and cottage (recreational) properties are subject to a decrease in value.

Table A.5 Population of Communities Surrounding Lake Winnipeg 2006

Community	Number	Population	Percent
Towns	4	12,454	17.5
Villages	2	1,229	1.7
Rural Municipalities	6	33,200	46.6
First Nation Reservations: South Basin	4	3,667	5.1
First Nation Reservations: North Basin	10	13,350	18.7
Unorganized Census Districts	3	7,455	10.4
Total Population	--	71,355	

Source: Data obtained from Statistics Canada (2010)

There are several First Nation communities surrounding the Lake. A list is shown in Tables A.6 and A.7. There are 14 communities including 10 in the North basin and four in the South basin. The combined population of these is estimated at 17,017 people in 2006, distributed 21 percent around the South basin and 79 percent around the North basin. These communities are affected by Lake water quality in terms of fishing activity (including subsistence, sport, and commercial fishing), and any drinking water (unless other sources of water are used), and sewage disposal. The Lake also has an important place in First Nation people and culture.

Table A.6 Socio-Economic Details on First Nation Communities Around the South Basin of Lake Winnipeg					
Item	**Fort Alexander**	**Brokenhead**	**Black River**	**Hollow Water**	**Total**
	Population and Its Characteristics				
Population in 2006	2121	467	460	619	3667
Population in 2001	1998	372	389	622	3381
% Change	6.2%	25.5%	18.3%	-0.5%	8.5%
Median Age (years)	22.3	24.7	18.3	20.6	
% of Population over 15 years	66.7%	66.0%	57.6%	60.5%	
	Dwellings and Their Characteristics				
Total number of families	520	115	110	155	900
Total number of households	540	145	120	150	955
Total number of private dwellings	598	155	135	181	1069
Dwellings occupied by usual residents	540	149	122	154	965
Dwelling not typically occupied	58	6	13	27	104
% Dwellings not typically occupied	9.7%	3.9%	9.6%	14.9%	9.7%
Average value of dwelling ($)	0	0	0	0	0
	Family Income and Earnings				
Median Income Level all census families	$23,488	$25,792	$20,416	$28,448	
Median earnings (Workers 15+ age	$12,656		$10,464	$12,512	
Median earnings Full time workers	$23,339		$21,864	$28,800	
	Workforce and Employment				
Total Population over 15 years	1325	310	265	375	2275
Labor force	675	185	125	200	1185
Employed	520	160	95	140	915
Unemployed	155	25	30	60	270
Participation Rate	50.9%	59.7%	47.2%	53.3%	52.1%
% Unemployed	23.0%	13.5%	24.0%	30.0%	22.8%
	Employment by type of industry				
Agriculture and resource based	65		10	30	105
Construction	40		15	20	75
Manufacturing	10		0	0	10

Table A.6 Socio-Economic Details on First Nation Communities Around the South Basin of Lake Winnipeg

Item	Fort Alexander	Brokenhead	Black River	Hollow Water	Total
Trade and Finance	50		0	0	50
Business services	50		10	15	75
Other services	305		60	75	440

Blank cells not available or not estimated.
Source: Statistics Canada (2010)

Table A.7 Socio-Economic Details on First Nation Communities Around the North Basin, and Total of Lake Winnipeg

Item	North Basin											Total Lake Winnipeg
	Berens River 13	Cross Lake 19	Cross Lake 19A	Dauphin River 48A	Fisher River 44	Grand Rapids 33	Jack-head 43	Norway House 17	Peguis 1B	Poplar River 16	Total	
	Population and Its Characteristics											
Population in 2006	739	1,586	1,663	84	1,129	651	271	4,071	2,513	643	13,350	17,017
Population in 2001	625	1,491	502	89	867	591	162	3,950	2,515	644	11,436	14,817
% Change	18.2%	6.4%	231.3%	-5.6%	30.2%	10.2%	67.3%	3.1%	-0.1%	-0.2%	16.7%	0
Median Age (years)	21.4	22.4	19.2	28.5	29.9	21.6	23.5	22.4	2704.0	21.8		
% of Population over 15 years	63.9%	67.8%	59.8%	75.0%	69.3%	63.8%	60.7%	65.7%	70.5%	61.2%		
	Dwellings and Their Characteristics											
Total number of families	165	375	375	25	285	155	70	1,005	765	160	3,270	4,170
Total number of households	210	345	335	30	360	170	80	1,020	808	170	3,485	4,440
Total number of private dwellings	216	376	369	38	397	173	80	1,168	752	185	3,810	4,879
Dwellings occupied by usual residents	209	348	333	30	361	170	77	1,018	56	168	3,466	4,431
Dwelling not typically occupied	7	28	36	8	36	3	3	150	6.9%	17	344	448
% Dwellings not typically occupied	3.2%	7.4%	9.8%	21.1%	9.1%	1.7%	3.8%	12.8%	$0	9.2%	9.0%	9.2%
Average value of dwelling ($)	$0	$0	$0	$0	$0	$0	$0	$0		$0	$0	$0
	Family Income and Earnings											
Median Income Level all census families	$16,157	$23,792	$18,816		$34,752	$37,888	$22,144	$24,192	$10,991	$25,408		

Table A.7 Socio-Economic Details on First Nation Communities Around the North Basin, and Total of Lake Winnipeg

Item	North Basin											Total Lake Winnipeg
	Berens River 13	Cross Lake 19	Cross Lake 19A	Dauphin River 48A	Fisher River 44	Grand Rapids 33	Jack-head 43	Norway House 17	Peguis 1B	Poplar River 16	Total	
Median earnings (Workers 15+ age	$3,665	$11,488	$10,896		$15,648	$19,987	$7,664	$11,232	$27,549	$11,989		
Median earnings Full time workers	$16,042	$26,432	$26,368		$28,016	$33,920	$30,048	$24,448		$22,976		
	Workforce and Employment											
Total Population over 15 years	495	1,060	995	55	780	415	170	2,655	1,775	400	8,800	11,075
Labor force	235	515	370	35	450	275	70	1,210	885	200	4,245	5,430
Employed	145	350	280	30	360	185	60	620	620	165	2,815	3,730
Unemployed	90	165	90	5	90	90	10	590	265	35	1,430	1,700
Participation Rate	47.5%	48.6%	37.2%	63.6%	57.7%	66.3%	41.2%	45.6%	49.9%	50.0%	48.2%	0
% Unemployed	38.3%	32.0%	24.3%	14.3%	20.0%	32.7%	14.3%	48.8%	29.9%	17.5%	33.7%	0
	Employment by type of industry											
Agriculture and resource based	40	25	25	10	65	70	15	70	30	20	370	475
Construction	10	30	30	0	30	10	0	85	120	10	325	400
Manufacturing	0	10	0	0	0	0	0	10	10	0	30	40
Trade and Finance	20	45	30	0	20	25	0	140	70	20	370	420
Business services	0	35	15	10	35	15	0	135	55	15	315	390
Other services	75	205	180	10	210	65	45	180	335	100	1,405	1,845

Blank cells not available or not estimated.
Source: Statistics Canada (2010)

In addition, with a change in water quality, communities drawing water from the Lake may have to make alternative arrangements for drinking water supply. The following communities currently draw their drinking water needs from the Lake: Victoria Beach and Seymourville (LWSB, 2006). Pine Dock, Matheson Island, Loon Straits, and Princess Harbour may have individual households drawing their water directly from the Lake. Some may also be using the Lake for sewage disposal. In many of the towns and villages, economic development is not independent of the Lake. The Lake supports tourism which in turn supports other economic activity in the communities. The Lake can also provide value in flood control. Without the Lake, areas of the province may experience greater flooding and related damage.

Around the South basin are numerous recreational properties for rent to visitors. Although the precise number of these properties is not available, a proxy can be obtained from Statistics Canada's community profile data. For example, in Winnipeg Beach, the data suggest that 20 percent or more of all dwellings are for rental purposes. Any change in the Lake's water quality could change current property rental opportunities and values.

Manitoba Hydro is responsible for managing the Lake and the timing of hydroelectric generation. (Demand in winter months is generally higher). Water quality is not reported as a factor that affects the operations of Manitoba Hydro.

Local business in many of the towns and communities depend on tourism as a source of economic activity. To the extent tourism in these communities is related to water quality, any decrease in water quality may affect tourism and local businesses and through that economic development of the community.

The Lake offers many opportunities for recreational activities. Major recreational sites include: Grand Beach Provincial Park, and Hecla / Grindstone Provincial Park. Grand Beach has 189 basic and 163 electrical sites plus other facilities. The Hecla / Grindstone park has two sites: Gull Harbour with 161 camping sites (910 electrical sites included), and Hecla cabins with 19 electrical sites. If the water in the Lake is deemed not suitable for human contact, these recreational sites would not be visited to the same extent as at present. Unfortunately the present level of visitation to these sites is not known.

Agricultural activity is very common around the Lake particularly in the South basin. There are nearly 55 million hectares of farm land in the Lake Winnipeg watershed (LWSB, 2006) Surrounding the Lake, agriculture is also prominent and consists primarily of crop production farms. It is not known whether producers in the surrounding region use the Lake for farm purposes.

Lake Winnipeg has several adjacent wetlands which are a prominent site for duck habitat. Ducks Unlimited has offices in the region, and is a major stakeholder in the Lake's water quality.

(2) Revisit to Stakeholders -- Stakeholders in the Agricultural Region Adopting BMPs: The economic status of farmers who adopt BMPs with potential to reduce P exports from the agricultural landscape into the watershed may be affected by said adoption.

Other producers and members of the local society in the region where the BMPs are adopted may also be affected e.g., if water quality in the local watershed also changes.

As noted in the report, some of the BMPs may lead to an improved level of biodiversity including habitat and wildlife population. This may result in an improved level of consumptive wildlife use (hunting), as well as non-consumptive use (wildlife viewing).

Creation or expansion of wetlands through adoption of some BMPs could lead to several types of benefits to society. These include water filtering, increased wildlife, improved aesthetics, and carbon sequestration.

(3) Revisit to Stakeholders -- Global Society: In addition to local changes in the level of ecological goods and services, adoption of some BMPs may result in changes beyond Manitoba borders. This change is related to reduced greenhouse gases (GHG), benefits which are enjoyed by the global society.

The total benefit from adoption of a BMP is the sum of change in the utility of all the stakeholders noted above.

(4) Valuation Context: TEV Conceptual Considerations: Lake Winnipeg is an important ecosystem. Determination of the TEV of the Lake requires an understanding of some basic concepts from the field of ecological economics, particularly those related to value.

All values, regardless of how they are defined, reflect either explicitly or implicitly what the people assigning them care about (US Environmental Protection Agency USEPA, 2009) Values differ from individual to individual. The value of an ecological change (such as reduced algal bloom resulting from lower nutrient loading) to one individual might be very different than its value to someone else.

People value nature for perhaps two purposes: 1) nature and its services as means, called anthropogenic value; and 2) environmental value (nature valued for its own sake). The former is easy to estimate and therefore, are recommended for use. The broad definition of value used here extends beyond what are sometimes called the benefits derived from ecosystem services. The MEA (2005) defines benefits as the contributions of ecosystem services to human well-being. The USEPA (2009) defines it in the context of regulatory impact analyses by the economic concept of willingness to pay for a good or service or willingness to accept compensation for its loss.

The most important link in the valuation of ecosystem services is between environmental state and valuation, which depends critically on the use of water. There is little disagreement in the literature that removal of P will help control algae in the Lake. All living things need P. Consequently, restricting P inputs will eventually reduce concentrations in the Lake to result in fewer algae. However, the exact time that these reductions would be witnessed is not clear. According to the Lake Winnipeg Foundation, it will be a slow process (decades) as decades of overloading must be overcome (LWF, 2007)

One possible procedure uses the time required on the basis of the Lake's eutrophic state. For example, assuming the Lake were to regain from a state of P loading of 10-20 µg/L, all previous benefits would return. If the current level of P is 160 µg/L, and if, for example, reduction through the adoption of BMPs is 15 µg/L/yr, then it would take the Lake 9 to 10 years to reach the normal use state.

(5) **<u>Disaggregated Approach to Valuation</u>**: Table A.8 summarizes the stakeholders and activities affected by algal blooms, and methods for estimating each associated social value. Goods and serviced affected are categorized under Direct and Indirect use, columns 2 and 3. Column 4 presents the method or measure of value. Column 5 notes challenges and the potential for estimating each associated value. Each of these values can be estimated using the methodology described in the next sub-section.

A.5 Valuation Methodology: Estimation of Direct Use Values

(1) <u>Commercial Fishers:</u> Manitoba Water Stewardship estimated that in 2008/09, 6,277 tonnes of fish were caught in the Lake valued at $19.8 million MWS (2010) A part of this fish is marketed through the FFMC. From 2000 to 2009, the average price of fish increased from $1.69/kg $1.98/kg Round – an increase of 17 percent (FFMC, 2010). Figure A.5 illustrates the level and composition of fish caught.

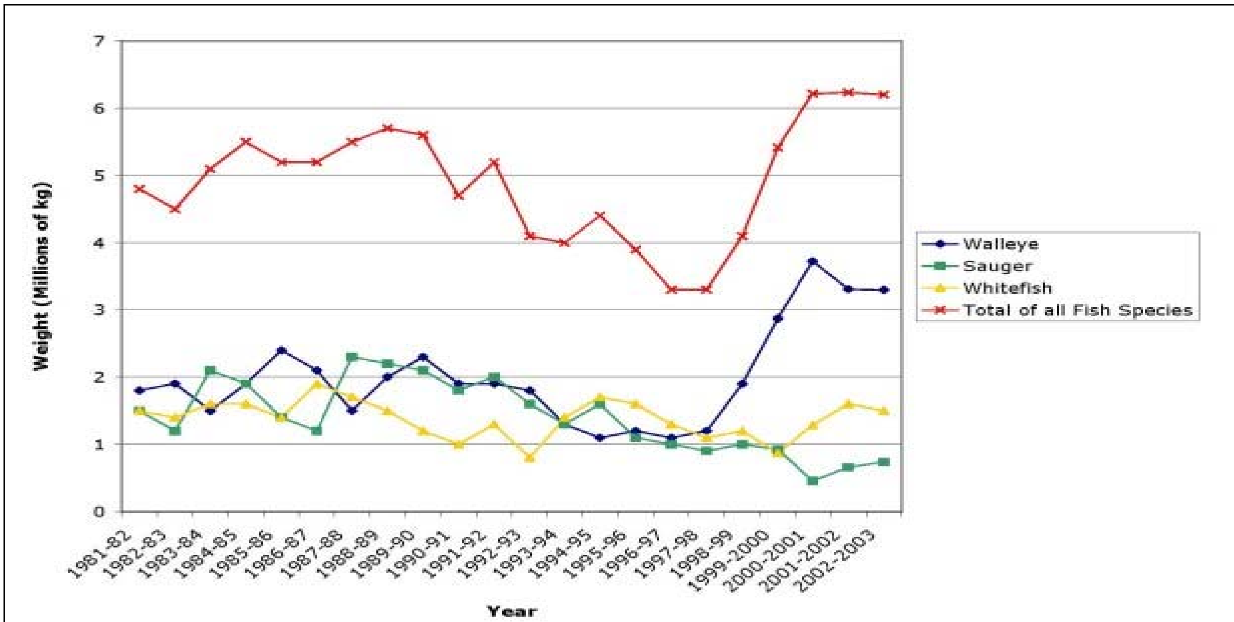


Figure A.5 Lake Winnipeg Fish Catch by Major Species 1981

Source: (Government of Manitoba, Undated)

Table A.8. Estimation of Various Components of Lake Winnipeg Use Values

1	2	3	4	5
Stakeholder	**Direct Use Value**	**Indirect Use Value**	**Measure of Use Value**	**Challenge in Estimation**
Commercial Fishing including First Nation fishers	Welfare change of commercial fishermen		Net income of fishermen defined as the quantity of fish caught times price minus cost of operations net of any subsidy payments.	• Catch size and price data is available, operating costs by size are not. Some assumptions required. • Data on frequency of algal bloom required but not available.
Manitoba Freshwater Fish Corporation	Welfare change of workers		Change in net income of workers	Employment data available; compensation data not available.
	Welfare change of investors		Change in corporation profits, including dividends to investors	Investors and dividend policies to be investigated / unavailable.
Fish Processing Plants	Change in welfare of workers		Change in net income of workers	Employment and wage data not available
	Change in welfare of plant owners		Change in the return to labor and management to plant owners	Data not available
Fish Packing Stations	Change in welfare of workers		Change in net income of workers	Employment and wage data not available
	Change in welfare of plant owners		Change in the return to labor and management to plant owners	Data not available
First Nation Fisheries (Domestic)	Decrease in food available for consumption		Alternative cost approach	Data on amount used for domestic consumption are not available
First Nation Communities	Water treatment		• Change in the cost of water treatment; or • Cost of alternative source water	• First Nation communities that use Lake directly not known. • Available alternatives not known
	Sewage Disposal		• Change in the cost of sewage disposal; or • Cost of alternative method of	

Table A.8. Estimation of Various Components of Lake Winnipeg Use Values				
1	*2*	*3*	*4*	*5*
Stakeholder	**Direct Use Value**	**Indirect Use Value**	**Measure of Use Value**	**Challenge in Estimation**
			sewage disposal	
		Cultural and aesthetics	Willingness to pay (WTP) for improved aesthetics	Studies of WTP by Aboriginal people not reported
	Flooding		Not relevant in water quality context	
Urban communities local governments	Flooding		Not relevant in water quality context	
		Economic development		Change in commercial activities related to water quality needs to be estimated
	Water treatment		• Change in the cost of water treatment; or • Cost of alternative source water	Data not available
	Sewage disposal		• Change in the cost of sewage disposal; or • Cost of alternative method of sewage disposal	
Community residents	Flooding		Not relevant in water quality context	
		Rental opportunities	Lost Revenue by rental property owners	• Data on number of properties not available • Relationship between rental rates and water quality not available
		Aesthetics	WTP for better aesthetics	
		Property values	Change in property value resulting from water quality	Data for Lake Winnipeg not available
		Recreation: Parks and Beaches	Travel cost or Benefit transfer	Participation rate data not available
		Recreation: Angling		
		Health Benefits	Cost changes related to Mortality / Morbidity	No secondary data collected

Table A.8. Estimation of Various Components of Lake Winnipeg Use Values				
1	*2*	*3*	*4*	*5*
Stakeholder	**Direct Use Value**	**Indirect Use Value**	**Measure of Use Value**	**Challenge in Estimation**
Tourism - Resident and Non-Resident		Recreation: Parks and Beaches	Travel cost or Benefit transfer	Participation rate data not available
		Recreation: Angling		
Cottage Owners	Water treatment		• Change in the cost of water treatment; or • Cost of alternative source water	• Number of cottage owners not available • Source of drinking water for cottage owners not reported
	Sewage disposal		• Change in the cost of sewage disposal; or • Cost of alternative method of sewage disposal	Data not available
	Flooding		Not relevant in water quality context	
		Property values	WTP for better aesthetics	No reported market data
		Aesthetics	Change in property value resulting from water quality	
Agricultural Producers	Drinking water		Cost of drawing water from alternative sources	Number of producers in these categories not known
	Livestock watering needs		Cost of drawing water from alternative sources	
	Manure disposal		Cost of manure disposal to alternative sources	

The walleye catch has increased relative to other species. This fish is high value resulting in higher gross revenue of fishermen than previously. Higher nutrient levels have also resulted in a greater quantity (weight) of fish caught in the Lake, as shown in Figure A.5. Although the data are for a shorter period of time, the evidence suggests that there has not been a decline in the total weight of fish caught in the Lake. Comparison of these data with the 1980-89 period, as shown in Figure A.6 supports this conclusion.

To estimate the benefits of nutrient reduction in the Lake, the following data are required: 1) change in the quantity and composition of fish catch with reduced nutrient level (as shown in Figure A.6 where the column on the left shows the quantity to fish caught under reduced P-loading); 2) price of fish due to change in quantity; 3) any change in fishing costs resulting from nutrient reduction; 4) value of quota; and 5) number of licensed fishermen.

Benefits can be estimated for two situations. One, the current situation where the quantity of fish caught has increased with nutrient loading. Two, what the situation might look like if the Lake became a "dead zone." Dead zones are hypoxic (low-oxygen) areas in the world's oceans and large lakes. Low oxygen levels can lead to reproductive problems in fish involving decreased size of reproductive organs, low egg count, and lack of spawning. This leads to lower rate of reproduction and fish catch over time. The net benefit of BMPs can be estimated using differences in the fish catch over time and the factors as noted above. (Note that dead zones are reversible, but that the length of time required for this process for Lake Winnipeg is not known with any certainty).

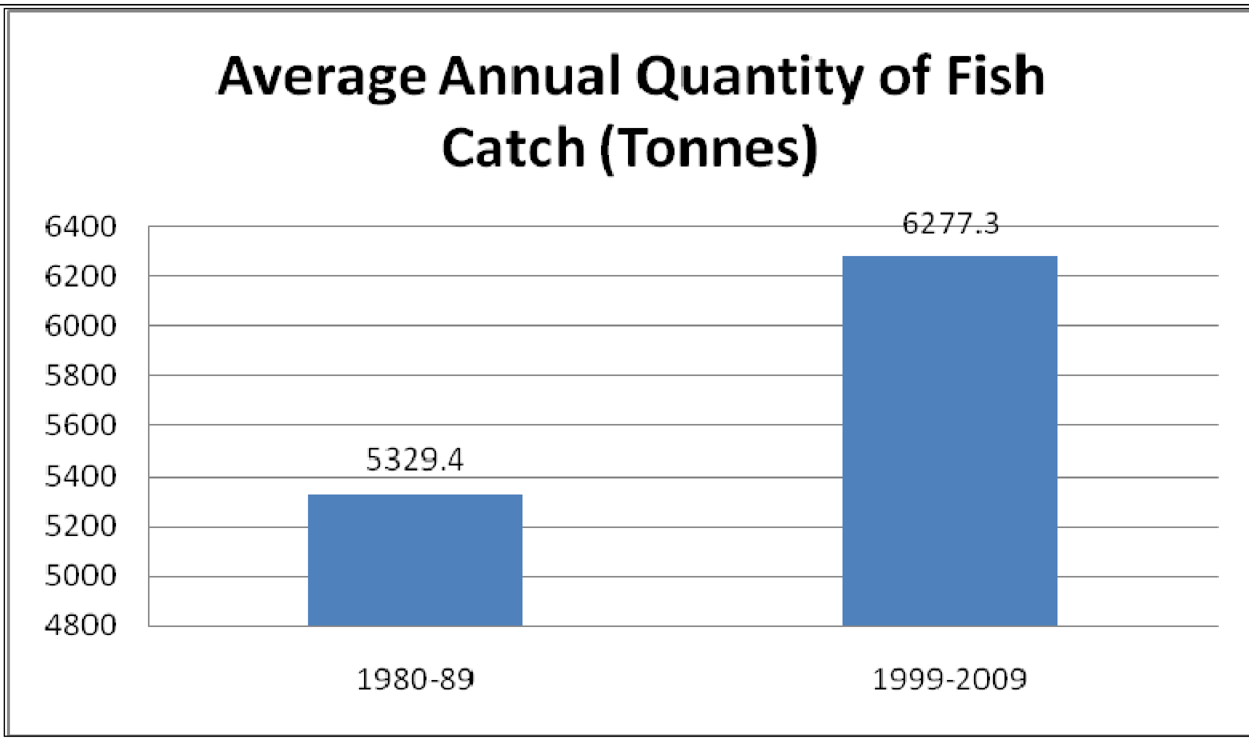


Figure A.6 Change in Lake Winnipeg Average Fish Catch 1980-1989 and 1999-2009, tonnes

Source: 1980-89 data from North/South Consultants Inc. (2006); 1999-2009 data from MWS (2010)

In addition to 889 licensed fishers in Lake Winnipeg during the period 1999/2000 to 2008/09), they hire some 177 workers as helpers (MWS, 2010) These jobs would be affected by change in the P-loading.

(1) Manitoba Freshwater Fish Corporation: As introduced in previous sections, a majority of the commercial fish catch is bought by the FFMC. The FFMC employs workers to market this fish, and retains earnings from these sales. The corporation had total retained earnings of $2.8 million, or about $0.17 per kg of fish sold FFMC (2010).

The 6,818 tonnes of fish from Lake Winnipeg translates into retained earnings of $1.15 million. Detail on the cost of marketing and other FFMC activity is not available. If the fish catch is negatively affected, the FFMC would have reduced operations and earnings. In order to assess the value reduced P-loadings in the Lake, interviews with FFMC officials would need to be conducted. These interviews would attempt to ascertain the cost (reduction or increase) and revenues associated with reduced P-loading.

(3) Fish Processors: Currently there is one fish processing plant located at the Fisher River Cree Nation Reservation. It is owned and operated by the Fisher River Cree nation with support from the Government of Canada. No further details are available. An extensive survey of this plant and impact of reduced P-loading would have to be undertaken.

(4) Fish Packing Stations: There are several fish packing stations around Lake Winnipeg as shown in Figure A.7. Information other than the location of these plants is not available, and would need to be collected in order to estimate any associated costs and benefits.

(5) Aboriginal Stakeholders: Aboriginal people and their communities could be affected by reduced P-loading in several ways:

a. Amount of fish caught – which may include level caught for commercial purposes, which affects their income, and for their personal requirements, domestic fishing. This activity is under the various treaties signed between the First Nations and the Government of Canada. Domestic fishing is legitimately required to meet basic subsistence requirements (Government of Manitoba, Undated):

b. Aesthetic purposes, which may affected in regions where algae boom is frequent.

c. Recreational purposes, which may include a variety of activities details of which are not known.

d. Drinking water - some Reserves may be withdrawing water for meeting their domestic needs, including drinking purposes.

Since no further details are available on the amount of Lake fish caught or consumed, intensive surveys of Indian Reserves are needed. Development of a questionnaire would be a necessity.

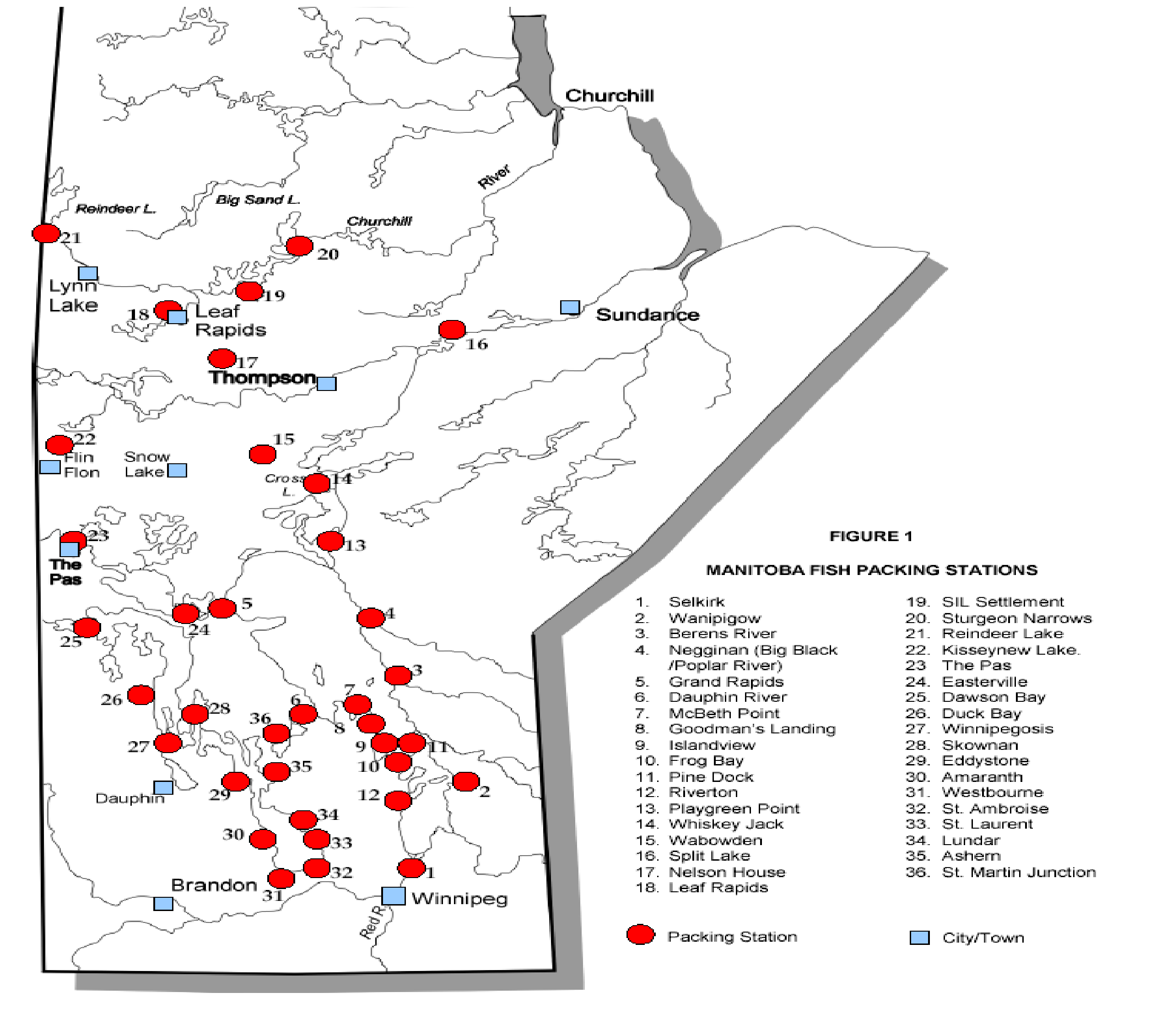


Figure A.7 Fish Packing Stations in Manitoba

Source: MWS (2010)

(6) Drinking Water: Lake water and ground water wells are used for drinking and other household purposes by the First Nation communities, small towns and villages, agricultural producers and cottage owners. The amount of water used for this purpose is not recorded.

The Rural Municipality of Victoria Beach has a population of 388 persons, and has grown significantly since 2001. No data are available for the community of Seymourville. Given the state of data, estimation of drinking water costs and benefits associated with the BMPs is not possible. It is conceivable that some producers located close to the Lake may be drawing drinking water from the Lake. However, the magnitude of this use is not known, and this benefit cannot be estimated at this time without further data collection.

One alternative method to estimate benefits of reduced P-loading for drinking water is to estimate reduced cost. Under high P-loading levels, many residents may purchase bottled water, which is an expensive alternative. Another way to estimate what the value of reduced P-loading in the Lake water would be for communities that have a municipal water system and further process this water before delivering it to consumers. One plausible cost to these agents could be reduced water treatment cost.

Collection of data for these purposes would involve a survey of residents and communities. A discussion of present costs and future costs that might result under reduced P-loading from these agents would be the target information to be collected.

(7) Sewage Disposal: The Lake could be used for disposal of sewage from various communities and households. Included among these could be First Nation and other urban communities, cottage owners, and agricultural producers. Details concerning use of the Lake for sewage disposal are not collected. A survey of various communities and residents living within close proximity to the rivers and the Lake needs to be undertaken. Collection of details of their sewage treatment and disposal would be the focus of this survey.

(8) Manure Disposal: Although manure disposal in the Lake is illegal, anecdotal information is that it occurs. A discussion of frequency of this practice with local agricultural representatives and/or other farm association leaders may help determine this practice. If the magnitude is believed to be very small, it can be excluded. If this is not the case, two issues would need to be examined further: 1) increase in the cost to producers for disposal of their manure; and 2), improvement in Lake and river water quality, if any.

A.6 Valuation Methodology: Estimation of Estimation of Indirect Use Values

One of the types of values that make up the TEV of an environmental resource is indirect use values. According to Markandya et al. (2002), the definition of indirect values lies somewhere between use and non-use values, and can refer to two types of situations: 1) when a person makes use of water (such as for fishery) but where that fishery benefits from the services of another environmental resource such as a freshwater spawning ground; and 2) when a resource is used in a way that does not involve depleting the resource, for example for recreation. These values are also called passive use values. Many of the non-use values in the context of the Lake and surrounding region are passive values.

In this section, indirect use values are interpreted to include the latter definition above. Even here, some regulating services, such as climate regulation, flood protection, and water purification, among others are excluded since they are not directly related to water quality and adoption of the BMPs. Major indirect use values related to water quality are described below.

(1) Culture and Aesthetics: Water bodies such as Lake Winnipeg, rivers and tributaries have become a part of the culture of people living in semi-arid climates, where water bodies are in short supply. One may postulate that for First Nation peoples, local community residents,

and cottage owners[12] the aesthetic and cultural values derived from the Lake are significant. Loss of scenic beauty of the Lake (under a high infill of algal bloom) presents a large loss to these people. Such losses are an important consideration in developing estimates of the change in the TEV of the Lake.

It is difficult to quantify the economic value of lost aesthetic or cultural resources. Two techniques that have been suggested in the literature are Hedonic Price methods, and contingent valuation method. Unfortunately no study was found that has applied this technique in the context of Lake Winnipeg. Implementation of either of these methods using a well-structured survey of the local residents, Indian Reserve residents, and other members of the society is needed here.

(2) Tourism: In addition to local residents, the Lake has value to people not living in the local area. However, to avoid any double counting, a precise definition of tourist is to be decided at the very beginning of the study. Tourists may be assumed to be those individuals who visit the Lake for a variety of recreational purposes including angling (sport fishing)[13]. However, tourism creates may other benefits, some of which are captured in economic development of communities.

Tourism activities related to the Lake and rivers in the region can be divided broadly into two types: 1) visitation by residents from other parts of the region beyond the vicinity of the Lake Winnipeg; and individuals that rent properties, some of which are Lake front properties. To estimate the value of first type of tourism, a survey of major tourist points around the Lake is required. This survey would include a contingent valuation value of their experience.

2) In addition to day and short-period visitors, there is another class of tourist to the region. These are the individuals that rent properties, some of which are Lake front properties. Unfortunately no record is kept of owner-occupied vs. rental properties. One crude estimate can be obtained from the community profile data by Statistics Canada. Data of the number of dwellings not typically occupied (assumed to be rented out to others) indicates 66 percent of dwellings in Winnipeg Beach, 22 percent of dwellings in Grand Rapids, and 17 percent of dwellings in Gimli fall in this category. For all towns and villages, there are 2,116 dwellings in the South basin that are not occupied by the owner. In the event the Lake loses aesthetic beauty, these rental opportunities may be reduced, if not totally lost. Such a loss will eventually result in lower property values (described below). However, estimation of this value requires a primary survey of all individuals (and families) who rent properties at these communities.

(3) Recreational Activities: Lake Winnipeg is a major attraction for residents of the City of Winnipeg plus many other people in and outside the province. Major recreational sites around the Lake include Grand Beach provincial Park, Victoria Beach, Winnipeg Beach, plus the Hecla/Grindstone Provincial Park. Collection of number of visitors to these sites is not recorded and published.

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[12] This is not to suggest that people living outside the region do not value water for these purposes. These values do exist. However, they are captured under tourism, described later on in this section.

[13] In order to avoid double counting, recreational angling values are described below.

The presence of algal bloom can affect the rate of visitation by people to these sites. This in part may be a result of closure of the beach for swimming due to algal bloom or deposit of algal bloom on the beach itself. Algal and cyanobacterial blooms are most common during summer months particularly in the lakes classified as hypereutrophic (TP > 100 µg TP· L^{-1}). According to Dodds et al. (2009), it is probable that during such time the Lake would be closed or not used for recreational activities. The value of recreation activity can be estimated by calculating loss of trips and trip-related expenses (e.g., travel, lodging, fuel, food, bait).

Estimation of this value requires primary surveys of recreationalists at various sites. A regression analysis of the effect of Lake algae bloom can then be determined from the results. Recreational activity valuation would require a survey of visitors using contingent valuation. Alternatively, recreational expenditures for Manitoba have been collected by Environment Canada. A division of Environment Canada is leading a study on the "Value of Nature to Canadians in 2010" to collect, analyze and synthesize data on the economic, social and ecological value of nature in urban, rural and wilderness contexts. The applicability of this data to the Lake Winnipeg sites needs to be ascertained.

(4) Angling: Lake Winnipeg is a major attraction for North American anglers. Although more recent data are not available, a 2005 survey of anglers found some 238,372 angler-days per annum, of which 14,073 angler-days are non-residents of Manitoba (Table A.9). While recent estimate of expenditures by these anglers are not available, 2005 expenditures were estimated for 2010 using the consumer price index. The total annual value of the Lake for angling purposes is estimated at $2.87 million (Table A.10). To estimate the benefits for angling in the Lake, one needs an estimated impact of poor water quality on angling (one with algal blooms). This could be undertaken using Hedonic Price Model based methodology including a primary survey of these individuals.

Table A.9 Estimated Lake Winnipeg Angler-Days by Type, 2005

Type	Manitoba	Lake Winnipeg	
	Angler Days Number	As a Percent of Manitoba	Angler Days Number
Residents	2,288,761	9.8	224,299
Canadian Residents	88,866	2.3	2,044
Non-Residents	176,904	6.8	12,029
Total	2,554,531		238,372
Total Excl. Residents			14,073

Source: Estimated from Government of Manitoba (Undated)

Table A.10 Value of Angling Experience at Lake Winnipeg			
	Expenditures Per Angler Day		Total Expenditures
Type	2005	2010	2010
Residents	$28.00	$30.10	$6,751,387
Canadian Residents	$48.13	$51.74	$105,752
Non-Residents	$214.26	$230.33	$2,770,742
Total			$9,627,881
Total Excl. Residents			$2,876,494
Source: Estimated from Government of Manitoba (Undated)			

(5) Economic Development: In terms of economic development, many communities such as Gimli, Winnipeg Beach, and Victoria Beach rely on tourism for growth. A total loss of aesthetics and decreased water quality affecting recreation would likely result in a sharp decline in the number of tourists coming to these sites, which would have further multiplier effect on these communities. Many businesses rely on tourism. For example, Interlake Tourism lists 30 accommodation providers, 12 providing arts, culture and galleries, four members providing 'On the Farm Experience', and several food services establishments, among others. A survey of tourism vs. local residents needs to be determined using primary surveys of these concerns.

(6) Property Values: In addition to rental properties, owned properties may also be affected by reduced aesthetics of the Lake. Property values will first be directly impacted by Lake aesthetics, and indirectly though loss of rental opportunities. Property values are affected by a number of variables including the number of days a water body is closed for contact and non-contact use, fish kills, human and livestock deaths and sicknesses. The aesthetics of a lake is correlated with Secchi depth[14], which is strongly correlated with property values (Dodds et al., 2009)

To estimate these values, data on sales of properties over a period of time needs to be collected. A combined time series – cross section regression of these data perhaps could shed some light on the role played by water quality on property values.

(7) Human Health: Algal blooms can have health effects. According to Dodds et al. (2009), an example of algal toxins working their way into humans involves shellfish poisoning. Biotoxins created during algal blooms are taken up by shellfish (mussels, oysters) causing them to become toxic and poisonous to humans consuming them. Examples include paralytic, neurotoxic, and diarrhoeic shellfish poisoning. Other marine animals can be vectors for such toxins, as in the case of ciguatera, where it is typically a predator fish that accumulates the toxin and then poisons humans. In order to estimate this value, detailed interviews of physicians and health agencies will need to be collected to ascertain the nature of diseases associated with algae bloom and poor water quality.

(8) Livestock: Some algal blooms, otherwise called "nuisance algae" or "harmful algal blooms", are toxic to plants and animals. The toxic compounds they produce can make their

[14] Secchi depth is a measure of the clarity of water. It is measured using a circular plate, known as a Secchi disk, which is lowered into the water until it is no longer visible. High Secchi depths indicate clear water; whereas low Secchi depths indicate cloudy or turbid water.

way up the food chain, resulting in animal mortality. Freshwater algal blooms can pose a threat to livestock (Dodds et al., 2009). Survey of local producers to ascertain the extent of this problem would shed some light on the value of improved water quality (through reduced P-loadings).

(9) Biodiversity: The value of total diversity is difficult to quantify. Dodds et al. (2009) used threatened and endangered species recovery plan costs to do this. They assumed 25 percent of all imperilled aquatic species are threatened in part by human-induced eutrophication and therefore 25 percent of all costs from U.S. Federal Endangered Species Act plans can be attributed to impacts of human-induced eutrophication.

Estimation of the value would requires two major exercises: 1) a detailed literature review on value of biodiversity, and deciphering the value appropriate for the Lake Winnipeg watershed; and 2) ascertaining losses of species and plants as a result of algae bloom.

A.7 Estimation of Co-Benefits

McCandess et al. (2008) have identified several co-benefits of adopting the following BMPs: 1) N reduction in surface water; 2) other water quality benefits through reduction in sediments, pesticides, and pathogens; 3) soil quality benefits through reduction in soil erosion and compaction among others; 4) air quality benefits through reduction in greenhouse gas emissions; 5) other air quality benefits from reduction in dust emissions and odour; and 6) biodiversity - enhancement in wildlife and wildlife habitats. A sample of relevant values reported by this study is presented in Table A.11.

A review of literature was undertaken to ascertain benefits from certain bio-physical changes resulting from adoption of BMPs. These include: soil erosion; shoreline stabilization; water quality; and biodiversity. Reviews of other EGS can be added to this list[15].

(1) Benefits of Reduced Soil Erosion: North American researchers have thoroughly documented the physical effects of soil erosion caused by wind and water on the farm or at the in-situ level. However, researchers barely touched upon the social cost of soil erosion – economic externalities and provision of public goods (or costs). Private soil erosion cost is typically on-site thus producer borne. It reduces crop yields thus lowers future net income. Alternatively, producers may bear mitigation costs such as mechanical solutions to erosion or input costs to countervail the negative productive impacts.

Soil erosion creates problems for the producers on the land as well as to other members of the society, including some of their institutions. Therefore, the traditional measure of the amount of soil displaced presents only a partial picture. The real measure of severity of wind erosion is the cost of the damage it does (Huszar & Piper, 1986). Wind erosion costs are incurred both on and off the farm. These damages are typically called on-site costs and off-site costs of soil erosion. On-farm erosion costs include decreased soil productivity through loss of soil organic matter in the topsoil. This results in lower yields to the producers, and therefore, is

[15] This review needs to be updated.

a private good. Shelterbelts can reduce the rate of soil erosion and thus produce private benefits to the landowner.

Table A.11. Non-Market Values of BMP Benefits			
BMP	Impact Mode	Direct Use value	Indirect Use Value
		$/ha	
Conservation tillage	Decreased sedimentation of water conveyance infrastructure	$5.21	
	Decreased sediment load for water treatment		$59.97
	Decreased phosphorus concentrations for water treatment		$13.51
	Mitigation / sequestration of GHG		$1.80
Crop selection	Decreased sedimentation of water conveyance infrastructure	$7.23	
	Decreased sediment load for water treatment		$83.24
	Decreased phosphorus concentrations for water treatment		$52.64
	Mitigation / sequestration of GHG		$6.60
Surface water control structures	Decreased infrastructure maintenance	$62.65	
Source: McCandless et al. (2008)			

Off-site costs of soil erosion represent costs external to the farming operations, as they are not borne by the farmers and they do not influence the farming operations. These damages may include costs to individuals as well as to various institutions, such as local governments, local industry and higher levels of government.

A number of studies have identified either qualitatively or quantitatively benefits on crop production of reduced soil erosion. According to Schaefer and Ball (1994), "the proper use of trees and shrubs in support of agriculture will: protect the soil so that erosion, contamination of surface water from sediments, and losses of water and nutrients are reduced and overall soil quality is maintained or improved; provide for the cultivation of a diversity of crop species to improve the biological and economical stability of agriculture; improve farm profitability without sacrificing production; and enhance the quality of life on the farm and for society as a whole." The Plains and Prairie Forestry Association of North America (2002) has also suggested that the yield increases occur because of reduced wind erosion of topsoil and wind damage to crops, improved microclimates and better snow (moisture) retention". According to Timmermans and Larney (1996), Alberta crop production systems that are threatened by wind erosion are: rotations that include summerfallow, continuous cropping, irrigated cropping and forage production. According to these researchers, field shelterbelts can provide extra protection against wind erosion no matter what cropping system is used.

Field shelterbelts provide private benefit to producers through arrested wind erosion levels and improve crop yields. The yield … "increases occur because of reduced wind erosion of topsoil and wind damage to crops, improved microclimates and better snow (moisture) retention" (Plains and Prairie Forestry Association of North America, 2002), and improved nutrient retention (Pimentel and Wightman, 1999). Several researchers report that … "erosion by water and wind adversely affect soil quality and productivity by reducing infiltration, water holding capacity, nutrients, organic matter, soil biota and soil depth, (Troeh et al., 1991; OTA – Office of Technology Assessment, 1982; El-Swaify et al., 1985; Pimentel and Wightman, 1999)

External costs of soil erosion are typically off-site financial impacts of on-site changes. According to the Australian Treegrowers Program, some examples of these costs include: non-point pollution; increased sedimentation in water channels (drainage and watercourses) and reservoirs; effect on social activities such as sport fishing or camping; cost of water treatment; and health related incidents (Australian Treegrowers Program, 2003). The off-farm costs of soil erosion occur as sediment and other erosion-related contaminants enter streams and lakes. This disrupts fish reproduction and feeding, reduces the value of water recreation activities, reduces the capacity of water-storage facilities and navigation channels, affects preservation values of concerned individuals, increases the frequency and volume of floods, increases water-treatment costs and maintenance costs of water-using machinery and appliances, and clogs water-conveyance systems, such as drainage ditches and irrigation channels (Dickson and Fox, 1989). Huszar and Piper (1986) suggest the following external costs can be related to soil erosion.

1: Secondary impacts associated with reduced production[16]. When farm production is reduced there is a reduced demand for certain goods and services, such as marketing, processing, transportation and storage.

2: Blowing sand and dust can impair the production possibilities of private firms. These may include: 1) Machinery maintenance, repair and replacement costs for various businesses; 2) Cost of inventory (that needs to be kept in a clean condition); (3) Maintenance of irrigation canals; (4) Water quality for water utilities.

3: Households consumption may also be affected by blowing sand and dust. The effects on the households may come from two types of costs:

A: <u>Damage to structures and buildings</u>

- Damages to the exteriors of buildings;
- Damage to gardens though accumulated soil;
- Damage to automobiles and trucks;
- More frequent cleaning of the interior of the buildings;

B. <u>Personal Costs</u>

- Impaired health from blowing dust;
- Reduced visibility and blocked transportation arteries;

[16] It should be cautioned that under a national accounting perspective losses from reduced farm production would be equivalent to re-distribution of income. Shortfall in one region would be made up increases in other regions.

- Interference with outdoor recreational activities, such as recreational fishing;

4: Government sectors may also be affected through increased cost of maintenance for government buildings and equipment, and roads and highways.

To estimate external costs, each of these sources of damages (costs) needs to be evaluated. Unfortunately many have not been estimated in the context of the Canadian Prairies. In addition, how much of these costs can be reduced by shelterbelts is another deficiency in our knowledge. An attempt is offered below to estimate these costs in an indirect manner. For this reason, no distinction can be made between benefits from non-public externalities and those from public goods.

The majority of wind-eroded soils are deposited behind soil clods, weeds or grass, or in depression, ditches or coulees. Up to 80 percent of water-eroded soils remain in the field and though unproven up to 75 percent of wind eroded soil remains in-situ (Smith and Hoppe, 2002). The remaining 25 percent of wind-eroded dust, referred to as “fugitive dust”, can be blown thousands of kilometres off-site and re-deposited elsewhere. The fugitive dust provides a physical measure of public benefits of wind erosion abatement. The re-deposition of fugitive dust in ditches and waterways effects water quality by direct contact, reduces visibility around airports, roads, and highways during dust storms posing economic costs and higher risks, and small suspended dust particles create potential health problems when inhaled.

Fugitive dust is seldom inert and contains organic matter, absorbed plant nutrients, heavy metals and agricultural pesticides, all of which can pollute. Inhaled particulate matter alone not to mention the chemical and pesticide carry loads can cause respiratory health problems leading to exacerbation of asthma and bronchitis, as well as increased hospital visits, admissions and rates of mortality (Smith and Hoppe, 2002; Pretty et al., 2000).

To measure the off-site economic costs and benefits of wind erosion abatement, economists have employed a variety of methods. One such method is Willingness to Pay (WTP) estimates using contingent valuation methods (CVMs). Here individuals are asked their willingness to pay for better quality air or water. Another method employed is the hedonic price models to estimate the effect of soil drifting and erosion on property values. Using this type of method, one can estimate the monetary loss to individuals or businesses. Valuation of these benefits has not been a very popular topic in Canada, particularly in the context of shelterbelts, although a few general studies investigate soil erosion.

Dickson and Fox (1989) reported savings to municipalities from reduced soil erosion in Ontario at $13.40 per tonne of sediment loading. Similarly, the municipality of Morris in south central Manitoba in 1988 reported spending approximately $250,000 to remove 250,000 tonnes of wind eroded topsoil from roadsides ditches. Dickson and Fox also estimated the cost of sedimentation on recreational fishing in Ontario of $35 million annually based on loss in the number of fish caught (and its value using market method) with increased sedimentation.

A New Mexico study estimates a $466 million (U.S.) annual cost of wind erosion, (Huszar and Piper, 1986). This is an annual off-site cost of wind erosion for households $457 million, businesses, $7.57 million, and conservancy and irrigation districts, $0.105 million, based on a replacement/repair cost estimation taken from a CVM survey.

(2) Benefits of Shoreline Stabilization: Shoreline stabilization is a benefit from riparian buffer zones. These zones can contain shelterbelts. They generate benefits to the society at large, some of which are public goods. Stabilized banks of water bodies result in reduced silting into the water bodies. This would result in a set of benefits similar to those described for soil erosion. This may add to the flood protection benefit since increased sediments would reduce the peak period carrying capacity of the channel. In addition, the reduced sediments result in improved water quality, which may lead to reduced water treatment costs for municipalities. Shelterbelts filter out sediments from runoff water.

Reduced silting of the shores, particularly during period of rapid flows in the water bodies can result in benefits to the society through fish population. Sediment harms fish in lakes and streams by damaging spawning and feeding areas and by reducing respiration efficiency. The problem is not sedimentation itself but excess sedimentation, especially in the spring when spawning occurs. As Dickson and Fox (1989) have suggested, this leads to benefits to the society through improved recreational fishing. In addition, riparian shelterbelts benefit the aquatic community by regulating water temperature (Maisonneuve, 2001).

According to Wells (2002), biotechnical streambank protection uses plant materials to reinforce soil and stabilize slopes. Plants can be used as the primary structural component or in combination with rocks. Among various primary benefits from such remedial measures are:

- Improved water quality through reduced sediments;
- Improved terrestrial and aquatic habitat;
- Improved soil quality;
- Reduce water temperature by shading;
- Improved aesthetics.

If shelterbelts were planted in these regions, social benefits from stabilized shorelines would emerge in two ways: 1), improvements in wildlife and aquatic (fish) populations and through that in recreational fishing; and 2), water quality improvement and associated benefits.

To estimate the social benefits from riparian shelterbelts, two pieces of information is required: 1), area planted under such shelterbelts and the resulting improvement in those physical attributes leading to social benefits; and 2), social value of the benefits generated by the identified physical changes. Unfortunately information on either of these items is weak or non-existent. This is because the social value of changes related to shoreline stabilization has not been studied exclusively. Average sediment under conservation cover, is reported to be between 4.7 to 32.5 t/ha/yr, depending upon the texture of the soil and rotation followed. The social cost of this erosion also varied from $1.34 to $9.34 /ha/yr (Belcher and Gray, 2001).

(3) Benefits from Improved Water Quality: Water quality generally encompasses four main categories of benefits: Benefits from drinking water, those for livestock, those from recreational water, and benefits through aquatic habitats. The latter category would include both an-

thropocentric and ecocentric (intrinsic) benefits. In a comprehensive assessment all these categories of benefits need to be investigated.

The quality of water for human consumption has come into a close scrutiny since the occurrence of problems in Walkerton, Ontario and North Battleford, Saskatchewan. This is because social costs from such disasters can be very high financially, and because their impact on humans is a highly emotionally charged issue. The immediate effect of water contamination is increased mortality of humans, and animals, and/or increased incidence of water-borne diseases. According to Livernois (2002), the tangible costs to society from any future contamination in magnitude similar to Walkerton are estimated at $64.5 million. Although no economic costs for the North Battleford incident were reported, the Commission of Inquiry recommended measures to protect water quality in the province, which may have various cost implications for water users and regulating authorities (Laing, 2002).

Benefits of improved water quality have been noted for livestock water consumption. A study by the Western Beef Development Centre reported that aerated and coagulated water improved weight gains on steers significantly, approximately 20 percent, compared to direct-accessed water (Kirychuk and Braul, 2001). In addition, there was a strong relationship between water consumption and weight gain of the yearlings.

Water quality is important for recreation. According to Parkes (1974), users of lakes with poor water quality are willing to pay a significant amount per user-day per season over and above additional costs normally incurred in recreation. Fewer Canadian studies have investigated freshwater recreational values. In the context of Conservation Reserves Program in the US, Ribaudo and Young (1989) estimated a value of $21.4 million (US). Feather et al. (1999) estimated the fresh water recreational benefits in the US to be $35.4 million. Adjusting for the price difference, fishing benefits are 81 percent of the total fresh water benefits. These are estimated to be 81 cents per acre (US). Converting them to Canadian dollars, a value of $1.36 per acre in 1999 dollars or $1.40 in 2000 dollars is estimated. Loomis et al. (2000) discovered by survey a willingness to pay $21/month for ecosystem services of dilution of wastewater, natural purification of water, erosion control, habitat for fish and wildlife and recreation provided from riparian vegetation.

Belcher and Gray (2001), in estimating the economics of the conservation cover program, indicated its benefits through improving water quality but did not report a separate value. Improper management of riparian areas also affects recreational fishing. This activity can be very important in many parts of the prairies. For example, they indicated that consumer surplus from recreational fishing is $14.60 per day for Manitoba and $10.70/day for Saskatchewan. Again these benefits vary from site to site. Existence of such activities in the riparian areas has not been a subject of study. Some of the creeks and waterways that would dry up during the summer would likely not have such activities, or have them during a limited season.

Some BMPs may also improve groundwater quality. Hauser and van Kooten (1993), in a study of the Abbotsford aquifer in British Columbia, estimated the lower bound for this benefit at $70/household in terms of defensive expenditures. Their willingness-to-pay was estimated from $78 - $90 per household. Similar results were shown by Athwal (1994). Weersink (1996) reviewed livestock production related externalities, and concluded, "At the present time there are no studies using any of the approaches that have examined the economic value of environmental damages caused by manure pollution. There are a few related studies that have determined that households would be willing to pay from $50 to $1,150 annually to lower nitrates in groundwater. However, no study has examined total impacts from manure which has a host of pollutants (nitrates, P, and odours) and a number of effects on the natural resource systems." Estimated groundwater protection values, estimated using a variety of estimation methodologies, varied from $56 to $1,154 (US $ 1992) per household, which is equivalent to $97 to $1,997 (CAN $ 2000) per household.

A Saskatchewan study estimated the benefits of riparian area improvement. Spasic (2002) surveyed 300 randomly selected Saskatchewan residents and estimated their willingness-to-pay for riparian management. The sample consisted of 60.7 percent urban households, 15.3 percent rural non-farm (towns) households, and 15.3 percent farm households. The average willingness to pay for such improvements was estimated at $39.92 per household, with the median value being $23.60 per household. The willingness-to-pay in this study was an average over all households. No distinction was made for the type of households.

(4) <u>Biodiversity Related Benefits</u>: Biodiversity is important to society. A survey of 818 individuals related to North Carolina's Nantahala and Pisgah National Forests indicated maintaining biodiversity as the second most important value of forest ecosystems (Schaberg et al., 1999). Economic value of biodiversity can be measured either as value based on an anthropocentric framework or using a more comprehensive framework of combining both anthropocentric and ecocentric frameworks. For some, biodiversity has a high intrinsic value, which compels arguing for maintaining or increasing biodiversity. Freese & Trauger (2000) suggest the value of biodiversity cannot and should not be reduced to exclusively monetary measures. For biodiversity conservation in North America to succeed, non-monetary values placed on wildlife and natural ecosystems must form the backbone of our conservation, ethic, policies and practices. Pretty et al. (2000) indicated that it is not currently possible to put a cost (or value) to the declining agricultural diversity resulting in losses of genetic diversity, particularly where whole species or varieties are concerned.

Two groups of methods can be identified if one pursues the anthropocentric approach: 1) identification of benefits that can be provided by biodiversity now or in the future; and 2) opportunity cost of maintaining or increasing biodiversity. In the first approach, specific services provided by biodiversity will have to be identified and their respective benefits estimated. In the second approach, loss of human welfare caused by land being occupied under less commercially productive uses is primary focus. A part of the complicating factor in studying biodiversity is that it is not a local but a global phenomenon.

Using the anthropocentric framework, two approaches to valuation can be considered in the context of direct value of biodiversity: (1) Willingness to pay for biodiversity, and (2) Value of biodiversity *per se*. In a study conducted by Amigues et al (2002), the willingness of the residents in Garonne River near Toulouse, France to pay was computed using a variety of estimation methods. The range of WTP was $7 (USD) for a semi-Log estimation to $26 (USD) for a Heckman model. Use of non-market values (particularly bequest values) has also been suggested by Loomis et al. (2000). Their results indicate a value of various ecosystem services to be $21 per month or $252 annually. Services related to biodiversity that were included in the above estimate were: habitat for fish and wildlife, and recreational use, which are directly related to use values of biodiversity.

Scott et al. (1998) estimated the value of biodiversity using the cost of re-establishing groundcover with natural vegetation as an essential step to establishing habitat. Based on this approach, a value of US$52 – 75 per acre was estimated. This would translate into a value of $204 to $295 per ha.

Biodiversity can benefit society through improving forms of existing crops, developing new foods, use for medicines and pharmaceuticals, industrial products, and biotechnology (Myers, 1997). Pearce and Moran (1994) estimated the value of biodiversity using the opportunity cost of medicinal plants. Plants species are used in medicine in two forms: (1) Major commercial use, whether by prescription or over-the-counter sales; and (2) as traditional medicines. Much of the research has concentrated on the first use of plants. In this study a value of land for this purpose was estimated at US$0.1 to 21 per hectare. The upper value discounted at 5 percent over a long period of time would result in a land value of US$420 per ha. Converting it to Canadian dollars, and to 2000 prices results in a value of $719 per ha.

A.8 Aggregated Accounting of Benefits

The above discussion points to a need to collect additional data for a disaggregated approach to valuation of benefits and costs of adopting BMP to reduce P-loadings in Lake Winnipeg. An alternative method to primary survey is to use existing studies that estimate an overall value for a situation comparable to Lake Winnipeg. Further review of such studies is needed to confirm whether this method would provide representative estimates of the benefits from adoption of the study BMPs in Manitoba. Table A.12 includes valuation references compiled as part of a first screening. This preliminary list can be further refined to identify a short list of reference values that can be applied to the Lake Winnipeg situation.

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
Agriculture	Environmental Benefits and Economic Costs of Manure Incorporation on Dairy Waste Application Fields	Osei et al. (2003)	Texas, Upper North Bosque River	cost benefit	Cost of incorporating solid manure on waste application fields is $38.75/ha (1996) or about 1% of net returns under the N-based application rate and $75.30 to $106.00 per hectare or about 2 to 3% of net returns under the P-based rates. Cost is 37% reduction in P losses in edge-of-field runoff relative to surface manure applications. $USD
	Direct and Indirect Shadow Price and Cost Estimates of Nitrogen Pollution Abatement	Shaik et al. (2002)	Nebraska	costs estimates of nitrogen pollution reduction	1936-1997, estimated shadow price and cost of N pollution abatement for Nebraska ranges from $0.91 to $2.21 / pound, and from $300 to $729 million, respectively (real1936 US Dollar)
	Economic Benefits Resulting from Irrigation Water Use: Theory and an Application to Groundwater Use	Kim and Schaible (2000)	Nebraska Mid-State	comparison of evaluation technique, overestimation of economic benefits	Aggregate economic benefits resulting from irrigation water use would be overestimated by nearly 29%. Net benefits would be overestimated by 82% (US$177.6 million compared with US$97.4 million) for Buffalo county, 76% (US$224.7 million vs. US$127.5 million) for Hall county, and 86% (US$159.6 million vs. US$86 million) for Merrick county
	Voluntary Cost-Share Programs: Lessons from Economic Theory and Their Application to Rural Water Quality Programs	Weersink et al. (2001)	Ontario		

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
	Full Cost Accounting for Agriculture – Final Report. Valuing public benefits accruing from agricultural beneficial management practices: An impact pathway analysis for Tobacco Creek, Manitoba	McCandless et al. (2008)	Manitoba	public benefit of agricultural BMPs, public benefits valuation methodology	Estimated public benefit of the three BMPs at: zero-till – $80/ha/yr; forage conversion – $150/ha/yr; and small dams – $1,667/dam/yr (all 2008, Canadian dollars). The portion of the aggregate public benefit attributable to these three BMPs in the STC watershed is $13.63/ha/yr.
Agriculture & Municipal	Modeling Relationships Between Use and Non-Use Values for Surface Water Quality: A Meta- Analysis	Loomis et al. (2000)	Colorado	valuing benefits of restoring ecosystem services, cost benefit	Program costs would be $12.3 million / annum which was lower than the most conservative estimate of benefits: $18.54 million leaving $6.24 million annually to rent water from farmers to increase in stream flow. $USD
	Benefit Transfer of Water Quality Improvements From Agricultural Landscapes: A Meta Analysis involving	Thomassin and Johnston (2007)	CAN	WTP value of water quality improvements	Household WTP to improve water quality were $6.81 (2002 $CDN) $8.66 and $11.01 for one, two and three unit increase in water quality from baseline condition of seven on the RFF water quality ladder
	The Economic Value of Groundwater (Original title: a valeur économique des eaux souterraines)	Kroeger (2005)	Florida	annual value of (11) ecosystem services	TTL annual value of the services provided by ecosystems estimated at US$3.2 billion, larger than the sum of the annual direct use and non-use values estimated (2002) at US$2.6 billion.

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
	Estimates of Passive Use Values of Wetland Restoration and Retention in Southern Manitoba	Ecological Goods & Services Technical Meeting (2009)	Lake Winnipeg	WTP wetland restoration, Survey	Conservative WTP estimates ranged from $290/household/yr for retaining existing wetlands to $360/household/yr for restoring wetlands to 1968 levels. Aggregated to the entire province over a five year period (discounted), the values are about $600 and $730 million, respectively. $CDN
	Contingent Valuation, Net Marginal Benefits, and the Scale of Riparian Ecosystem Restoration	Holmes et al. (2004)	North Carolina	economic benefits. Contingent valuation, WTP, contingent valuation survey	Annual economic benefit, range from US$6.91 (BMPs only) to US$27.26 (BMPs + 6 miles of riparian restoration or full restoration). PV for a 10-year stream of annual benefits generated by full restoration was estimated at US$2.835 M, about US$472,560/mile of restoration or US$4.54/household/mile (r=5%). For BMPs plus 2 (or 4 miles), the PV of benefits was estimated at US$243,732 (or US$401,645) per mile of restoration. Discount Rate: 5%
Agriculture, Municipal, Recreational	Economic Value of Water in Alternate Uses in the South Saskatchewan (Alberta and Saskatchewan Portions) River Basin	Kulshreshtha (2006)	Alberta, SK	economic value of water	Irrigation - value of water ranges from $36 to $70.90. Agricultural use values ranges from $7.68 to $28.87. Municipal - from $1,270 to $2,170. Hydroelectric power generation - from $0.11 to $0.24. Recreation value ranges from $2.90 to $1,139.42. 2004 $CDN / cubic deciliters.
Agriculture, Outdoor Tourism, Kayaking, Camping	Port-induced Erosion Prediction And Valuation Of A Local Recreational Beach	Alberini et al. (2006)	North Carolina	demand model, WTP	For an increase by 100 in trail miles at sites 2 and 7, the mean annual WTP per individual was US$4.64 and US$24.44 for an improvement in water quality to an IWI of at least 2 in the paddling areas (2000 US$). Imposition of a $30 access fee for paddling had a mean annual welfare impact of -US$41.35 per individual

Table A.12 Valuation References

Topic	Title	Author & Year	Location	Valuation Method	Values
Beaches	Estimating the Economic Burden from Illnesses Associated with Recreational Coastal Water Pollution - A Case Study in Orange County, California	Dwight et al. (2006)	California	cost-of-Illness / economic burden of polluted recreational coastal beaches	Based on an effective daily income of US109.30 and average medical cost / doctor visit of US$108.98, the estimated total cost / illness is US$36.58 for GI, US$76.76 for ARD, US$37.86 for ear ailment, and US$27.31 for eye infection (2001 US$). Assuming an annual GI illness rate of 36,778 during a typical year, The estimated public health costs are US$1.3 million, US$951,378, US$767,221, US$304,335, respectively or an annual cumulative public health cost of US$3.37 million for the two beaches. The economic burden is expected to reach US$7.1 million if the two beaches complied exactly with US EPA's current water quality standard for recreational marine which has a 1.9% threshold illness rate for GI.
Hunting	Valuing Ecosystem Services For Sustainable Landscape Planning In Alpine Regions	Knoche and Lupi (2007)	Michigan	services provided by agro ecosystem for hunting. survey	For a change in deer population by 10,000 / trip values $3.94 (2003 USD) and $1.75 (firearm and archery hunters). For change in access by 100,000 acres, per trip values were $1.70 and $1.87 (firearm and archery hunters). Aggregate welfare change associated with opening 10% of agricultural land for hunting was $19 million. Welfare change associated with 50% reduction in deer population was -$14.7 million.

Table A.12 Valuation References

Topic	Title	Author & Year	Location	Valuation Method	Values
Municipal	A Contingent Valuation Study of Winnipeg Munici-pal Water Using Bounded Rational-ity	McComb (2002)	Winnipeg	WTP for water quality improve-ment, contingent	Mean WTP for water quality improvement was estimated at $9.60 per month (1999, $CDN) Annual WTP was estimated at $115.20 / household. The 1996 number of households was multiplied by $115.20 to obtain estimate of the annual benefits from improved water quality - $20.384 million. Discount rate: 5%, 8% and 10%
Municipal	Applying Contin-gent Valuation To The Saint John Harbour	Foster (2002)	Newfoundland	WTP for waste-water treatment	WTP between $ CDN 4.50 and $ CDN 28.00 / person. The lower value of WTP includes protest zero response while the higher value does not. Overall, WTP ranged from $ CDN 448,000 to $ CDN 2,820,000.
Municipal	Estimating Will-ingness to Pay for Improved Water Quality in the Presence of Item Non-response Bias	Brox et al. (2003)	Ontario	WTP	Average WTP between $4.56 and $9.42 / household / month. 1994 $CDN
Municipal	The Economic Value of Pollution Damage in the Pantanal, in Valu-ing Environment in Developing Coun-tries: Case Stud-ies, edited by David Pearce, Corin Pearce and Charles Palmer	Martin and Marceau (2001)	Montreal	WTP for groundwater protection	WTP an average of $48,24 / year for a groundwater protection and conservation programme. Aggregate economic value of groundwater was estimated at $250 million for the region under study. Results extrapo-lated to estimate the aggregate economic value of groundwater for Québec at $5 Bil-lion. Average expenditure costs per house-hold were estimated at $78.30 per year. Actualised and aggregated economic value of groundwater was estimated at $250 mil-lion.

Table A.12 Valuation References

Topic	Title	Author & Year	Location	Valuation Method	Values
Municipal	Change in Ecosystem Service Values in the San Antonio Area, Texas	Kreuter et al. (2001)	Texas	ecosystem service values	For an estimated annual land-use change ranging from -0.5 to 11%, the value of ecosystem services declined from US$21.94 million/year in 1976 to US$21.16 million/year in 1991 or an estimated loss of S$5.58/hectare per year (4%) or a total of US$6.24 million over the 15-year period. Assuming that the shift of rangelands to woodlands produced no net change in the value of ecosystem services per hectare, the estimated loss increased to US$23.22/ha per year (15.4%) or a total of US$26.32 million over the 15-year period
Municipal	Regulatory Impact Analysis for the Proposed Ground Water Rule	The Cadmus Group, Inc. (2000)	USA		The overall upper bound (consumer valuation) annual health benefits of the Sanitary Survey Option range from a low (10th percentile) of $8.8 million to a high (90th percentile) of $57.6 million, with a mean of $32.5 million (1999 $USD) The upper bound annual benefits for the Sanitary Survey and Triggered Monitoring Option range from a low $147.4 million to a high $208.6 million with a mean of $177.9 million (1999 United States Dollars). The upper bound annual benefits for the Multi-barrier approach range from a low $168.5 million to a high $241.9 million with a mean of $205.0 million (1999 $USD) The Across-the-Board Disinfection Option produces the greatest upper bound annual benefits ranging from a low $255.0 million to a high $311.1 million with a mean of $283.1 million $USD

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
Municipal	Measuring the Total Economic Value of Restoring EcoSystem Services in an Impaired River Basin: Results from a Contingent Valuation Survey.	Loomis et al. (2000)	Colorado	WTP for ecosystem services. benefits of restoring ecosystem services along River	Program costs would be $12.3 million per annum which was lower than the most conservative estimate of benefits: $18.54 million. This would leave $6.24 million annual to rent water from farmers to increase instream flow.
Municipal	Measuring Principals' Values for Environmental Budget Management: An Exploratory Study	Blomquist et al. (2003)	Kentucky	willingness to trade off public programs for environmental programs	Of the environmental state programs, drinking water was valued highly, with an allocation of $US1.67 million out of the US$10 million budget increment. Indoor environmental quality received the lowest allocation (US$0.77 M). Increments to programs addressing untreated sewage were the most valued (US$1.89 M) while increments to programs addressing radon in homes were least valued (US$0.49 M).
Municipal, Property Values	Exploring the Hedonic Value of Ambient Water Quality: A Local Watershed Based Study	Poor et al. (2007)	Maryland	impact of water quality on housing values	Marginal implicit price for one milligram per litre change in total suspended solid was estimated to be $1,086 (2003 USD) while similar change in dissolved inorganic nitrogen was estimated to be $17,642
Municipal Property Values	The Effect of Environmental Zoning and Amenities on Property Values: Portland, Oregon	Netusil (2005)	Oregon	hedonic-price-method	The impact of environmental zoning is found to vary with the type of environmental zoning and the property's location. Amenities are found to influence a property's sale price with the effect varying by amenity type and proximity. The net effect on a property's sales price is dependent on the type of environmental zoning, location in the study area, amenities on the property, and amenities in the surrounding neighborhood

Table A.12 Valuation References

Topic	Title	Author & Year	Location	Valuation Method	Values
Municipal, Recreational Fishing	An Iterative Choice Approach to Valuing Clean Lakes, Rivers, and Streams	Magat et al. (2000)	North Carolina, Colorado	economic value of water quality improvement	Overall benefit values were then calculated for a 15% improvement in water quality and yielded values per household which ranged from $91.06 (value if improvement was only to fishing) to $485.23 (value if improvement reduces Toxic Waste Pollution)
Pollution, Fish Consumption	The Estimation of Ecosystem Services' Value in the Region of Misi Rural Development Project: Results From a Contingent Valuation Survey	Whitehead (2002)	USA	risk perceptions, seafood demand, and WTP for a seafood inspection program. Survey	Quantity demand is more responsive to price decreases than price increases. The total consumer surplus per meal was between $11 for price increase and $7 for price decrease (2001 USD). The regression results from a simple willingness to pay model are presented in Table 3. The effect of the price change on the probability of a vote for the seafood inspection program was negative and statistically significant
Property Values	Estimating the Benefits of Maintaining Adequate Lake Levels to Homeowners Using the Hedonic Property Method	Loomis and Feldman (2003)	California	economic benefits - Property and sales data	Each additional one foot of exposed shoreline reduces the property price by $108-$119. A view of the lake added nearly $31,000 to house prices, while lakefront properties sold for $209,000 more than non-lake front properties. $USD
Property Values	Loss of Value of Szigetkoz due to Gabeikovo-Nagymaros Barage System Development: Application of Benefit Transfer in Hungary.	Krysel et al. (2003)	Mississippi	hedonic models	For one metre increase in water clarity, the price change ranged from $3.14 to $423.58 (2003 US). For one meter decrease in water clarity, the price change ranged from $1.43 to $594.16 (2003 $US).

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
Property Values	Objective Versus Subjective Measures of Water Clarity in Hedonic Property Value Models	Poor et al. (2001)	Maine	hedonic models, perceptions, survey	Estimated implicit price for water clarity in - Augusta and Lewiston - where water clarity significantly influenced the price of lakefront properties. Estimates based on the subjective measures of clarity were larger by 6% and 43%, respectively than those based on the objective measures
Property Values, Recreation	Linking Physical and Economic Indicators of Environmental Damages: Acid Deposition	Phaneuf et al. (2008)	United States	hedonic model	Morrisville - losses ranged from $.30 to $18.58 (2004 $USD). Wake Forest losses ranged from $0 to $1.11. Lynn Lake recreation loss resulted in welfare decline by a maximum of $15.81 while amenity loss resulted in loss of $2.13. Discount Rate: 5%
Recreation	Recreation Demand Using Physical Measures of Water Quality	Egan et al. (2004)	Iowa	impact of water quality on recreational value	Welfare estimates were made based on 3 scenarios. # 1- improvement of all 128 lakes to that of the cleanest lake in the state, West Okoboji Lake. # 2 - improvements in 9 lakes to the standard of West Okoboji. # 3- improvements of 65 impaired lakes to the median level of the 64 non-impaired lakes. Per Iowa household compensating variation estimates for the 3 scenarios were US$ 208.68, $39.71 and $4.87
Recreation	Modeling Congestion as a Form of Interdependence in Random Utility Models	Boxall et al. (2000)	Manitoba, Ontario	instrumental variable approach, congestion model	Economic benefit of expansion of access through provision of additional road is estimated to be $CDN 200 / trip for wilderness canoeing. Additional roads resulted in negative welfare in the range of $CDN -100 to -200 / trip. No welfare changes from provision of additional roads.

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
Recreational Boating	Eutrophication Of U.S. Freshwaters: Analysis Of Potential Economic Damages	Dodds et al. (2008)	USA	cost of eutrophication, economic losses	Annual recreational losses were estimated to range between $189-589 million (boating), $182-527 million (fishing). Biodiversity losses were estimated using annual costs for all U.S. endangered species recovery plans devoted to eutrophication-linked biodiversity loss - amounted to $44 million annually. Annual costs for drinking water treatment necessitated by eutrophication were proxied with total annual U.S. expenditure on bottled water due to compromised taste and odour associated with eutrophication, and were estimated to reach $813 million annually. 2001 $USD
Recreational Boating	The Value of Improved Water Quality To Chesapeake Bay Boaters	Lipton (2003)	Maryland	WTP water quality recreational boating, Present Value, valuation of water quality improvement	Median willingness to pay for a one step improvement in water quality was $17.50 per year and the mean was $63, with 38% expressing a zero willingness-to-pay. A tobit model was estimated to determine what factors influenced willingness to pay amounts. Sailboaters and boats that were kept in the water rather than trailered were willing to pay more for water quality improvements. Additionally, the lower the individual ranked water quality and the greater concern for the health effects from water quality, the more the willingness to pay for a water quality improvement. Boaters were willing to pay approximately $7.3 million per year to achieve the stated water quality improvement. The present value of this improvement, at a 5% discount rate is $146 million. $USD

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
Recreational Fishing	Comparison of the Contingent Valuation Method and the Stated Choice Model for Measuring Benefits of Ecosystem Management: A Case Study of the Clinch River Valley, Tennessee	Takatsuka (2004)	Tennessee	WTP for environmental quality changes, model comparison	In the CHOICE models, the mean WTP ranged from US$48.97 to US$161.42 for water quality improvement (W), from US$54.83 to US$166.86 for improvement in aquatic life (A), and from US$-81.16 to US$19.45 for improvement in sport fishing (S). In the TRAD-CVM model and MOD-CVM, the WTPs were US$24.89 and US$29.13 per year, respectively. In the without SC MULT-CVM model, the annual WTP estimates were positive only for W, ranging from US$17.38 to US$21.00 per household. Welfare values derived from CHOICE are much higher than those derived from the corresponding CVM. WTP for aquatic life improvement in the TRAD-CVM and CHOICE are positive, while those of MULT-CVM and POOLED TRAD-CVM are negative.
	Economic Analysis of the Potential Impact of Climate Change on Recreational Trout Fishing in the Southern Appalachian Mountains: An Application of a Nested Multinominal Logit Model	Ahn et al. (2003)	North Carolina	economic analysis, potential impacts of climate change on recreational fishing - trout anglers' welfare losses	The median angler's consumer surplus value in 1995 dollars for a trip occasion is $266. This is interpreted as the value an angler places on a single trout-fishing trip occasion. Contingent valuation measures can be interpreted as the trout angler's welfare loss in dollar terms based on the trout habitat and population reduction scenarios. The estimated median welfare loss (compensating variation) ranged from $5.63 to $53.18 per angler per single occasion under the various diminished trout habitat and/or population scenarios. Per angler mean welfare loss approximations for the entire year ranged from $285 to $2,692. $USD

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
	Narrow Choice Sets in a Random Utility Model of Recreation Demand	Parsons et al. (2000)	Maine, USA	welfare effects associated with loss of fishing sites, random utility model of recreation demand	The mean per trip compensating variation averaged over the entire sample of 3,519 anglers ranged from $0.37 to $0.86 / trip and was largest with the Baseline model. The estimates from the other models were 43% to 60% of the Baseline. Narrowing the choice set definition increased welfare loss but also reduced the size of population affected. In the Region Only version, welfare loss among those fishing in the Region (n=334) increased from $0.46 to $4.80 per trip, more than 3 times the mean loss in the Baseline model. The sensitivity of the welfare estimates to narrowing choice sets was explained largely by variations in the travel cost coefficients across the different models considered. $USD
	An Application of the Kuhn-Tucker Model to the Demand for Water Trail Trips in North Carolina	Phaneuf and Siderelis (2003)	North Carolina	WTP for improvements in water quality etc	Mean annual WTP / individual was US$4.64 for an increase by 100 in trail miles at sites 2 and 7 and US$24.44 for an improvement in water quality to an IWI of at least 2 in the paddling areas (2000 US$). Imposition of a $30 access fee for paddling in area five had a mean annual welfare impact of -US$41.35 per individual.

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
Tourism, Recreational Fishing, Biking, Property Values	New Evidence on the Economic Benefits of Controlling Salinity in Domestic Water Supplies	Hitzhusen et al. (2000)	Ohio	Benefits and costs, economic value of improving water quality, through different programs, benefits transfer and non-market estimation, WTP, contingent valuation	Table 1 shows the average annual (1983-1997) river-related surplus value by type of recreation. Average annual consumer surplus from all types of recreation is about US$5.2 million with anglers accounting for 36% of the surplus. Average annual WTP for proposed improvements, ranged from US$0.86 to US$2.07 per individual or a total of US$7.2 million to US$11.5 million. Aggregate values of the effects of corridor attributes on residential property values in the corridor, determined from the hedonic model, were as follows: zoning - US$912,497, central sewer system - US$678,300, household septic system - US$1,469,650, and river proximity - US$636,650. Discount rate: r = 10%, n = 20 years
Tourism	Using Random Parameters to Account for Heterogeneous Preferences in Contingent Valuation of Public Open Space	Nahuelhual et al. (2004)	Wyoming	WTP for management strategies. Random Parameter Logit, dichotomous choice CV survey	Mean WTP estimates for 100 extra acres of open space were similar for both models - US$9.88 for the logit model and US$9.77 with a standard deviation of US$17.46 for the RPL model. WTP for recreation was not calculated since the parameters for this attribute were insignificant. With the logit and RPL Model with interaction terms of individual characteristics and acres, marginal WTP computed at the mean values of the individual characteristics and attitudinal variables were equal to US$9.03 for the logit model and US$9.61 with a standard deviation of US$36.39 for the RPL model.

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
Tourism, wildlife protection	Estimation Of The Economic Benefits Of Marine Mammal Recovery In The St. Lawrence Estuary	Olar et al. (2007)	Quebec	Cost benefit/economic value, contingent value, survey	Canadians are willing to pay on average up to 242$ per household to improve the risk status of the harbour seal and the beluga whale from "threatened" to "not at risk" (CAD, 2006). Program 4 was the most valued, followed by in a decreasing order of importance 3.1, 5, 3.2, 2 and 1. The WTP values for all programs ranged from 82$ (program 1) to 242$ (program 4) (CAD, 2006). Aggregate values showed WTP values for Canadians (2001), are estimated to be between 948$ million (program 1) and 2,798$ million (program 4) (CAD, 2006).

Table A.12 Valuation References					
Topic	**Title**	**Author & Year**	**Location**	**Valuation Method**	**Values**
	The value of ecosystem services provided by the U.S. National Wildlife Refuge System in the contiguous U.S	Ingraham and Foster (2000)	USA	value of ecosystem services	Total value of ecosystem services provided by National Wildlife Refuge System was evaluated at $26.9 billion/year, approximately $2.4 thousand/acre/year. Wetland provided the largest value, estimated at $22.9 billion/year, $8.8 thousand/acre/year. Forest values across all regions accounted for $94.4 million/year, $8.5 hundred/acre/year (USD 2004). Open water provided $467 million or $2.9 hundred/acre/year in annual ecosystem services. Services from shrubland contributed to $2.5 billion/year, $51.40 acre/year). Carbon sequestration was assessed at $3.3 billion/year. Disturbance prevention services accounted for $6.2 billion/year, for wetlands only. Freshwater regulation and supply services were estimated at $6.5 billion/year, for water and wetlands. Habitat provision services accounted for $562.6 million/year, for wetland and forests. Nutrient removal and waste assimilation services were assessed at $10.2 billion/year, applied to wetlands only (USD 2004).
Water Quality	Willingness to Pay for Water Quality Improvements in the United States and Canada: Considering Possibilities for International Meta-Analysis and Benefit Transfer	Johnston and Thomassin (2010)	USA, CAN	willingness to pay for surface water quality improvements, meta-function transfer	Model results provide a mixed message regarding the possibilities for valid and reliable international benefit transfer. … limitations in Canadian sample size preclude a more comprehensive analysis of systematically varying slopes for all moderator variables. There might be significant value surface differences between the two countries that remain unidentified by the current analysis. Results suggest the substantial errors that can occur in unadjusted transfers

Table A.12 Valuation References

Topic	Title	Author & Year	Location	Valuation Method	Values
	Differences among Watershed Sub-Populations in Willingness to Pay for Water Quality Improvements: The Impact of TMDL Development	Collins et al. (2006)	Virginia	Contingent valuation, WTP for water quality improvements in watershed	Average annual mean and median WTP estimates varied from $49 to $69 in VA compared with $32 to $45 in WV, across both supporter and non-protest zero sample respondents. For VARL respondents, average annual WTP ranged from $64 to $80, greater than both VA and WV general public respondents. For out-of-state water quality improvements, the average WTP for a one-time donation ranged from $28 to $43 while those of VARL respondents varied from $8 to $35. Table 2 shows the impact of the TMDL process on WTP for VA in-state watershed clean-up. It also compares the median WTP for WA and VA respondents. WTP was 100% higher for those who were aware of the TMDL and had a college education. $USD
	The Economic Value Of Improved Environmental Health In Victorian Rivers	Ko (2007)	Texas	value of ecosystem services, Replacement cost, market valuation	Flood mitigation services provided by the wetland were valued at $5,800 per acre. Restoration cost of the Galveston Bay is estimated at $6,000 per acre. The non-use value of the Galveston Bay wetlands was estimated at $5.77 billion (USD 2007).

Table A.12 Valuation References

Topic	Title	Author & Year	Location	Valuation Method	Values
	Valuing a Spatially Diverse Non-market Good: The Benefits of Reduced Non-point Source Pollution in Green Bay, WI	Moore et al. (2007)	Wisconsin	WTP for water clarity improvement. Contingent Valuation method, Mail CV survey	Predicted WTP values vary significantly between counties for bayfront and inland properties. For a 4 foot improvement in water clarity, the WTP was lowest for rural Oconto County ranging from US$326.36 to US$364.26 for bayfront property owners and US$0.0 to US$24.14 for inland property owners. WTPs were highest for owners in Brown and Kewaunee counties, (more urban and located where water clarity is poorest) with values ranging from US$390.32 to US$640.59 for bayfront owners and US$96.80 to US$276.49 for inland owners.
	The Economic Value Of Water Quality	Viscusi et al. (2008)	USA	annual economic value, iterative choice survey	Mean water quality benefits estimated at the equitable tradeoff point was $31.70 for each percent increase in lakes and rivers in the region for which water quality is rated Good. The conjoint benefit estimates were lower, ranging from $24.96 based on the conditional logit model to $26.50 based on the mixed logit model. Using the mean equitable tradeoff value, the annual economic value of the decline in inland US water quality from 1994 to 2000 was estimated at $196.54/household or a total annual loss of $21.8 billion. $USD
Property Values	Evidence of the Effects of Water Quality on Residential Land Prices	Leggett and Bockstael (2000)	Maryland	benefit of water quality improvement on property values, WTP	Projected increase in values due to a hypothetical reduction in fecal coliform concentration to 100 counts/100 ml was about 2% of the assessed value or about $230,000 (1997 US$). The upper bound to the benefits for raising water quality to the state standard of 200 counts/100 ml for all residential properties was about $12.145 million.

Appendix B. Nutrient Management

Management BMPs (form, rate, timing and placement) to optimize nutrient use by crops are compared to conventional nutrient management practices. Both synthetic fertilizers and livestock manure are considered, and manure storage, as it affects the timing of manure applications is also considered.

B.1 Nutrient Forms Considered in Estimates

Using Statistics Canada Census of Agriculture data (Agriculture and Agri-Food Canada - Prairie Farm Rehabilitation Administration, 2005). Johnston (2001) estimated that approximately 85 percent of P applied to Manitoba farmland is in the form of synthetic fertilizer, and 15 percent is applied as livestock manure. Using a similar approach, Halket et al. (2003) estimated that approximately 95 percent of the N applied to Manitoba farmland is in the form of synthetic fertilizer and 5 percent is in the form of livestock manure. For the current study, these proportions were also used to separately estimate the relative proportion of nutrients lost in runoff after applying these two forms of nutrients.

In reality, nutrient sources vary in their susceptibility to loss. For example, all major sources of synthetic P fertilizer (e.g., granular mono-ammonium phosphate and liquid ammonium polyphosphate) are very soluble in water, so there are no significant differences in their susceptibility to surface runoff and losses. However, during the period immediately after application, the high solubility of synthetic fertilizer P makes it more susceptible to surface runoff loss than liquid or solid livestock manure. Livestock manure has less water soluble P and is less susceptible to runoff loss than synthetic fertilizer, and solid manure is less susceptible to runoff loss than liquid manure when all forms are applied to soil in a similar manner (Kumaragamage, Flaten, Akinremi, Sawka, Ige, & Zvomoya, 2009). Therefore, the difference in P availability among nutrient sources shortly after application are especially significant for livestock manure and synthetic fertilizers that are broadcast onto the surface of soil without incorporation. However, after manures and fertilizers interact with soil for several weeks, all of these differences in runoff risk between sources are accounted for by differences in their effects on Olsen soil test P concentrations in soil (Kumaragamage, Flaten, Akinremi, Sawka, Ige, & Zvomoya, 2009).

B.2 Rate of Application

The rate of nutrient application relative to crop removal is the key long term factor for agronomic and environmentally sustainable nutrient management. To maintain long term productivity, nutrients must be added to agricultural land at a rate that is sufficient to replace the nutrients that are exported as food, feed, fibre, or fuel. However, in some water quality studies, only the rate of fertilizer nutrient application has been considered, for example in the study of Lake Winnipeg's sediments by Mayer (2006). The correct way to determine the net rate of nutrient addition to a watershed is to also consider the rate of nutrient removal by crops, so that the balance between the rate of N and P application and removal can be calculated.

When rates of nutrient application exceed rates of crop removal, the accumulation of surplus nutrient increases the risk of loss to surface and groundwater. However, when the rate of application is less than the rate of crop removal, the long term sustainability of agricultural production is threatened. Unfortunately, the world has many examples of imbalances, where rates of nutrient application are either excessive or inadequate, relative to rates of removal (Vitousek, 2009). Fortunately, in Manitoba, the rates of fertilizer N and P addition are nearly in balance with the rates of crop removal (Figures B.1 and B.2). Even though the application of livestock manure nutrients is not considered in these calculations and figures, as mentioned previously, manure nutrients represent a small portion of the nutrients applied to agricultural land in Manitoba.

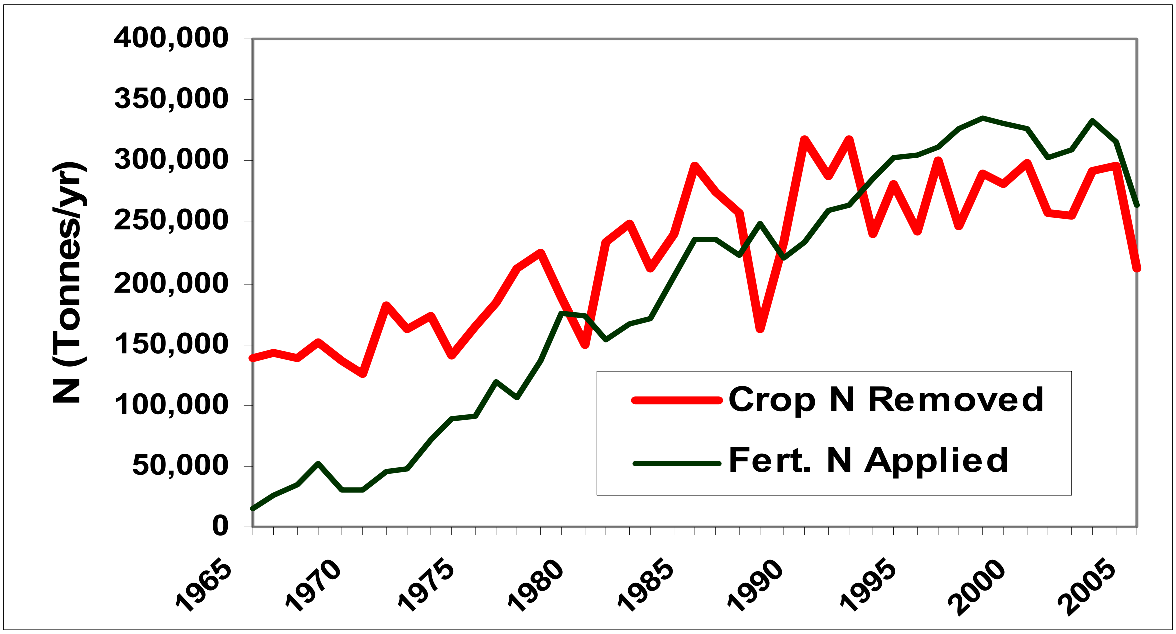

Figure B.1. N Balance for Crop Removal and Synthetic Fertilizer Application in Manitoba 1965-2006

Source: Personal Communication 2010 with Adrian Johnston, International Plant Nutrition Institute

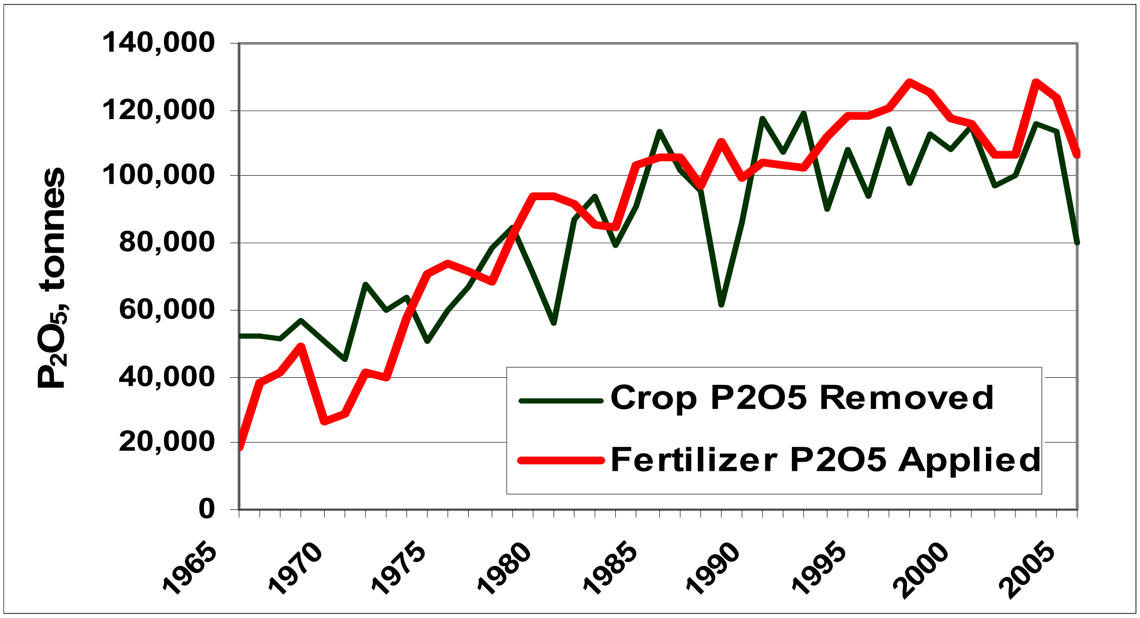

Figure B.2. P Balance for Crop Removal and Synthetic Fertilizer Application in Manitoba 1965-2006

Source: Personal Communication 2010 with Adrian Johnston, International Plant Nutrition Institute

Variable rate fertilization is an increasingly popular practice, but it is not "guaranteed" to improve nutrient use efficiency and water quality. This technology could allow a farmer to apply less than average rates of fertilizer and/or manure to areas within fields that have above average fertility, and thereby help to reduce the risk of water quality problems. However, in the water-limited, semi-arid regions of Manitoba (e.g., the Prairie pothole region of western Manitoba), the average yield potential of depressional areas may be greater than that for upper slope positions, encouraging greater than average rates of nutrient application to the most hydrologically active part of the landscape and greater risk of loss (Manning, 2001). Therefore, this practice, in its current form, should not be regarded as a reliable means of providing substantial reductions in nutrient loading to Lake Winnipeg.

B.3 Phosphorus Application Rate Scenarios

Over the 2000-2005 period, Manitoba crops removed an average of approximately 100,000 tonnes of P_2O_5 and received approximately 114,000 tonnes of P_2O_5 as synthetic fertilizers (Adrian Johnston, personal communication 2010), and 16,000 tonnes of livestock manure Halket et al. (2003) for an average total annual surplus of approximately 30,000 tonnes of P_2O_5. However, due to high prices for phosphate fertilizer in recent years, this surplus has declined. For example, in the 2008-2009 fertilizer year, phosphate fertilizer sales declined to 98,000 tonnes of P_2O_5 (Canadian Fertilizer Institute, 2009) substantially reducing the total surplus of P for that year.

Also, Manitoba's modest overall P surplus is not evenly distributed across the province. In recent years, the rate of P application is less than the rate of crop removal in over half of

Manitoba's rural municipalities (Gyles, 2009), indicating that soil P reserves are declining in those areas. Furthermore, depending on the region, 20-66 percent of Manitoba soils tested by AgVise Labs in 2009 contained less than 10 ppm Olsen P (AgVise Labs, 2009), which is regarded as "low" agronomically, according to the Manitoba Soil Fertility Advisory Committee (MAFRI, 2007). However, significant surpluses of P are applied onto a small proportion of Manitoba's agricultural land. For example, surpluses of more than 5 kg P_2O_5 per ha occur in only 9 of Manitoba's 82 rural municipalities (Gyles, 2009).

Even though runoff losses of P are affected by many factors, soil test P has a substantial effect on runoff P losses for a particular soil or site, especially if the soil or site has high concentrations of soil test P. According to simulated runoff experiments with Manitoba soils (Figure B.3; Sawka, 2009) and natural runoff in Alberta watersheds Little et al. (2006), runoff losses of dissolved P (the dominant form of P loss from Prairie fields) respond in a linear manner to changes in soil test P concentration and can be expected to decrease by approximately 10 percent as a result of decreasing Olsen soil test P values from the agronomic optimum of 15 ppm to 12 ppm. The linear nature of this relationship means that the overall average soil test P concentration is critical, because above average losses from high P soils are offset equally by lower than average losses from low P soils.

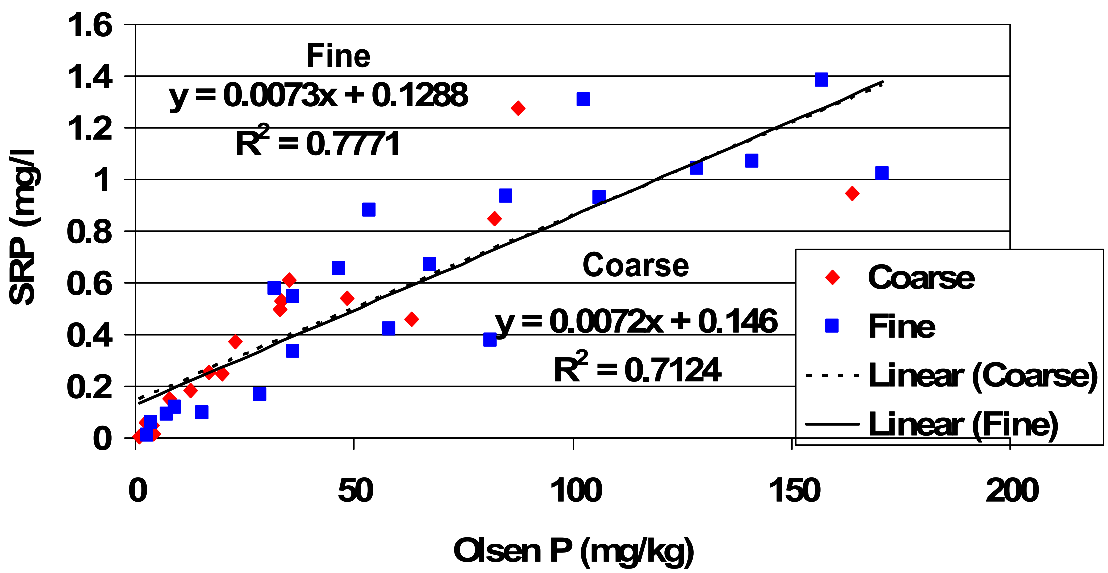

Figure B.3. Relationship Between Olsen Soil Test P and Soluble Reactive P in Simulated Runoff from 38 Manitoba Soils

Source: Sawka (2009)

Increases in runoff P in high P soils occur only in areas of the landscape that generate run-off; therefore, soil test P increases in areas that are not hydrologically active will have no impact on runoff P. However, given that overland flow is common on Manitoba landscapes during snowmelt and there is no readily available information to define Manitoba's hydrologically active areas for generating P in runoff, for this study the P rate targets area applied universally across all farmland in Manitoba. It is also important to recognize that soil test P concentrations are strongly buffered and do not change quickly in response to P surpluses or deficits. In other words, reducing the P surplus will not quickly reduce existing P losses from the soil's substantial P reserves, so-called "legacy-P."

B.3.1 Rate BMP Scenario 1

In this scenario, P balance is neutral overall, maintaining existing overall average soil test P concentrations and avoiding overall increases in P losses. Average Olsen (sodium bicarbonate) extractable soil test P concentrations in Manitoba's agricultural soils are approximately 15 ppm, (Salvano and Flaten, 2006) which is regarded as agronomically optimum (at the threshold between medium and high) for field crop production (MAFRI, 2007). If livestock manure production is maintained at current levels and it is distributed so that manure P is applied at the rate of crop removal, the average rate of synthetic P fertilization will need to be reduced by approximately 20 percent to adjust for this improved use of manure P, as well as from current synthetic fertilizer P application which currently exceeds crop removal by a small margin.

This scenario may result in savings in P fertilizer costs for some crop producers. However, this scenario will require substantial investment in manure transport and/or treatment for some livestock producers, especially in regions where livestock density is high relative to crop export of P. For example, Mann and Grant (2006) estimated that the annual costs for Manitoba's pig industry, alone, to adapt to manure P balance would be approximately $28 million per year. Considering that pigs produce approximately 50 percent of the mechanically applied manure in Manitoba Halket et al. (2003), the costs for Manitoba's entire livestock to adapt to this challenge could exceed $50 million per year.

B.3.2 Rate BMP Scenario 2

In this more ambitious scenario, P is depleted to reduce average soil test P concentrations from an average of 15 ppm Olsen P to 12 ppm. Although rates of P application and removal must be in balance for long term agricultural sustainability, there may be an opportunity to deplete soil P reserves in soils that contain more than 15 ppm Olsen P without severely impairing crop productivity. For example, in these situations, P can be applied at half the rate of crop removal, providing much-needed "starter-P" for early season growth and encouraging net depletion of soil P reserves for the remainder of the growing season. However, to reduce the average soil test P concentration to below 15 ppm, further increases in Olsen P in low P soils must also be prevented; otherwise high P and low P soils will eventually converge around the current average. This option will be very difficult to implement in areas where crop production is intensive (due to agronomic losses by crop producers) or where the livestock density is high, where even more investment in manure treatment will be required than for the P balance scenario.

It is also important to realize that the buffering effect of existing P in the soil means that the effect of P deficits on soil test P and runoff P losses will require several years to have any significant effect on Lake Winnipeg's water quality. For example, a typical "rule of thumb" used elsewhere is that a 20 lb/acre surplus or deficit in P_2O_5 is required to raise or lower Olsen soil test P values by 1 ppm e.g., Quebec studies show that a surplus of 2-5 kg P per ha will increase

Mehlich 3 soil test P by 1 kg/ha, which translates into the equivalent of 15-38 kg P_2O_5 per ha to raise Olsen P by 1 ppm (Gouvernement du Quebec, 2002). Therefore, with average crop removals of 24 kg P_2O_5/ha, a deficit of 12 kg/ha per year would reduce Olsen P values by 0.6 ppm per year (i.e., it could take 100 years to reduce soil test P in a high testing field by 60 ppm). Manure treatment/transport costs for livestock producers will be much greater than for Scenario 1 and crop producers with perpetually low P soils may deserve compensation; however, applying fertilizer and manure at half the rate of P removal will not cause nearly as much loss in crop yield as a zero rate would.

B.4 Nitrogen Application Rate Scenario

Over the 2000-2005 period, the rates of N fertilizer application exceeded the rates of crop removal by approximately 17 percent (Adrian Johnston, personal communication). This surplus is relatively small, considering that some N fertilizer is inevitably lost (e.g., volatilization, denitrification or leaching) or converted into new soil organic matter (i.e., immobilization). Although these figures do not account for manure N application or recent increases in consumption of N fertilizer (Canadian Fertilizer Institute, 2009), the balance between N application and N removal has resulted in a downward trend in Manitoba's soil residual nitrate concentrations since 2000 (AgVise Labs, 2009).

Although N surpluses are a matter of concern for nitrate accumulation and leaching to groundwater (Drury, 2007; Yang et al., 2007), the low rates of loss of ammonium N in runoff from agricultural fields and the small role of N in eutrophication (Schindler et al., 2008; Carpenter, 2008) imply that adjustments to the rate of N applied will have little impact on water quality in Lake Winnipeg.

B.5 Timing of Nutrient Application

If fertilizer or manure is applied onto frozen soils or snow or when runoff is likely, the risk of N and P loss is greater than when nutrients are applied to thawed soil and when runoff is unlikely Sharpley et al. (2006).

Fortunately, very little fertilizer is applied on frozen soils or snow in Manitoba. Furthermore, the only fertilizer that is applied in significant quantities in the fall in all of Western Canada is anhydrous ammonia (Korol, 2004). Anhydrous ammonia is applied in bands underneath the surface, usually in late fall, minimizing the risk of N loss to surface water. As a result, in Manitoba's semi-arid to subhumid climate, fall banded ammonia is often as agronomically efficient as spring banded ammonia (Grant, 2001). Similar to the trend reported for Western Canada (Korol, 2004), almost all P fertilizer in Manitoba is banded in the spring so that it can be placed underneath the soil surface, in or near the seed in order to maximize early season uptake. For these reasons, there is only a very small benefit to water quality in Lake Winnipeg from changing the timing of fertilizer application.

According to the 2001 Census, less than 3 percent of Manitoba's livestock manure was applied during winter months (Beaulieu, 2004). Although many studies have identified substantial losses from manure applied onto frozen soils and snow (Schulte, 1979; Green, 2002; Young, 1976; Srinivasan, 2006), few have quantified the increase in nutrient runoff losses for winter compared to non-winter applications. However, under snowmelt conditions in Minnesota, Young (1976) found that up to 16 percent of orthophosphate was lost during spring runoff when manure was applied to frozen soil. In the same study, losses of less than 4 percent of P were observed when the manures were incorporated into the soil in the fall following application. Even though this comparison is confounded by changes in placement as well as timing, we have used this study to estimate that losses of P can be reduced by 75 percent when manure is applied in fall or spring instead of winter.

Timing manure applications to avoid application onto frozen soils or snow requires sufficient manure storage. All large livestock facilities in Manitoba are currently required to have adequate storage for 400 days of manure production and are forbidden from applying manure on frozen soils or snow. Although some smaller livestock operations are currently allowed to apply manure during winter conditions, all winter application of manure will be prohibited in Manitoba by 2013. However, given the low proportion of manure that is applied during winter months, the net reductions in nutrient loss from abandoning this practice are very small.

B.6 Placement of Nutrients

Incorporation, banding, or injection of fertilizer and manure will reduce the risk of N and P loss to surface water Sharpley et al. (2006). For example, incorporating or injecting manure markedly reduces all fractions of P in runoff relative to surface applications (Daverede et al., 2004; Tarkalson, 2004). These authors found runoff P loads and concentrations from soils where manure was incorporated were not significantly different than runoff from unamended soils (soil without manure).

According to Beaulieu (2004), approximately 55 percent of manure in Manitoba was injected or incorporated within 7 days of application. More recently, the 2006 Census of Agriculture reported that approximately 60 percent of solid manures and 83 percent of liquid manures are injected or incorporated in Manitoba (Statistics Canada, 2007). For the farms where manure is not injected or incorporated, 77 percent of those farms apply the manure onto perennial forage (Statistics Canada, 2007) where incorporation would destroy the forage stand and is not a practical option for placement. Therefore, the opportunity to reduce nutrient losses by increasing the proportion of manure that is injected or incorporated is limited to an estimated 10 percent of the manure that is applied.

Given that nearly all of the P fertilizer in Manitoba is band-applied underneath the soil surface, with the seed, at planting and after snowmelt, there is very little improvement that can be achieved in P fertilizer placement.

B.7 Manure

Given its high mobility, liquid manure in storage is probably of greater risk to water quality than solid manure. For liquid manure, earthen manure storages (EMS) are the most common storage structure used in Manitoba. It is ideal for these storages to have a non-permeable liner to protect them from leaking manure into groundwater. However, compacted soil with extremely low hydraulic conductivity is also allowed for construction of EMS in MB. All storages are inspected by MB Conservation on a regular basis, so although the area within a few metres immediately adjacent to the storage may be impacted (Fonstad, 1996; Fleming, 1999) these storages probably present no significant threat to water quality in Lake Winnipeg.

Providing adequate storage capacity to allow for proper timing of land application is the major benefit of proper manure storage for improving water quality. The benefits of this aspect of proper manure storage have been discussed in sections above (Timing of Nutrient Application). All large livestock facilities in Manitoba are currently required to have adequate storage for 400 days of manure production and are forbidden from applying manure on frozen soils or snow. Although some smaller livestock operations are currently allowed to apply manure during winter conditions, all winter application of manure will be illegal in Manitoba by 2013. On a per gallon basis, the cost of constructing liquid manure storage for these small livestock operations is much more expensive than for large operations (Salvano and Flaten, 2006). Therefore, the economic impact of this regulation on small farms will be substantial. However, only a very small portion, less than 3 percent of Manitoba's livestock manure, is typically applied during winter months (Beaulieu, 2004). As a result, the water quality benefits from increasing manure storage capacity will be very small.

Table B.1 Estimated Effects of Nutrient Management BMPs on P and N Losses to Surface Water Relative to Common Current Practice				
BMP Group and Nutrient Sources Considered	**Description of BMP Scenario vs. Current Practice**	**Ratio for Loss of P Relative to Current Practice (kg P/ha)**	**Ratio for Loss of N Relative to Current Practice (kg N/ha)**	**Comments**
Rate BMPs for nutrient balance and nutrient reduction scenarios				
Scenario 1 - no overall P surplus and no net increase in average soil test P or nutrient loss				
- livestock manure and synthetic fertilizer	Rates of N application are unchanged because the current overall average surplus of manure and fertilizer N is very small, after accounting for unavoidable losses. For reducing Manitoba's modest overall P surplus and to avoid increases in soil test P, manure could be transported and treated wherever necessary to apply manure P at rates no greater than crop removal. Then, after accounting for manure P, reduce average applications of synthetic P fertilizer application by 20% province-wide to apply manure and fertilizer P to meet crop P removal for average yields, not crop requirements for target yields.	1.00	1.00	- Current average soil test P concentrations in MB soils are estimated to be near optimum for agricultural production (15 ppm Olsen P, Salvano and Flaten, 2006) - Given that relationships between runoff P and soil test P in Prairie soils are often linear (Sawka, 2009, Little et al., 2007), high losses from high P soils are generally offset equally by low losses from low P soils. Therefore, overall average values for soil test P determine average runoff losses. - Due to the high costs of transporting or treating manure, this BMP will be costly e.g., $50 million per year if estimates from Salvano et al. (2006) are extrapolated.

Table B.1 Estimated Effects of Nutrient Management BMPs on P and N Losses to Surface Water Relative to Common Current Practice				
BMP Group and Nutrient Sources Considered	**Description of BMP Scenario vs. Current Practice**	**Ratio for Loss of P Relative to Current Practice (kg P/ha)**	**Ratio for Loss of N Relative to Current Practice (kg N/ha)**	**Comments**
Scenario 2 - 10% decrease in overall average runoff P loss due to a 20 % decrease in average soil test P				
- livestock manure and synthetic fertilizer	Reduce overall average soil test P concentrations by 20%, from 15 ppm Olsen P (transition from medium to high) to 12 ppm (midrange medium). For example, for fields with <12 ppm Olsen P, treat or transport manure as necessary to apply manure and fertilizer P at rates no greater than crop removal. For all fields where soil test P concentrations are >12 ppm Olsen P apply P at rates of 1/2 of crop removal	1.00 short term 0.90 long term	1.00	- This scenario requires that average soil test P concentrations in MB soils be lower than optimum for agricultural production, incurring costs to farmers. - Long term reductions are based on linear equations for relating runoff P loss in response to soil test P in Manitoba soils (Sawka 2009) and Alberta soils (Little et al. 2006). - The short term benefit of this scenario will be very modest due to the large amount of P already present in the soils and vegetation within the landscape (legacy P).
Timing BMPs for nutrient management				

Table B.1 Estimated Effects of Nutrient Management BMPs on P and N Losses to Surface Water Relative to Common Current Practice

BMP Group and Nutrient Sources Considered	Description of BMP Scenario vs. Current Practice	Ratio for Loss of P Relative to Current Practice (kg P/ha)	Ratio for Loss of N Relative to Current Practice (kg N/ha)	Comments
- livestock manure (accounts for 15% of P and 5% of N applied onto agricultural land in Manitoba)	- eliminate winter spreading for the remaining 3% of manure that is spread during this period (i.e., could reduce P loss by up to 75% for that 3% of manure)	0.98	0.99	Decent estimates for manure management practices in Manitoba are available from the 2006 and 2001 Censuses. However, the fertilizer estimates are very approximate, because detailed information for MB fertilization practices are not readily available
- synthetic fertilizer (accounts for 85% of P and 95% of N applied onto agricultural land in Manitoba)	- eliminate winter application of fertilizer. However, for agronomic reasons, only a very small proportion of fertilizer P is broadcast and most broadcast N is applied after snowmelt.	0.99	0.95	
Placement BMPs for nutrient management				
- livestock manure and synthetic fertilizer	- eliminate broadcast manure or fertilizer without incorporation in late fall or winter; continue to allow manure to be broadcast on perennial forage or zero till. However, only a small proportion of manure and fertilizer are not subsurface banded or incorporated when applied onto cultivated cropland	0.95	0.95	Same as above.
Overall impact of nutrient management BMPs				
Scenario 1 - rate BMPs for no increase in nutrient loss	assumes all timing and placement BMPs are fully implemented	0.94	0.90	

Table B.1 Estimated Effects of Nutrient Management BMPs on P and N Losses to Surface Water Relative to Common Current Practice

BMP Group and Nutrient Sources Considered	Description of BMP Scenario vs. Current Practice	Ratio for Loss of P Relative to Current Practice (kg P/ha)	Ratio for Loss of N Relative to Current Practice (kg N/ha)	Comments
Scenario 2 - rate BMPs for 10% decrease in nutrient loss - short term	"	0.94	0.93	
Scenario 2 - rate BMPs for 10% decrease in nutrient loss - long term	"	0.84	0.95	

Appendix C. Conservation Tillage

Table C.1 Estimated effects of conservation tillage on P and N losses to surface water relative to "conventional tillage".

						--------- Ratio for Conservation/Conventional Till ---------								
Source	**Location**	**Practices* Assessed**	**Applicability to Conservation Tillage Issue for MB Cropland & Watersheds**	**Years Assessed**	**%TDP/TP****	**TDP Conc'n (mg/L)**	**TDP Export (kg/ha/y)**	**TP Conc'n (mg/L)**	**TP Export (kg/ha/y)**	**TN Conc'n (mg/L)**	**TN Export (kg/ha/y)**	**Other (eg. sediment)**	**Spatial Scale**	**Uncertainties**
Studies directly relevant to quantifying impact of conservation tillage on nutrient export in Lake Winnipeg's watershed														
Tiessen et al., 2010	S. Tobacco Ck., MB, with 5% slope	"zero till" vs. low intensity conventional till on small grains & oilseeds	excellent for sloping MB cropland; relevance for nearly level land or watershed is not fully known	1993-1996 & 2004-2007	75%	1.52 (0.79/0.52)	1.35 (0.066/0.049)	1.41 (0.99/0.70)	**1.12 (0.076/0.068)**	0.59 (3.3/5.6)	0.31 (0.16/0.51)	0.36 sediment (1.9/5.3 kg/ha)	edge of field/small catchment	not watershed scale
Studies indirectly relevant to quantifying impact of conservation tillage on nutrient export in Lake Winnipeg's watershed (e.g., application of principles for snowmelt runoff)														
Elliott et al., 2001	Prince Albert, SK	"zero till" vs. low intensity conventional till	provides possible trends, only … experimental design does not provide robust statistical rigour for attributing differences in wetland water quality to the tillage treatments per se	1994-1998			trend was higher for ZT than CT		trend was higher for ZT than CT		no trends		wetland basin scale	water quality measured within wetlands, not runoff, and no statistically rigorous methods for quantifying
Uusitalo et al., 2007	Southwest Finland, with 2% slope	Period 1: moldboard plow vs no fall tillage	low percentage of loss is DP, so may not be applicable. Also, plots were subsurface drained, but results in this table are for surface drainage, only	1993-1996	10-30%		3.73 (0.112/0.030 for DRP		**1.20 (0.338/0.286)**				plot scale (0.5 ha each)	
		Period 2: moldboard plow vs shallow fall tillage		1996-2001	13-15		3.53 (0.106/0.030 for DRP		**3.00 (0.820/0.206)**					
Puustinen et al., 2005	Southwest Finland, with 8-9% slope	various, including **cultivation vs direct seeding**	probably quite high for the DRP portion; higher rates of erosion in Finland plots depreciate application of TP measures	1990-1994 & 1997-2002	63% on cult. vs18% on direct		2.77 (2.02/0.73)		0.77 (3.2/4.15)			0.35 erosion (620/1760 kg/ha	plot scale (18x36-51m)	
Ulen, 1997	Southern Sweden, 10% slope	**Fall plowed** vs winter wheat vs **grass cover crop, then spring plowed**	low proportion of TP was DP and overall concentrations and exports of P are much smaller than for MB conditions; also tillage treatments are not representative of MB conservation tillage	1993-1996 but mainly 1 year with signif. runoff	25%	1.94 (0.070/0.036 short plots) 2.26 (0.061/0.027 long plots)	2.00 (0.002/0.001 short plots) 1.50 (0.006/0.00	1.26 (0.24/0.19 short plots) 0.83 (0.57/0.69 long plots)	**1.33 (0.008/0.006 short plots) 2.40 (0.004/0.00**	0.88 (3.0/3.4 short plots) 1.23 (4.8/3.9			2 plot scales (1.2x5m &10x22m)	
Hansen et al., 2000a	Lower Minnesota River Basin, near Minneapolis, Minnesota	**ridge till (93% cover)**, fall chisel plow vs. **moldboard plow** on corn	very similar % of TP found as DP, so principles may be similar, but not typical tillage & cropping systems and measured only snowmelt, not rainfall runoff	**snowmelt** 1996 & 1997	75%	na	3.33 (~1.0/0.3)	na	3.25 (~1.3/0.4)	na	na	no signif. difference in sediment; 300% more COD	plot scale (3mx22m), with 8-10% slope	not field or watershed scale
Hansen et al., 2000b	same as above	same as above	similar to above, except huge reduction in losses of PP due to cons. tillage during rainfall runoff season	**rainfall** 1996 & 1997	<10%	na	0.5 (~0.05/0.1)	na	0.11 (~0.2/1.9)	na	na	huge reduction in sediment	same as above	same as above
Hansen et al., 2000a+b,	same as above	same as above	huge reduction in losses of PP due to cons. tillage during rainfall runoff season more than offset the increased losses during snowmelt	**rainfall plus snowmelt**		na	2.63 (~1.05/0.4)	na	**0.61 (~1.4/2.3)**	na	na	overall reduction in sediment	same as above	same as above
Ginting et al., 1998	W. Central Minnesota (Morris)	manure vs no manure, **ridge till vs moldboard plow on corn**	principles are similar, with higher DP and TP losses during snowmelt runoff but tillage and cropping systems are not typical for MB	**snowmelt** 1993-1994			6.50 (0.13/0.02 for DRP)		29.3 (0.88/.03)		na		plot scale (3mx22m), with 12% slope	not field or watershed scale
			huge reduction in losses of PP due to cons. tillage during rainfall runoff season	**rainfall** 1993-1994			similar in most cases		0.16 (0.21/1.35)					
			low proportion of TP was DP, so huge reduction in losses of PP due to cons. tillage during rainfall runoff season more than offset the increased losses during snowmelt	**snowmelt plus rainfall** 1993-1994, but mainly	**<10%**		3.13 (~0.25/0.08 for DRP)		**0.50 (~0.7/1.4)**					
Gaynor, 1995	Harrow, SW Ontario	**zero till (95%)** & ridge till (88% cover) vs **moldboard plow on corn**	trends match Manitoba's, but most differences were not statistically signficant due to large variability; cropping and tillage systems not typical for MB	Jan 1988 - Sept 1990	84%	+2.0 (0.79/0.39, but NS)	3.7 (0.65/0.18 for DRP)		na (but likely similar to DRP losses)		na	numerical, but not signif. reductions in sediment loss	plot scale (12.2 x 82.5m)	not field or watershed scale
Harmel, 2006	40 papers from 15 US states & 2 provinces	**conventional,** conservation and **no till**	mostly data collected from areas of US with little or snowmelt runoff	various	various		5.26 (1.00/0.19, medians for 18 & 71 studies, respectively		**0.60 (0.63/1.05, medians)**		0.17 (1.32/7.88, medians)			

Table C.1 Estimated effects of conservation tillage on P and N losses to surface water relative to "conventional tillage".

						--------- Ratio for Conservation/Conventional Till ---------								
Source	**Location**	**Practices* Assessed**	**Applicability to Conservation Tillage Issue for MB Cropland & Watersheds**	**Years Assessed**	**%TDP/TP****	**TDP Conc'n (mg/L)**	**TDP Export (kg/ha/y)**	**TP Conc'n (mg/L)**	**TP Export (kg/ha/y)**	**TN Conc'n (mg/L)**	**TN Export (kg/ha/y)**	**Other (eg. sediment)**	**Spatial Scale**	**Uncertainties**
Studies with little or no relevance to quantifying impact of conservation tillage on nutrient export in Lake Winnipeg's watershed														
Thoma et al., 2005	Lamberton, Minnesota	fall chisel vs moldboard plow on corn	tillage system and crop not typical for MB										plot scale	
Bundy et al., 2001	Arlington and Madison, Wisconsin	spring chisel, shallow till, no till plus dairy manure on corn	tillage system and crop not typical for MB, simulated rainfall on small plots										plot scale with simulated rainfall	
Burwell et al., 1975	W. Central Minnesota	crop rotation experiment, but not tillage	no tillage comparison											
Panuska et al., 2008	Arlington, Wisconsin	corn grain, corn silage, manured corn silage, but not tillage	no tillage comparison											
Sharpley and Smith, 1994	Kansas, Texas, Oklahoma	conventional till vs no till wheat	Minimal … southern US, dominated by erosion and PP loss				much higher		much lower					
Ontkean et al., 2005	Crowfoot Creek, S. Alberta	snowmelt vs growing season P flux, no tillage comparison	no tillage comparison	1997-1999	31-97%; highest with grassland									
McConkey et al., 1997	Swift Current, SK	seasonal variation in estimated erosion, all conventional tillage	no tillage comparison											
Daverede et al., 2003	Monmouth, Illinois	chisel plow vs no till on soybean with simulated rainfall	not suitable for snowmelt dominated runoff in MB										plot scale, rainfall simulation	
Zhao et al., 2001	Lamberton, Minnesota	ridge till vs moldboard plow for corn, simulated rainfall	not suitable for snowmelt dominated runoff in MB										plot scale, rainfall simulation	
Puustinen et al., 2007	Southwest Finland	tillage systems data are same as for Puustinen et al., 2005 … new info is for effect of precipitation pattern	no new information beyond Puustinen et al. 2005 for tillage comparisons	1990-1994 & 1997-2002										
Baker and Laflen, 1983	Iowa		not suitable for snowmelt dominated runoff in MB											
Langdale et al., 1985	Georgia		not suitable for snowmelt dominated runoff in MB											
Kimmel et al., 2001	Kansas		not suitable for snowmelt dominated runoff in MB											
Ranaivoson et al., 2005	Minnesota		did not measure N or P losses											

*Where more than 2 practices are listed, the practices used calculating the impact of conservation tillage are boldfaced

**Abbreviations

DRP = Molybdate reactive P (or "ortho-P")

TDP = Total Dissolved P (molybdate reactive P (DRP) plus non-reactive P)

TP = Total P (dissolved plus particulate)

TN = Total N (dissolved plus particulate)