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Costs and Benefits of Instruments to Reduce Nutrients in the Lake Winnipeg Basin: Using an ecological goods and services approach - Synthesis Report

Final Report

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Environment Canada

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Executive Summary

This work focuses on strategies for reducing eutrophication of Lake Winnipeg caused by excess nutrients discharging to the lake as a result of various human activities. Eutrophication poses a serious threat to water quality and imposes economic costs on residents of the basin. Eutrophication is 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. In order to choose the most effective and efficient nutrient reduction program package, decision-makers need to understand the costs imposed by poor water quality and its corollary, the benefits of reversing the problem.

The very large ratio of Lake Winnipeg's land drainage area to surface water area, coupled with its relatively shallow depths, make the lake particularly vulnerable to contaminant loadings from land activities and uses. Given the location and size of Lake Winnipeg's drainage area, the majority of agricultural lands on the Canadian Prairies drain to the lake. Both the Saskatchewan and Red Rivers are tributaries to Lake Winnipeg and flow through both agricultural and urban land development areas in western Canada and the U.S. A third tributary, the Winnipeg River, drains to the lake from the east through smaller lakes, forests and municipalities on the Pre-Cambrian Shield. This report summarizes work to date to assess the ecological goods and services associated with reducing phosphorus loads from two sources in Manitoba: municipal wastewater effluents from medium and small communities; and, agricultural sources in Manitoba.

This report provides synopses of the two key studies regarding reduction of phosphorus loading to Lake Winnipeg from agricultural practices and wastewater from small and medium sized communities. The objective of the first study, *Agricultural Beneficial Management Practices for Lake Winnipeg – Cost-benefit analysis using an ecological goods and services approach* (Thomsen, Kulshreshtha, Lobb, Flaten, and MacDonald (2010)), 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 (EG&S). The project focused on the non-market benefits to nutrient reduction, but also included the market benefits. Benefits were compared against the costs of each beneficial management practice. The scope of all calculations and assumptions pertain to agricultural practices in Manitoba. The analysis included estimation of the following aspects of implementing the BMPs: goods production, carbon sequestration benefits, energy use and greenhouse gas emissions, soil erosion changes resulting from use of the BMPs examined, soil nitrogen changes, water regulation services, changes in pollination services, cultural and aesthetic services, other natural support services (such as refugium and nursery habitat).

The second study, which was built from a study conducted by ICF Marbek in 2008 for Manitoba Water Stewardship, evaluated nutrient reduction strategies for wastewater treatment facilities suitable for small communities in Manitoba. These strategies specifically focused on phosphorus removal options. Subsequently, Environment Canada commissioned an analysis that applied Environment Canada's analytical framework for decisions involving EG&S to the costs and benefits for five different wastewater treatment strategies (Biological Nutrient Removal (BNR) and Sequencing Batch Reactors (SBR), Free Water Surface Wetlands, Land Application and Chemical Precipitation). These options were assessed for three community sizes: 500, 2,000 and 10,000 people.

In order to synthesize and compare the nutrient reduction strategies from the case studies examined, we converted the results to a common metric of annualized net cost per tonne of phosphorus reduced. This common metric facilitates a comparison across nutrient reduction strategies of their cost-effectiveness for achieving a given level of reductions in phosphorus loadings into Lake Winnipeg. The net cost per tonne of phosphorus reduced is calculated by first estimating the total cost of each nutrient reduction strategy for the given analysis period. We next subtract from this total cost the value of the environmental co-benefits (i.e., increases in EG&S) associated with each nutrient reduction strategy, except those relating to reduced phosphorus loadings. To estimate the value of the environmental co-benefits of the nutrient reduction strategies, the case studies identified the affected EG&S and which ones could be quantified. Next, because the case studies conducted cost-benefit analyses of the nutrient reduction strategies across different numbers of years, we convert all total costs to annualized values, using a 3 percent discount rate. Lastly, we divide the annualized net cost for each nutrient reduction strategy by the annual tonnes of phosphorus it will remove to obtain the annualized net cost per tonne of phosphorus removed.

The BNR/SBR plant strategy has by far the highest annualized net cost per tonne of phosphorus removed, followed by the pivot system strategy for land application. Because the vegetated filter strips and crop selection strategies have a net benefit (i.e., have improvements in EG&S that are greater than their costs), their resulting annualized net cost per tonne of phosphorus removed is negative. Lastly, we conducted various sensitivity analyses to demonstrate how results would change under different assumptions on the amount of phosphorus removed by the agricultural BMP strategies, and under different assumptions of the values of pollination services, nitrogen, and carbon. We also examined the impact of the choice of discount rate on the results. The sensitivity analyses showed that the results were fairly robust, with the rank ordering of the cost-effectiveness of the strategies remaining largely unchanged. For the wetland-low cost strategy, the annualized net cost per tonne of phosphorus removed became negative (i.e., the benefits exceeded the costs) under the high-cost assumptions for the values of nitrogen and carbon.

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1 Introduction

Ecosystems provide a variety of important provisioning, regulating, supporting and cultural functions that benefit humans both directly and indirectly and provide the means for life itself on this planet. Ecosystems therefore contribute to the well-being of Canadians in numerous ways. *The Economics of Ecosystems and Biodiversity* (TEEB) report stresses that we cannot afford to disregard the value that ecological goods and services (EG&S) have for both our economies and for human well-being. However, these benefits are often excluded from decision making and policy analysis because of a lack of data and incomplete information on their contributions to society. These limitations have led to decisions being made which could potentially put at risk our valuable natural capital.

Estimation of the value of EG&S derived from ecosystems is a subject of increasing study, including work by Environment Canada. This report provides a synthesis of the project by the Regulatory Analysis and Valuation Division (RAVD) of Environment Canada, "*Costs and Benefits of Instruments to Reduce Nutrients Using an Ecological Goods and Services (EG&S) Approach*".

This work focuses on the eutrophication of Lake Winnipeg caused by excess nutrients discharging to the lake as a result of various human activities. Eutrophication poses a serious threat to water quality and imposes economic costs on residents of the basin. Eutrophication is 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. In order to choose the most effective and efficient nutrient reduction program package, decision-makers need to understand the costs imposed by poor water quality and its corollary, the benefits of reversing the problem.

The scope of this report is select options to reduce phosphorus nutrient loading to Lake Winnipeg from Manitoba sources. The synthesis of the project is presented in this report in 5 sections other than this introduction section:

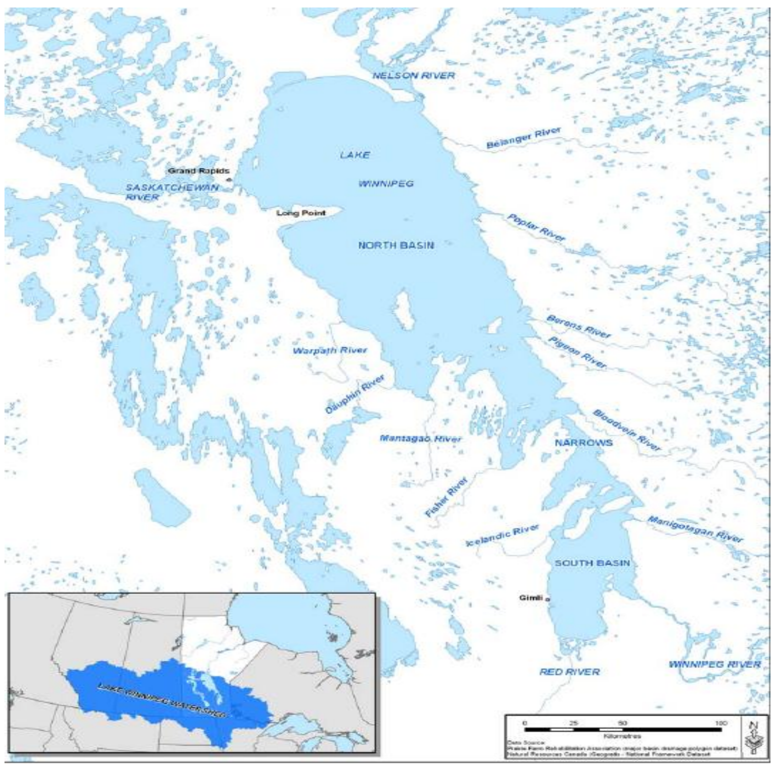
- Section 2 provides background on Lake Winnipeg and one of Environment Canada's research projects into EG&S for nutrient stress reduction for the lake
- Section 3 provides a brief overview of EG&S terminology and Environment Canada's framework for analysis of EG&S
- Section 4 provides a synopsis of the background reports for this Summary
- Section 5 provides the results of an analysis of the costs and benefits using a commensurate metric for reporting results from the background studies
- Section 6 provides conclusions and recommendations for additional study.

2 Background

2.1 Lake Winnipeg and Nutrients

Lake Winnipeg is the world's 10th largest freshwater lake in terms of surface area, covering about 24,500 square kilometres (Lake Winnipeg Stewardship Board (LWSB, 2006)), and is the second largest watershed in Canada next only to the MacKenzie River Basin (Thomsen, 2010). At an estimated 953,000 km^2, it has the largest land to drainage surface ratio of all the great lakes in the world, (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. Exhibit 1 following provides a map of the Winnipeg Basin.

Exhibit 1 Map of Lake Winnipeg Basin



Source: North/South Consultants Inc., 2006

In 2001, 5.5 million Canadians and 1.1 million Americans lived within the Lake Winnipeg watershed, about 80% of whom lived in major urban centres (LWSB, 2006). The watershed is also home to 17 million livestock, and comprises 55 million hectares of agricultural land (LWIC, 2005/2006).

Commercial fishing is an important economic activity within the watershed and the Lake Winnipeg commercial freshwater fishery is the largest in Canada west of the Great Lakes (LWSB, 2006). Fish harvested from the lake include walleye, whitefish, sauger, and goldeye. Jobs created by the commercial fishing industry include the fishers, as well as packing, shipping and processing jobs. Recreational, bait and sports fishing also make important economic contributions in the watershed. Subsistence fishing is undertaken in fisheries-based communities and as a traditional cultural activity by First Nations peoples (LWSB, 2006). Cottages, recreation and tourism, and eco-tourism contribute to local economies within the watershed. These activities are supplemented and augmented by special events that attract tourists and participants (e.g., championships and festivals), specialized resorts and provincial parks and facilities within the watershed.

The very large ratio of Lake Winnipeg's land drainage area to surface water area, coupled with its relatively shallow depths, make the lake particularly vulnerable to contaminant loadings from land activities and uses. Given the location and size of Lake Winnipeg's drainage area, the majority of agricultural lands on the Canadian Prairies drain to the lake. Both the Saskatchewan and Red Rivers are tributaries to Lake Winnipeg and flow through both agricultural and urban land development areas in western Canada and the U.S. A third tributary, the Winnipeg River, drains to the lake from the east through smaller lakes, forests and municipalities on the Pre-Cambrian Shield. Exhibit 2 provides estimations of annual phosphorus loadings from Manitoba sources (natural and anthropogenic) and Exhibit 3 identifies estimations of annual phosphorus loadings from jurisdictions outside of Manitoba (natural and anthropogenic).

Exhibit 2 Distribution of Annual Phosphorus Loading to Lake Winnipeg, 1994-2001, by Manitoba Sources

Manitoba Sources	Source and Load			
	Jurisdiction	Average Total P Loading* in tonnes/year	Percent of Lake Total	Percent of 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** 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 (including upstream sources from other jurisdictions)		**7,900**	**100**	

*Numbers are rounded to the nearest 100 tonnes.
** These estimates may include contributions from sources such as forests, wildlife, and septic fields.
Source: LWSB, 2006

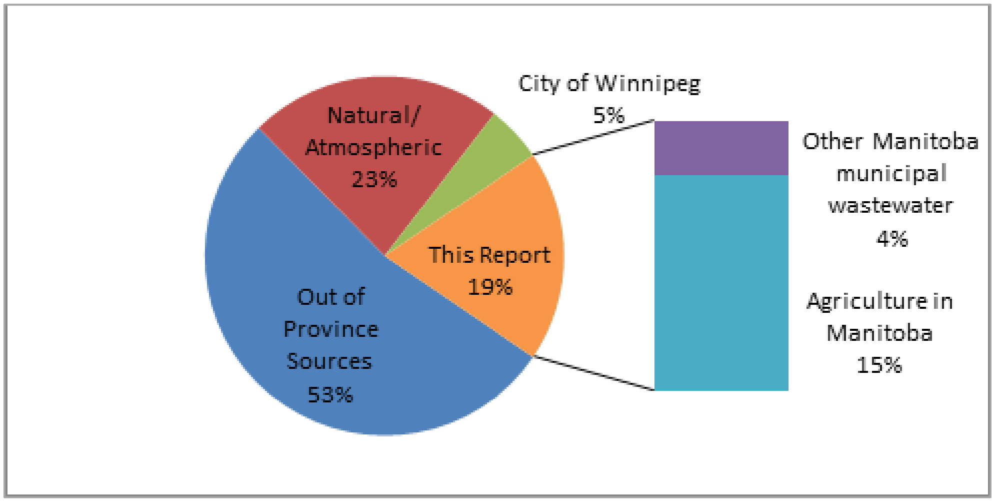
Exhibit 3 Annual Phosphorus Loading to Lake Winnipeg, 1994-2001, from Other Jurisdictions

Water Body	Jurisdiction	Average Total P Loading* in tonnes/year	Percent of Lake Total
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**

*Numbers are rounded to the nearest 100 tonnes.
Source: LWSB, 2006

Much of the nutrient load is contributed by economic activity in the watershed, although a portion is also created through natural processes. Agricultural activities (within and outside of Manitoba) and natural and undefined sources make up almost two-thirds of the total phosphorus load in the Lake on an annual basis. Since the 1970s, phosphorus concentrations in most of the rivers within Lake Winnipeg's watershed have been increasing, resulting in increasingly high loading of phosphorus into the lake (Jones and Armstrong, 2001). Exhibit 4 summarizes the proportions of phosphorus loading to Lake Winnipeg.

Exhibit 4 Summary of Annual Phosphorus Loading to Lake Winnipeg, 1994-2001



Data Source: LWSB. 2006.

This report summarizes work to date to assess the EG&S associated with reducing phosphorus loads from two sources in Manitoba: municipal wastewater effluents from medium and small communities; and, agricultural sources in Manitoba. From Exhibit 4, it can be seen that the total phosphorus loading addressed within the scope of this report is less than 19% of the total annual loading.[1]

Concern over the likelihood of nutrients, contaminant and sediment loadings to the lake exceeding the lake's natural capacity to assimilate them prompted the Lake Winnipeg Action Plan development and formation of the Lake Winnipeg Stewardship Board (LWSB) in 2003. 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 phosphorus (P) is the leading cause of the problem of eutrophication.

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 EG&S, a decrease in water quality may have significant impact on the human welfare of Lake Winnipeg stakeholders.

[1] Some larger municipalities' wastewater effluent loads, in addition to those of the City of Winnipeg, are excluded from the scope of the Municipal Wastewater Treatment Options analysis, making the total scope of other municipal wastewater effluents addressed somewhat less than 4%.

2.2 Environment Canada's Research

The objective of the Environment Canada project "*Costs and Benefits of Instruments to Reduce Nutrients Using an Ecological Goods and Services (EG&S) Approach*" is to assess the effectiveness of policy options to manage or reduce nutrient loads in Lake Winnipeg and to consider their effects on other EG&S. The outcomes of the project inform decision-makers about the costs and benefits of policy options with practical recommendations regarding instrument choice. The project also enhances the department's expertise in EG&S and supports identified objectives for the improved health of the Lake Winnipeg Basin.

As part of the project, several studies were commissioned and/or undertaken by EC, including:

- *Status of Current Work – Measurement and Valuation of Ecological Goods and Services in Canada* by Sara Wilson (2009)
- *Analytical Framework for Decisions Involving Ecological Goods and Services* by Regulatory Analysis and Valuation Division – EC (2009)
- *Agricultural Beneficial Management Practices for Lake Winnipeg – Cost-benefit analysis using an ecological goods and services approach* by Thomsen, Kulshreshtha, Lobb, Flaten, and MacDonald (2010)
- *Nutrient Reduction Strategies for Wastewater Treatment Facilities for Lake Winnipeg: Cost-Benefit Analysis using an Ecological Goods and Services Approach* by ICF Marbek, Lantz, and Delcan (2011)

This paper summarizes and synthesizes the results of these studies.

2.3 Literature Review Synopsis

A comprehensive literature review was commissioned by Environment Canada to review current work that has identified, quantified and valued EG&S in Canada. The study focused on EG&S studies carried out in Canada and reported on the types of EG&S studied, the frameworks and methods used to value EG&S, as well as any outcomes or values reported. The review also examined various models used to map and value EG&S and the underlying data used. The review found that interest in defining and valuing EG&S in Canada is growing. Some of the key findings of relevance to the current project are highlighted below.

- Watershed and wetland studies have been conducted in watersheds such as Broughton's Creek in southwestern Manitoba, the Credit Valley in southern Ontario, Lake Winnipeg and Lake Simcoe. In the studies reviewed, carbon storage services and water-related services such as water regulation by wetlands and water filtration services provided by forests had the highest assessed value.

- Water regulation and supply services provided by wetlands and forests feature prominently in many of the studies that evaluated non-market EG&S. In the Pimachiowin Aki (P.A.) study, water related values were based on contingent valuation transferred from an earlier study where the average willingness to pay for improved water conservation and protection by Manitobans was approximately $420 per household per year. Water supply services were estimated based on the water supply volumetric value from a study of the Assiniboine Aquifer water supply. Applied to the main rivers volume of flow in the P.A. study the potential economic value was estimated between $0.27 to $5.55 billion. Water regulation values reported in the studies reviewed ranged from $408/ha/year to $8, 209/ha/year.

- In the study *Water Quantity and Quality Benefits from Wetland Conservation and Restoration in the Broughton's Creek Watershed* (Yang, W., Wang, X., Gabor, S., Boychuk, L, and Badiou, P. 2008.), the SWAT-based modeling system was applied to examine the effects of wetland conservation and restoration in the Broughton's Creek watershed. The researchers report that restoring wetlands in the watersheds drained by the major tributaries of the Red River of the North is likely to alleviate the eutrophication of Lake Winnipeg.

- In the study *An Ecosystem Services Assessment of the Lake Winnipeg Watershed. Phase 1 Report – Southern Manitoba Analysis* (Voora, V., and Venema, H.D. 2008), the authors examine the Lake Winnipeg watershed's potential to deliver billions of dollars more a year in ecosystem services through the restoration of the natural environment. The ecosystem services investigated included water quantity and quality, climate change, biodiversity, material benefits, social well-being and environmental integrity services. Despite the limitations of economically valuing ecosystem services, the report concludes that it is important to draw attention to the valuable services provided by natural environments.

- In the study *Pimachiowin Aki World Heritage Project Area Ecosystem Services Valuation Assessment (*Voora, V. and Barg, S. 2008), the authors estimated that ecosystem goods and services have an annual economic value of Cdn$121 to $131 million in the study area. The services with the greatest value are fishing (at $35 million/year), pure water ($32 million/year) and carbon sequestration (between $12 and $21 million/year).

It was found that many of the reports identify data limitations for measurement and valuation of EG&S, mostly due to a lack of ecological and economic information, such as data on the current state of ecosystems and the services they provide and a lack of information on how these services may change under different conditions, such as changing land use.

The frameworks and methods used by the various studies were valuable for informing the development of the Analytical Framework for Decision Involving Ecological Goods and Services.

3 Ecological Goods and Services

3.1 Concepts

3.1.1 Ecological Goods and Services

EG&S are the positive environmental benefits that result from the physical, chemical and biological functions of healthy ecosystems, such as clean water, air and biodiversity. EG&S benefits include:

- **Market goods produced from ecosystems**, such as food, fresh water, fibre, fuel, etc.;
- **Ecosystem processes that result in goods and services**, such as climate regulation, water purification, waste treatment, pollination, nutrient cycling, etc.; and
- **Non-material benefits**, such as aesthetic value, recreation, etc.

These EG&S are provided by natural capital (the natural environment and ecosystem resources) such as forests, grasslands, wetlands, lakes, rivers and croplands. The concept of natural capital is similar to that of economic capital in that it provides continued flow of EG&S.

3.1.2 Total Economic Value (TEV) Framework

Environmental economists generally refer to Total Economic Value (TEV) as the sum of all ecosystem service values provided by a given ecosystem (Pascual and Muradian, 2010). Conceptually, the TEV of a resource consists of its direct-use, indirect-use, option-use, and non-use value, as further detailed below. Value here refers to economic surplus, which consists of consumer surplus and producer surplus. Under the TEV framework, economic surplus is approximated through the use of valuation techniques that monetize a set of human preferences towards the given ecosystem (Wattage and Mardle, 2008).[2]

Examples of these values are illustrated in Exhibit 5. Direct-use values reflect the direct use of the environment for fishing, space for recreation, and water use by residential, agricultural and industrial/commercial sectors (Pascual and Muradian, 2010). Indirect-use values include the ecosystem functions and services that the environment supports and that benefit society, including waste assimilation and flood control. Option value refers to the option of directly or indirectly using specific goods and services provided by the natural environment in the future, even if they are not being used today. Finally, non-use values consist of existence and bequest values. Existence value recognizes that some Canadians may benefit from the improvement in environmental conditions even if they will not use them (instead they benefit from the knowledge that the environment is being enhanced). Bequest value recognizes that some Canadians may benefit from knowing that the environment is being enhanced specifically for future generations.

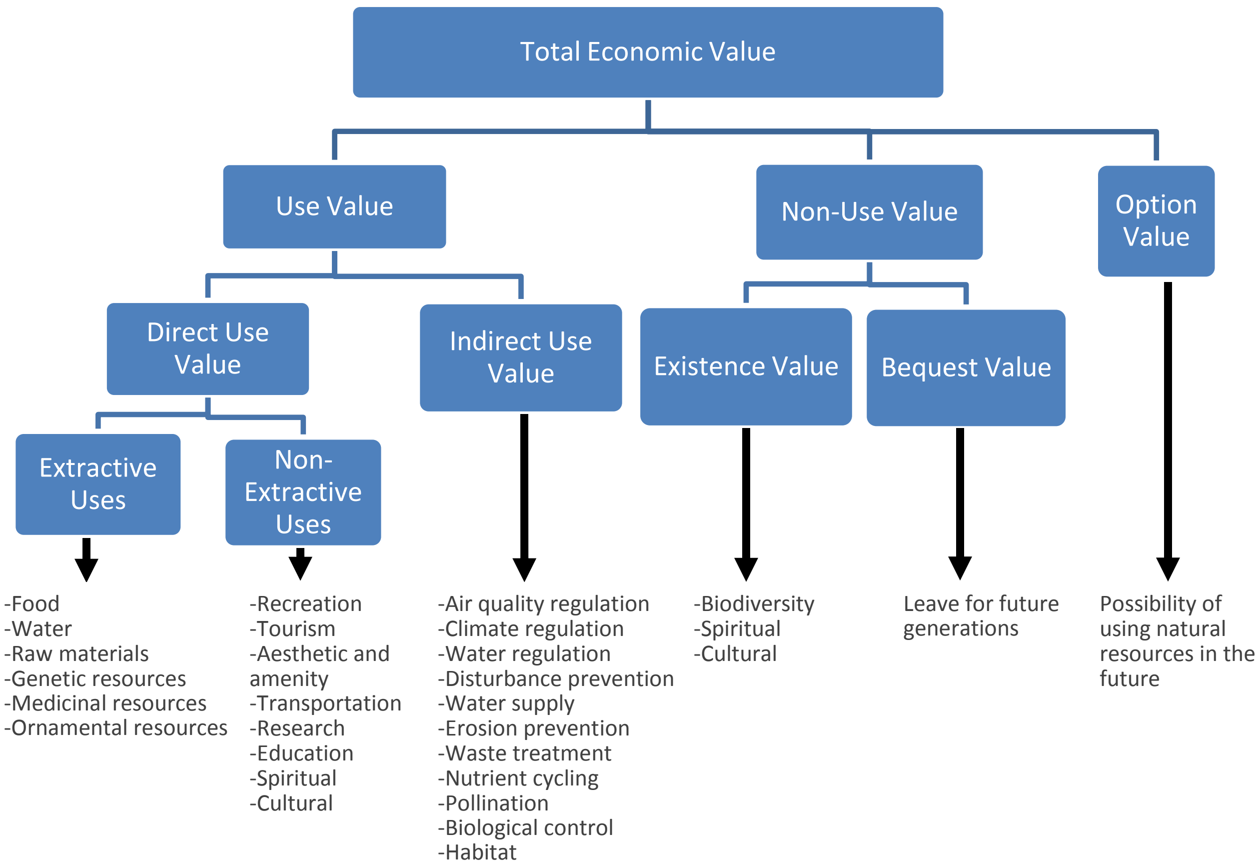
In addition, ecosystem services can be characterized in terms of quality and quantity. For example, drinking water (in the extractive use water category) can be valued for the quality of drinking water (i.e. willingness-to-pay (WTP) for reduction in chemical contaminants) and the quantity of drinking water available.

[2] There exist multiple theories of value and therefore, not surprisingly, there are many different approaches to valuation. The two main valuation paradigms are the economic method selected in this report and biophysical methods (Pascual and Muradian, 2010). Biophysical methods measure the physical cost of producing goods and services and use a "cost of production" perspective for valuation (Pascual and Muradian, 2010). The economic valuation method was chosen over alternative approaches because it allows for a robust measurement and comparison of values and presents these values in terms that people are familiar with.

Using the concepts of TEV, the value of environmental improvements can be presented using a common approach (i.e., economic valuation) and metric (e.g., dollars).

Many ecosystem services have often been ignored in private valuations and even in the evaluation of public projects. Historically, the focus of governments has been on the far left branch of Exhibit 5, namely on consumptive, direct use values for which market values are often readily available. Exhibit 5 presents the TEV framework in a single graphic.

Exhibit 5 Total Economic Value of the Environment



3.2 Ecological Goods and Services Analytical Framework

The *Analytical Framework for Decisions Involving Ecological Goods and Services* was developed by Environment Canada. The Framework provides a step-by-step approach for incorporating the value of EG&S into decision-making processes where policies that will affect ecosystems are proposed. The Framework is based on the TEV approach, where the value of each good or service is the sum of its cumulative values from a range of activities, from subsistence hunting to bird-watching.

Using a TEV approach to explicitly include EG&S values informs the federal government's regulatory approach, which requires a cost benefit analysis (CBA), including to the extent possible EG&S values, be done before consideration and approval of a policy, regulation or program. This approach is consistent with the Cabinet Directive on Streamlining Regulation and Treasury Board Secretariat's Guidelines for Benefit-Cost Analysis.

The Analytical Framework has six steps, as shown below in Exhibit 6.

Exhibit 6 Analytical Framework Steps

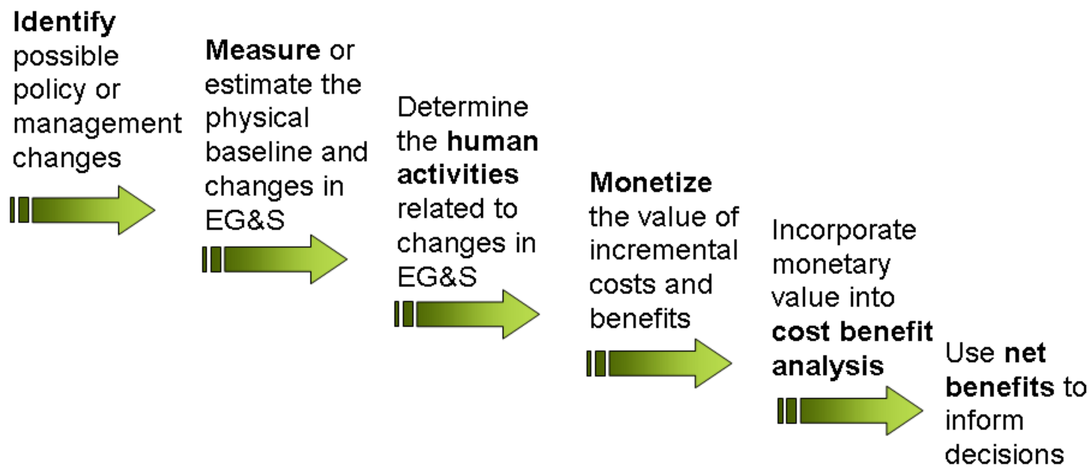


Figure Source: Environment Canada, 2011. Analytical Framework for Decisions Involving Ecological Goods and Services. Draft Document.

3.3 Discount Rates

The stream of costs and EG&S values of a policy or investment are usually spread over several years. Discounting is used to aggregate future on-going operation costs and EG&S values into a common metric – the present value. The social discount rate (SDR) is the rate that society discounts future costs and EG&S values and converts them into present values.

The choice of a SDR is an important and controversial decision in the valuation literature. It is important because the overall level of support for many projects is critically dependent on the value of this rate. It is controversial because there is no consensus amongst economists on either the principals on which the discount rate is based, or the exact rate itself. The two main approaches for calculating the discount rate are the social opportunity cost of capital and the social time preference.[3] The social opportunity cost rate of capital is usually identified as the real rate of return earned on a marginal project in the private sector. The social time preference rate is the rate at which society is willing to trade off present and future consumption. This rate takes into account factors other than the economic opportunity cost of funds and is often used for circumstances where environmental goods and services are substantial.

For the purpose of this summary, results are presented using a SDR of 3% as the central rate, with examination of the sensitivity of the analysis to changes in SDR in undiscounted terms and at a SDR of 7%. These SDRs and the sensitivity analysis approach is in keeping with Federal Treasury Board Secretariat guidance on this issue.

[3] In addition to the rate itself, there are also cases made for using a declining SDR for evaluating intergenerational projects (Gollier et al., 2008).

4 Case Study Synopses

This section provides synopses of the two key studies regarding reduction of phosphorus loading to Lake Winnipeg from agricultural practices and wastewater from small and medium sized communities.

4.1 Agricultural Beneficial Management Practices

The objective of the study *Agricultural Beneficial Management Practices for Lake Winnipeg – Cost-benefit analysis using an ecological goods and services approach* (Thomsen, Kulshreshtha, Lobb, Flaten, and MacDonald (2010)) 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 EG&S. The project focused on the non-market benefits to nutrient reduction, but also included the market benefits. Benefits were compared against the costs of each BMP. The scope of all calculations and assumptions pertain to agricultural practices in Manitoba.

The study used a special compilation of the Census of Agriculture to develop estimates of the quantity of nutrients from agriculture in Manitoba to Lake Winnipeg. Cropland within the study area represents about 23% of Manitoba's cropland. Full adoption of BMPs is assumed to take 30 years or more. An avoided cost approach was adopted to estimate nutrient reduction impacts and values. The cost of wastewater treatment by the City of Winnipeg was used as a replacement cost proxy for the value of nitrogen and phosphorus reduced by the BMPs.

The BMPs analyzed include:

1. Nutrient management
2. Crop selection
3. Conservation tillage
4. Vegetated filter strips
5. Surface water control structures.

Each of these BMPs required assumptions regarding the scenarios for implementation of each measure as follows:

- The nutrient management scenario was based on a simulation of the costs of manure management practices for the Manitoba pig producing sector to meet a phosphorus threshold not exceeding the one time crop phosphorus removal rate, which was estimated by Mann and Grant (2009). In addition the cost-benefit calculation included an assumed 10% yield loss on 50% of the croplands due to yield losses arising from reduced applied nutrients, using the average net income from wheat and canola production in Manitoba from 2000-2009.
- Crop selection was assumed to have a maximum potential adoption equivalent to five per cent of the crop land of the study area.
- A conservation tillage implementation scenario was not developed as this practice leads to an increase in phosphorus release to watersheds.
- Vegetated filter strips were assumed to apply to all croplands in the study area. The installation of 10 foot wide vegetated filter strips around every quarter section (160 acres) would be equivalent to 1.5% of all crop land in the area. Note that this estimate likely over-estimates the area due to practical limitations on-the-ground of implementing filter strips on every applicable field.

- Surface water control structures were assumed to apply to 3% of the study area due to Manitoba's topography. At an installation rate of 1 dam per section (640 acres) of the 3%, a total of 128 dams would be built in this scenario.

The analysis included estimation of the following aspects of implementing the BMPs: goods production, carbon sequestration benefits, energy use and greenhouse gas emissions, soil erosion changes resulting from use of the BMPs examined, soil nitrogen changes, water regulation services, changes in pollination services, cultural and aesthetic services, and other natural support services (such as refugium and nursery habitat).

Exhibit 7 following summarizes the estimated phosphorus reduction by the BMP scenarios in tonnes per year at full adoption of the techniques. Conservation tillage is estimated to increase phosphorus loading and was therefore excluded from further study in the report. Nutrient management has, by far, the greatest potential to reduce phosphorus loading from agricultural practices of all techniques assessed.

Exhibit 7 Estimates of Phosphorus Reduction Potential by BMP Scenario (tonnes/yr)

BMP Scenario	Change in Phosphorus Load, tonnes P/yr		
	Central Estimate	Lower	Upper
Nutrient Management	-96.9	-10.7	-254.6
Crop Selection	-3.9	-0.4	-11.4
Surface Water Control Structures	-2.4	-0.3	-6.5
Vegetated Filter Strips	-1	-0.1	-3
Sum of above	**-104.2**	**-11.5**	**-275.5**
Conservation Tillage (increases P load)	18.3	53.6	2.1

Source: Thomsen, Kulshreshtha, Lobb, Flaten, and MacDonald (2010)

Exhibit 8 following summarizes the distribution of EG&S benefits by type of benefit.

As noted in the Thomsen et al. report (p. 47), the Surface Water Control Structures technique has little scientific evidence in support of benefits assessment. The Thomsen et al. report assumes improved habitat would be realized from this technique and assigns a positive EG&S result associated with this technique. However, it should be noted that surface water control structures are associated with aquatic biodiversity decline due to disconnection of aquatic ecosystem pathways, hydrological regime disruption, sediment and pollutant accumulation behind structures and sediment transport regime changes in watercourses. It is unlikely surface water control structures would have a net positive EG&S result. It is due to the negative ecological consequences of dams that institutions around the world (for example the US Army Corps of Engineers) are removing dams whenever possible. This Summary Report takes the analysis of this technique as presented by Thomsen et al. but caution is required in accepting the relative portion of EG&S allocated from this technique (i.e., wildlife habitat improvements valued at $1.43M Net Present Value (2010)).

Exhibit 8 Distribution of EG&S Benefits by Type, Central Estimate NPV (30 yrs, 3% discount rate, 2010$)

Ecological Good/ Service	NPV $million	% Distribution
Lower Phosphorus Exports	189.37	66.4
Wild Pollination of Crops	82.51	28.9
Increased Soil Nitrogen	4.77	1.7
Improved Wildlife Habitat	4.5	1.6
Reduced GHG emissions from reduced fertilizer use	1.46	0.5
Reduced GHG emissions from reduced energy use	1.2	0.4
Protected water regulation services	0.55	0.2
Carbon Sequestration Services	0.52	0.2
Natural erosion control (e.g. from vegetation)	0.32	0.1
Total	**285.19**	**100**

Source: Thomsen, Kulshreshtha, Lobb, Flaten, and MacDonald (2010)

The Thomsen et al. analysis includes sensitivity analysis of the quantity of phosphorus reduction, the value of phosphorus reductions, private and social costs of carbon, and, as illustrated in Exhibit 9, discount rate. The uncertainty and potential variation of the amount of phosphorus removed by each BMP is the greatest determinant of the BMP viability and is much larger than the variation in costs and benefits.

Exhibit 9 Sensitivity Analysis. Discount Rate, 2010$

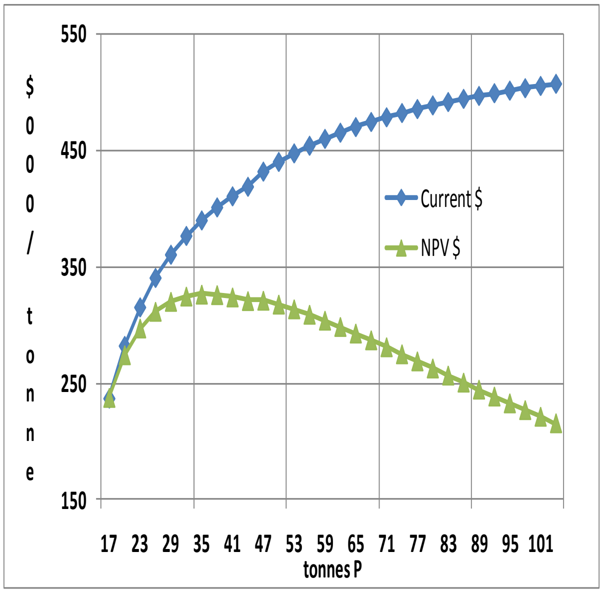
BMP Scenario	NPV $ / tonne P / year[4]		Cost Benefit Ratio	
Discount Rate (over 30 years)	3%	7%	3%	7%
Vegetated Filter Strips	-306,798	-157,011	0.8 : 1	0.8 : 1
Surface Water Control Structures	765,125	410,601	6.3 : 1	8.4 : 1
Crop Selection	-307,015	-151,893	0.8 : 1	0.8 : 1
Nutrient Management	244,361	148,689	3.1 : 1	4.7 : 1

Source: Thomsen, Kulshreshtha, Lobb, Flaten, and MacDonald (2010)

Exhibit 10 and Exhibit 11 present possible supply curves for P reduction. The horizontal axis measures the tonnes of phosphorus reduction to Lake Winnipeg that would occur with full BMP implementation by the Manitoba farming industry over a 30 year period. The vertical axis is the unit net cost (costs minus benefits) in $/tonne of reducing agriculture phosphorus exports resulting in a net unit cost in current dollars in net present value (assuming a three percent discount rate). The Linear Adoption curve assumes the BMPs will be adopted in equal annual increments. The Gradual BMP Adoption curve assumes a more gradual adoption pattern that accelerates over time and is more typical of BMP technique implementation.

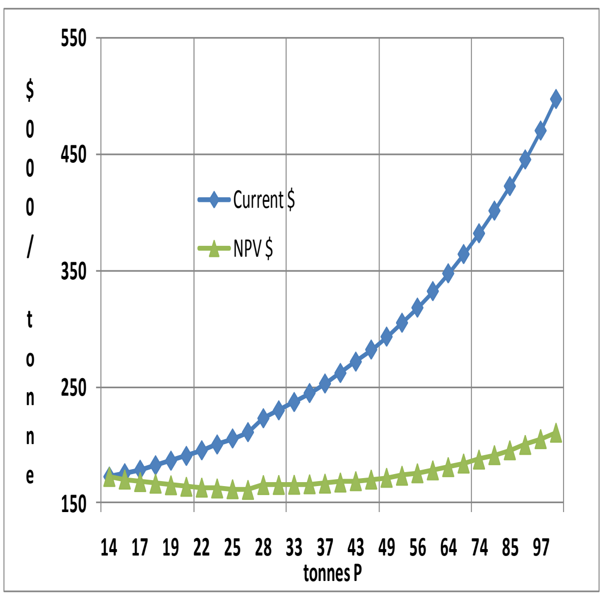
[4] Positive NPV indicates an overall cost, whereas a negative value indicates that the estimated present value of benefits exceeds the costs.

Exhibit 10 Potential Phosphorus Reduction Supply Curve – Linear BMP Adoption (2010 dollars)



Source: Thomsen, Kulshreshtha, Lobb, Flaten, and MacDonald (2010)

Exhibit 11 Potential Phosphorus Reduction Supply Curve – Gradual BMP Adoption (2010 dollars)



Source: Thomsen, Kulshreshtha, Lobb, Flaten, and MacDonald (2010)

As indicated by comparing the two figures, both the scenarios (linear and gradual adoption) ultimately result in the same cost and tonnes phosphorus removed at the end of the study period. However, the gradual implementation of BMPs results in accelerating unit costs whereas the unit costs of linear implementation stabilize (and at decline at a NPV discounted at 3%). Realistically, gradual adoption is the most likely scenario for social reasons, such as farmer familiarity with the techniques and changes in normative farming practices over time. Policies to accelerate implementation will result in higher costs per tonne during the initial adoption period than would otherwise be experienced.

Although for summary purposes, all BMPs are presented in the supply curves, BMPs are not necessarily additive in their benefits. A key uncertainty noted in the report is regarding the performance of each of the BMPs to remove phosphorus. In addition, the net present value of EG&S such as pollination and wildlife habitat are inherently highly uncertain.

4.2 Municipal Wastewater Treatment Options

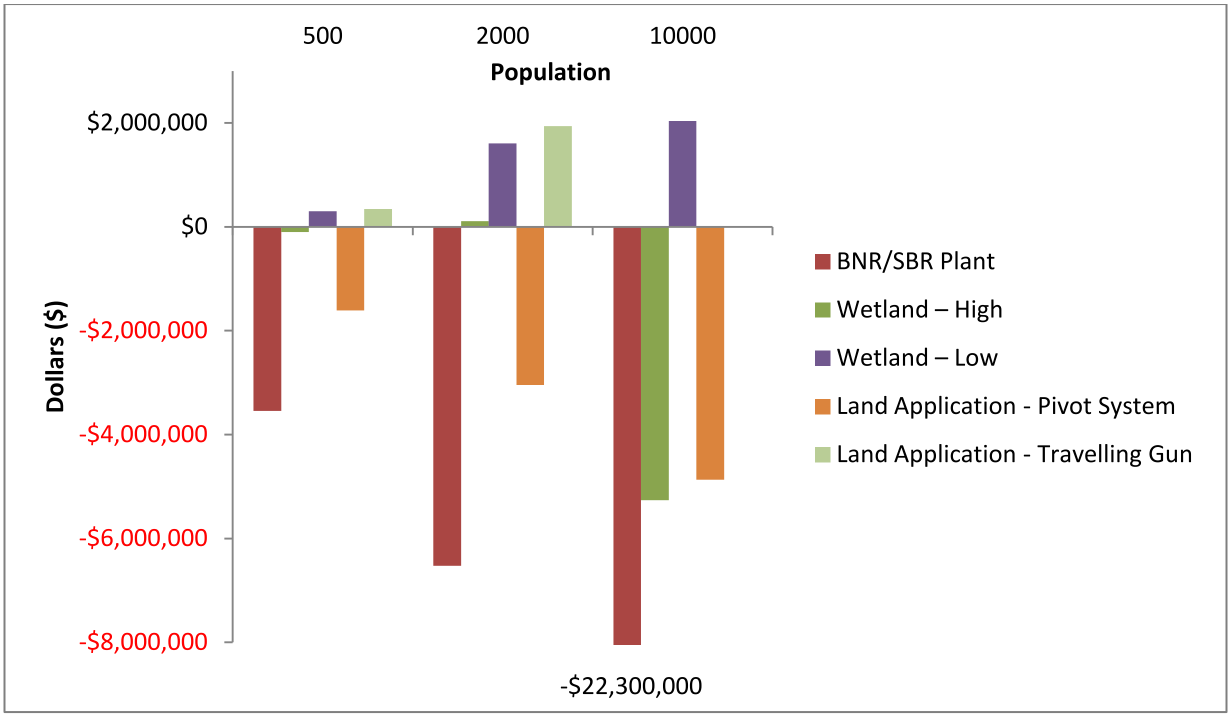
The province of Manitoba and its larger municipalities have identified specific steps to reduce nutrient loadings from wastewater releases, and these are currently being implemented. Challenges, however, exist for smaller municipalities and communities to reduce their nutrient loadings within their available financial and other resource constraints. In 2010, ICF Marbek produced an analysis for Manitoba Water Stewardship evaluating nutrient reduction strategies for wastewater treatment facilities suitable for small communities in Manitoba. These strategies specifically focused on phosphorus removal options. Subsequently, Environment Canada commissioned an analysis that applied Environment Canada's *Analytical Framework for Decisions Involving EG&S* to the costs and benefits for five different wastewater treatment strategies (Biological Nutrient Removal (BNR) and Sequencing Batch Reactors (SBR), Free Water Surface Wetlands, Land Application and Chemical Precipitation). These options were assessed for three community sizes: 500, 2,000 and 10,000 people.

Chemical precipitation was used as a reference case to provide a consistent benchmark for comparison. Three basic steps were taken to include EG&S values in the analysis. Firstly, the potential suite of EG&S benefits were identified. Next, the relative difference in human and environmental impacts between each of the wastewater treatment strategies and the reference case scenario (i.e., the chemical precipitation strategy) were determined. Finally, the quantified EG&S values were monetized to the extent possible, employing a variety of market and non-market valuation techniques.

Excluding consideration of EG&S benefits, the chemical precipitation strategy is the least cost wastewater treatment strategy for reducing phosphorus concentrations in wastewater effluents. Including EG&S values, the relative costs and benefits of the different wastewater treatment strategies change. The Land Application strategy using the travelling gun technology and the wetland-low cost strategy for all community sizes, as well as the wetland-high cost strategy for communities of 2,000 people, become more cost competitive than the chemical precipitation strategy when the value of EG&S are included in the analysis.

Exhibit 12 presents the incremental (i.e., additional to the reference case, chemical precipitation, wastewater treatment strategy) NPV with EG&S of the different wastewater treatment strategies for the three community sizes, relative to chemical precipitation, over a 20 year period, and discounted at 3%. Positive values in the graph suggest choosing a wastewater treatment strategy over the chemical precipitation strategy yields a positive net benefit to society while a negative value suggests that the option would be more costly compared to chemical precipitation, even when some EG&S values are considered.

Exhibit 12 Incremental Net Present Value of Alternative Wastewater Treatment Strategies (relative to the Chemical Precipitation strategy) – for three community population levels, over 20 Years, Discounted at 3%



ICF Marbek, Lantz, and Delcan (2011)

These results indicate there is a positive incremental NPV in using the land application strategy with travelling gun technology (not applicable to the largest community size in the study) and the wetland-low cost strategy (for all three community sizes) in preference to chemical precipitation.

EG&S that were not monetized in the report include: 1) biogas potential (which was not a technology included in the Background Study); 2) groundwater quality change with land application (a possible dis-benefit of the technique); 3) aesthetic and amenity value change with land application (a possible dis-benefit if the technique); 4) other EG&S that may not have been included in the literature for estimation of wetland benefits (including recreation, commercial fishing and hunting, flood control and storm buffering, option, cultural, spiritual, or bequest values).

The sensitivity of results of the analysis were tested for differing values of nitrogen, carbon, different quantities of avoided irrigation water use and different discount rates. The results favouring land application using the travelling gun technology and wetland-low cost strategies are generally found to hold in the sensitivity analyses. Therefore, the results imply that the Land Application strategy using the travelling gun technology and the Wetland-low cost strategies can be supported on economic grounds over the Chemical Precipitation strategy.

5 Synthesized Results

This section presents the synthesized results of the case studies examined. The two key studies used to derive the values presented in this section investigated phosphorus loading reductions to Lake Winnipeg from agricultural practices and wastewater from small and medium sized communities.

While agricultural activities (within and outside of Manitoba) and natural and undefined sources make up almost two-thirds of the total phosphorus load in the Lake on an annual basis, the total phosphorus loading to Lake Winnipeg addressed within the scope of these studies represents less than 19 percent of the total annual loading (approximately 15 percent from agriculture in Manitoba; approximately 4 percent from other Manitoba municipal waste water). The remainder of this section presents a number of tables summarizing the various metrics used in the case studies and the synthesized results.

5.1 Methodology

In order to synthesize and compare the nutrient reduction strategies from the case studies examined, we converted the results to a common metric of annualized net cost per tonne of phosphorus reduced. This common metric facilitates a comparison across nutrient reduction strategies of their cost-effectiveness for achieving a given level of reductions in phosphorus loadings into Lake Winnipeg.

The net cost per tonne of phosphorus reduced is calculated by first estimating the total cost of each nutrient reduction strategy for the given analysis period. We next subtract from this total cost the value of the environmental co-benefits (i.e., increases in EG&S) associated with each nutrient reduction strategy, except those relating to reduced phosphorus loadings, which are considered later in the calculation of net cost per tonne of phosphorus reduced. We then use a 3 percent discount rate to estimate the present value total net cost for each reduction strategy. Next, because the case studies conducted cost-benefit analyses of the nutrient reduction strategies across different numbers of years, we convert all total costs to annualized values, again using a 3 percent discount rate. Lastly, we divide the annualized net cost for each nutrient reduction strategy by the annual tonnes of phosphorus it will remove to obtain the annualized net cost per tonne of phosphorus removed.

To estimate the value of the environmental co-benefits of the nutrient reduction strategies, the case studies identified the affected EG&S and which ones could be quantified. For EG&S that could be quantified, the case studies quantified and monetized the changes in EG&S from each nutrient reduction strategy. Changes in EG&S were monetized based on the per-unit values shown below in Exhibit 13.

Exhibit 13 Values of Ecological Goods and Services[5]

Ecological Goods and Services	Annual Value
Nutrient Reduction – N (average)	$8.26 per kg N
Nutrient Reduction – N (low)	$1.56 per kg N
Nutrient Reduction – N (high)	$14.96 per kg N
Gas Regulation (average)	$25 per tonne of CO_2 equivalent
Gas Regulation (low)	$10 per tonne of CO_2 equivalent
Gas Regulation (high)	$100 per tonne of CO_2 equivalent
Biosolids – N	$1.29 per kg N
Biosolids – P	$4.22 per kg P
Water Supply	$0.82 per cubic metre
Wetland Services – 4 ha wetland	$4,738 per year/ha
Wetland Services – 40 ha wetland	$2,695 per year/ha
Wetland Services – 80 ha wetland	$2,274 per year/ha
Fertilizer Savings (20% savings MAP kg/ha|$/tonne)	$606.16 per year/ha
Pollination (average)	$127.06 per year/ha
Pollination (low)	$63.53 per year/ha
Pollination (high)	$139.76 per year/ha
Water Regulation	$0.85 per year/ha
Wildlife Habitat	$4.73 per year/ha
Erosion Control	$0.49 per year/ha

5.2 Nutrient Cost Results

The first step in the calculation of the annualized net cost per tonne of phosphorus removed was to obtain the total cost for each nutrient reduction strategy. Exhibit 14 below presents the total present value of costs (using a 3 percent discount rate) of the agricultural BMP strategies over the 30-year analysis period, as estimated by the Thomsen et al. (2010) case study. As shown in the exhibit, nutrient management is by far the costliest strategy, with costs over an order of magnitude higher than the other three nutrient reduction strategies. The much higher costs for the nutrient management strategy are largely due to a more extensive, province-wide scenario being considered for this strategy. As discussed above, conservation tillage increases phosphorus loadings, and is thus not considered in these synthesized results.

Exhibit 14 Total Present Value Costs of Agricultural BMP Nutrient Reduction Strategy Scenarios

Agricultural BMP Strategy	Total 30-year Cost – 3% Discounting
Nutrient Management	$376,874,475
Vegetated Filter Strips	$10,356,695
Crop Selection	$34,892,406
Surface Water Control Structures	$20,975,201

Next, we calculated the total present value of costs for the wastewater treatment facility nutrient reduction strategies from the ICF Marbek (2010) study. Because the ICF Marbek study considered costs for typical wastewater treatment facilities of different sizes, we used data (provided previously by Manitoba Water Stewardship to ICF Marbek) on the number of small and medium communities that discharge wastewater to Lake Winnipeg to estimate the total

[5] Refer to original reports for sources of these values.

costs of the wastewater treatment facility strategies. Exhibit 15 presents the summary costs for each strategy for three different sizes of communities (populations of 500, 2,000, and 10,000).

Exhibit 15 Summary of Total Present Value Costs per Wastewater Treatment Facility

Nutrient Reduction Strategy	Total 20-year Cost per Wastewater Treatment Facility – 3% Discounting		
	Population		
	500	*2,000*	*10,000*
BNR/SBR Plant	$4,181,288	$7,997,960	$27,219,821
Wetland – High	$1,022,154	$3,181,052	$13,868,245
Wetland – Low	$622,154	$1,681,052	$6,568,245
Land Application - Pivot System	$2,923,753	$7,256,936	$24,139,670
Land Application - Traveling Gun	$971,839	$2,276,156	N/A[a]
Chemical Precipitation	$551,676	$1,135,847	$3,820,683

[a] The travelling gun technology is not suitable for communities of 10,000 people.

Next, in Exhibit 16, we multiply the present value of total costs for each strategy and community size by the total number of communities to obtain the present value total 20-year costs for each strategy. As shown in Exhibit 16, the BNR/SBR plant is the costliest strategy, followed by the pivot system strategy for land application.

Exhibit 16 Total Present Value Cost of Wastewater Treatment Facility Strategies

Nutrient Reduction Strategy	Total 20-year Cost by Community Size – 3% Discounting			Total 20-year Cost – 3% Discounting
	Population (Number of Communities)			
	500 (247)	*2,000 (128)*	*10,000 (34)*	
BNR/SBR Plant	$1,032,778,080	$1,023,738,885	$925,473,905	$2,981,990,870
Wetland – High	$252,471,990	$407,174,632	$471,520,331	$1,131,166,953
Wetland – Low	$153,671,990	$215,174,632	$223,320,331	$592,166,953
Land Application - Pivot System	$722,167,082	$928,887,847	$820,748,769	$2,471,803,699
Land Application - Traveling Gun	$240,044,277	$291,347,963	N/A	$531,392,240
Chemical Precipitation	$136,263,954	$145,388,416	$129,903,228	$411,555,598

We next used a 3 percent discount rate and the number of years in the analysis period for each case study to calculate the annualized cost of each nutrient reduction strategy. The annualized costs for each nutrient management strategy are shown in Exhibit 17.

Exhibit 17 Annualized Cost of Nutrient Reduction Strategies

Nutrient Reduction Strategy	Total Cost - 3% Discounting	Years in Analysis Period	Annualized Cost – 3% Discounting
BNR/SBR Plant	$2,981,990,870	20	$200,436,626
Wetland – High	$1,131,166,953	20	$76,032,187
Wetland – Low	$592,166,953	20	$39,802,921
Land Application - Pivot System	$2,471,803,699	20	$166,144,035
Land Application - Traveling Gun	$531,392,240	20	$35,717,905
Chemical Precipitation	$411,555,598	20	$27,663,001
Nutrient Management	$376,874,475	30	$19,227,857
Vegetated Filter Strips	$10,356,695	30	$528,391
Crop Selection	$34,892,406	30	$1,780,185
Surface Water Control Structures	$20,975,201	30	$1,070,139

5.3 Nutrient Benefit Results

The next step in the estimation of the net cost per tonne of phosphorus removed for the nutrient management strategies was to estimate the environmental co-benefits associated with each of the strategies. The benefits for each strategy can then be subtracted from the costs to obtain the net costs of each strategy. To estimate the value of the environmental co-benefits, we used information from the case studies on the quantity of EG&S improvements provided by the different strategies multiplied by the values ascribed to the various EG&S as presented above in Exhibit 13. Exhibit 18 presents the total EG&S benefits for the different strategies and the annualized benefits, using the number of years in the analysis period of the case studies and a 3 percent discount rate. The largest annualized benefits are provided by the land application and wetland strategies for wastewater treatment facilities.

Exhibit 18 Present Value Total and Annualized Benefits of Nutrient Reduction Strategies for Lake Winnipeg

Nutrient Reduction Strategy	Total Benefit – 3% Discounting	Years in Analysis Period	Annualized Benefit – 3% Discounting
BNR/SBR Plant	$118,465,912	20	$7,962,770
Wetland – High	$509,770,222	20	$34,264,566
Wetland – Low	$509,770,222	20	$34,264,566
Land Application - Pivot System	$821,969,413	20	$55,249,256
Land Application - Traveling Gun	$431,723,331	20	$29,018,589
Chemical Precipitation	$17,611,430	20	$1,183,765
Nutrient Management	$45,783,973	30	$2,335,864
Vegetated Filter Strips	$22,614,484	30	$1,153,799
Crop Selection	$83,805,514	30	$4,275,780
Surface Water Control Structures	$7,569,876	30	$386,209

In considering the results presented in Exhibit 18, it is important to note that not all EG&S benefits could be estimated due to the difficulties involved in quantifying and/or monetizing EG&S and changes in their level of provision. In addition, since the analysis estimates the cost per tonne of phosphorus reduced, the value of phosphorus reduction has not been monetized. This means that any benefits resulting from reduced phosphorus and improved water quality at the lake level, such as benefits to lake property owners, beach-goers, fisheries, etc., would be incremental to the EG&S benefits presented in Exhibit 18.

The results indicated in this exhibit reflect the benefits presented by wastewater technologies in terms of reduced nitrogen loadings to watersheds, recoverable nutrients in the form of biosolids and specific services provided by wetlands (carbon sequestration and other EG&S) and land application (reduced water supply needs). In comparison with the agricultural BMPs, the wastewater strategies generally provide a wider range of benefits, albeit at higher total costs (as indicated in Section 5.2 above).

5.4 Annual Net Cost per Tonne of Phosphorus Reduced

We next estimated the net cost per tonne of phosphorus reduced by calculating the net cost for each nutrient reduction strategy and dividing it by the annual tonnes of phosphorus that each strategy is expected to remove. First, we calculated the net cost for each strategy by subtracting the annualized benefits for each strategy (presented above in Exhibit 18) from the annualized costs (presented above in Exhibit 17), as shown in Exhibit 19. Because the annualized environmental co-benefits of the vegetated filter strips and crop selection strategies are greater than their annualized costs, the net costs for these agricultural BMP strategies are negative.

Exhibit 19 Annualized Net Cost of Nutrient Reduction Strategies, Discounted at 3%

Nutrient Reduction Strategy	Annualized Cost	Annualized Benefit	Annualized Net Cost
BNR/SBR Plant	$200,436,626	$7,962,770	$192,473,856
Wetland – High	$76,032,187	$34,264,566	$41,767,621
Wetland – Low	$39,802,921	$34,264,566	$5,538,355
Land Application - Pivot System	$166,144,035	$55,249,256	$110,894,779
Land Application - Traveling Gun	$35,717,905	$29,018,589	$6,699,316
Chemical Precipitation	$27,663,001	$1,183,765	$26,479,236
Nutrient Management	$19,227,857	$2,335,864	$16,891,992
Vegetated Filter Strips	$528,391	$1,153,799	-$625,408
Crop Selection	$1,780,185	$4,275,780	-$2,495,595
Surface Water Control Structures	$1,070,139	$386,209	$683,930

Next, we divided the annualized net cost of each nutrient reduction strategy by the annual tonnes of phosphorus it is expected to remove to estimate the annualized net cost per tonne of phosphorus removed (shown in Exhibit 20). The BNR/SBR plant strategy has by far the highest annualized net cost per tonne of phosphorus removed, followed by the pivot system strategy for land application. Because the vegetated filter strips and crop selection strategies have a net benefit (i.e., have improvements in EG&S that are greater than their costs), their resulting annualized net cost per tonne of phosphorus removed is negative.

Exhibit 20 Annualized Net Cost per Tonne of Phosphorus Removed of Nutrient Reduction Strategies

Nutrient Reduction Strategy	Annualized Net Cost – 3% Discounting	Annual Tonnes of Phosphorus Removed	Annualized Net Cost per Tonne of Phosphorus Removed – 3% Discounting
BNR/SBR Plant	$192,473,856	114	$1,688,367
Wetland – High	$41,767,621	114	$366,383
Wetland – Low	$5,538,355	114	$48,582
Land Application – Pivot System	$110,894,779	140	$792,106
Land Application – Traveling Gun	$6,699,316	140	$47,852
Chemical Precipitation	$26,479,236	114	$232,274
Nutrient Management	$16,891,992	96.9	$174,324
Vegetated Filter Strips	-$625,408	1	-$625,408
Crop Selection	-$2,495,595	3.9	-$639,896
Surface Water Control Structures	$683,930	2.4	$284,971

5.5 Sensitivity Analysis

In this section, we examine the sensitivity of the results by varying key parameters used in the estimation of the annualized net cost per tonne of phosphorus removed for the nutrient reduction strategies. First, Exhibit 21 presents the annual net cost per tonne of phosphorus reduced for the agricultural BMPs under the three different scenarios for phosphorus reduction potential as presented in the Thomsen et al. (2010) case study (shown above in Exhibit 7). The wide range of annualized net cost per tonne values reflects the large spread of phosphorus reduction potential between the lower, average and upper estimates. There is almost an order of magnitude difference in phosphorus removed between the lower and average scenarios, resulting in the almost order of magnitude difference in the annualized net cost results.

Exhibit 21 Annualized Net Cost per Tonne of Phosphorus Reduced for Agricultural BMPs by Phosphorus Reduction Potential

Agricultural BMP Scenario	Annualized Net Cost per Tonne of Phosphorus Removed – 3% Discounting		
	Phosphorus Removed		
	Lower	Average	Upper
Nutrient Management	$1,578,691	$174,324	$66,347
Vegetated Filter Strips	-$6,254,081	-$625,408	-$208,469
Crop Selection	-$6,238,987	-$639,896	-$218,912
Surface Water Control Structures	$2,279,766	$284,971	$105,220

Exhibit 22 presents the annualized net cost per tonne of phosphorus removed for the agricultural BMPs under three different assumptions of the value of pollination services. As shown in the exhibit, the assumed value of pollination services has a large impact on the results for the vegetated filter strips and crop selection agricultural BMPs.

Exhibit 22 Annualized Net Cost per Tonne of Phosphorus Reduced for Agricultural BMPs by Value of Pollination Services

Agricultural BMP Scenario	Annualized Net Cost per Tonne of Phosphorus Removed – 3% Discounting		
	Value of Pollination Services		
	$63.53 per ha per year	$127.06 per ha per year	$139.76 per ha per year
Nutrient Management	$174,324	$174,324	$174,324
Vegetated Filter Strips	-$148,603	-$625,383	-$723,822
Crop Selection	-$210,251	-$639,874	-$725,785
Surface Water Control Structures	$284,971	$284,971	$284,971

Next, Exhibit 23 presents the annualized net cost per tonne of phosphorus removed for the wastewater treatment facility strategies under different assumed values for nitrogen reduction as presented in the ICF Marbek (2010) case study. The impact of the value of nitrogen on the results varies substantially across the different strategies. For the wetland-low cost strategy, the annualized cost per tonne of phosphorus removed becomes negative (indicating a net benefit) under the high-cost assumption for the value of nitrogen.

Exhibit 23 Annualized Net Cost per Tonne of Phosphorus Reduced for Wastewater Treatment by Value of Nitrogen

Wastewater Treatment	Annualized Net Cost per Tonne of Phosphorus Removed – 3% Discounting		
	Value of Nitrogen		
	$1.56/kg	$8.26/kg	$14.96/kg
BNR/SBR Plant	$1,729,976	$1,688,367	$1,646,759
Wetland – High	$425,823	$366,383	$306,942
Wetland – Low	$108,023	$48,582	-$10,858
Land Application - Pivot System	$864,708	$792,106	$719,503
Land Application - Traveling Gun	$86,146	$47,852	$9,558
Chemical Precipitation	$232,274	$232,274	$232,274

Next, Exhibit 24 presents the annualized net cost per tonne of phosphorus removed for each nutrient reduction strategy under the different marginal values per tonne of CO_2 equivalent used in the ICF Marbek (2010) case study. For the wetland-low cost strategy, the annualized cost per tonne of phosphorus removed again becomes negative (indicating a net benefit) under the high-cost assumption for the value of carbon. The crop selection and vegetated filter strips agricultural BMPs are the most affected by the value of carbon assumptions.

Exhibit 24 Annualized Net Cost per Tonne of Phosphorus Reduced by Value of Carbon

Nutrient Reduction Strategy	Annualized Net Cost per Tonne of Phosphorus Removed – 3% Discounting		
	Value of Carbon		
	$10/tCo2 eq	$25/tCo2 eq	$100/tCo2 eq
BNR/SBR Plant	$1,688,242	$1,688,367	$1,688,992
Wetland – High	$377,119	$366,383	$312,702
Wetland – Low	$59,318	$48,582	-$5,099
Land Application - Pivot System	$792,106	$792,106	$792,106
Land Application - Traveling Gun	$47,852	$47,852	$47,852
Chemical Precipitation	$232,255	$232,274	$232,370
Nutrient Management	$179,294	$174,324	$149,476
Vegetated Filter Strips	-$586,245	-$625,383	-$821,074
Crop Selection	-$552,075	-$639,874	-$1,078,874
Surface Water Control Structures	$285,517	$284,971	$282,238

Lastly, Exhibit 25 presents a sensitivity analysis of the discount rate used to calculate the annualized net cost per tonne of phosphorus removed. In Exhibit 23, we present the results shown above using a 3 percent discount rate and compare them to the results obtained using a 0 percent and a 7 percent discount rate.

Exhibit 25 Annualized Net Cost per Tonne of Phosphorus Reduced by Discount Rate

Nutrient Reduction Strategy	Annualized Net Cost per Tonne of Phosphorus Removed		
	Discount Rate		
	0% Discounting	3% Discounting	7% Discounting
BNR/SBR Plant	$1,419,712	$1,688,367	$2,107,320
Wetland – High	$239,094	$366,383	$568,377
Wetland – Low	$2,690	$48,582	$122,081
Land Application - Pivot System	$589,219	$792,106	$1,112,389
Land Application - Traveling Gun	$29,539	$47,852	$76,953
Chemical Precipitation	$215,683	$232,274	$257,115
Nutrient Management	$196,387	$174,324	$147,012
Vegetated Filter Strips	-$670,743	-$625,383	-$239,588
Crop Selection	-$700,487	-$639,874	-$380,290
Surface Water Control Structures	$327,901	$284,971	$148,583

The sensitivity results indicate robust results. For instance, the rank order and sign of agricultural BMPs does not change with amount of phosphorus reduced or the value of pollination services. For the wastewater treatment facility strategies, the annualized net cost per tonne of phosphorus for the wetland-low cost strategy became negative under the high-cost assumptions for the values of nitrogen and carbon. Higher discount rates result in higher annualized net cost per tonne for the wastewater treatment options. This trend reflects the high up-front capital investment costs of these options (which are annualized over 20 years); as the discount rate increases, these costs are off-set to a lesser degree by benefits returned. The annualized net cost per tonne for agricultural BMPs (which are annualized over 30 years) decreases with increasing discount rate. For Nutrient Management and Surface Water Control Structures, the strategies are less costly given a higher discount rate. For Vegetated Filter Strips and Crop Selection, the strategies are less beneficial given a higher discount rate. Thus, the discount rate has the same effect in each case for agricultural BMPs, with the net impact (whether positive or negative) decreasing as the discount rate increases.

The most commonly adopted wastewater technology – chemical precipitation – is not the most favourable when EG&S are included: wetland–low cost and land application (travelling gun) have lower annualized net costs per tonne phosphorus removed. For smaller communities, the annualized net cost per tonne of wetland–high also closely rivals that of chemical precipitation. The cost of the wetland-high strategy requires significant land area for larger communities and therefore is less advantageous on a cost per tonne basis for the 10,000 population communities. Two of the agricultural BMPS – vegetated filter strips and crop selection – provide net benefits per tonne of phosphorus removed, a reflection of their low implementation cost relative to the nutrients removed and other EG&S benefits. The net cost result for surface water control structures must be treated with caution due to the lack of accounting for negative effects of dams on aquatic ecosystems in the EG&S background report.

6 Conclusions and Recommendations

In this section, we present some concluding remarks and lessons learned from this synthesis report. Next, we present some recommendations on how the lessons learned from this report can be used to inform policy decision-making on the choice of nutrient reduction strategies for Lake Winnipeg.

6.1 Conclusions and Lessons Learned

This synthesis report presents information on the costs and benefits of nutrient reduction strategies for Lake Winnipeg, and compares these strategies across a common metric of annualized cost per tonne of phosphorus removed. In evaluating the results presented in this synthesis report, it is important to remember that this report only considers strategies for Manitoba, and, as shown above, is only covering less than one quarter of the total phosphorus load into Lake Winnipeg. While the results of this report can be used to evaluate nutrient reduction strategies for phosphorus loadings from Manitoba sources, it cannot be used to evaluate how the costs and cost-effectiveness of these strategies compare to strategies to control non-Manitoba sources of phosphorus loadings. In other words, there may be "low hanging fruit" in other jurisdictions that may be more cost-effective before implementing the nutrient reduction strategies for Manitoba sources.

From the synthesis analysis of the nutrient reduction strategies and the evaluation of all strategies across a common metric, we can draw some conclusions on the cost-effectiveness of the strategies. First, the wastewater treatment facility strategies are generally less cost-effective than the agricultural BMP strategies when the annualized cost per tonne of phosphorus removed is considered. For example, the two strategies with the highest annualized cost per tonne of phosphorus are BNR/SBR plants and the pivot system strategy for land application. In contrast, two of the four agricultural BMPs (vegetated filter strips and crop selection) actually have a negative annualized net cost per tonne of phosphorus due to the fact that the improvements in EG&S resulting from these strategies are greater than the cost to implement them. However, it should be noted that that the vegetated filter strips and crop selection scenarios have a limited overall potential to reduce phosphorus loading in the watershed compared to other scenarios examined in this analysis (see Exhibit 20).

The results observed for the various nutrient reduction strategies were generally robust across the different sensitivity analyses that were conducted. For the agricultural BMPs, for example, the rank order of the cost-effectiveness of the strategies did not change across assumptions on the amount of phosphorus reduced or the assumed value of pollination services. The sign of the resulting annualized cost per tonne of phosphorus removed for the agricultural BMP strategies also was the same across these sensitivities. The nutrient management and surface water control structures strategies had a positive net cost per tonne of phosphorus removed and the vegetated filter strips and crop selection strategies consistently had a negative annualized cost, or a benefit per tonne of phosphorus removed. For the wastewater treatment facility strategies, the annualized net cost per tonne of phosphorus for the wetland-low cost strategy became negative under the high-cost assumptions for the values of nitrogen and carbon.

In using the results of this synthesis report to compare nutrient reduction strategies, it also is important to consider that this summary only considers co-benefits for a limited number of the full range of EG&S provided by these strategies. This omission relates to the difficulty in quantifying and or monetizing some EG&S and changes in their level of provision. As an example, this report does not monetize the benefits of less phosphorus in Lake Winnipeg, such as improved water quality and fewer algal blooms.

6.2 Recommendations

From the results of this synthesis report, we can make some recommendations for selection of nutrient reduction strategies for Lake Winnipeg based on the cost-effectiveness of each strategy for removing a tonne of phosphorus. As discussed earlier, however, it is important to consider the focus of this study on Manitoba sources, and that there may be less costly strategies for reducing nutrient loadings from other jurisdictions.

From a more comprehensive watershed-level perspective, the literature review by Wilson (2009) commissioned by Environment Canada on efforts to quantify and value EG&S resulted in findings relevant to nutrient loadings in Lake Winnipeg. For example, watershed and wetland studies conducted in various Canadian watersheds have demonstrated that water regulation by wetlands and water filtration services provided by forests have had the highest assessed values of the EG&S that were considered. Other studies demonstrated the large values of other EG&S, such as those arising from fishing, pure water, and carbon sequestration. An important finding of many of these studies, however, was that data limitations hamper the ability of researchers to measure and value EG&S. As suggested by the studies, this difficulty largely stems from a lack of ecological and economic information, such as changes in the current levels of provision of EG&S, and how this provision might change under different land use scenarios.

The limitations of this report underscore the need for a larger and more comprehensive study for Canadian jurisdictions and strategies for controlling nutrient loadings into Lake Winnipeg. Results of this more comprehensive study could potentially be used to cooperate with the United States on nutrient reduction targets and measures for the U.S.-based sources of nutrient loadings. Another recommendation is that, due to the importance of EG&S and the value of the improvements in EG&S provided by nutrient reduction strategies, municipal and provincial as well as conservation/watershed authorities need to begin to identify, measure, and monitor EG&S as part of their jurisdictional reporting. As part of this process, the development of a standard approach for the measurement and valuation of EG&S for Canada would greatly improve EG&S research and valuation. Lastly, the data gaps described above highlight the importance of promotion of applied EG&S research to support policy decision-making. For example, there is a need for studies that look at changes in marginal values (rather than total values), and the impacts that various policies have on the provision of EG&S. Increased research in this area would improve the accuracy of analyses of the costs and benefits of policy alternatives, and would thus help decision-makers choose between competing policies or resource uses.

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