Nutrient Reduction Strategies for Wastewater Treatment Facilities for Lake Winnipeg:

Cost-Benefit Analysis using an Ecological Goods and Services Approach
Final Report

Submitted to

Environment Canada

Submitted by

Marbek in cooperation with Dr. Van Lantz and Delcan

January 4, 2011

222 Somerset Street West, Suite 300
Ottawa, Ontario, Canada K2P 2G3
Tel: +1 613 523-0784
Fax: +1 613 523-0717
info@marbek.ca
www.marbek.ca

Executive Summary

Municipal wastewater effluent is currently one of the many sources of nutrients to Lake Winnipeg. Recently, the province 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.

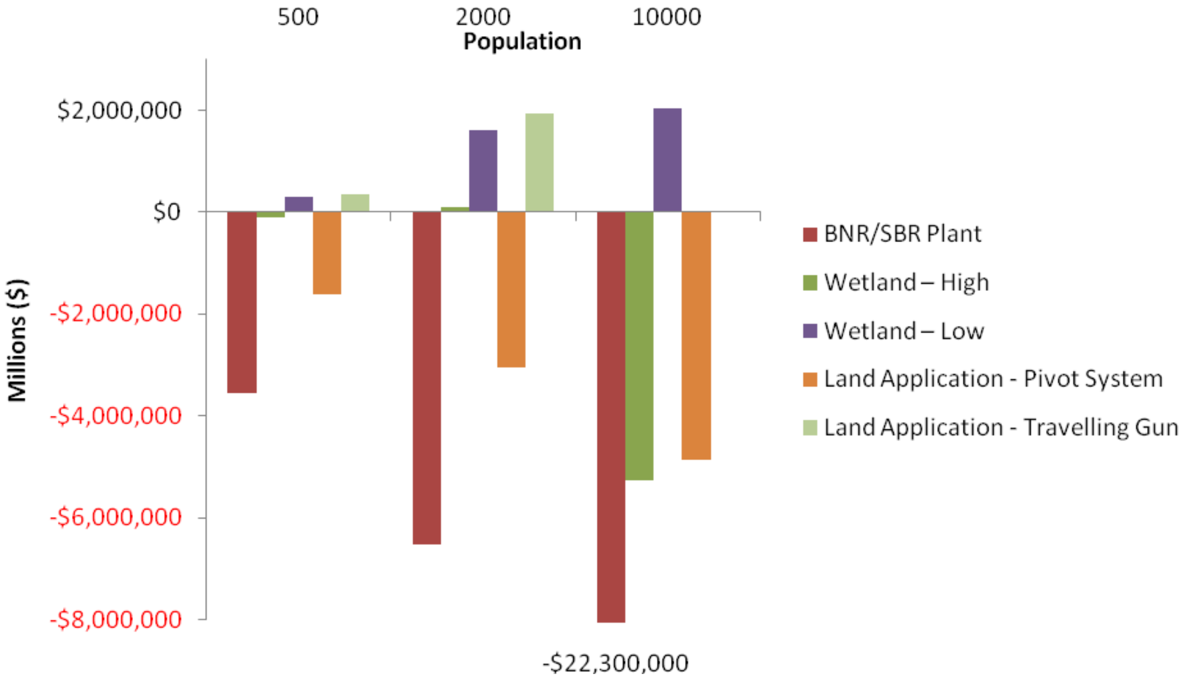
In March 2010, Marbek, with CH_2M Hill, completed a report on behalf of Manitoba Water Stewardship (MWS) to assess options for nutrient reduction from wastewater facilities serving small communities in Manitoba, called *Evaluation of Nutrient Reduction Strategies for Wastewater Treatment Facilities in Manitoba* (hereafter called the Background Report). This report builds on the work undertaken by Marbek for MWS by applying Environment Canada's analytical framework for decisions involving ecological goods and services (EG&S) to evaluate nutrient reduction strategies for wastewater treatment facilities suitable for small communities in Manitoba. Specifically, we analyze 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) in three community sizes of 500, 2,000 and 10,000 people.

A formal cost-benefit analysis using the EG&S framework was conducted using the Chemical Precipitation strategy as the reference case and analyzed the net present value (NPV) of implementing one of the other identified wastewater treatment systems. Although Chemical Precipitation is not currently in widespread use in Manitoba, this strategy is used as a reference case to provide a consistent benchmark for comparison and because it is often viewed as the least cost wastewater treatment strategy. Cost-benefit analysis is an important decision-making tool to assess development scenarios in terms of their impacts on social welfare. To include EG&S values in the analysis, we first identify the potential suite of EG&S benefits. Second, we determine 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). Finally, we monetize the quantified EG&S values 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 EG&S are included.

Exhibit 1 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 moving from the Chemical Precipitation strategy to the wastewater treatment strategy yields a positive net benefit to society while a negative value suggests negative net benefits.

Exhibit 1 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%



The results of this analysis are sensitive to many important variables and assumptions. We test the robustness of our results for differing values of nitrogen, values of carbon, different quantities of avoided irrigation water use and different discount rates.

There are many uncertainties and limitations of our analysis that are described and summarized in this report. Although this report assesses the costs and benefits of different wastewater treatment strategies, the report does not provide specific recommendations on the most appropriate treatment strategies for small communities in Manitoba. There are other considerations that may help guide decision makers such as operator availability and process control.[1] Notwithstanding these issues, this study provides an important first step toward a greater understanding of the full spectrum of values affected by wastewater treatment strategies for small communities across Manitoba and can help inform wastewater policies throughout the world.

---

[1] The Background Report provides a comprehensive qualitative assessment of the strengths and weaknesses of the specific strategies considered in this report

Table of Contents

List of Exhibits

1 Introduction

This introductory section presents the background, context, objectives, and boundaries of this study.

1.1 Background

This section provides background information on the Lake Winnipeg watershed and the Background Report undertaken by the Marbek and CH_2M Hill team to examine strategies to reduce wastewater effluent nutrient loadings from small communities within Manitoba.

1.1.1 Lake Winnipeg Watershed

Lake Winnipeg is the world's 10th largest freshwater lake in terms of surface area covering about 24,500 square kilometres (LWSB, 2006)[2]. It is 436 kilometres long and is comprised of a larger north basin and a smaller south basin, which are connected by a channel called The Narrows. While it is expansive in area, the lake is also shallow and therefore holds relatively less water volume than other large lakes on the continent. The Lake Winnipeg watershed is very large, at about 953,000 square kilometres. The catchment area extends from the Canadian Rockies east to within 20 kilometres of Lake Superior, encompassing parts of four Canadian provinces and four U.S. States. 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. 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 in 2003.

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.

1.1.2 Population and Economic Activities

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 centers (LWSB, 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

---

[2] The information contained in this sub-section comes from (LWSB, 2006).

tourists and participants (e.g., championships and festivals), specialized resorts and provincial parks and facilities within the watershed.

1.1.3 Environmental Changes and Stressors

Drainage of wetlands and the loss of wooded and prairie areas for agricultural and urban land uses have dramatically changed land drainage patterns within the watershed (LWSB, 2006). Loss of wetlands and natural riparian areas have also impacted habitat and food sources for fish, other aquatic species, waterfowl, shore birds and other wildlife. Erosion has increased in tributaries within the watershed as a result of land use alterations. Nutrient loadings (i.e., phosphorus and nitrogen concentrations) have also dramatically increased as a result of land based activities (e.g., farming and urban populations), soil erosion and in-stream erosion. High nutrient loadings are known to promote excessive growth of algae which can deplete the water of oxygen and cause death to important organisms such as fish. This is a process known as eutrophication. Historic dredging of the Red River for navigation has also impacted nutrient loadings to Lake Winnipeg, and has caused significant deterioration in the marshland stability and extent in the region.

Starting in the early 1970s, the focus of nutrient reduction strategies has been on reducing phosphorus loads into Lake Winnipeg. In fact, scientists at the time established phosphorus as the primary limiting nutrient (Schindler et al., 2008). However, more recent evidence suggests an increasing role of nitrogen in causing eutrophication and algae blooms in freshwater environments (Paerl and Scott, 2010).

Municipal wastewater effluent is currently one of the major sources of nutrient loadings to Lake Winnipeg.[3] Recently, the province 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 March 2010, Marbek, with CH_2M Hill, completed a report on behalf of Manitoba Water Stewardship (MWS) to assess options for nutrient reduction from wastewater facilities serving small communities in Manitoba, called *Evaluation of Nutrient Reduction Strategies for Wastewater Treatment Facilities in Manitoba* (Marbek and CH_2M Hill, 2010) (hereafter called the Background Report). A long list of 23 strategies was developed and a short list of four strategies was identified for detailed assessment and cost estimation. Criteria for short-listing of techniques included: effectiveness in removal of phosphorus; suitability for small municipalities; and, nutrient reuse potential, in particular without the reliance on coagulation for phosphorus control. Operator skill level requirements were also a factor considered as well as cold climate experience with the technique. Operating and capital costs were estimated for the four strategies and for three population sizes of 500, 2,000 and 10,000 people, which generally represented the extent of the smaller municipalities and communities of interest. The strategies examined included:

- Biological Nutrient Removal (BNR);
- Sequencing Batch Reactors (SBR);
- Land Application through Irrigation of Pre-treated Wastewater Effluent; and
- Free Water Surface Wetlands (Wetlands).

---

[3] It has been estimated that wastewater sources account for 11% and 19% of total nitrogen and phosphorus loadings to Lake Winnipeg from Manitoba sources (LWSB, 2006).

BNR and SBR are both mechanical plants that include an activated-sludge process. BNR plants can have various configurations but are designed for wastewater to flow through the facility to undergo successive stages of treatment. SBR plants, on the other hand, are designed so that one tank is used to process effluent in five successive steps. SBR plants therefore often require less space than BNR plants. Land application involves the intermittent application of pre-treated wastewater to suitable soils through sprinklers or other irrigation options. The two spray irrigation techniques for land application examined in detail in the Background Report were: centre pivot sprinkler irrigation systems; and, travelling gun irrigation systems. The former is fixed in place and therefore may not be shared among farmers. The traveling gun is a mobile system which may be transported for use on multiple fields. FWS wetlands are similar in appearance to natural wetlands in that they contain areas of open water, floating/submerged vegetation and emergent plants. They are constructed wetlands designed to polish secondary treated wastewater for further removal of nutrients, sediments and other contaminants. The configurations examined in the Background Report assumed the land application and FWS received water from an existing lagoon system.

Techniques requiring the use of coagulation (i.e., chemical precipitation) were specifically excluded from the short list of strategies to reduce nutrient loadings for the Background Report due to the fact that coagulants bind up phosphorus, potentially reducing its availability for use as a fertilizer. Phosphorus rock reserves have been declining worldwide and future shortages (resulting in higher fertilizer prices) are anticipated. Thus, phosphorus recovery from wastewater may become an important source of phosphorus for the agriculture sector in Canada.

1.2 Project Context and Objectives

The federal government and the Province of Manitoba have committed to address the eutrophication of Lake Winnipeg. Most recently, a Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin has been signed by these two levels of government which aims to improve the ecological health of the watershed.[4] Community wastewater facilities have been identified as key contributors of nutrients to the lake watershed, and work has therefore been undertaken by MWS to assess options to reduce nutrient loadings from these facilities.

This report builds on the work undertaken by Marbek for MWS by applying Environment Canada’s analytical framework for decisions involving EG&S to evaluate nutrient reduction strategies for wastewater treatment facilities suitable for small communities in Manitoba. In addition to the four strategies evaluated in the Background Report, this report also includes an analysis of chemical precipitation.[5] The study undertakes a cost-benefit analysis using Environment Canada’s analytical framework for EG&S (as described in section 2.1).

The specific objectives of this study are:

- To examine the cost and benefits using an EG&S approach, of applying different wastewater treatment strategies for small and medium sized communities; and

---

[4] Accessed November 2010 from http://news.gov.mb.ca/news/index.html?archive=2010-9-01&item=9660

[5] Chemical precipitation was excluded from analysis in the Background Report because nutrient recovery was a priority for that study. Chemical precipitation is included in this current analysis since, conventionally, it is the most common technology applied when increasingly stringent phosphorus effluent criteria must be met. Since it is typically the least capital intensive technology, coagulation is used as a reference case and a comparison of the costs and benefits of alternative wastewater treatment strategies is made.

- To provide knowledge to help decision-makers compare different wastewater treatment strategies.

1.3 Study Boundaries

1.3.1 Geography

This study examines small to medium sized communities in the Lake Winnipeg Basin within Manitoba.[6]

1.3.2 Community Sizes

The analysis is conducted for three community sizes: 500, 2,000 and 10,000 people.

1.3.3 Wastewater Treatment Strategies

The analysis considers five wastewater treatment strategies (as previously defined in Section 1.1.3):

- Conventional flow-through BNR processes (BNR);
- Sequencing batch reactors (SBR);
- Free water surface wetlands;
- Land application; and
- Chemical precipitation.

As described in the Background Report, the costs assumed for the BNR and SBR treatment strategies are the same. In addition, these two treatment strategies are expected to have negligible differences in EG&S. Consequently, these two treatment systems are evaluated together. Additionally, as described in the Background Report, since there is much uncertainty regarding the costs associated with constructed wetlands (depends on the characteristics of the site, etc), we consider two types of wetlands: those with a high cost vs. those with a low cost.[7] Finally, there are two technologies considered for land application with differing costs: pivot system and travelling gun.

With these modifications, there are a total of six wastewater treatment strategies that are evaluated:

- BNR/SBR;
- Wetlands – high cost;
- Wetlands – low cost;
- Land application – pivot system;
- Land application – traveling gun[8];
- Chemical precipitation.

---

[6] Throughout this report, the Lake Winnipeg Basin only refers to the area found within the province of Manitoba.

[7] The low cost option would be applicable if soil conditions require little human alteration and a high cost option would be applicable if substantial topsoil stripping and manipulation of the wetland site is needed. The final project costs are likely to be between these two estimates.

[8] Note that in the Background report, the travelling gun technology was deemed to be impractical for deployment in communities of 10,000 people.

As described in subsequent sections, the analysis compares the costs and benefits of each wastewater treatment strategy relative to the Chemical Precipitation strategy (i.e., the latter is treated as the reference case strategy).

1.3.4 *Timeline*

Our timeframe for the analysis spans a period of 20 years. This timeframe closely approximates the expected lifetime of the various wastewater treatment systems such as BNR/SBR and chemical precipitation.

We assume the capital costs for each wastewater treatment strategy occur in the first year and operating and maintenance costs are streamed over the remaining 19 years. Additionally, we assume that EG&S benefits occur annually, and remain at a constant level over the period of analysis.

1.4 Overview of this Report

The remainder of this report is organized as follows:

- Section 2 Approach and Methodology
- Section 3 Analysis
- Section 4 Results
- Section 5 Summary and Conclusions

2 Approach and Methodology

This section outlines the approach and methodology used to assess costs and benefits of the six nutrient reduction strategies for wastewater treatment facilities considered in this analysis. Section 2.1 provides background on the total economic value (TEV) framework that is used to categorize the different benefits.[9] The overall framework for assessing costs and benefits is outlined in Section 2.2. Section 2.3 summarizes some of the key uncertainties and limitations of the analysis.

2.1 Total Economic Value (TEV) Framework

Environmental economists generally refer to TEV as the sum of all function-based (i.e., EG&S) 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 monetise a set of human preferences towards the given ecosystem (Wattage and Mardle, 2008).[10]

In the current study, the ecosystem under investigation is the Lake Winnipeg Basin in Manitoba. This ecosystem provides a wide array of EG&S values to society. Examples of these values are illustrated in Exhibit 2. Specifically, direct-use values reflect the direct use of the Basin for fish, space for recreation, and water use by residential, agricultural and industrial/commercial firms (Pascual and Muradian, 2010). Indirect-use values include the ecosystem functions and services supported by the Basin 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 Basin 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 Manitobans[11] may benefit from the improvement in environmental conditions in the Basin even if they will not use it (but rather just from the knowledge that it is being enhanced). Bequest value recognizes that some Manitobans may benefit from knowing that the Basin will be enhanced specifically for future generations.

While some of the social values provided by the Basin are reflected in the market as economic transactions (referred to as market values), many are not (referred to as non-market values) (Voora and Venema, 2008). Estimation of these values, particularly non-market values, presents a significant challenge.

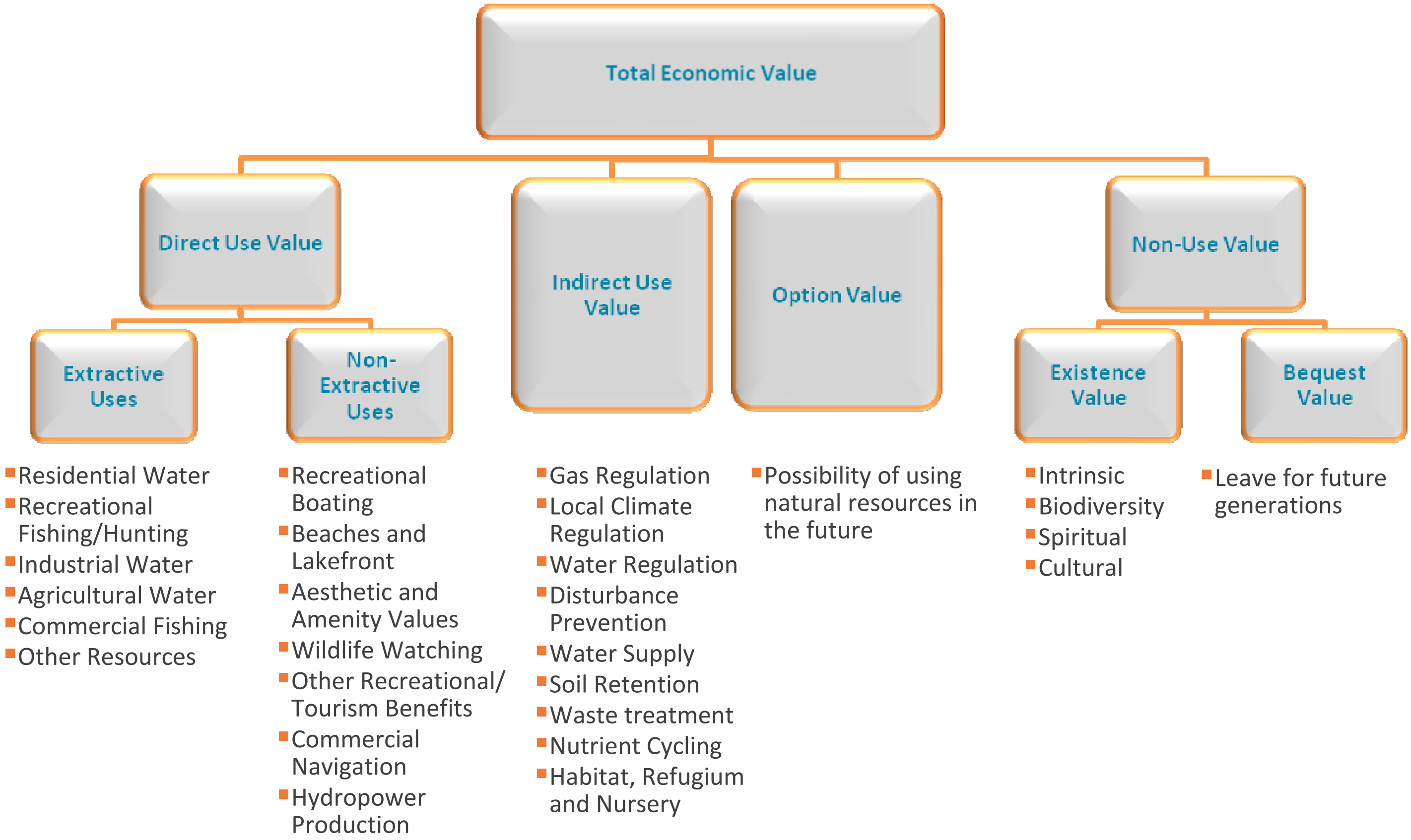
---

[9] The appeal of using the TEV framework is that it is both logical and comprehensive. The logical nature of the framework comes from its foundations in microeconomic theory and emphasis on marginal values while the comprehensiveness stems from its ability to include all aspects of the Lake Winnipeg Basin's value. In addition, because this is the approach taken by economists in valuing EG&S, the relevant literature can be consistently analyzed using this TEV framework.

[10] 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.

[11] For this study, we propose to limit the analysis of benefits to Manitoba and qualitatively discuss benefits that can be attributable to other jurisdictions (i.e., rest of Canada, neighbouring US states).

Exhibit 2 Total Economic Value of Natural Resources (Adapted from Pascual and Muradian, 2010)



To estimate the full range of social values produced by ecosystems such as the one considered in this study, economists typically employ an array of market and non-market valuation methods.[12] A selection of market valuation methods include: (i) the **market price approach**, where an increase in an EG&S is multiplied directly by its observed market price (such as potable water, fish, or carbon); (ii) the **substitute cost approach**, where an increase in an EG&S allows for cost savings that are associated with a substitute good or service traded in the market (such as phosphorus recovery from wastewater used as a substitute for commercial fertilizer); (iii) the **damage cost avoided approach**, where expenditures are made to avoid the lost and decline of EG&S (such as the cost of removing nutrients from wastewater, or the cost of sequestering greenhouse gases (GHG)); and (iv) the **replacement cost method**, where expenditures are made to replace the EG&S that are no longer provided by a degraded ecosystem (such as the building of dykes to replace lost EG&S that control flooding). The substitute, damage, and replacement cost approaches typically specify dose-response functions, where changes in an EG&S (i.e., the dose) are related to biophysical changes (i.e., the response). Once the dose-response relationship is established, market prices can be applied, and consumer/producer surplus is computed which represents the value of EG&S change under consideration.

While market methods are relatively straight-forward, non-market methods are more complex. Generally, non-market methods attempt to estimate the maximum amount of money that

---

[12] For a discussion of the full range of valuation methods, see http://www.ecosystemvaluation.org/ dollar_based.htm

individuals in society are willing to pay for a change in a non-marketed good or service provided by a given ecosystem. The maximum willingness-to-pay (WTP) value is assumed to represent the level of economic surplus that is derived from the change in a good or service being valued.

Non-market valuation methods commonly used to value changes in EG&S include: (i) the **contingent valuation method**, which is a survey-based method that directly asks households about their maximum WTP for improvements in an EG&S; (ii) the **travel cost method**, which is another survey-based method that typically asks recreationists about their costs of recreating at different sites with varying EG&S (statistical analysis allows researchers to estimate the surplus associated with changing these goods and services); (iii) the **hedonic pricing method**, where linkages are drawn between property values and surrounding EG&S (again, statistical analysis allows researchers to estimate the consumer surplus[13] associated with changing these goods and services); and (v) the **benefit transfer method**, where researchers rely on previous non-market valuation studies at other ‘study’ sites and apply them to the ‘policy’ site under consideration.

We do not conduct primary valuation estimation in this analysis, but rather use the benefit transfer method as the valuation technique. Therefore, it seems appropriate to elaborate further on some of the important aspects of this approach. The benefit transfer method has become a popular method for valuation, largely due to time and resource constraints that limit the ability of researchers to conduct primary valuation studies. The benefit transfer method is not a single approach, but rather refers to a collection of related approaches. The three main approaches[14] to transferring values from the study site to the policy site are:

- **Unit value transfer** uses a single unit value point estimate from one study site or average unit value estimate from several study sites and applies this value to the policy site under consideration. It can be used to estimate the value of a change in an EG&S at the policy site by multiplying the change in the quantity of that good or service at the policy site by the mean unit value estimated at the study site. Unit values are presented as values per individual or household or values per unit of area. Adjustments to income or price levels are often made to account for differences between the policy and study sites. The main advantage of using unit value transfer is that it is simple and easy to understand. The main limitation of using unit value transfer is that it requires that the study site is similar to the policy site in content and context.

- **Value function transfer** uses the functional relationship between the value of a change in an EG&S and the socio-economic/biophysical characteristics at the study site (estimated using data from a study site) and applies this function to the policy site under consideration, using socio-economic/biophysical characteristics of the policy site. The main advantage of this approach is that it presents a systematic/precise way of transferring values compared to the unit value transfer approach. However, it shares the limitation of the unit value transfer in that it requires that the study site is similar to the policy site in content and context.

---

[13] In economics, consumer surplus is defined as the difference between the price that a consumer pays for a good in the market and their maximum willingness-to-pay for that good.

[14] Some academics include a new fourth approach: preference calibration. Preference calibration uses information from the study site to identify parameters that identify underlying preferences (Pattanayak et al., 2007). These preference relationships are then used to estimate benefits at the policy site. This relatively new transfer method has limited use in environmental economics because it requires the time-consuming specification of the structure of individual preferences.

- **Meta-analysis** uses unit value estimates and socio-economic/biophysical characteristics of a large number of study sites (usually more than 20) to estimate a unit value function that can be applied to a policy site using policy-site characteristics. Once applied to the policy site, the unit value estimated can be multiplied by the change in the EG&S to estimate the value of that change. The two main advantages of using a meta-analysis as a benefit transfer method are that it utilizes information from a large number of studies and the independent variables can be set at levels that are specific to the policy site. This second advantage allows, to some degree, the differences to be accounted for between the study site and the policy site. The main limitations of using a meta-analysis are that they are only as good as the quality of the underlying original valuation studies and the content and context of past studies need to be similar enough to be able to be combined and statistically analyzed.

Using the concepts of TEV, the value of an ecosystem can be presented using a common approach (i.e., economic valuation) and metric (i.e., dollars).[15]

It is important to emphasize here that many EG&S provided by ecosystems 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 2, namely on consumptive, direct use values, for which market values are often readily available. In this study we attempt to gather information on indirect, option and existence values in addition to direct-use values to facilitate a more robust economic assessment.

2.2 Cost-Benefit Analysis Approach

2.2.1 *Overview of Approach*

This section outlines the cost-benefit analysis approach used in this report. Cost-benefit analysis is an important decision-making tool to assess development scenarios in terms of their impacts on social welfare. The aim of cost-benefit analysis is to objectively compare the advantages and disadvantages of decisions in monetary terms. Fundamental to the theory of cost-benefit analysis lays two basic principles: first that, to the extent possible, all the costs and benefits arising from a project should be assessed; and second, that they should be measured using a common metric of value. Our approach draws upon the principles and guidelines provided by Environment Canada’s Analytical Framework for Decisions Involving Ecological Goods and Services. In addition, other sources have been consulted including the US Environmental Protection Agency (US EPA, 2002), the World Bank (Belli et al., 2002), the Green Book of the UK (HM Treasury, 2003), and the Canadian Cost-Benefit Analysis Guide for Regulatory Proposals (TBS, 2007a).

For this study, the analysis consists of nine tasks, which can be divided into three main phases.

Phase I - Update Background Report and Develop Scenarios

- Task 1: Develop cost estimates for chemical precipitation
- Task 2: Develop wastewater treatment strategies and scenarios

Phase II - Value the Costs and EG&S values of Wastewater Treatment Strategies

- Task 3: Summarize the potential costs of each strategy
- Task 4: Identify the potential EG&S values of each strategy
- Task 5: Quantify the potential EG&S values of each strategy

---

[15] All values in this report are in 2009 Canadian dollars unless specified otherwise.

- Task 6: Monetize the potential EG&S values of each strategy
- Task 7: Describe intangible EG&S values of each strategy

Phase III - Compare Costs and EG&S values of Wastewater Treatment Strategies

- Task 8: Compare benefits and costs.
- Task 9: Conduct sensitivity analysis

2.2.2 Phase I – Update Background Report and Develop Scenarios

The objective of the first phase is to update the previously discussed Background Report which provides detailed scenario and costing information on a number of the wastewater treatment strategies considered in this study. These included: (i) BNR; (ii) SBR; (iii) Land Application through Irrigation of Pre-treated Wastewater Effluent (pivot system vs. travelling gun); (iv) Wetlands (high vs. low cost).

The first task in this study involves developing cost estimates for the Chemical Precipitation strategy for wastewater facilities (lagoons) serving the three community sizes (see Exhibit 36 in Appendix C for cost details). The assumptions used in this cost estimation are congruent with those made in the Background Report for the other four wastewater treatment strategies (see the Background Report for details).

The second task involves defining the relevant scenarios to be assessed in this analysis. In the Background Report, the BNR and SBR treatment options were estimated to have the same costs. In addition, these two systems are expected to have very similar impacts on EG&S. Consequently, for our current analysis, these two treatment options are grouped together and analyzed as one strategy.

Additionally, as described in the Background document, the Land Application strategy consisted of two technologies with differing costs: pivot system and travelling gun. Finally, since there is much uncertainty regarding the costs associated with constructed wetlands (i.e., costs depend on the characteristics of the site, etc.), two classifications of wetlands were considered: those with a high cost vs. those with a low cost.

With these modifications, there are a total of six wastewater treatment strategies that are evaluated:

- BNR/SBR;
- Wetlands – high cost;
- Wetlands – low cost;
- Land application – pivot system;
- Land application – traveling gun;
- Chemical precipitation.

In this analysis we use the Chemical Precipitation strategy as a reference case strategy and compare the costs and EG&S values of the other wastewater treatment to this one. The main reason for setting a reference case strategy is due to the lack of information needed to quantify the EG&S improvements moving from a "no treatment" strategy to one of the treatment strategies considered in this study. Currently, the majority of small community wastewater treatment facilities in Manitoba do not have any advanced nutrient removal capabilities such as the strategies analyzed in this report (LWSB, 2009). However, between January 2007 and March 2009, four small wastewater treatment facilities that were required to implement nutrient reduction strategies all use chemical precipitation (Pers. Comm. Nicole Armstrong). Therefore, using the Chemical Precipitation strategy as the status quo strategy moving forward is an appropriate assumption to make.

Consequently, we assess the costs and benefits of five wastewater treatment strategies (BNR/SBR, Wetlands - high vs. low cost, and Land Application - pivot system vs. travelling gun) relative to a common reference case (Chemical Precipitation).

Another important point to consider in formulating the scenarios is that the design of each treatment system was based on achieving proposed wastewater effluent design criteria for various parameters (total suspended solids, total phosphorus, *E. Coli*, etc.). These uniform criteria imply that all of the wastewater treatment strategies except one (Land Application) will have the same phosphorus reductions and associated phosphorus reduction EG&S benefits. However, there are other EG&S values unique to each strategy (as discussed below), which are evaluated relative to the reference case (Chemical Precipitation).

The implication of this last point is that because the analysis is a cost-benefit analysis of moving from the Chemical Precipitation strategy to the other three wastewater treatment strategies and all strategies have similar phosphorus reduction capabilities (except for Land Application), the additional EG&S benefits of each strategy is somewhat limited.

2.2.3 Phase II – Value the Costs and EG&S Values of Wastewater Treatment Strategies

The potential private financial costs from implementation of wastewater treatment strategies considered in this study (with the exception of the Chemical Precipitation strategy) were estimated in the Background Report.[16] Please consult the Background Report for a breakdown of the costs and a full discussion of the embedded assumptions. The discounted private financial costs for the wastewater treatment strategies are presented in Section 4.1.

To analyze the potential EG&S values realized by the implementation of different wastewater treatment strategies, we follow three main tasks (details are presented in Section 3):

1. Identify
2. Quantify
3. Monetize

Identify: This first step for the EG&S value analysis involves the full articulation of the potential EG&S values realized by the implementation of the different wastewater treatment strategies. This step uses the typology of EG&S proposed by The Economics of Ecosystem and Biodiversity (TEEB) as a framework (TEEB, 2010). These EG&S values are linked to relative changes in human and environmental impacts.

---

[16] As noted above, the costs of chemical precipitation was estimated as part of this report.

Quantify: This second step involves determining 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) and associating the change in human and environmental impacts with quantifiable human and/or environmental indicators such as tonnes of greenhouse gas (GHG) emissions and cubic meters (m^3) of avoided water use.

Monetize: This third step monetizes the quantified EG&S values to the extent possible. We base our valuation analysis on a range of valuation techniques, including the Avoided Cost Approach, the Social Cost Approach, the Market Price Approach, and the Benefits Transfer Method (meta-analysis approach), as introduced in Section 2.1. However, as discussed below, we do not include primary research on dose-response functions or meta-analysis in this study. Rather, we rely largely on previous studies that have conducted this analysis.

It is important to note that the focus of these three steps is on the incremental EG&S values attributable to the five wastewater treatment strategies compared to the Chemical Precipitation strategy. For example, if implementing the Wetland strategy improves an environmental service by X and implementing the Chemical Precipitation strategy improves the same environmental service by Y, the relevant EG&S is the difference, X-Y. Similarly, if implementing the Chemical Precipitation strategy degrades an environmental service by Z and the other wastewater treatment strategies do not change the same environmental service, then the relevant EG&S is Z (i.e., the avoided value loss to the environmental service).

Non-monetized EG&S Values

Intangible EG&S values are those that cannot be assigned a monetary value. These include EG&S values that are not quantified, and EG&S values that are quantified, but not monetized. This may be the case when data is not available or if it is not clear how to quantify/measure the value even with data. Although not monetized, it is important to identify and include these types of EG&S values in the analysis.

2.2.4 *Phase III – Compare Costs and EG&S Values*

In this analysis, we are using the Chemical Precipitation strategy as the reference case and comparing to the other five wastewater treatment strategies. Consequently, we compute the net benefits of moving from the Chemical Precipitation strategy to each of the other wastewater treatment strategies.

For costs, we subtract the financial costs of each alternative wastewater treatment strategy from the financial costs of the Chemical Precipitation strategy. For benefits, we first assess the relative increase in each EG&S from each alternative treatment strategy compared to the Chemical Precipitation strategy, and multiply this quantity by a unit value (produced from our market or non-market valuation methods) to produce the relative benefit. The relative costs and benefits are compared in a cost-benefit analysis in order to help provide insight into the most appropriate strategy.

All values in this analysis are presented in present value form (i.e., discounting future values). The discount rates employed are discussed below.

A sensitivity analysis is also conducted on important variables. Specifically, we examine the effects of changing the value of nitrogen, the value of carbon, the quantity of avoided irrigation water and the discount rate.

2.2.5 *Discount Rate*

The stream of costs and EG&S values of a policy or investment are usually spread over several years. As noted above, we are considering a 20 year time horizon. Therefore, we are aggregating the stream of ongoing operation costs and EG&S values. Discounting is used to aggregate these future 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 agreement 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.[17] 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.

Current “interim” guidelines from the Federal Treasury Board Secretariat (TBS, 2007b) use a weighted social opportunity cost rate of capital approach to recommend a SDR of 7% with sensitivity rates of 3% and 10%.[18] However, this choice has been severely criticized for not reflecting the empirical or theoretical literature. Using the social time preference rate approach, Boardman et al. (2009) proposes that Canada should use a SDR of 3.5% with sensitivity rates of 2% and 5% for intragenerational projects, and a SDR between 2% and 5% for intergenerational projects.

The research and policy trends in other countries also support using a relatively lower social discount rate. In the USA, Moore et al. (2004) proposes a SDR of 3.5% in many circumstances. The EPA is currently reviewing its guidelines for economic analysis, including the recommended discount rate. The United Kingdom government has recently lowered their recommended SDR from 6% to 3.5% (HM Treasury, 2003). Finally, in France, a reduction in the SDR from 8% to 4% has recently been recommended by a group of experts commissioned by the ministry of Finance (Lebegue et al., 2005). Recommendations and use of even lower discount rates exist as well. In his now famous report on the economics of climate change, Stern (2006) uses a SDR of 1.3%.[19]

For the purpose of this economic analysis, we present our results in undiscounted terms, and using two different SDRs of 3% and 7% as recommended by the TBS (2007b). We use a SDR of 3% as our central rate, and examine the effects of using a 0% and 7% SDR in the sensitivity analysis.

2.2.6 *Data Sources*

Information and data sources were compiled from an extensive literature search of relevant economic databases, recent conference presentations and Marbek’s past work. Economic

---

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

[18] Until these new guidelines, the TBS required the use of a real SDR of 10%, then 8%.

[19] It is important to note that, because Stern’s analysis took place in an uncertain environment, his Monte Carlo simulations actually used thousands of SDRs. The reported value is the central or average SDR.

databases consulted include several of the world's largest abstract and citation databases of research information, peer-reviewed articles and quality internet sources (ECONLIT[20], Repec[21] and Scopus[22]). In addition, primary valuation data came from Environment Canada's Environmental Valuation Reference Inventory (EVRI).[23] We focus on using studies and research that is most relevant to the Lake Winnipeg watershed. Where possible, we base our results on peer-reviewed studies. However, due to the paucity of empirical evidence regarding some of the EG&S value categories, methods and data from other "grey sources" of literature are also referenced, such as working papers, reports commissioned by industry and environmental NGO's, and others. Demographic data regarding population densities are from Statistics Canada.

2.3 Uncertainties and Limitations

There are a number of uncertainties and limitations related to this study. These are discussed in this section.

2.3.1 Uncertainties

Below is a list of some of the most important uncertainties associated with this study.

- **Biophysical changes in EG&S.** The environmental response to intervention measures is complex and typically non-linear. Some environmental conditions are inter-related in ways that are not fully understood, such as water clarity, algal blooms, and fish habitats. Therefore, the actual benefits may be greater or less than assumed by the functions and values employed from the literature.
- **Timing of benefits**. Our analysis assumes that, while construction costs of a new wastewater treatment facility occur over one year, EG&S benefits are derived over the next 19 years (by an equal amount per year). The benefits derived from restoration may vary depending on the restoration measures and the period of time considered. However, certain benefits may be more significant directly after construction (e.g., nutrient loadings for fertilizer use), while other benefits may take several years to ensue (e.g., carbon sequestration in wetlands). Therefore, the actual benefits may be greater or less than assumed.
- **Unit values of non-market benefits**. There are inherent uncertainties involved in nonmarket valuation. These uncertainties are compounded when using the benefit transfer method as value estimates are transferred from study sites to the policy site. For example, some empirical literature suggest that the WTP of Canadians for certain EG&S is lower than many other jurisdictions such as the USA or Europe (Johnston and Thomassin, 2010). However, robust cross-country comparisons of WTP for the exact same EG&S are often lacking. Therefore, it is uncertain whether additional adjustments to WTP estimates derived outside of Canada are necessary for application in the Canadian context.
- **Tradeoffs between EG&S. T**here may be trade-offs among different ecosystem services. For example, there may be an explicit trade-off between water purification services of wetlands and gas regulation. Wetland soils that denitrify wastewater and improve water quality in receiving waters may convert this nitrogen to nitrous oxide (N_20) and release it into the atmosphere, thus negatively impacting the GHG balance of wetlands (Elmqvist and Maltby, 2010).

---

[20] http://www.aeaweb.org/econlit/index.php
[21] http://repec.org/
[22] http://www.scopus.com/
[23] http://www.evri.ca

- **Environmental thresholds**. There is the potential for thresholds to be a limiting factor in EG&S valuation. In the presence of environmental thresholds or "tipping points", the marginal values inherent in economic analysis may not be the most appropriate measure of value.

2.3.2 Limitations

Our analysis has the following limitations:

- This analysis focuses on answering the question: what are the costs and benefits of different wastewater treatment strategies? Therefore, this analysis examines the aggregate costs and benefits of the wastewater strategies. However, the important question of *who* benefits and bears the burden of costs remains unanswered. Determining the distribution of costs and benefits on affected stakeholders is beyond the scope of the current project.
- The analysis of the benefits deals primarily with the quantity (e.g., wetland hectares) of EG&S and does not necessarily take into account changes in the quality of these goods and services. This is an important limitation of our study and the EG&S valuation literature in general. Incorporating changes in EG&S quality into our analysis would require information on the specific state of the wetland ecosystem and valuation estimates that link varying qualities of wetlands to economic benefits. Both of these pieces of information were lacking at the time of study.
- In quantifying all benefits, a full-life cycle analysis of the wastewater treatment strategies was not conducted and therefore, not all of the potential environmental impacts of the wastewater treatment strategies were quantified. This is particularly important for the carbon impacts. This analysis only considered operational energy use and carbon storage and sequestration of wetlands. However, other carbon impacts exist. For example, Chemical Precipitation requires aluminum sulphate products that need to be continuously extracted, processed and transported to the wastewater treatment site. All these activities involve the combustion of fossil fuels, and consequently, the emission of GHG emissions. In addition, these secondary environmental impacts can be potentially significant.[24]
- In developing the benefits, we were not able to monetize all benefits. This is an important limitation of the nonmarket valuation literature in general. In addition, we do not consider benefits to individuals residing outside of the studied watershed.[25] The non-monetized benefits relevant to this analysis are described in Section 3.4.
- This analysis relies on the avoided cost approach to value the incremental nutrient reduction benefits. Developing economic welfare estimates associated with reducing nutrients from these facilities is problematic for two reasons. First, the difference between a community using these secondary wastewater treatment strategies and meeting the proposed wastewater effluent criteria (Exhibit 4) is relatively insignificant for overall nutrient loads into Lake Winnipeg given the large number of relatively small nutrient loads to Lake Winnipeg. Therefore, we are dealing with rather negligible improvements in surface water quality. Second, scientific limitations impact our ability to develop robust assumptions regarding some of the environmental changes and improvements attributable to reducing phosphorus flows into Lake Winnipeg. Changes in conditions in the Lake, such as temperature and currents, will cause variability in the impacts in the Lake of stressors such as nutrients and suspended solids. In addition, the scientific relationships between variables are not fully understood. For example, the specific relationship between phosphorus loadings and algal blooms is not documented to the degree that a reduction in

---

[24] Appendix B presents a summary of recent life-cycle analyses of wastewater treatment strategies.

[25] The exception to this statement is the benefits associated with the carbon impacts. The social cost of carbon is based on the estimates of marginal damages to individuals residing inside and outside the Lake Winnipeg basin.

phosphorus loading can be used as a predictor of algal bloom reductions; this relationship cannot be assumed to be linear given other variables such as temperature. It is generally believed that avoided cost methods understate the true EG&S values (i.e., the maximum WTP) to reduce nutrients (EPA, 2007).

- This analysis assumes the wastewater effluent is needed for irrigation under the Land Application strategy. However, in years with high precipitation, the need for irrigation (and therefore wastewater effluent) will be reduced. On the other hand, in years of lower precipitation, the value of avoided irrigated water will be higher. The extent of these demand fluctuations is uncertain.

3 Analysis

This section presents details of the analysis to identify, quantify and monetize the changes in EG&S of the various wastewater treatment strategies relative to the Chemical Precipitation strategy.

3.1 Identifying EG&S

This section presents the approach to identifying the EG&S impacted by the wastewater treatment strategies considered in this study. Wastewater treatment plants have a variety of environmental impacts. Traditionally, the emphasis of environmental regulations and permits has been on nutrient removal requirements and surface water quality standards, and has ignored the other environmental impacts of wastewater treatment facilities (Foley et al., 2010). However, a growing body of scientific and engineering literature is identifying a wide range of environmental impacts such as GHG emissions, acidification, ecotoxicity and ozone layer depletion (Foley et al., 2010; Machado et al., 2006; Hospido et al., 2004). In addition, a complementary body of literature is identifying a range of positive economic benefits associated with certain wastewater treatment strategies, such as carbon sequestration and biodiversity benefits (Ko et al., 2004; Ghermandi et al., 2009).

Life Cycle Assessments (LCA) are becoming increasingly utilized to evaluate the environmental performance of wastewater treatment facilities (Foley et al., 2010). There have been several applications of LCA to wastewater treatment systems as summarized in Appendix B (Hospido et al., 2004; Machado et al., 2006; Gallego et al., 2008; Weiss et al., 2008; Pasqualino et al., 2009; Dogan et al., 2010; Foley et al., 2010). These studies have shown that the environmental impacts of wastewater treatment facilities extend beyond issues surrounding surface water quality. In addition to the environmental impacts of the wastewater treatment facilities themselves, the final disposal of sludge also carries consequences for the environment (Hospido et al., 2004).

Using the environmental impacts identified from LCAs of wastewater treatment facilities as a basis, it is necessary to integrate the environmental impacts into the TEV framework and link these impacts with specific EG&S value categories. In addition, other values that have not been considered in the LCAs should also be included. Some of the environmental impact categories are closely associated with EG&S categories while other environmental impact categories have more indirect links with EG&S categories. For example, the environmental impact of climate change is associated with GHG emissions. Therefore, the relevant EG&S category is Gas Regulation.

Exhibit 3 outlines the various impacted EG&S associated with the wastewater treatment strategies considered in this study.

Exhibit 3 Identified EG&S Associated with the Wastewater Treatment Strategies

EG&S	BNR/ SBR[a]	FWS Wetland	Chemical Precipitation	Land Application
Nutrient Reduction	Yes	Yes	Yes	Yes
Biosolids	Yes	Yes	Yes[b]	Yes
Biogas Potential	Yes	Yes	Yes	Yes
Amenity and Aesthetic		Yes		Yes
Hunting		Yes		
Wildlife Watching		Yes		
Gas Regulation[c]	Yes	Yes	Yes	
Water Supply				Yes[d]
Water Regulation		Yes		Yes
Soil Retention		Yes		
Natural Habitat, Biodiversity		Yes		
Option Values	Yes	Yes	Yes	Yes
Non-Use Values	Yes	Yes	Yes	Yes

Notes:

a As noted earlier, BNR and SBR are considered together because they have similar costs and environmental impacts.

b The scientific literature is highly uncertain to the degree in which chemical precipitation reduces the amount of nutrients available for re-use.[26] A large part of the uncertainty is how long the chemical bonds between the alum and phosphorus holds.

c Gas Regulation is EG&S terminology referring to both local and global air pollutants.

d Reduces the need for irrigation and watering of agricultural crops.

3.2 Quantifying Ecological Goods and Services

This step involves quantifying, to the extent possible, the identified EG&S associated with the wastewater treatment strategies considered in this study. The EG&S that are not quantified/monetized are presented in Section 3.4, along with the primary reasons for not formally including them in this analysis. The EG&S quantified in this study include:

- Nutrient Reduction
- Biosolids
- Gas Regulation
- Water Supply
- Other EG&S

---

[26] See for example a comparison of plant growth using a variety of phosphorus sources, including wastewater sludge in Weinfurtner et al., (2009).

3.2.1 Nutrient Reduction

There are two main nutrients that are included in this analysis: nitrogen and phosphorus. However, the phosphorus reductions only apply to the Land Application strategy. The other wastewater treatment facilities are all designed to meet the proposed phosphorus effluent criteria as outlined in the Background Report and shown in Exhibit 4. In the case of the Land Application strategy, the wastewater effluent is applied directly to agricultural land and hence, the nutrients do not flow directly into Lake Winnipeg. Therefore, for this treatment strategy, it is necessary to include the incremental reduction in phosphorus loadings into the Lake beyond the proposed wastewater effluent criteria (which would be met under the reference case Chemical Precipitation strategy). Consequently, we need to determine the nutrient load differences between meeting the effluent criteria and the Land Application strategy (i.e., no net phosphorus deposited into the Lake).[27]

Exhibit 4 Background Report Target Wastewater Effluent Criteria

Parameter	Effluent Design Criteria (mg/L) – Monthly Averages	Comment
$cBOD_5$ (Carbonaceous Biochemical Oxygen Demand – 5 day)	25	Never to Exceed
Total Suspended Solids (TSS)	25	Never to Exceed
Total Phosphorus	1	30-day Rolling Average
Total Nitrogen	<15	30-day Rolling Average
NH_3 (Ammonia)	Loading Based	Daily Targets
E. Coli	200	Monthly Geometric Mean

Notes:
1. CBOD and TSS limits are based on the Canada-Wide Strategy for Municipal Wastewater Effluent (CCME, 2009).
2. Ammonia limits (loads) are part of Manitoba's approach to licensing wastewater treatment facilities.

For phosphorus reductions associated with the Land Application strategy, the approach to quantifying the reduction in phosphorus is to determine the volume of phosphorus that would be deposited into the Lake under the target wastewater effluent criteria. As noted above, this quantity is the amount of avoided phosphorus flowing into the Lake under the Land Application strategy. As shown in Exhibit 4, the effluent criterion for phosphorus is 1 mg/L which is equivalent to 0.001 kg/m^3.

For nitrogen, a similar approach is used to quantify the incremental reduction. However, in this case, we need to determine the incremental difference in expected effluent quality between the different wastewater treatment strategies and the reference case. Because Chemical Precipitation does not remove additional nitrogen, Chemical Precipitation results in the target wastewater effluent criteria for nitrogen of 15 mg/L. Most small wastewater treatment facilities in Manitoba are wastewater lagoons and total nitrogen concentrations in lagoon effluent are expected to be about 15 mg/L. As shown in Exhibit 5, the various wastewater treatment strategies have different expected effluent nitrogen concentration levels. These expected effluent nitrogen concentration levels are subtracted from the effluent nitrogen concentration level of Chemical Precipitation to derive the incremental reductions in nitrogen concentration levels.

---

[27] It should be noted that although run-off of effluent based nutrients from agricultural lands will occur under land application, these effluent based nutrients are assumed to displace synthetic fertilizer and therefore, no net nutrients flow into the Lake with land application.

Exhibit 5 Nitrogen Reduction Effectiveness from the Background Report

Strategy	Expected Effluent Quality	Effluent Quality Calculation	Incremental Nitrogen Concentration Reductions from Reference Case (Chemical Precipitation in a Wastewater Lagoon 15mg/L)
SBR	5 to 8 mg/L	8 mg/L[a]	7 mg/L
BNR	8 mg/L	8 mg/L	7 mg/L
Wetlands	66 % nitrogen removal	10 mg/L	5 mg/L
Land Application	0 mg/L	0 mg/L	15 mg/L

Notes:
[a] Conservative and same as BNR

Using these incremental nutrient concentration reductions from the reference case, we can now use the different wastewater effluent volumes for each community size considered in this study (i.e., a community of 500, 2,000, and 10,000 people) to determine the incremental nutrient loading reductions. An example calculation of the phosphorus reductions using the Land Application strategy for a community of 2,000 people, which has an average daily wastewater flow of 800 m^3, is,

$$0.001\ kg/m^3 \times 800\ m^3/day \times 365\ days/year = 292\ kg\ of\ phosphorus\ each\ year.$$

A similar calculation is conducted for nitrogen and the other community sizes to yield the incremental amount of nutrients removed from the Lake Winnipeg Basin and summarized in Exhibit 6.

Exhibit 6 Incremental [a] Annual Nutrient Reduction

Strategy	Nutrient (kg)	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	Avoided Nitrogen	511	2,044	10,220
	Avoided Phosphorus	N/A	N/A	N/A
Wetland	Avoided Nitrogen	730	2,920	14,600
	Avoided Phosphorus	N/A	N/A	N/A
Land Application	Avoided Nitrogen	1,095	4,380	21,900
	Avoided Phosphorus	73	292	1,460

Notes:
[a] The term "incremental" refers to an amount in excess of the reference case wastewater treatment strategy (i.e., chemical precipitation in a wastewater lagoon)

3.2.2 Gas Regulation

The different wastewater treatment strategies will have differing impacts on gas regulation. The quantitative focus of this section is on GHG emissions as represented by tonnes of carbon dioxide equivalent (tCO_2 eq).[28] Conducting a full GHG quantification assessment for the all

---

[28] Other local air pollutants that have been associated with wastewater treatment plants, such as sulphur oxide, are not included in this analysis due to data limitations. Appendix B presents a list of life-cycle assessments of wastewater treatment systems. These sources may be consulted for additional information on the impact of various wastewater treatment systems for a wider class of air pollutants.

wastewater treatment strategies (i.e., the LCA of GHG emissions) is beyond the scope of the present study. In this report, we focus on the two main sources of GHG: GHG emissions associated with the operation of wastewater treatment facilities (i.e., fossil-fuel energy used); and, carbon storage and sequestration in wetlands.

Electricity consumption is an important factor in the overall environmental performance of wastewater treatment facilities (Gallego et al., 2008). However, relative to other jurisdictions, electricity generation in Manitoba is relatively GHG emission free. Manitoba is overwhelmingly supplied by hydro power production and has a very low operating GHG emission content. For example, the GHG emission factor (kg of CO_2 eq/kWh) in Manitoba is 0.013 kg of CO_2 eq/kWh compared to 0.805 kg of CO_2 eq/kWh in Alberta (RETScreen, 2010).[29] The annual quantity of electricity used by the different wastewater treatment facilities are multiplied by the GHG emission factor for Manitoba.

An example calculation of the annual operational electricity consumption from using BNR/SBR for a community of 10,000 people, which has an average annual electricity use of 1,316,817 kWh, is,

1,316,817 kWh x 0.013 kg of CO_2 eq /kWh x 10% Transmission and Distribution Loss x 1 tonne/1000kg = 18.8 tonnes of CO_2 eq.

The second category of gas regulation relates to carbon storage and sequestration by wetlands. Although wetlands sequester carbon, they also release methane (CH_4) and nitrous oxide (N_20) emissions. Therefore, in determining the net GHG impact for wetlands, we subtract these emissions from the gross carbon sequestration rate. There have been several recent estimates of the soil organic carbon (SOC) storage change rates of wetlands that are suitable for use in this study. Bedard-Haughn et al. (2006) estimated that wetlands in St. Denis National Wildlife Area in Central Saskatchewan sequester 3.8 tCO_2 eq per hectare per year (not including CH_4 and N_20 emissions). Euliss Jr. et al. (2006) estimated that wetlands in the Prairie Pothole Region of North America sequester 11.2 tCO_2 eq per hectare per year (not including CH_4 and N_20 emissions). Presenting preliminary research, Badiou et al. (2008) estimate that, in the Prairie Pothole Region of North America, restored wetlands are capable of sequestering 11.8 tCO_2 eq per hectare per year. However, including CH_4 and N_20 emissions from wetlands, they calculate the net sequester rate is 9.6 tCO_2 eq per hectare per year (with a range 7.3 to 11.8 tCO_2 eq).

Because we are interested on the net impact of wetlands on carbon storage, it is pertinent to include CH_4 and N_20 emissions. Consequently, we use the net sequester rate of 9.6 tCO_2 eq per hectare per year from Badiou et al. (2009).[30]

The above carbon impact categories are used to determine the carbon impacts associated with each of the treatment strategies. Exhibit 7 presents a summary of the carbon impacts for the BNR/SBR, Wetland, and Chemical Precipitation strategies. Here, incremental impacts of BNR/SBR and Wetland strategies are calculated by subtracting the BNR/SBR and Wetland impacts from the Chemical Precipitation strategy impacts.

---

[29] GHG emission factors for electricity calculate the amount of GHG emissions (kg of CO_2 eq) used in the production of electricity (kWh). These GHG emission factors exclude transmission and distribution (T&D) losses which are generally around 10%.

[30] There is some evidence that wetlands sequester more carbon in their first years (year 1 through 5), than their later years (year 6 through 10) (Euliss Jr. et al., 2006). However, gas regulation dynamics in wetlands is an uncertain science and for the purpose of this analysis we keep the annual sequester rate constant at 9.6 tCO_2 eq per hectare.

Exhibit 7 Summary of Carbon Impacts

Treatment Strategy	Annual Carbon impacts (tCO_2 eq)			Incremental Carbon Impacts (tCO_2 eq)		
	Population = 500	Population = 2,000	Population = 10,000	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	0.6	1.6	18.8	0.3	1.1	18.1
Wetland	-38.4	-384.0	-768.0	-38.7	-384.4	-768.7
Chemical Precipitation	0.3	0.4	0.7			

Notes: Negative values represent carbon sequestered, while positive values represent GHG emissions.

3.2.3 *Biosolids*

Several of the wastewater treatment strategies will allow for the recovery of biosolids (nutrients) that can be used to displace synthetic fertilizers. We calculate the physical amount of biosolids produced (and fertilizer avoided) in two steps:

1. Use the results of the Background Report to determine the annual amount of recoverable nutrients for the different wastewater treatment facilities.
2. Determine the avoided quantity of synthetic fertilizer.

Exhibit 8 presents the annual amount of recoverable nutrients for the three community sizes. These results come from the Background Report.

Exhibit 8 Annual Recoverable Nutrients

	Recoverable Nutrients (kg)					
	Population = 500		Population = 2,000		Population = 10,000	
Treatment Strategy	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
BNR/SBR	730	365	2,920	1,460	2,920[a]	1,460[a]
Wetland	183	365	730	1,460	3,650	7,300
Land application	1,278	365	5,110	1,460	25,550	7,300
Chemical precipitation	183	365	730	1,460	3,650	7,300

Notes:

[a] As costed in the Background Report, for communities of 10,000 people, the BNR/SBR biosolid disposal option is composting rather than land application. It was assumed that this compost material will be given away for free. The degree to which this composting material would be used on agricultural lands and displace synthetic fertilizer is unknown. To the degree that the compost material is used to displace synthetic fertilizer, the benefits of BNR/SBR for communities of 10,000 will be underestimated in this report. In this analysis, we consider that for communities of 10,000 people, the same amount of nutrients are land applied as the communities of 2,000 (at the same cost), and the rest of the biosolids are composted. Therefore, the potential recoverable nutrients are the same for communities of 2,000 and 10,000 for BNR/SBR.

The second step involves determining how much synthetic fertilizer is displaced due to the application of biosolids. Although applying wastewater sludge to agricultural land reduces the need for synthetic fertilizers, there is uncertainty in the degree to which nutrients in sludge can substitute for synthetic fertilizer due to several factors such as soil properties and spreading techniques. Nutrient substitutability will vary across the different wastewater treatments. Substitutability between nutrients in sludge and synthetic fertilizer has been generally found to be less than 100% because nutrients in synthetic fertilizer are generally more available for plants compared to nutrients in sludge. The exception is the BNR/SBR processes considered in the Background Report which included enhanced P removal. In this case, the biosolids have the same phosphorus and nitrogen bioavailability as fertilizer (i.e., 100%) (O'Connor et al., 2004).

The remaining wastewater treatment strategies have sludge vs. synthetic fertilizer nutrient substitutability of less than 100%. In a widely cited study, Bengtsson et al. (1997) use a nutrient substitutability factor of 70% for phosphorus and 50% for nitrogen for the Land Application strategy. These factors imply that for every one kilogram of nitrogen in synthetic fertiliser displaced, two kilograms of nitrogen in sludge needs to be applied to the land. These values have been extensively used in subsequent literature (Lundin et al., 2004; Houillon et al., 2005; Gallego et al., 2008; and Hospido et al., 2010) and we assume the same degree of substitutability in this analysis for the Land Application and Wetland strategies. For the Chemical Precipitation strategy, O'Connor et al. (2004) indicate that the substitutability is on average 48% for the P availability of biosolids from the coagulant process. Therefore, in the case of the Chemical Precipitation strategy, we use 50% from Bengtsson et al. (1997) for nitrogen and 48% for phosphorus.

Exhibit 9 displays the incremental synthetic fertilizer displaced by BNR/SBR, Wetland, and Land Application strategies (relative to the Chemical Precipitation strategy).

Exhibit 9 Incremental Synthetic Fertilizers Displaced

Treatment Strategy	Recoverable Nutrients (kg)					
	Population = 500		Population = 2,000		Population = 10,000	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
BNR/SBR	638.8	189.8	2,555.0	759.2	1,095.0[a]	-2,044.0[a]
Wetland	0.0	80.3	0.0	321.2	0.0	1,606.0
Land application	547.5	80.3	2,190.0	321.2	10,950.0	1,606.0

Notes:

[a] As noted above, the potential recoverable nutrients are the same for communities of 2,000 and 10,000 for BNR/SBR. Consequently, for BNR/SBR, the incremental synthetic fertilizer displaced (relative to Chemical Precipitation) is lower for communities of 10,000 people than communities of 2,000.

It should also be noted that applying biosolids to agricultural land can only be done as long as heavy metals in the sludge are at admissible levels. This is not expected to be a concern for small communities in Manitoba that do not have industrial wastewater contributions (Pers. Comm. Nicole Armstrong).

3.2.4 *Water Supply*

The Land Application strategy involves spreading wastewater effluent (i.e., wet effluent) over agricultural lands, which can act as a substitute for withdrawing water directly from the Lake Winnipeg Basin for irrigation purposes. While we know the volume of the average wastewater flow for the different community sizes, we do not know the potential relationship between the volume of wet effluent spread on the agricultural land and the amount of displaced agricultural water use. There are several reasons to believe that there is more wastewater flow available than the amount of displaced agricultural water. For example, raw wastewater typically flows into holding lagoons before being transported and applied to the land, and evaporation and infiltration into the soil will decrease the available wet effluent. In addition, the timing of the Land Application strategy may not be when the farmer would have irrigated his crops and therefore the substitutability between wet effluent and irrigation water may be less than 100%.

To account for these issues, but still provide robust estimates, we consider three scenarios of potential water use avoided: a low scenario where 50% of the wet effluent displaces irrigation water, a middle scenario where 70% of the wet effluent displaces irrigation water and a high scenario where 90% of the wet effluent displaces irrigation water. Exhibit 10 presents the resulting incremental water use avoided due to the Land Application strategy for the different community sizes and scenarios.

Exhibit 10 Incremental Water Use Avoided due to Land Application for the three Scenarios

Water Use Avoided (m^3/year)	Population = 500	Population = 2,000	Population = 10,000
Low scenario	36,500	146,000	730,000
Middle scenario	51,100	204,400	1,022,000
High scenario	65,700	262,800	1,314,000

Notes:
The low, middle, and high scenarios are associated with 50%, 70%, and 90% of the wet effluent displacing irrigation water.

The annual values provide the quantity of irrigation water avoided due to the Land Application strategy. We present the middle scenario in our cost-benefit analysis, and examine the low and high scenarios in the sensitivity analysis section.

3.2.5 Other EG&S

The Wetland strategy provides a host of unique EG&S not provided by other strategies. These include amenity, biodiversity, recreation, commercial activity (e.g., fishing, hunting), spiritual, bequest, and other such services (see Ghermandi et al., 2009).

As explained in the subsequent section, the approach used to monetize the value of these 'other' wetland EG&S relies on the Benefit Transfer Method (meta-analysis approach). To conduct a robust benefit transfer, we use the meta-analysis approach of Ghermandi et al. (2009), together with the following three key variables:[31]

1. Population density within 50km radius of wetland site (people per km^2);
2. Size of wetland site (ha); and,
3. Degree of human pressure.

Population density estimates for Manitoba from Statistics Canada's 2006 Census show that there is an average of 2.1 people per square kilometre. For wetland size, we use the same areas as the Background Report. As determined in the Background Report, the three communities of 500, 2,000 and 10,000 people have constructed wetlands of 4, 40 and 80 hectares, respectively.

In addition, for the meta-analysis, we need to determine the degree of anthropogenic pressure exerted on the constructed wetlands. Ghermandi et al. (2010) consider three binary variable criteria to determine the state of human pressure: alterations in the natural hydrologic regime of wetland (yes = 1, no = 0), whether the wetland is located in an urban or rural setting (urban = 1, rural = 0) and the wetland's protection status (not protected = 1, protected = 0). These criteria rank from lowest level of human pressure (all human pressure variables 0 - low) to the highest level of human pressure (all three human pressure variables 1 - high) with two intermediate states (one human pressure variables 1 (medium-low) and two human pressure variables 1 (medium-high)). In our analysis, the wetlands in the Wetland strategy generally have alterations in the natural hydrologic regime of the wetland, are located in rural areas, and can be considered protected. Therefore, the wetlands are considered to have medium-low human pressure (one binary variable is 1).

---

[31] GDP per capita and wetland area in 50km radius were not found to be statistically significant in the model version used in this analysis and are therefore excluded from our regression equation.

3.3 Monetizing EG&S

This section monetizes the quantified EG&S associated with the five wastewater treatment strategies. Exhibit 11 outlines the approaches to monetizing these EG&S.

Exhibit 11 Approaches to Monetizing the EG&S Associated with the Five Wastewater Treatment Strategies.

EG&S	BNR/ SBR	FWS Wetland	Land Application	Chemical Precipitation
Nutrient Reduction	Damage Cost Avoided	Damage Cost Avoided	Damage Cost Avoided	Damage Cost Avoided
Gas regulation	Damage Cost Avoided	Damage Cost Avoided	Damage Cost Avoided	Damage Cost Avoided
Biosolids	Substitute Cost	Substitute Cost	Substitute Cost	Substitute Cost
Water Supply	-	-	Market Price	-
Wetland Services	-	Benefit Transfer Method	-	-

3.3.1 *Phosphorus Reduction*

We assess the marginal value of reducing incremental phosphorus flows into Lake Winnipeg from the Land Application strategy using the damage cost avoided approach. Specifically, the marginal value of phosphorus reductions in Lake Winnipeg can be estimated by the expenditures associated with eliminating phosphorus from wastewater effluent.

Various abatement actions from point and non-point sources have a wide array of costs. For example, one study in the 1990s that estimated abatement costs of phosphorus can range from $13 to $5,876 per kg for sewage treatment plants, $676 to $3,004 per kg for industry and $39 to $78 per kg for agriculture (International Joint Commission, 1998). Olewiler (2004) reports the cost to remove nitrogen and phosphorus fall in the range of $3.20 to $9.09 (average of $6.15) per kg for nitrogen and $24 to $65 per kg for phosphorus for wastewater treatment plants.

Most relevant for our purposes, it has been estimated that the City of Winnipeg is planning to invest approximately $670 million in wastewater treatment infrastructure to reduce nutrients into Lake Winnipeg (McCandles et al., 2008; Shkolny, 2008).[32] Associated Engineering (2008) estimated that 7% ($46.9 million) of these total capital costs provide nitrogen removal. In addition, another 60% of the costs can be attributed to converting ammonia to nitrogen (Pers. Comm. Nicole Armstrong). Therefore, the remaining $222.1 million is spent to reduce phosphorus emissions. Annualizing over 20 years, the annual cost to reduce phosphorus is estimated to be $36.85 per kg.[33] For nitrogen, it is not certain whether the costs of converting ammonia to nitrogen should be included in the costs of nitrogen removal. Annualizing both the costs of converting ammonia to nitrogen ($402 million) and the direct costs of nitrogen removal ($46.9 million), yields a cost per kg of nitrogen of $14.96, while annualizing only the direct costs

---

[32] It should be noted that this costs includes only the capital costs of plant upgrades and excludes the incremental operating and maintenance costs. Therefore, the avoided costs calculated in this section may underestimate the actual avoided costs.

[33] An annual total of 300 tonnes of phosphorus is expected to be removed.

of nitrogen removal ($46.9 million) yields a cost per kg of nitrogen of $1.56.[34] Clearly, whether or not these additional costs are included significantly impacts the results. Because of the uncertainty regarding which costs to include, we consider the average of these two unit costs which is $8.26.

For our analysis, we use the per kg abatement cost estimate of $8.26 and $36.85 for nitrogen and phosphorus, as a proxy for the marginal benefits of reducing nutrients.[35]

We calculate the value of this EG&S category by multiplying the quantity of nitrogen and phosphorus (summarized in Exhibit 6) that does not enter Lake Winnipeg due to the various strategies by the abatement costs of wastewater treatment plants for nitrogen and phosphorus.

Exhibit 12 presents the annual value of nutrient reductions.

Exhibit 12 Incremental Annual Value of Nutrient Reductions

Strategy	Nutrient	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	Avoided Nitrogen	$4,223	$16,890	$84,451
	Avoided Phosphorus	N/A	N/A	N/A
Wetland	Avoided Nitrogen	$6,032	$24,129	$120,645
	Avoided Phosphorus	N/A	N/A	N/A
Land Application	Avoided Nitrogen	$9,048	$36,193	$180,967
	Avoided Phosphorus	$2,690	$10,760	$53,801

3.3.2 Value of Gas Regulation

Determining an exact marginal value of GHG reductions is a controversial and difficult task. We considered two main approaches to valuing marginal GHG emissions: the carbon price necessary to achieve national GHG emissions reductions as per Canada's commitment to the Kyoto Protocol; and the social cost of carbon. These approaches are related to the damage cost avoided approach, discussed previously.

In terms of the carbon price, a recent climate change report estimated the carbon prices necessary to achieve specific targets to estimate the value of reducing GHG emissions. The 2009 report by M.K. Jaccard and Associates Inc. (2009) produces carbon prices for two scenarios. The first is the carbon prices estimated to achieve a 25% reduction in GHG emissions below 1990 levels by 2020 and is considered consistent with limiting the maximum temperature increase to 2^{o} C.[36] The second scenario is Canada's old official GHG target levels of

---

[34] An annual total of 1500 tonnes of nitrogen is expected to be removed.

[35] In economic theory, marginal costs equal marginal benefits at the optimal quantity of pollution abatement. If the actual quantity of pollution abatement is not at the optimal, using marginal costs as a proxy for marginal benefits will underestimate or overestimate the benefits of pollution reductions. Assuming marginal costs increase and marginal benefits decrease as more pollution is abated, if the actual abatement of pollutant is less than the optimal level, then using marginal costs as a proxy for marginal benefits will underestimate the benefits of pollution abatement. Conversely, if the actual abatement of pollutant is more than the optimal level, then using marginal costs as a proxy for marginal benefits will overestimate the benefits of pollution abatement.

[36] This is the maximum temperature increase target endorsed in the Copenhagen Accord agreed to by Canada.

a 20% reduction in GHG from 2006 levels by 2020.[37] The carbon prices for 2011, 2020 as well as the 30 year levelized price using both a 3% and 7% discount rate are presented in Exhibit 13.

Exhibit 13 Carbon Prices Necessary to Achieve Certain Canadian Emission Targets

	MKJA – 2°C Max Temp Scenario	MKJA – Canada's targets
Year	($/tonne of CO_2 eq	
2011	50	40
2020	200	100
30 year levelized @ 3% real discount rate	78	49
30 year levelized @ 7% real discount rate	123	78

In terms of the social cost of carbon, the International Panel on Climate Change (IPCC) reports the peer reviewed average estimate of the social cost of carbon to be $56/t CO_2 eq with a range of $13 to $451/t CO_2 eq (IPCC, 2007). The social cost of carbon is the present value of the future stream of marginal damages associated with the emission of one tonne of carbon. The large range in values reflects the fact that the social cost of carbon depends on a large range of variables.

In this analysis, we use an average social cost of carbon value of $56/t CO_2 eq. This is the value used by the IPCC and tends to be a central estimate in the work of MKJA (2009). To test the sensitivity of our results, we also consider a low carbon value of $13 from the IPCC and a high carbon value of $195 from Tol (2008).[38]

We multiply the GHG impacts determined in Section 3.2.2 by the three different social costs of carbon to calculate the annual value of GHG impacts for the wastewater treatment strategies. Exhibit 14 presents the results of these calculations.

Exhibit 14 Annual Value of Carbon Benefits

	$13/t$CO_2$ eq			$56/t$CO_2$ eq			$195/t$CO_2$ eq		
Treatment Strategy	Pop= 500	Pop= 2,000	Pop= 10,000	Pop= 500	Pop= 2,000	Pop= 10,000	Pop= 500	Pop= 2,000	Pop= 10,000
BNR/SBR	-$8	-$20	-$245	-$33	-$87	-$1,055	-$116	-$302	-$3,672
Wetland	$499	$4,992	$9,984	$2,150	$21,504	$43,008	$7,488	$74,880	$149,760
Chemical Precipitation	-$4	-$5	-$9	-$17	-$23	-$40	-$58	-$81	-$139

Notes: Negative values represent value of GHG or CO_2eq emissions, while positive values represent value of carbon sequestered.

---

[37] The new emissions target for Canada is for a 17% reduction in GHG emissions from 2006 levels by 2020. Although not modelled by M.K. Jaccard and Associates Inc., a less ambitious emission reduction target will cause the price of carbon to decrease. Therefore, the carbon price associated with a 17% reduction in GHG emissions will be lower than the carbon price associated with a 20% reduction in GHG emissions.

[38] The $195 value of social cost of carbon is the 95th percentile result from a meta-analysis of carbon values by Tol (2008).

Incremental annual carbon benefits from BNR/SBR and Wetland are presented in Exhibit 15.

Exhibit 15 Incremental Annual Value of Carbon Benefits

	$13/tCO_2$ eq			$56/tCO_2$ eq			$195/tCO_2$ eq		
Treatment Strategy	Pop= 500	Pop= 2,000	Pop= 10,000	Pop= 500	Pop= 2,000	Pop= 10,000	Pop= 500	Pop= 2,000	Pop= 10,000
BNR/SBR	-$4	-$15	-$236	-$16	-$64	-$1,015	-$58	-$221	-$3,533
Wetland	$503	$4,997	$9,993	$2,167	$21,527	$43,048	$7,546	$74,961	$149,899

3.3.3 *Value of Biosolids*

The fertilizer value of biosolids can be valued using the substitute cost approach. As discussed above, the fertilizer value of biosolids is equal to the market value of synthetic fertilizer that does not need to be applied due to the recovery of biosolids (nutrients) in the wastewater that can be applied to agricultural lands as a substitute.[39]

The value of nitrogen and phosphorus in synthetic fertilizer has varied considerably in the last few years. In fact, the costs decreased 27% between 2008 and 2009. In 2009, the costs for nitrogen and phosphorus fertilizer were $1.29 per kg of nitrogen and $4.22 per kg phosphorus (USDA Economic Research Services, 2010). We use these values to represent the avoided value of synthetic fertilizer due to applying biosolids from the wastewater treatment strategies to agricultural land.

We calculate the value of this EG&S category by multiplying the quantity of phosphorus and nitrogen that is recoverable and useable in agriculture by the market price of synthetic nitrogen and phosphorus fertilizer. Exhibit 16 presents the results of these calculations.

Exhibit 16 Annual Value of Synthetic Fertilizer Displaced

	Recoverable Nutrients ($)					
	Population = 500		Population = 2,000		Population = 10,000	
Treatment Strategy	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
BNR/SBR	$942	$1,540	$3,767	$6,161	$3,767	$6,161
Wetland	$118	$1,078	$471	$4,313	$2,354	$21,564
Land application	$824	$1,078	$3,296	$4,313	$16,480	$21,564
Chemical precipitation	$118	$739	$471	$2,957	$2,354	$14,787

Incremental annual value of synthetic fertilizer displaced from BNR/SBR, Wetland, and Land Application strategies are presented in Exhibit 17.

---

[39] The costs of applying the biosolids on agricultural lands are included in the operating and maintenance costs for the relevant treatment options. These costs include transportation, handling and actual costs for land application at the fields, including labour.

Exhibit 17 Incremental Annual Value of Fertilizer Displaced

Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	$1,625	$6,500	-$7,213
Wetland	$339	$1,356	$6,777
Land application	$1,045	$4,181	$20,903

3.3.4 *Value of Water Supply*

The value of avoided water supply used from the Lake Winnipeg Basin from the Land Application strategy can be valued using the market price approach. Water is valued differently depending on its use (i.e., residential, commercial, recreational and agricultural). For our purposes, the most relevant value of water to consider is the value of water in agriculture. There are several estimates of the value of water for agricultural use in Canada. The most relevant estimates for this analysis are summarized in Exhibit 18.

Exhibit 18 Estimates of the Value of Water for Agriculture Irrigation and Livestock Watering

Study	Geographic Location	Description of Value	Values ($/m^3)
Dacheaoui and Harchoui (2003)	All of Canada	All agricultural uses (irrigation and livestock watering water uses)	$0.592
Kulshreshtha (1994)	Manitoba (Assiniboine Delta Aquifer)	Potatoes	$0.898
		All crops other than potatoes	$0.289
		Watering of unspecified livestock	$0.907
Bruneau (2004)	South Saskatchewan River Basin (mostly AB)	Average across all crops	$0.378
Gardner Pinfold (2006)	South Saskatchewan River Basin (only Alberta)	Average Long-Run Value	$0.014
		Average Short-Run Value	$0.068
Kulshreshtha and Brown (1990)	South Saskatchewan River Irrigation District No 1	Average Long-Run Value	$0.036
		Average Short-Run Value	$0.106

As shown above, agricultural water values per cubic metre vary across uses (irrigation versus livestock watering; types of crops), regions and between the short-run and long-run. In this analysis, we use the values estimated by Kulshreshtha (1994) because these are specific for Manitoba. From a report estimating the water use in Canadian Agriculture in 2001, we know that in Manitoba, approximately 53% of agricultural water is used for crops and 47% is used for livestock watering (Beaulieu, 2007). The 2006 Manitoba Irrigation Survey shows that potatoes represent 75% of the irrigated acres in Manitoba (Gaia Consulting Limited, 2007). Consequently, we can state that 47% of the avoided water would have been used for livestock watering, 40% used for potato irrigation (3/4 of 53%), and 13% (1/4 of 53%) used for all other irrigated crops other than potato.

Using these percentages and the per cubic metre values from Kulshreshtha (1994), the marginal value of water for agriculture in Manitoba is $0.823 per cubic metre.[40] The annual quantity of

---

[40] This value is calculated as $0.898 x 40% + $0.289 x 13% + $0.907 x 47% = $0.823.

water use avoided by using the Land Application strategy in the three scenarios is multiplied by this per cubic metre value to yield the annual value of this EG&S category. Exhibit 19 presents the results of these calculations.

Exhibit 19 Incremental Annual Value of Avoided Water Use Due to Land Application

Irrigation Water Displaced (m^3/year)	Population = 500	Population = 2,000	Population = 10,000
Low scenario	$30,040	$120,158	$600,790
Middle scenario	$42,055	$168,221	$841,106
High scenario	$54,071	$216,284	$1,081,422

Notes:
The low, middle, and high scenarios are associated with 50%, 70%, and 90% of the wet effluent displacing irrigation water.

3.3.5 *Value of Other EG&S*

The approach used to estimate the economic value of other EG&S provided by the Wetland strategy is the benefit transfer method (employing the recent meta-analysis of Ghermandi et al., 2009). The main reason for using the Ghermandi et al. (2009) meta-analysis over other wetland valuation meta-analyses is that it explicitly considers the value of constructed wetlands.[41] Ghermandi et al. (2009) provides the most comprehensive wetland meta-analysis to date and includes 418 wetland valuation observations from 189 studies.[42] This meta-analysis includes numerous EG&S provided by wetlands, but in this analysis the focus is on amenity and aesthetic, natural habitat, and biodiversity benefits. The full meta-regression model is presented in Appendix D.

Meta-analysis utilizes information from a large number of studies to statistically summarize the relationship between benefit measures and quantifiable characteristics of the studies. Therefore, meta-analyses are able to estimate a single wetland value (in terms of WTP) for a set of input variables.

The specific steps for estimating the value of other EG&S provided by the Wetland strategy in our analysis are:

1. Use the quantified variables in Section 3.2.5 as inputs into Ghermandi et al.'s (2009) meta-analysis regression equation.
2. Use the meta-regression function, along with important study characteristics that can be 'turned-on' in the meta-analysis regression equation, to estimate the per hectare annual value of other EG&S provided by the constructed wetland, according to each community size.
3. Multiply the per hectare community population-specific other EG&S values by the area of each constructed wetland to estimate the total value of other EG&S values provided by the Wetland strategy.

The advantage of using this approach is that it explicitly incorporates the effect of biophysical variables (such as wetland size and neighbouring population levels) on these EG&S values.

---

[41] Other recent meta-analyses of wetland valuation studies include Brander et al. (2010), Woodward and Wui (2001), and Brouwer et al. (1999).

[42] Ghermandi et al. (2009) construct four different specifications of the meta-regression model which consider different weights assigned to observations from the same study. In this analysis we use Model C which weights each study equally, as opposed to each observation.

Specifically, according to the regression equation, higher neighbouring population levels are associated with higher per hectare values (coefficients in meta-regression model are positive and significant), while larger wetlands are associated with lower wetland values (coefficients in meta-regression model are negative and significant).[43]

Exhibit 20 summarizes the annual other EG&S values provided by the Wetland strategy. It is interesting to note how much the annual wetland value per hectare decreases as the size of the constructed wetland increases. The annual wetland value per hectare decreases from $4,738 for a 4 ha wetland to $2,274 for an 80 ha wetland.

Exhibit 20 Incremental Value of Other EG&S Provided by Wetland Strategy[a]

	Population = 500	Population = 2,000	Population = 10,000
Annual wetland value per hectare	$4,738	$2,695	$2,274
Number of hectares	4	40	80
Annual value for constructed wetland	$18,952	$107,810	$181,944

Notes:
[a] Other EG&S values refer to amenity and biodiversity, and may include recreation, commercial activities (fishing, hunting), flood control and storm buffering, option, cultural, spiritual, bequest, and other such social values provided by wetlands, as perceived by households.

---

[43] It should be noted here that we did not 'turn-on' the water quality characteristic included in Ghermandi et al.'s (2009) regression equation since we did not want to double-count this EG&S with the other valuation method we used that targeted water quality (i.e., the damage cost avoided approach for nutrient reduction).

3.4 Non-monetized EG&S values

This section outlines some of the identified EG&S that are not monetized in this report. In Exhibit 21, the main reason the EG&S category cannot be quantified or monetized is given, as well as some notes regarding factors affecting the significance of the value.

Exhibit 21 Non-monetized EG&S

EG&S	Reason Not Quantified/Monetized	Treatment Strategy	Possible Significance
Biogas Potential	Would require extra onsite equipment and machinery that were not costed in Background Report.	BNR/SBR	Possible value by incinerating sludge to generate electricity.
Groundwater Quality	High degree of scientific uncertainty regarding the linkages between land application of wastewater, groundwater contamination, and decrease in economic welfare.	Land Application	Possible dis-benefit due to groundwater contamination from excess nutrients (i.e., nitrogen) being applied to the land.[44]
Aesthetic and Amenity Value	The value of the dis-benefit people may experience due to raw wastewater application on agricultural lands is unknown.	Land Application	People may have dis-benefits associated with raw wastewater being applied to agricultural land.
Other EG&S	Unclear whether or not the 'other' EG&S value estimates produced using Ghermandi et al.'s (2009) meta-analysis included recreation, commercial activities (fishing, hunting), flood control and storm buffering, option, cultural, spiritual, or bequest values[a]; difficult to robustly transfer benefits for each value.	Wetland	Individuals may have additional values associated with wetland construction.

Notes:
[a] These values were either found to be insignificant in the meta-analysis regression equation of Ghermandi et al. (2009), or they were not included as explanatory variables (due to lack of information about whether or not they were identified in the primary studies).

---

[44] It should be noted that regulations exist to protect groundwater quality (Specifically, Nutrient Management Regulation (Regulation 62/2008) http://www.gov.mb.ca/waterstewardship/wqmz/index.html Accessed November 2010). The Regulation includes buffer set backs from groundwater features, nitrogen application rates that are restricted depending on soil residual nitrate-nitrogen, and prohibition on the application of nitrogen (and phosphorus) in sensitive areas where groundwater could be contaminated (soil classes 6 and 7). Application of municipal sludge, biosolids or effluent to land would fall under this regulation.

4 Results

This section presents the results of the cost-benefit analysis and is divided into 4 sections:

1. Private Financial Lifetime Costs
2. EG&S Values
3. Cost-benefit Analysis
4. Sensitivity Analysis

4.1 Private Financial Lifetime Costs

The present values of private financial costs of each wastewater treatment strategy are summarized in Exhibit 22 for different community population levels over a 20-year period, discounted at 3%. These estimates do not include the EG&S values assessed in this report. Bolded values are associated with the wastewater treatment facilities with the least cost. As shown, the Chemical Precipitation strategy is the least cost strategy of achieving the wastewater effluent criteria when only private costs are considered. The Wetland-low cost strategy is the second least cost strategy. BNR/SBR and the Land Application strategy using the pivot system technology are by far the most expensive two wastewater treatment strategies. In addition, it should be noted that because we are only including the costs of wastewater treatment strategies, the higher the discount rate, the lower the present value of costs.

Exhibit 22 Private Financial Costs – Over 20 Years, Discounted at 3%

Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	$4,181,000	$7,998,000	$27,220,000
Wetland – High cost	$1,022,000	$3,181,000	$13,868,000
Wetland – Low cost	$622,000	$1,681,000	$6,568,000
Land Application – Pivot System	$2,924,000	$7,257,000	$24,140,000
Land Application – Travelling Gun	$972,000	$2,276,000	N/A[a]
Chemical Precipitation	**$552,000**	**$1,136,000**	**$3,821,000**

Notes:

[a] As noted in the Background Report, the travelling gun technology is not suitable for communities of 10,000 people.

Exhibit 23 provides a summary of the incremental private financial costs for each wastewater treatment strategy, beyond the Chemical Precipitation strategy (i.e., the reference case strategy). As an example, implementing the Wetland-low cost strategy for a community size of 2,000 people will cost $0.545 million more than implementing Chemical Precipitation.

Exhibit 23 Incremental Private Financial Costs – Over 20 Years, Discounted 3%

Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	$3,629,000	$6,862,000	$23,399,000
Wetland – High cost	$470,000	$2,045,000	$10,047,000
Wetland – Low cost	$70,000	$545,000	$2,747,000
Land Application – Pivot System	$2,372,000	$6,121,000	$20,319,000
Land Application – Travelling Gun	$420,000	$1,140,000	N/A

4.2 EG&S Values

Exhibit 24 presents the incremental present value of EG&S benefits for the different treatment strategies for the different community population levels over 20 years, discounted at 3%. As shown, the Land Application strategy has the highest incremental present value of EG&S benefits followed by the Wetland strategy and then the BNR/SBR strategy.

Exhibit 24 Incremental Present Value of EG&S Benefits for the Different Treatment Strategies – Over 20 years, Discounted 3%

Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	$84,000	$334,000	$1,092,000
Wetland	$372,000	$2,152,000	$4,784,000
Land Application [a]	$764,000	$3,076,000	$15,447,000

Notes:

[a] Both the travelling gun and pivot system strategies are considered to have the same impacts on EG&S.

4.3 Cost-Benefit Analysis

This section presents the cost-benefit analysis, including the EG&S values as benefits. As noted above, this analysis considers the Chemical Precipitation strategy is the reference case scenario and computes the costs and benefits from moving from a chemical precipitation wastewater treatment system to one of the other four wastewater treatment strategies.

Examining the central results discounted at 3%, Exhibit 25 summarizes the NPV of wastewater treatment strategies relative to the Chemical Precipitation strategy. Positive values in Exhibit 25 suggest moving from the Chemical Precipitation strategy to the wastewater treatment strategy yields a positive net benefit to society while a negative value suggests negative net benefits. Exhibit 25 shows that for communities of 500 people, the Wetland-low cost strategy and the travelling gun system for the Land Application strategy result in positive NPV of $0.301 million and $0.344 million per community respectively. Therefore, the travelling gun system results in the highest NPV to society of the wastewater treatment strategies considered for this community size. The BNR/SBR has the highest negative NPV value for this community size.

Similar results are found for communities of 2,000 people. For this community size, the Wetland-low cost ($1.606 million) and Wetland-high cost strategies ($0.106 million) as well as the travelling gun system for the Land Application strategy ($1.936 million) are found to have positive NPV, with the travelling gun system once again having the highest positive NPV.

For communities of 10,000 people, the Wetland-low cost strategy is the only wastewater treatment strategy to yield a positive NPV with a NPV of $2.037 million. It should be noted that the travelling gun technology was assessed to be not practical for communities of this size and therefore was not costed in the Background Report.

Exhibit 25 Incremental Net Present Value of Alternative Wastewater Treatment Strategies – Over 20 Years, Discounted 3%

Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	-$3,546,000	-$6,528,000	-$22,307,000
Wetland – High cost	-$99,000	$106,000	-$5,263,000
Wetland – Low cost	$301,000	$1,606,000	$2,037,000
Land Application - Pivot System	-$1,608,000	-$3,045,000	-$4,872,000
Land Application - Travelling Gun	$344,000	$1,936,000	N/A

Exhibit 26 presents the results as benefit-cost ratios of wastewater treatment strategies relative to the Chemical Precipitation strategy. The benefit-cost ratio is defined as the PV of costs of the Chemical Precipitation (with EG&S benefits) divided by the PV of the costs of alternative wastewater treatment strategies with EG&S. Therefore, if the benefit cost ratio is greater than one (less than one), then there is a positive (negative) net benefit in implementing these wastewater treatment strategies compared to implementing Chemical Precipitation. In two cases, the benefit-cost ratio is negative because the PV of the EG&S are greater than the PV of the costs of implementing these strategies. Therefore, the net costs of implementing these strategies are negative for these two cases.

Exhibit 26 Benefit-Cost Ratios of Alternative Wastewater Treatment Strategies – Over 20 Years, Discounted 3%

Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	0.13	0.14	0.14
Wetland – High cost	0.85	1.11	0.40
Wetland – Low cost	2.26	Negative[a]	2.32
Land Application - Pivot System	0.25	0.26	0.42
Land Application - Travelling Gun	2.75	Negative[a]	N/A

Notes:
[a] The benefit-cost ratio is negative because, in these two cases, the PV of the EG&S are greater than the PV of the costs of implementing these strategies. Therefore, the net costs of implementing these strategies are negative.

4.4 Sensitivity Analysis

This section presents the sensitivity analysis results for four key parameter values:

1. Value of Nitrogen

2. Value of Carbon,
3. Quantity of Avoided Water Use, and
4. Discount Rate

4.4.1 *Value of Nitrogen*

The avoided cost proxy for the marginal value of nitrogen reduction in the previous analysis is \$8.26/kg. In this section, we present the results of the NPV calculations using a low marginal value of nitrogen of \$1.56/kg and a high marginal value of nitrogen of \$14.96/kg. Exhibit 27 presents these results for the different wastewater treatment strategies. Not surprising due to the large range in values considered, changing the value of nitrogen significantly changes the NPV values. An important case to note is the Wetland-high cost strategy for communities of 2,000. In this case, the NPV changes from positive \$0.106 million using a nitrogen value of \$8.26/kg to negative \$0.174 million using a nitrogen value of \$1.56/kg.

Exhibit 27 Sensitivity of Net Present Value to changes in Incremental Nitrogen Values – 20 Years, Discounted 3%

Treatment Strategy	Population = 500		Population = 2,000		Population = 10,000	
	\$1.56/kg	\$14.96/kg	\$1.56/kg	\$14.96/kg	\$1.56/kg	\$14.96/kg
BNR/SBR	-\$3,595,000	-\$3,497,000	-\$6,724,000	-\$6,332,000	-\$23,289,000	-\$21,327,000
Wetland – High cost	-\$169,000	-\$29,000	-\$174,000	\$387,000	-\$6,665,000	-\$3,863,000
Wetland – Low cost	\$231,000	\$371,000	\$1,326,000	\$1,887,000	\$635,000	\$3,437,000
Land Application - Pivot System	-\$1,713,000	-\$1,503,000	-\$3,465,000	-\$2,625,000	-\$6,975,000	-\$2,772,000
Land Application - Travelling Gun	\$238,000	\$449,000	\$1,516,000	\$2,356,000	N/A	N/A

4.4.2 *Value of Carbon*

The marginal value of carbon used in the previous analysis is \$56 per tCO_2 eq. In this section, we present the results of the NPV calculations using a low marginal value of carbon of \$13 per tCO_2 eq and a high marginal value of carbon of \$195 per tCO_2 eq. Exhibit 28 summarizes these results for the BNR/SBR and Wetland strategies. As shown, the NPV of the BNR/SBR is relatively insensitive to the marginal value of carbon. This result is not surprising because the BNR/SBR has a small GHG impact. The NPV of the Wetland strategy is quite sensitive to the marginal value of carbon although for all cases considered, the NPV of the Wetland strategy does not change from positive to negative and vice versa.

Exhibit 28 Sensitivity of Net Present Value to changes in Incremental Carbon Values – 20 Years, Discounted 3%

Treatment Strategy	Population = 500		Population = 2,000		Population = 10,000	
	\$13/tCO_2 eq	\$195/tCO_2 eq	\$13/tCO_2 eq	\$195/tCO_2 eq	\$13/tCO_2 eq	\$195/tCO_2 eq
BNR/SBR	-\$3,546,000	-\$3,547,000	-\$6,527,000	-\$6,530,000	-\$22,296,000	-\$22,343,000
Wetland – High cost	-\$123,000	-\$22,000	-\$130,000	\$872,000	-\$5,737,000	-\$3,733,000
Wetland – Low cost	\$277,000	\$378,000	\$1,370,000	\$2,372,000	\$1,563,000	\$3,567,000

4.4.3 Avoided Water Use

As noted above, there is a high degree of uncertainty regarding the quantity of irrigation water avoided using the Land Application strategies. In our central results, we considered that 70% of the raw wastewater effluent was displacing irrigation water. To test the sensitivity of our results, we use both a lower (50%) and higher (90%) avoided water use scenario. Exhibit 29 summarizes the results. As expected, the NPV decreases under the low avoided water use scenario and increases under the high avoided water use scenario. However, the NPV of the pivot system remains negative and the NPV of the travelling gun remains positive under these different scenarios.

Exhibit 29 Sensitivity Results for Avoided Water Use Net Present Value (relative to the Chemical Precipitation strategy) – 20 Years, Discounted 3%

Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
Pivot System – Lower scenario	-$1,780,000	-$3,733,000	-$8,314,000
Pivot System – Higher scenario	-$1,436,000	-$2,356,000	-$1,430,000
Travelling Gun - Lower scenario	$171,000	$1,248,000	N/A
Travelling Gun - Higher scenario	$516,000	$2,625,000	N/A

Notes:
The low, middle, and high scenarios are associated with 50%, 70%, and 90% of the wet effluent displacing irrigation water.

4.4.4 Discount Rate

In our central analysis, we assumed a discount rate of 3%. To test the robustness of the results under varying discount rates, we compute the NPV of the wastewater treatment strategies under a discount rate of 0% and 7%. The results are presented in Exhibit 30, showing values discounted at 0%, 3% and 7% for comparison. Results reveal that using different discount rates can significantly change the incremental NPVs, causing some of the values to turn positive from negative, and vice versa. For instance, when considering communities of 500 people, the Wetland-high cost strategy has a positive incremental NPV of $0.068 million using a 0% discount rate compared to a negative NPV of $0.099 million using a 3% discount rate. Using a 7% discount rate, the Wetland-high cost strategy results in a negative incremental NPV of $0.513 million for communities of 2,000 people compared to a positive NPV of $0.106 million using a 3% discount rate.

Exhibit 30 Sensitivity Results for 0% and 7% Discount Rate – 20 Years Net Present Value with EG&S (relative to the Chemical Precipitation strategy)

Discount Rate	Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
0%	BNR/SBR	-$4,015,000	-$7,184,000	-$24,543,000
	Wetland – High cost	$68,000	$833,000	-$3,730,000
	Wetland – Low cost	$468,000	$2,333,000	$3,570,000
	Land Application - Pivot System	-$1,510,000	-$2,563,000	-$1,612,000
	Land Application - Travelling Gun	$484,000	$2,689,000	N/A
3%	BNR/SBR	-$3,546,000	-$6,528,000	-$22,307,000
	Wetland – High cost	-$99,000	$106,000	-$5,263,000
	Wetland – Low cost	$301,000	$1,606,000	$2,037,000
	Land Application - Pivot System	-$1,608,000	-$3,045,000	-$4,872,000
	Land Application - Travelling Gun	$344,000	$1,936,000	N/A
7%	BNR/SBR	-$3,146,000	-$5,969,000	-$20,401,000
	Wetland – High cost	-$241,000	-$513,000	-$6,571,000
	Wetland – Low cost	$159,000	$987,000	$729,000
	Land Application - Pivot System	-$1,695,000	-$3,421,000	-$7,302,000
	Land Application - Travelling Gun	$228,000	$1,372,000	N/A

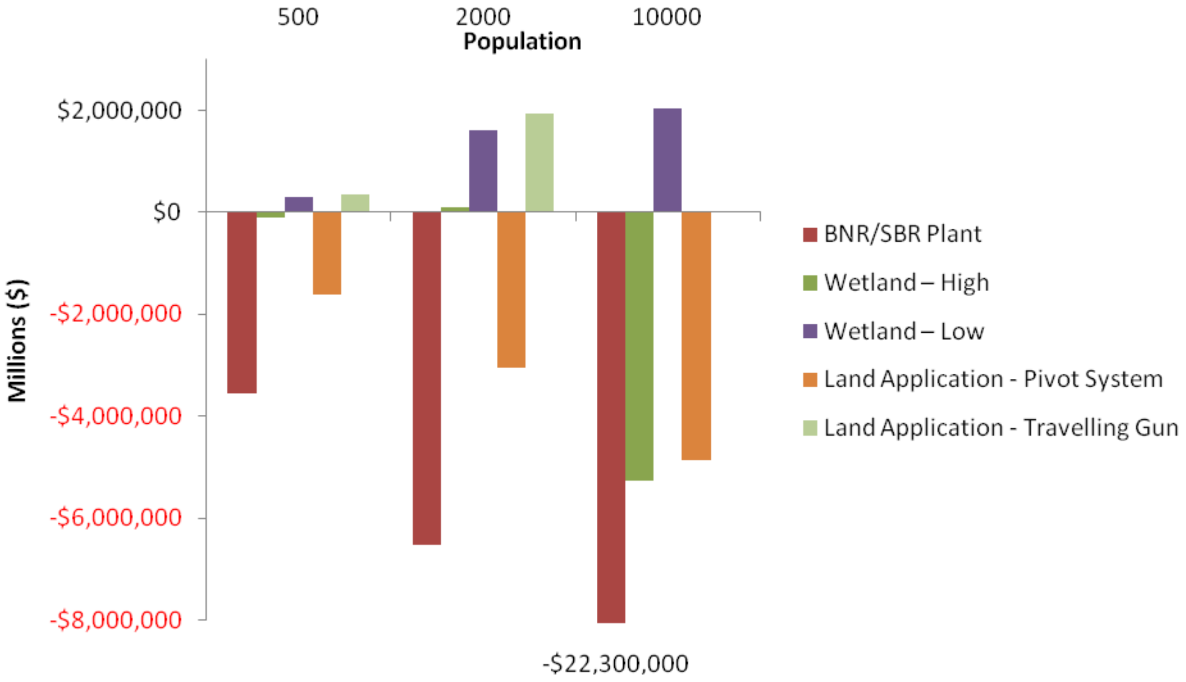
5 Summary and Conclusions

The key objective of this report is to analyze the costs and benefits of various wastewater treatment strategies for small communities in Manitoba using the EG&S framework. A formal incremental cost-benefit analysis was conducted for five alternative wastewater treatment strategies (using the Chemical Precipitation strategy as the reference case strategy). Although Chemical Precipitation is not in widespread use in Manitoba, this strategy is used as a reference case to provide a consistent benchmark for comparison and because it is often viewed as the least cost wastewater treatment strategy.

Findings reveal that the Chemical Precipitation strategy is the least financial cost option (i.e. not considering EG&S benefits) for meeting the requirements of the Canada-wide strategy and the nutrient reduction targets for phosphorus and nitrogen that are part of the Manitoba strategy to reduce nutrient loading to Lake Winnipeg. Recent decisions of small municipalities in Manitoba support this conclusion. Four municipalities that recently upgraded their wastewater treatment systems decided to use the Chemical Precipitation strategy due to lack of information on other available options and because of its low cost. However, wastewater treatment strategies have many important impacts on EG&S that are not included in the private financial costs of their construction and operation. It is important to consider these EG&S to provide a more comprehensive assessment of the costs and benefits of wastewater treatment strategies.

A subset of the EG&S impacts of each wastewater treatment strategy are quantified and monetized in order to include them in an incremental cost-benefit analysis of the strategies. When EG&S values are included, several of the alternative treatment strategies are found to exhibit positive incremental NPVs. Exhibit 31 presents a bar graph of these results.

Exhibit 31 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%



According to Exhibit 31, there is a positive incremental NPV in switching from the Chemical Precipitation strategy to Land Application strategy using the travelling gun technology and the Wetland-low cost strategy for all three community sizes.[45] These results are generally found to hold in a sensitivity analysis of various parameters (such as changes in the unit values of EG&S and discount rates). 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.

The results of this analysis are sensitive to many important variables and assumptions. Examining the impacts on the NPV of changing the value of nitrogen, the NPV of the Wetland-high cost strategy for communities of 2,000 changes from positive $0.106 million to negative $0.174 million as the nitrogen value changes from $8.26/kg to $1.56/kg.

In addition, we found that although changing the value of carbon changes the NPV values, the NPV of BNR/SBR and the Wetland strategies do not change from positive to negative, or vice versa.

We also analyze how changing the assumption on the quantity of avoided irrigation water due to the Land Application strategy would change the results. We find that although increasing (or decreasing) the quantity of avoided irrigation water increased (and decreased) the NPVs of the

---

[45] Note that in the Background report, the travelling gun technology was deemed to be impractical for deployment in communities of 10,000 people.

two land application technologies, the NPVs did not switch from positive to negative, nor negative to positive.

Finally, we complete the analysis with a lower (0%) and higher (7%) discount rate. Relative to a 3% discount rate, using a 0% discount rate results in the NPVs of the Wetland-high cost strategy for communities of 500 people switch from being positive to negative. Conversely, using a 7% discount rate results in the NPV of the Wetland-high cost strategy for communities of 2,000 people to switch from positive to negative, again relative to a 3% discount rate.

The findings in this report should be treated as preliminary for a number of reasons. Foremost, there has been no primary non-market valuation research conducted for the EG&S quantified. Rather, this study relied on benefit estimates transferred from existing studies. Second, assumptions were made on best available information and may need revision as additional information becomes available. This is particularly true for assumptions that have a higher impact on the results such as the quantity of avoided irrigation water use. In this specific area, more research is needed that examines the practicality of wastewater effluent to displace irrigation water. In addition, there are a number of important uncertainties and limitations in our analysis as outlined in Section 2.3. Five main uncertainties are (i) the biophysical changes in EG&S, (ii) the timing of benefits, (iii) the appropriateness of unit values of non-market benefits, (iv) the tradeoffs between EG&S, and (v) environmental thresholds. Limitations and data gaps of this analysis include the focus on aggregate and not the distribution of costs and benefits, the focus on quantity of EG&S rather than quality, and the fact that not all of the EG&S benefits and dis-benefits could be monetized for inclusion in the cost-benefit analysis.

Although this report assesses the costs and benefits of different wastewater treatment strategies, the report does not provide specific recommendations on the most appropriate treatment strategies for small communities in Manitoba. There are other considerations that may help guide decision makers, such as operator availability and process control.[46]

Notwithstanding these issues, the report has calculated valid and defensible estimates of the value to society of these EG&S benefits. In addition, the results of this report highlight the importance of incorporating these EG&S values into the assessment of wastewater treatment strategies. Due to the importance and validity of the EG&S approach, opportunities will increase for using this approach in future decision-making processes involving environmental impacts. This study provides an important first step toward a greater understanding of the full spectrum of values affected by wastewater treatment strategies for small communities across Manitoba and can help inform wastewater policies elsewhere.

---

[46] The Background Report provides a comprehensive qualitative assessment of the strengths and weaknesses of the specific strategies considered in this report.

Appendix A References

Associated Engineering (2008). *"Assessment of Cost of Nitrogen Removal from City of Winnipeg Wastewater".* Report prepared for the Province of Manitoba. Accessed November 2010 from http://www.gov.mb.ca/conservation/eal/registries/4864wpgww/assess_costnitrremoval.pdf

Badiou, P., D. Pennock, and R. McDougal (2008). *"Carbon sequestration and greenhouse gas emissions in Canadian prairie wetlands".* PowerPoint presentation to summarize results of Agriculture and Wetlands Greenhouse Gas Initiative research results.

Beaulieu, M.S. (2007). "*Estimation of Water Use in Canadian Agriculture in 2001"*. Agriculture and Rural Working Paper Series. Statistics Canada, Ottawa, ON. Catalogue no. 21-601-MIE -- No. 087.

Bedard-Haughn, A., F. Joengbloed, J. Akkerman, A. Uijl, E. de Jong, T. Yates, and D. Pennock (2006). "*The effects of erosional and management history on soil organic carbon stores in ephemeral wetlands of hummocky agricultural landscapes"*. Geoderma 135: 296-306.

Belli, P. J.R. Anderson, H.N. Barnum. J.A. Dixon, and J-P Tan (2002). *"Economic Analysis of Investment Operations: Analytical Tools and Practical Applications"* World Bank Institute Development Studies.

Bengtsson M, Lundin M, and S. Molander (1997). *"Life cycle assessment of wastewater systems: case studies of conventional treatment, urine sorting and liquid composting in three Swedish municipalities".* Report 1997:9. Chalmers University of Technology, Gothenburg, Sweden.

Boardman, A., M. Moore and A. Vining (2009). *"Proposed Social Discount Rate(s) for Canada Based on Future Growth"* PRI Project.

Brander, Luke M., Ghermandi, Andrea, Kuik, Onno, Markandya, Anil, Nunes, Paulo A. L. D., Schaafsma, Marije and A. Wagtendonk (2010). *"Scaling Up Ecosystem Services Values: Methodology, Applicability and a Case Study"*. FEEM Working Paper No. 41.2010.

Brouwer, R., I.J. Langford, T.C. Bateman, T.C. Crowards and R.K. Turner (1999). "*A meta-analysis of wetland contingent valuation studies*". Regional Environmental Change 1:47–57.

Bruneau, J. (2004) *"Economic Value of Water in the SSRB"* report prepared for the South Saskatchewan River Basin Project.

CCME (2009). *"Canada-wide Strategy for the Management of Municipal Wastewater Effluent"*. Accessed September 2010 from, http://www.ccme.ca/assets/pdf/cda_wide_strategy_mwwe_final_e.pdf

Dachraoui, K. and T. Harchaoui (2004). *"Water Use, Shadow Prices and the Canadian Business Sector Productivity Performance"* Statistics Canada Economic Analysis Research Paper Series no. 30, Ottawa.

Dogan, B., Merih K. and U. Yetis (2010). "*Assessment of the best available wastewater management techniques for a textile mill: cost and benefit analysis*". Water Science & Technology 61(4): 663-970.

Elmqvist, T and E. Maltby (2010). "*Biodiversity, Ecosystems and Ecosystem Services"*. Chapter 2 of the Ecological and Economic Foundation Report. Accessed October 2010 from http://www.teebweb.org/EcologicalandEconomicFoundation/tabid/1018/Default.aspx.

EPA. (2007). *"Draft Regulatroy Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder: Chapter 6 Cost-Benefit Analysis"*. Assessment and Standards Division, Office of Transportation and Air Quality. EPA420-D-07-001. Accessed October 2010 from http://www.epa.gov/nonroad/420d07001chp6.pdf.

Euliss, N.H. Jr., R.A. Gleason, A. Olness, R.L. McDougal, H.R. Murkin, R.D. Robarts, R.A. Bourbonniere, and B.G. Warner (2006). *"North American prairie wetlands are important non-forested land-based carbon storage sites".* Science of the Total Environment 361:179-188.

Foley, J., D. de Haas, K. Hartley, and P. Lant (2010). *"Comprehensive life cycle inventories of alternative wastewater treatment systems"* Water Research 44: 1654-1666.

Gaia Consulting Limited (2007). *"2006 Manitoba Irrigation Survey"*. Report to the Association of Irrigators in Manitoba's. Accessed October 2010 from http://www.gov.mb.ca/agriculture/crops/potatoes/pdf/bdasurvey.pdf.

Gallego, A., A. Hospido, M. Teresa Moreira, and G. Feijoo (2008). *"Environmental performance of wastewater treatment plants for small populations"* Resources, Conservation and Recycling 52: 931–940.

Gardner Pinfold Inc. In association with the Kurt Klein Group and M. Weber (2006). "*Natural Capital – Value of Water, South Saskatchewan River Basin in Alberta"* report prepared for the Government of Alberta.

Ghermandi, Andrea, Jeroen C.J.M. van den Bergh, L. M. Brander, H. L.F. de Groot, P. A.L.D. Nunes (2009). "*The Values of Natural and Constructed Wetlands: A Meta-Analysis*". Tinbergen Institute Discussion Papers 09-080/3, Tinbergen Institute.

Gollier, C., P. Koundouri, and T. Pantelidis (2008). *"Declining discount rates: Economic justifications and implications for long-run policy"* Economic Policy 23: 757-795

HM Treasury (2003). *"Appraisal and Evaluation in Central Government (The Green Book)"* London: HMSO.

Hospido, A., Teresa Moreira, M., Fernandez-Couto, M., and G. Feijoo (2004). *"Environmental performance of a municipal wastewater treatment plant"*. International Journal of Life Cycle Assessment 9 (4), 261–271.

Houillon, G. and O. Jolliet (2005). "*Life cycle assessment of processes for the treatment of wastewater urban sludge: energy and global warming analysis"* Journal of Cleaner Production 13: 287–299.

International Joint Commission. (1998). "*Beacons of Light: Successful Strategies Toward Restoration in Areas on Concern".* Accessed October 2010 from www.ijc.org/php/publications/html/beacon/beacon.html.

IPCC (2007). *"Summary for Policymakers".* In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

Johnston, R.J., and P.J. Thomassin (2010). *"Willingness to Pay for Water Quality Improvement in the United States and Canada: Considering Possibilities for International Meta-Analysis and Benefit Transfer".* Agricultural and Resource Economics Review. 39(1): 114-131.

Ko, J-Y, J.W. Daya, R.R. Lanea, J.N. Daya (2004). *"A comparative evaluation of money-based and energy-based cost–benefit analyses of tertiary municipal wastewater treatment using forested wetlands vs. sand filtration in Louisiana"* Ecological Economics 49: 331–347.

Kulshreshtha, S.N. (1994) *"Economic Value of Groundwater in the Assiniboine Delta Aquifer in Manitoba"*, Social Science Series No. 29, Environment Conservation Service, Ottawa, Environment Canada.

Kulshreshtha, S.N. and W.J. Brown (1990) *"The Economic Value of Water for Irrigation: An Historical Perspective",* Canadian Water Resources Journal 15, no. 3 201-215.

Lake Winnipeg Stewardship Board (LWSB) (2006). *"Reducing Nutrient Loading to Lake Winnipeg and its Watershed Our Collective Responsibility and Commitment to Action"* Report to the Minister of Water Stewardship - December 2006.

Lake Winnipeg Stewardship Board (LWSB) (2009). *"Manitoba's Progress Towards Implementing the Recommendations of the Lake Winnipeg Stewardship Board"* Report to the Minister of Water Stewardship - December 2009.

Lebegue, D., L. Baumstark and P. Hirtzman (2005). *"Revision Du Taux D'Actualisation Des Investissements Publics"* Rapport du Groupe d'Experts Présidé par Daniel Lebegue, Commissariat General du Plan.

Lundin, M., M. Olofsson, G.J. Pettersson and H. Zetterlund (2004). *"Environmental and economic assessment of sewage sludge handling strategies"* Resources, Conservation and Recycling 41: 255–278.

M. K. Jaccard and Associates Inc. (2009). *"Exploration of two Canadian greenhouse gas emissions targets: 25% below 1990 and 20% below 2006 levels by 2020".* Prepared for David Suzuki Foundation and Pembina Institute.

Machado, A.P. L. Urbano, A.G. Brito, P. Janknecht, J.J. Salas and R. Nogueira (2006). *"Life cycle assessment of wastewater treatment strategies for small and decentralized communities"* Water Science & Technology 56(3): 15–22.

Marbek and CH_2M Hill (2010). "*Evaluation of Nutrient Reduction Strategies for Wastewater Treatment Facilities in Manitoba".* Report for Manitoba Water Stewardship: Water Science and Management Branch.

McCandless, M., Venema, H. D., Barg, S. and B. Oborne (2008). "*Full Cost Accounting for Agriculture (Final Report) – Valuing public benefits accruing from agricultural beneficial management practices: An impact pathway analysis for Tobacco Creek, Manitoba"*. Winnipeg, Manitoba: International Institute for Sustainable Development.

Moore, M.A., A. Boardman and D. Greenberg (2004). "*Just Give Me a Number!': Practical Values for the Social Discount Rate"* Journal of Policy Analysis and Management 23(4): 789-812.

O'Connor, G.A., D. Sarkar, S. R. Brinton, H. A. Elliott, and F. G. Martin (2004). "*Phytoavailability of Biosolids Phosphorus"*. Journal of Environmental Quality 33:703-712.

Olewiler, N. (2004). “*The Value of Natural Capital in Settled Areas in Canada”.* Ducks Unlimited Canada and the Nature Conservancy of Canada.

Paerl, H.W. and J.T. Scott (2010). *”Throwing Fuel on the Fire: Synergistic Effects of Excessive Nitrogen Inputs and Global Warming on Harmful Algal Blooms”.* Environmental Science & Technology 44: 7756-7758.

Pascual, U and R. Muradian (2010). “*The economics of valuing ecosystem services and biodiversity”*. Chapter 5 of the Ecological and Economic Foundation Report. Accessed October 2010 from http://www.teebweb.org/EcologicalandEconomicFoundation/tabid/1018/Default.aspx.

Pasqualino, J.C., Meneses, M., Abella, M. and F. Castells (2009). *“LCA as a decision support tool for the environmental improvement of the operation of a municipal wastewater treatment plant”*. Environmental Science & Technology 43 (9), 3300–3307.

RETScreen (2010). 'RETScreen international clean energy project analysis software', *RETScreen International, Clean Energy Decision and Support Center*, Accessed from http://www.retscreen.net/ang/home.php.

Schindler, D.W., R.E. Hecky, D.L. Findlay, M.P. Stainton, B.R. Parker, M. Paterson, K.G. Beaty, M. Lyng and S.E.M. Kasian (2008). *“Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37 year whole ecosystem experiment”.* Proc. Natl. Acad. Sci. *USA* 105: 11254-11258.

Shkolny, M. (2008). “*Major Capital Program Challenges to Improve Winnipeg’s Water and Wastewater Systems*”. Paper presented at the 25th Annual Red River Basin Land and Water International Summit Conference, Fargo, ND, 23 Jan 2008.

Stern, N. (2006). “*Stern Review on the Economics of Climate Change”* London, UK: Her Majesty’s Treasury.

The Economics of Ecosystems and Biodiversity (TEEB) (2010). *“The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations”*. Edited by P. Kumar. Earthscan, London and Washington.

Tol, R.J. (2008). *“The social cost of carbon: trends, outliers, and catastrophes”.* Economics—the Open-Access, Open-Assessment E-Journal 2(25):1-24.

Treasury Board of Canada Secretariat (TBS). (2007a). “*Social Discount Rates for Canada (Draft)”* PRI Project.

Treasury Board of Canada Secretariat (TBS). (2007b). *“Canadian Cost-benefit Analysis Guide: Regulatory Proposals (Interim)”.*

US EPA (2002). *“Guidelines for Preparing Economic Analysis”* EPA 240-R-00-003.

USDA Economic Research Services (2010). “*Agricultural Prices”*. Accessed October 2010 from http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1002.

Voora, V., and H.D. Venema (2008). “*An Ecosystem Services Assessment of the Lake Winnipeg Watershed: Phase 1 Report – Southern Manitoba*” International Institute for Sustainable Development.

Wattage, P. and S. Mardle (2008). “*Total economic value of wetland conservation in Sri Lanka identifying use and non-use values”.* Journal of Wetland Ecology and Management 256(8): 1517-1572.

Weinfurtner, K., S.A. Gath, W. Kordel, C. Waida (2009). “*Ecological testing of products from phosphorus recovery processes – first results”* International Conference on Nutrient Recovery from Wastewater Streams. Edited by Ken Ashley, Don Mavinic and Fred Koch. ISBN: 9781843392323. Published by IWA. Publishing, London, UK.

Weiss, P, Eveborn, D. Kärrman, E. and J.P. Gustafsson (2008). *“Environmental systems analysis of four on-site wastewater treatment strategies”*. Resources, Conservation and Recycling 52: 1153-1161.

Woodward, R.T. and Y.S. Wui (2001). "*The economic value of wetland services: A meta-analysis*" Ecological Economics 37:257-270.

Appendix B Existing Life Cycle Assessments of Wastewater Treatment Systems

Exhibit 32 Existing Life Cycle Assessments of Wastewater Treatment Systems

Geographic region	Wastewater Treatment System	Environmental Indicators	Source
13 wastewater treatment facilities serving 20,000 people or less in Galica, Spain	Extended aeration, Biodenipho, Aerobic-anoxic	Abiotic depletion (kg Sb) Eutrophication (kg PO_4^{3-}) Global warming(kg CO_2 eq) Terrestrial ecotoxicity (kg Hg and Cr) Acidification (kg of NH_3) Ozone layer depletion (kg CFC) Photochemical oxidation (kg C_2H_4)	Gallego et al. (2008)
5-person on-site wastewater treatment facilities in Stockholm, Sweden	Infiltration, Filtralite P, Filtra P, Chemical Precipitation	Use of primary energy (MJ per p.e.) Abiotic depletion (kg Sb) Eutrophication (kg PO_4^{3-}) Global warming (kg CO_2 eq) Recycling of phosphorus	Weiss et al. (2008)
Textile mill in Turkey	Activated sludge, Membrane bioreactor	Global warming (kg CO_2 eq) Human toxicity (kg lead eq) Acidification (kg SO_2) Photochemical oxidation (kg ethylene eq)	Dogan et al. (2010)
Wastewater treatment facility in Australia	Anaerobic digestion and energy recovery, Activated sludge Bardenpho, (5 stage) BNR Activated sludge and stabilizing lagoon	Infrastructure resources (kg concrete) Chemical use (various synthetic chemicals) Operational energy (kWh) Global warming (kg CO_2 eq) Biosolids and heavy metals (daily displacement of fertiliser)	Foley et al. (2010)
90,000-person wastewater treatment facility in Spain	Aerobic-anoxic, Anaerobic digestor	Abiotic depletion (kg Sb eq) Eutrophication (kg PO_4^{3-}) Global warming (kg CO_2 eq) Terrestrial ecotoxicity (kg Hg and Cr) Acidification (kg SO_2 eq) Ozone layer depletion (kg CFC) Photochemical oxidation (kg C_2H_4)	Hospido et al. (2004)
144,000-person wastewater treatment facility in Spain	Aerobic-anoxic, Anaerobic digestor	Abiotic depletion (kg antimony-Eq) Eutrophication (kg PO_4^{3-}) Global warming (kg CO_2 eq) Ecotoxicity (terrestrial, human and aquatic) (kg 1,4-DCB eq) Acidification (kg $S0_2$ eq) Ozone layer depletion (kg CFC) Photochemical oxidation (kg C_2H_4)	Pasqualino et al. (2009)
Two 120-person wastewater treatment facilities in Spain and one 500-person wastewater treatment facility in Portugal	Slow rate infiltration, Constructed Wetland, Activated sludge	Abiotic depletion (kg Sb) Eutrophication (kg PO_4^{3-}) Global warming (kg CO_2 eq) Acidification (kg SO_2) Ozone layer depletion (kg CFC-11) Photochemical oxidation (kg C_2H_4)	Machado et al. (2006)

Appendix C Capital and Operating Costs of Wastewater Treatment Strategies

This appendix summarizes the capital, operating and biosolids disposal cost estimates for the various wastewater treatment strategies. For a complete description of the derivation of these all of these cost estimates except for the Chemical Precipitation strategy, please refer to page 19 to 30 of the Background Report.

For the analysis, capital costs are assumed to be spent in year 1 (see Exhibit 33), and annual operating and maintenance costs are streamed over the next 19 years (see Exhibit 34). Biosolids disposal costs occur annually (BNR/SBR and Chemical Precipitation) or at fixed time intervals (Wetland and Land Application) as per Exhibit 35.

Exhibit 33 Summary of Capital Cost Estimates

Treatment Strategy	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	$2,300,000	$4,800,000	$15,800,000
Wetland – High	$800,000	$2,400,000	$10,300,000
Wetland – Low	$400,000	$900,000	$3,000,000
Land Application – Pivot System	$2,100,000	$4,800,000	$15,200,000
Land Application – Traveling Gun	$277,000	$650,000	N/A
Chemical Precipitation	$190,000	$280,000	$340,000

Exhibit 34 Summary of Annual Operations and Maintenance Cost Estimates

Item	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR	$129,000	$214,000	$780,000
Wetland Treatment (Low and High)	$8,000	$32,000	$159,000
Land Application/Irrigation – Pivot System	$50,000	$149,000	$534,000
Land Application/Irrigation – Travelling Gun	$41,000	$91,000	N/A
Chemical Precipitation	$15,250	$28,750	$114,000

Exhibit 35 Biosolids Disposal Costs

Item	Population = 500	Population = 2,000	Population = 10,000
BNR/SBR – Annual	$2,340	$9,262	$17,262[a]
Lagoon Cleanout – Wetland or Land Application – Primary Cell – Every 8 years	$30,000	$90,000	$360,000
Lagoon Cleanout – Wetland or Land Application – Secondary Cell – Every 17 years	$90,000	$270,000	$1,080,000
Chemical Precipitation – Land Application – Annual	$10,000	$31,000	$129,000

[a] The biosolids disposal costs for the BNR/SBR for a community of 10,00 people include land application costs for 29 dry tonnes and composting costs for the remaining biosolids.

Chemical Precipitation Costs

Costs were derived generally as follows:

- It was assumed that 75 mg/L of $Al_2(SO_4)_3.14H_2O$ represents a reasonable estimate of the dosage rate required to reduce a total phosphorus concentration of about 5 mg/L (equivalent to a loading of 2.1 gm/capita/day) to 1 mg/L. This dosage rate was supported by analyzing recent data from an operating lagoon facility.[47]
- Chemical costs are generally higher than those used in the report provided for reference purposes. The costs used below are based on verbal advice from a single supplier operating in Manitoba.[48]
- Conceptual designs of chemical facilities sized for their respective populations were developed and costs estimated based on construction quantities and unit prices.
- Some engineering judgment was used to establish chemical storage volume requirements and the point of delineation between bulk and tote deliveries.
- Process designs were developed in CAPDET[49] and the cost output was checked against the quantity-derived estimates. The output agreed relatively well in terms of annual cost but the capital costs were too "coarse" and did not differentiate on the basis of facility size.
- Population-based algorithms for capital and annual cost estimates were developed by curve fitting and are shown on the graph axes below.
- Labour costs were based on accumulated time equivalent to daily work-week inspections of 15 minutes to monitor and record chemical consumption and on the assumption that maintenance requirements for chemical feed pumps are minimal and periodic chemical delivery supervision could be accommodated within the allotted time.
- Chemical phosphorus removal will increase solids accumulations in the lagoons by about 12% and removal costs by the same amount if land application remains a viable disposal option. Aluminum concentrations should not preclude land application but if they limit site availability such that landfill disposal is required, costs would essentially double.

Exhibit 36 Detailed Chemical Precipitation Costs

		Population		
	Assumptions/Units	**500**	**2,000**	**10,000**
Average Daily Flow	400 L/capita (c)/d	200 m³/d	800 m³/d	4,000 m³/d
Total Phosphorus	2.1 gm/c/d	1.1 kg/d	4.2 kg/d	21 kg/d
Concentration		5.3 mg/L	5.3 mg/L	5.3 mg/L
Alum				

---

[47] The dosage rates and costs assume coagulant is added continuously throughout the year. Phosphorus concentrations will decline as the flow passes through any lagoon system by means of particulate precipitation and biological assimilation – typically by about 50%. While it is reasonable to suggest that removals through natural processes might be higher for seasonal discharge lagoons, the effect is considered too small to influence the analysis at the high level used for this study.

[48] Chemical supply costs are set through individual contracts and are typically tendered. They are also heavily influenced by transportation distance and its associated cost. As a result, establishing a "real" average cost would require significant research beyond the scope of this study. As the analysis is primarily comparative and subject to wide variability in terms of phosphorus concentration, dosage rate, etc. any refinement of the "real" cost of alum is considered unnecessary. The information used was provided by ClearTech, a major supplier of water and wastewater chemicals with offices across Canada including Manitoba.

[49] CAPDET was developed originally by the U.S. Corps of Engineers and the U.S. EPA and subsequently adapted for desk-top computing. CAPDET includes capacity-based cost algorithms developed from actual cost data for approximately 300 treatment plants across the U.S. The algorithms are updated using construction cost indices and can be tailored to local conditions through current unit price inputs. The output includes a complete design summary for all unit processes and a complete quantity take-off. The cost summary provides capital costs for each unit process and operations and maintenance facilities.

		Population		
	Assumptions/Units	**500**	**2,000**	**10,000**
Concentration	48.5%			
Specific Gravity	1.335			
Dosage Rate $Al_2(SO4)_3.14H_2O$	75 mg/L			
Liquid Alum 48.5%	volume	23 L/d	93 L/d	463 L/d
		8,500 L/yr	33,900 L/yr	169,200 L/yr
	mass	11 T/yr	45 T/yr	226 T/yr
Delivery Volumes		totes	bulk	bulk
	mass	1.6 tonne	20 tonne	20 tonne
	volume	1,200 L	15,000 L	15,000 L
	loads p.a.	8	3	12
Bulk Storage Volume	30 days	N/A	2,800 L	14,000 L
	min 25%	N/A	3,750 L	3,750 L
Minimum Volume Required	select	N/A	2 tanks	2 tanks
			ea. 10,000 L	ea. 15,000 L
Chemical Feed Building		25 m^2	50 m^2	55 m^2
Total Capital Cost		$190,000	$280,000	$340,000
Annual Costs				
Chemical Costs				
Liquid Alum 48.5%		$800/T	$450/T	$450/T
Annual Alum Costs		$9,000	$20,000	$101,000
Labour Costs		65 hrs per annum (p.a.)	95 hrs p.a.	140 hrs p.a.
	$65 hr	$5,000	$7,000	$10,000
Building & Process Electricity		$1,250	$1,750	$3,000
Total Annual Operating Costs		$15,250	$28,750	$114,000
		$0.21 m^3	$0.10 m^3	$0.08 m^3
Lagoon Clean-Out & Biosolids Disposal				
Inorganic & Organic Sludge		39 kg/d	157 kg/d	786 kg/d
Chemical Sludge		5 kg/d	18 kg/d	92 kg/d
Total Mass		16 T/yr	64 T/yr	320 T/yr
Total Volume	6% solids	260 m^3/yr	1,040 m^3/yr	5,190 m^3/yr
Equivalent Annual Biosolids Disposal Costs				
Unit cost – Removal & Disposal/Dewatering		$40 m^3	$30 m^3	$25 m^3
Biosolids Disposal Costs – Land Application		$10,000 p.a.	$31,000 p.a.	$129,000 p.a.
Assumed Average Clean-Out Cycle	15 yr	$0.15 M	$0.47 M	$1.94 M
Landfill Disposal Fee		$100 /T	$100 /T	$100 /T
	25% solids	64 T/yr	256 T/yr	1,282 T/yr
		$6,000 p.a.	$25,000 p.a.	$128,000 p.a.
Biosolids Disposal Costs – Landfill		$16,000 p.a.	$56,000 p.a.	$257,000 p.a.
Average Clean-Out Cycle	15 yr	$0.24 M	$0.84 M	$3.86 M

Exhibit 37 Capital Costs of Chemical Precipitation

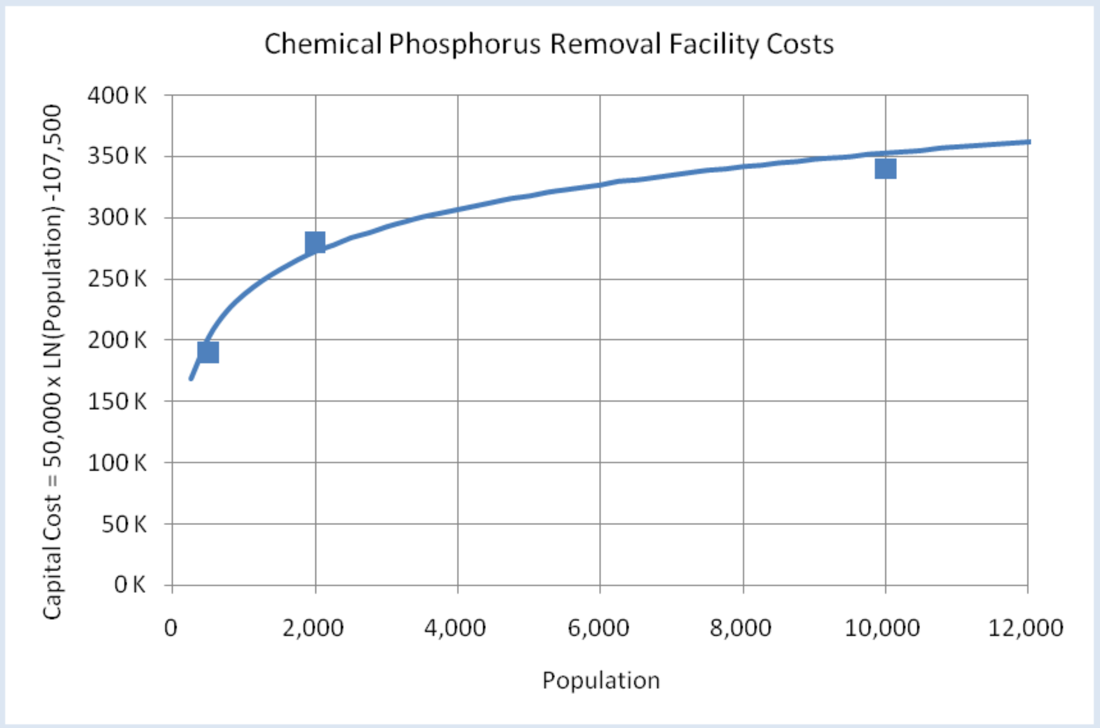
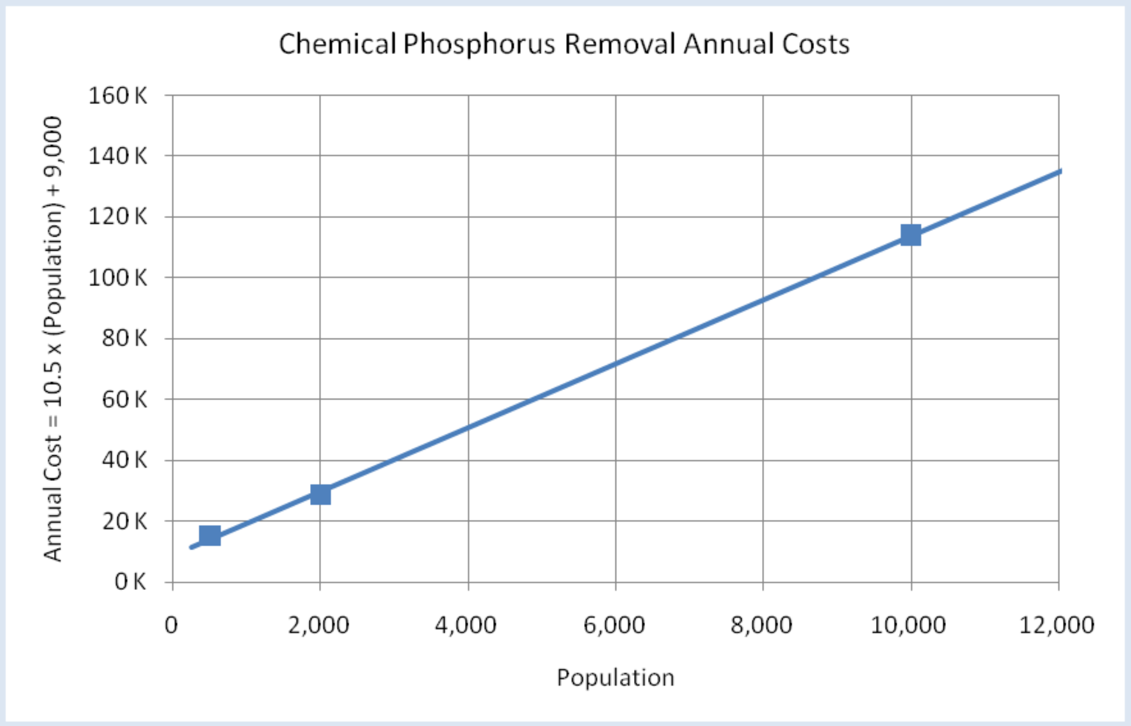


Exhibit 38 Annual Operating & Maintenance Costs of Chemical Precipitation



Appendix D Ghermandi et al. (2009) Meta-Analyses Results

Exhibit 39 Ghermandi et al. (2009) Meta-regression Results - Model C

	Variable	Coefficient	Variable Values Used in Analysis
	(constant)	1.245	1
Study variables	Year of publication	-.0290	0
	Marginal	0.643	0
Wetland variables	Estuarine	0.452	0
	Marine	0.789*	0
	Riverine	0.434	0
	Palustrine	-0.280	0
	Lacustrine	0.364	0
	Constructed	1.188*	1
	Wetland size (ln)	-0.245***	4[a], 40[a], 80[a]
	Flood control and storm buffering	0.286	0
	Surface and groundwater supply	-0.430	0
	Water quality improvement	0.720	0
	Commercial fishing and hunting	0.344	0
	Recreational hunting	-0.743	0
	Recreational fishing	-0.06	0
	Harvesting of natural materials	-0.143	0
	Fuel wood	-0.842	0
	Non-consumptive recreation	0.287	0
	Amenity and aesthetics	0.969*	1
	Biodiversity	1.168**	1
Context variables	Medium-low human pressure	0.805*	1
	Medium-high human pressure	1.260**	0
	High human pressure	1.922**	0
	GDP per capita (ln)	0.237	0
	Population in 50km radius (ln)	0.321***	16,493
	Wetland area in 50km radius (ln)	0.076	0

Notes: OLS results. R^2 = 0.46; *Adj.* R^2 = 0.36. Significance is indicated with ***, **, and * for 1, 5, and 10% statistical significance levels respectively.

[a] Wetland sizes are 4, 40 and 80 hectares for community sizes of 500, 2,000 and 10,000 people respectively.

222 Somerset Street West, Suite 300
Ottawa, Ontario, Canada K2P 2G3
Tel: +1 613 523-0784
Fax: +1 613 523-0717
info@marbek.ca
www.marbek.ca

We encourage you to print on recycled paper.
Marbek prints only on EcoLogo-certified paper.

Project ID: 10038