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An Ecosystem Services Assessment of the Lake Winnipeg Watershed

Phase 1 Report – Southern Manitoba Analysis

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Foreword

Leading-edge thinking is required to heal Lake Winnipeg
Billions of dollars could be gained by restoring natural environments

Lake Winnipeg is choking on excessive algae growth, caused by high phosphorous and nitrogen loads. It's a condition called eutrophication and Lake Winnipeg is the most eutrophic of the world's largest freshwater lakes.

The degraded state of the lake is a result of human activities—and the prognosis isn't good. Similar to a death by a thousand cuts, Lake Winnipeg's water quality is being degraded by a multitude of human activities influencing water and nutrient flows on its enormous (approximately 950,000 km2) multi-jurisdictional watershed.

The watershed contains around 90 per cent of the Canadian Prairies' agricultural land, supporting a multi-billion dollar industry. But development has come at a cost. Since the era of European settlement, we have lost, in the Manitoba portion of this watershed alone, ecosystem services worth a fortune, primarily through the conversion of wetlands and forests to agricultural lands.

This report, funded by Environment Canada, focuses on assessing the ecosystem services provided by the current and pre-settlement distribution of southern Manitoba's environmental assets, as this landscape contributes a substantial portion of the nutrient load flowing into the lake. It examines Manitoba's potential to deliver billions of dollars more a year in ecosystem services, through the restoration these natural environments. For example, water treatment and purification services could be obtained by wetland restoration, which also prevent floods by retaining surface runoff, sequesters carbon and provides wildlife habitat.

The study reconstructed three separate views of the Canadian Prairie, and focused on the Souris, Red and Assiniboine watersheds that are part of the massive Lake Winnipeg Watershed. These areas, which contribute about 60 per cent of the overall phosphorus load to the lake, were once a mosaic of forest, native prairie and wetlands, but have largely been cleared and drained for agriculture.

This report offers a way of valuing these once-abundant ecosystem services and provides an economic rationale for preserving and restoring environmental assets, which aren't often economically valued for the services they offer.

If pre-settlement landscapes could be re-created, they would provide, on an annual basis, between $500 million and $3.1 billion of ecosystem services, and between $80 million and $1.4 billion worth of carbon offsets in the emissions market. Having the means to value ecosystem services can help justify spending to preserve and restore these natural environments, rather than often more expensive hard infrastructure investments.

There are a number of other factors that have an impact on the lake. Climate change will likely increase nutrient loads as the lake's watershed is subjected to more frequent and extreme floods and droughts. Higher summer temperatures will tend to increase the size and duration of algal blooms in the lake. High commodity prices also put pressure on natural environments as farmers respond to market signals and put marginal lands back under the plough.

We can't turn back the clock completely, nor should we. Agriculture is an important component of the Manitoba economy, and sustainable agriculture provides many of the same ecosystem services as did the pre-settlement landscape.

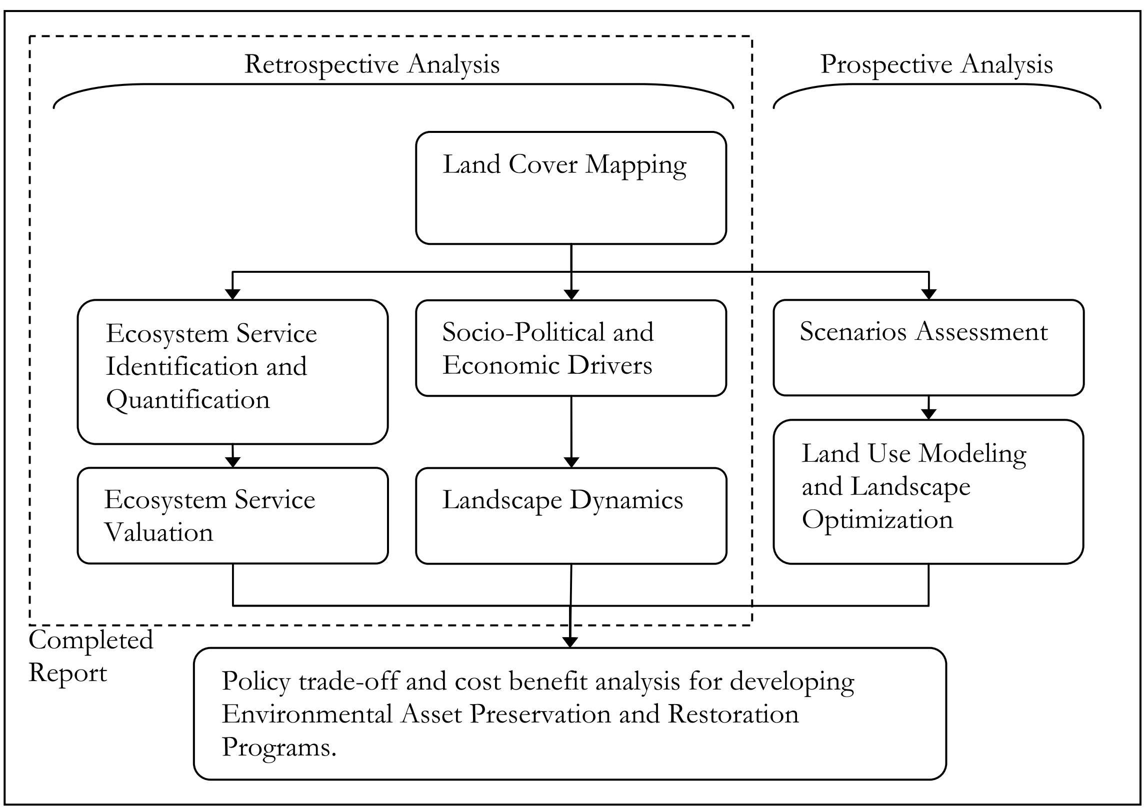
Our challenge is to find the right balance between productive and natural landscapes within our watersheds. The health of Lake Winnipeg depends on it.

Dr. Henry David (Hank) Venema, Director
Sustainable Natural Resources Management Program, IISD

Executive Summary

The general purpose of this study is to improve policy trade-off and cost benefit methodologies to better manage, preserve and restore natural environments. This research builds on the 2006–07 work completed for Environment Canada by the International Institute for Sustainable Development, which focused on exploring the underpinnings of a Natural Capital or Integrated Management of Environmental Assets (IMEA) Approach to develop a framework for its application within Canada. A working definition for the IMEA Approach was formulated as follows: "A means for identifying and quantifying the natural environment and associated ecosystem services leading to better decision making for managing, preserving and restoring natural environments." Environmental assets provide a number of ecosystem services that are important for maintaining human wellbeing. For instance, forests provide valuable services such as timber, water retention, erosion prevention, carbon sequestration, air filtration and wildlife habitat. The capacity of interconnected and healthy environmental assets to provide ecosystem services is improved when preserved, enhanced or reconnected and compromised when degraded, exploited, disturbed or fragmented (Aronson, Clewell, Blignault, & Milton, 2006).

The IMEA approach depicted in the figure below provides a retrospective (understanding the past and present) and prospective (future outlook) look at the environmental assets of a particular area which provides a sound basis for developing environmental asset restoration programs. This report focused on applying the retrospective element of the IMEA approach. Land cover mapping allows for the assessment of an area's environmental assets which can then be used to identify, quantify and value its ecosystem services. Landscape dynamics can be better understood by examining the socio-political drivers that have shaped a landscape. The application of the prospective element of the IMEA approach, which consists of exploring scenarios through land use modeling and optimization, will be explored in future research endeavours.



The historical loss of environmental assets within the Lake Winnipeg Watershed, as it relates to the eutrophication of the lake, makes it a relevant context for the application of the IMEA approach. Consequently, this study focuses on assessing the ecosystem services provided by the current and pre-settlement distribution of southern Manitoba's environmental assets, as this landscape contributes a substantial portion of the nutrient load flowing into the lake. The analysis is followed by a policy narrative that discusses the biophysical characteristics and socio-political drivers that have transformed southern Manitoba.

Addressing the eutrophication of Lake Winnipeg is a unique challenge that could be realized by preserving and restoring environmental assets at the watershed scale. Similar to a death by a thousand cuts, Lake Winnipeg's water quality is being degraded by a multitude of human activities influencing water and nutrient flows on its enormous (approximately 950,000 km^2) multi-jurisdictional watershed. Due to the landscape processes of its watershed, nonpoint sources account for approximately 75 to 90 per cent of the nutrient loads that make their way into the Lake (Lake Winnipeg Stewardship Board, 2006; Puckett, 1994; Roy, Venema, Barg, & Oborne, 2007). In contrast, Lake Erie, which was declared a "dead lake" in the 1960s and 1970s, has a watershed approximately one 12th the size of the Lake Winnipeg Watershed with nutrient loads dominated by point sources as opposed to nonpoint sources were largely responsible for its eutrophication (Great Lakes Information Network, 2006). Preventing the further degradation of Lake Winnipeg will require novel approaches to influence landscape processes and mitigate nonpoint nutrient loading.

The majority of the nutrients (47 per cent of the total phosphorus and 49 per cent of total nitrogen loads) making their way into Lake Winnipeg originate from Manitoba (Lake Winnipeg Stewardship Board, 2006). The phosphorus loading per surface area (tonnes/km^2) of southern Manitoba is five times greater than that of the Lake Winnipeg Watershed (Roy *et al.*, 2007). Furthermore, water quality monitoring data reveals that the Red, Assiniboine and Souris rivers flowing into the lake are nutrient-rich, corresponding to 63 per cent of total phosphorus and 39 per cent of total nitrogen loads (Lake Winnipeg Stewardship Board, 2006). For this reason, the IMEA approach was applied to the Manitoba portion of the Red, Assiniboine and Souris River system to lay a foundation for developing environmental asset preservation and restoration programs within the region.

The ecosystem services of the Red, Assiniboine and Souris River system were assessed and valued by mapping the land covers of the current and pre-settlement landscapes. Three pre-settlement landscapes were constructed by linking soil genesis information with land cover likelihood. Surface areas for each land cover type were determined for the four landscapes examined which provided the biophysical basis for assessing the environmental assets and associated ecosystem services. The table below summarizes the land cover areas determined for each landscape.

LAND COVER AREAS OF THE CURRENT AND PRE-SETTLEMENT LANDSCAPES in hectares				
Land Cover	**Current Landscape**	**Pre-Settlement Landscape 1** (Wetland Dominant)	**Pre-Settlement Landscape 2** (Forest Dominant)	**Pre-Settlement Landscape 3** (Prairie Dominant)
Forests	797,010	1,782,300	2,157,682	1,586,672
Wetlands	223,547	1,125,813	498,696	348,519
Water Bodies	113,241	89,113	89,113	89,113
Prairies	1,153,347	2,203,950	2,455,685	2,585,067
Agriculture	3,245,733	0	0	0
Built-up	182,671	0	0	0
Other	18,519	534,205	534,205	1,126,010

Seventeen ecosystem services, which are commonly used in the literature, were examined for each land cover type to carry out the valuation study (Anielski & Wilson, 2007; Costanza et al., 1997; R. S. de Groot, Wilson, & Boumans, 2002). The ecosystem services investigated are shown in the table below and are organized by contextual relevance to Southern Manitoba.

Ecosystem Services Examined		
Contextual Relevance	***Ecosystem Service***	***Description[a] – Function***
Water Quantity and Quality – Lake Winnipeg Eutrophication	Water Regulation	Regulation of water flows, which entrains pollutants and purifies water – Regulating.
	Water Supply	Filtering, retention and storage of fresh water – Provisioning.
	Erosion control and sediment retention	Maintains arable land and prevents water silting by lowering soil losses by wind and runoff – Regulating.
	Waste Treatment	Removal, breakdown or abatement of pollutants – Regulating.
Climate Change	Atmospheric Regulation	Regulation of atmospheric compositions by various processes such as carbon sequestration – Regulating.
	Climate Regulation	Influence of land covers on climate (temperature, precipitation, etc…) – Regulating.
Biodiversity	Biological Control	Control of populations, pests and diseases through trophic-dynamic processes – Regulating.
	Habitat/Refugia	Suitable living space for species to evolve and breed – Supporting.
Material Benefits	Food Production	The conversion of solar energy into edible plants and animals suitable for human consumption – Provisioning.
	Raw Materials	Conversion of solar energy into materials suitable for construction – Provisioning.
	Genetic Resources	Genetic evolution in plants and animals – Provisioning.
Social Well-being	Disturbance Prevention	Dampening of environmental disturbances such as storm protection and flood prevention – Regulating.
	Recreation	Opportunities for recreation, relaxation and refreshment – Cultural.
	Cultural	Spiritual, religious, historical and symbolic values – Cultural.
Environmental Integrity	Soil Formation	Rock weathering and organic matter accumulation leading to the formation of productive soils – Supporting.
	Nutrient Cycling	Storage processing and acquisition of nutrients within the biosphere – Supporting.
	Pollination	Movement of plant genes for reproduction –Supporting.

[a] All ecosystem services description were obtained from Anielski and Wilson (2007), de Groot (2006) and Farber *et al.* (2006).

Ecosystem service value ranges were compiled for each land cover type based on four relevant Canadian valuation studies (Anielski & Wilson, 2005, 2007; Kulshreshtha & Pearson, 2006; Olewiler, 2004). The ESV ranges were multiplied by the respective land cover areas mapped for each landscape, allowing for an assessment of potential ecosystem service values that could be derived from the Red, Assiniboine and Souris River system. Total ESVs for all four landscapes were compiled based on land cover type and contextual relevance.

The assessment determined that the current landscape provides ESVs ranging from CDN$0.33 to 1.03 billion/year, while pre-settlement landscape estimations provide ESVs ranging from CDN$0.5 to 3.02 billion/year. ESVs provided by forests and wetlands account for 79 to 96 per cent of the total ESVs by land cover. Ecosystem services influencing climate change and water quantity and quality, account for 74 to 91 per cent of total ESVs by contextual relevance. To compare similar sets of ESVs, one must evaluate the high or low values between the current and pre-settlement landscapes as they were compiled differently. The important benefits received from forests and wetlands and ecosystem services influencing climate change and water quantity and quality point to a potential opportunity for mitigating environmental issues, such as the degradation of Lake Winnipeg's water quality, by preserving and restoring environmental assets on the landscape. The table below summarizes the ESVs calculated.

SUMMARY OF THE CURRENT AND PRE-SETTLEMENT LANDSCAPE ECOSYSTEM SERVICE VALUES BY LAND COVER AND CONTEXTUAL RELEVANCE in 2007 billion CDN$/year				
Land Cover and Contextual Relevance (ESV ranges in CDN$/hectare/year)	**Current Landscape**	**Pre-Settlement Landscape 1**	**Pre-Settlement Landscape 2**	**Pre-Settlement Landscape 3**
Forests (65.15 – 677.43)	0.05 – 0.54	0.12 – 1.21	0.14 – 1.46	0.10 – 1.08
Wetlands (939.10 – 1,567.47)	0.21 – 0.35	1.06 – 1.76	0.47 – 0.78	0.33 – 0.55
Water Bodies (0.00)	0.00	0.00	0.00	0.00
Prairies (25.17 – 50.61)	0.03 – 0.06	0.06 – 0.11	0.06 – 0.12	0.07 – 0.13
Agricultural Land (12.59 – 25.31)	0.04 – 0.08	0.00	0.00	0.00
Built-up (0.00)	0.00	0.00	0.00	0.00
Other (0.00)	0.00	0.00	0.00	0.00
Land Cover Type Total	**0.33 – 1.03**	**1.23 – 3.08**	**0.67 – 2.37**	**0.50 – 1.75**
Water Quantity and Quality (923.75 – 985.23)	0.21 – 0.23	1.04 – 1.11	0.46 – 0.49	0.33 – 0.35
Climate Change (49.88 – 662.26)	0.08 – 0.56	0.08 – 1.17	0.09 – 1.41	0.08 – 1.05
Biodiversity (27.29 – 301.85)	0.02 – 0.08	0.05 – 0.36	0.06 – 0.20	0.04 – 0.14
Material Benefits (3.29 – 323.29)	0.00 – 0.12	0.01 – 0.37	0.01 – 0.20	0.01 - 0.15
Social Wellbeing (37.80 – 48.30)	0.02 – 0.04	0.05 – 0.07	0.05 – 0.07	0.04 – 0.06
Environmental Integrity (0.00)	0..00	0.00	0.00	0.00
Contextual Relevance Total	**0.33 – 1.03**	**1.23 – 3.08**	**0.67 – 2.37**	**0.50 – 1.75**

A number of methodological challenges had to be addressed for the analysis. The pre-settlement landscape constructions were based strictly on soil genesis information when other biophysical characteristics such as climate and geomorphology also influence land cover. This methodological shortfall was addressed by constructing three pre-settlement landscapes thus providing a range of potential land cover distributions. Some economic valuation methods used to value ecosystem services can be considered less rigorous, or less amenable to decision-making, than others. Revealed preference methods which typically give marginal values are considered more relevant for decision making than values derived from stated preference methods, which tend to be total or average values that are better suited to assess all-or-nothing situations. In addition, the assessment relied on transferring ESVs from four Canadian valuation studies to the study area, which introduces error as no two contexts are the same. To compensate for these inaccuracies, ESV ranges were compiled reflecting the extent to which the valuation estimates used for the analysis varied. It must be noted that the ESV ranges were derived by aggregating total, average and marginal values which does not lend itself well for decision making based on conventional economics as they cannot be compared to marginal values. Nevertheless, aggregate values provide a useful coarse measure at the macro scale to assess the loss or gain of environmental assets from a given baseline (Daly, 1998). Consequently, decision making based on marginal and aggregated values may lead to more sustainable outcomes. Despite the methodological limitations of the analysis, the results draw attention to the valuable services we receive from natural environments.

The driving forces that have transformed the landscape and related ecosystem services were examined to set the context required for prioritizing an environmental asset restoration agenda. Southern Manitoba's biophysical characteristics are conducive to agriculture. Consequently, the socio-political drivers that have transformed the landscape have been directed towards establishing, maintaining and expanding agriculture as the main economic activity for over a century. Southern Manitoba is now primarily covered by agricultural fields that were once wetlands, forests and prairie grasses providing numerous ecosystem services. A Lake Winnipeg Watershed restoration agenda would necessarily require some co-optimization of agricultural and ecosystem services production.
For example, finding the right balance between human altered landscapes such as agricultural land and natural environments such as riparian areas, wetlands and forests can lower nutrient loads into water bodies and attenuate climate change thus ensuring the long-term viability of local livelihoods. This analysis is a preliminary attempt to establish the potential ecosystem services that could be generated from restoration programs within a critical portion of the Lake Winnipeg Watershed.

A retrospective analysis of the environmental assets on the landscape provided two important policy insights. The first being the influence of past policies on the distribution and quantity of ecosystem services and the second being the economic value of ecosystem services lost or gained. A good comprehension of the landscape's transformation, dynamics and responses to various policies will facilitate the implementation of effective environmental asset preservation and restoration programs.
A historical understanding of the socio-political drivers that have transformed the landscape informs which key political levers can be influenced for a desired change and may assist in avoiding past mistakes. For example, the agricultural practices and policies of the United States which have led to the hypoxia of the Gulf of Mexico were repeated in the Canadian prairies leading to the eutrophication of Lake Winnipeg. Quantifying and valuing ecosystem service losses or gains provides an economic rationale for the preservation and restoration of environmental assets. Environmental assets supply numerous co-benefits which are not often economically valued. For example, water cleansing services provided by wastewater treatment plants can be obtained from wetlands which also prevent floods by retaining surface runoff, sequester carbon through plant growth and provide wildlife habitat. The economic valuation of ecosystem services can help justify expenditures in preserving and restoring environmental assets when measured against hard infrastructure investments. Overall, the economic valuation of ecosystem services allows for a more objective and rigorous policy trade-off and cost benefit analysis.

Potential future directions for this research include the development of an IMEA information architecture and scenarios work to explore the potential benefits of environmental asset restoration. An IMEA information architecture is required to inform high-level environmental asset strategic planning as well as to guide local or regional environmental asset management. Scenarios work would complement the development of the IMEA information architecture by enabling the exploration of land uses that could address environmental and socio-economic issues such as the eutrophication of Lake Winnipeg. This report imparts the retrospective element required for developing an IMEA information architecture to better manage, preserve and restore environmental assets and address ecological and socio-economic challenges.

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1. Introduction

The Environment Canada - IISD 2006-2010 directed research work plan agreement aims to provide insights for the valuation and management of natural environments. The overarching goal of this endeavour is to research the application of a Natural Capital or an Integrated Management of Environment Assets (IMEA) Approach to better manage the natural environment. This study is guided by the following objectives:

1. Explore the conceptual underpinnings of the approach.
2. Apply and test the approach in a sub-watershed of the Lake Winnipeg Watershed.
3. Identify lessons learned and generate recommendations for its implementation nationally.

The 2006–07 work completed for Environment Canada by the International Institute for Sustainable Development focused on exploring the underpinnings of a Natural Capital Approach or IMEA Approach to develop a framework for its application within Canada. The 2007-08 report begins fulfilling the second objective of the work plan agreement by applying the IMEA Approach within southern Manitoba's portion of the Red, Assiniboine and Souris River basin system (a sub-watershed of the Lake Winnipeg Watershed). This landscape is of great importance as it contributes a substantial share (over 25%) of the nutrient load flowing into Lake Winnipeg, which has become the most eutrophied large lake in the world (Roy et al., 2007). The eutrophication of the Lake is due primarily to nonpoint pollution sources facilitated in part by the loss of environmental assets within its watershed.

The depletion of environmental assets and environmental problems being experienced in the Lake Winnipeg Watershed are not unusual. Natural landscapes have been cleared and modified in numerous parts of the world, facilitating human expansion. The loss of natural environments has lowered the capacity of remnant ecosystems to provide us with services. The Millennium Ecosystem Assessment (2005) reports that over 60 per cent of the world's ecosystems have been degraded and are exploited unsustainably. For instance, the Millennium Ecosystem Assessment (2005) identifies dryland agro-ecosystems, such as the Canadian Prairies, as potential hotspots due to susceptibility to water shortages, nutrient over-enrichment and climate change (Venema, 2006). These potential stressors can be mitigated by restoring environmental assets and aligning human activities within environmental biophysical constraints (Aronson, Clewell, Blignault and Milton, 2006).

This report presents an evaluation of southern Manitoba's environmental assets and the driving forces that have transformed its landscape. The majority of the nutrients (47 per cent of the total phosphorus and 49 per cent of total nitrogen loads) making their way into Lake Winnipeg originate from Manitoba (Lake Winnipeg Stewardship Board, 2006). Furthermore, water quality monitoring data reveal that the Red, Assiniboine and Souris Rivers flowing into the lake are nutrient rich, corresponding to 63 per cent of total phosphorus and 39 per cent of total nitrogen loads (Lake Winnipeg Stewardship Board, 2006). For this reason, the ecosystem services of the Red, Assiniboine and Souris River Basin system were assessed and valued. The remaining and pre-settlement environmental assets and respective ecosystem services of Manitoba's Red, Assiniboine and Souris River Basin system were assessed by compiling land cover maps and evaluating 17 ecosystem services using four Canadian ecosystem valuation studies. The assessment revealed the potential for addressing environmental problems, such as the degradation of Lake Winnipeg's water quality, by preserving and restoring environmental assets.

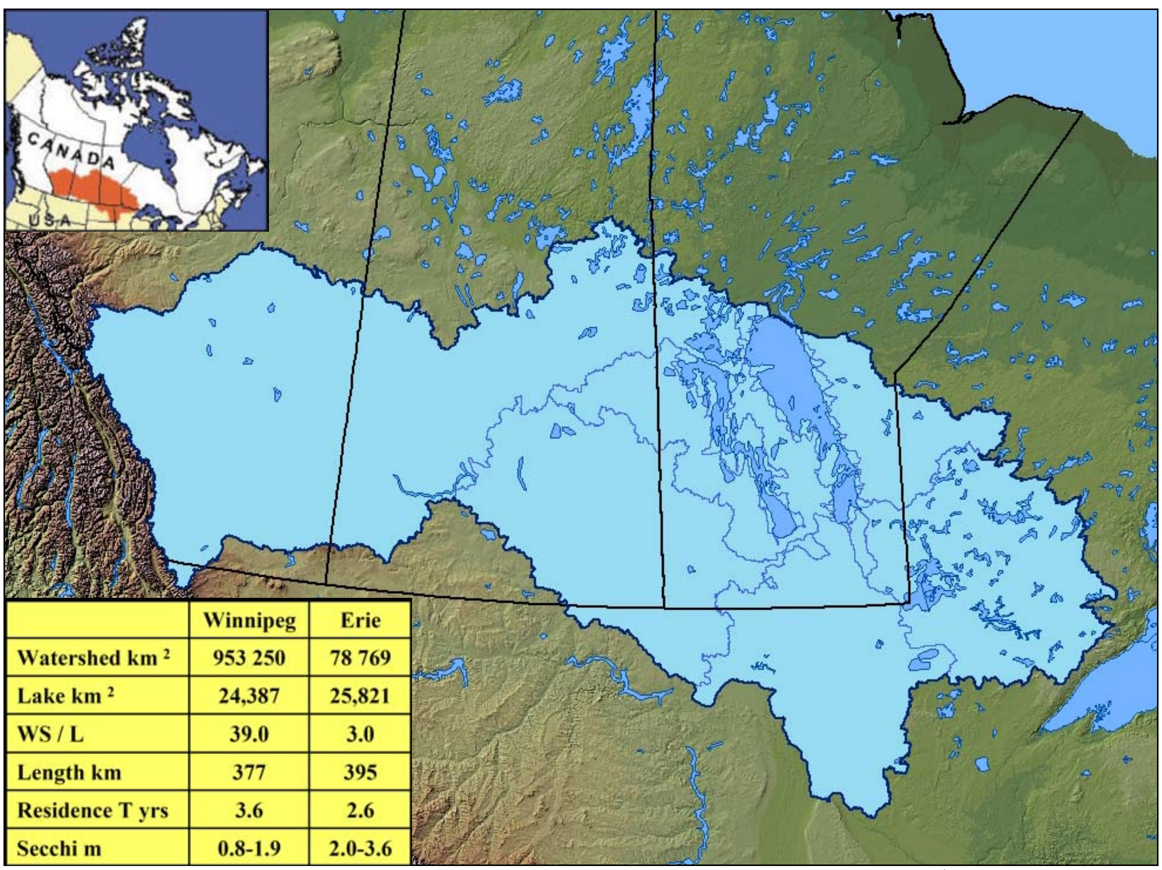
In parallel, key landscape transformation drivers were identified to understand the underlying causes of environmental asset losses. The socio-political drivers that have transformed southern Manitoba have been directed towards establishing, maintaining and expanding agriculture as the main economic activity for over a century. The landscape is now primarily covered by agricultural fields that were once wetlands, forests and prairie grasses providing numerous ecosystem services. A Lake Winnipeg Watershed restoration agenda will necessarily require some co-optimization of agricultural and ecosystem services production. For example, finding the right balance between human altered landscapes such as agricultural land and natural environments such as riparian areas, wetlands and forests can lower nutrient loads into water bodies and attenuate climate change thus ensuring the long-term viability of local livelihoods.

Overall, this report reveals the importance of incorporating ecosystem service considerations into the development of environmental management and land-use policies. The results draw attention to the real potential for improving the well-being of Canadians by preserving and restoring environmental assets. This analysis provides a preliminary attempt at establishing the potential ecosystem services available for a restoration agenda within a critical portion of the Lake Winnipeg Watershed which could inform similar initiatives in other parts of the country.

2. The Lake Winnipeg Problematique

Lake Winnipeg is the 10th largest freshwater lake globally and its watershed drains an extensive (984,000 km²) multi-jurisdictional landscape consisting of parts of Alberta, Saskatchewan, Manitoba, Northwestern Ontario, Minnesota, North Dakota and South Dakota (see **Figure 1**). The watershed is home to 5.5 million people (80 per cent of whom are urban dwellers) and 20 million livestock (Lake Winnipeg Stewardship Board, 2006). The lake supports a CDN $20 million/year commercial freshwater fishery and 23,000 Manitobans live along its shores (Roy *et al.*, 2007).

Human activities have degraded the environmental assets within the Lake Winnipeg Watershed. Nutrient pollution is threatening Lake Winnipeg's water quality (Venema, 2006). Phosphorus and nitrogen loading have resulted in significant toxic algal blooms in the summers of 2001 and 2005 (Venema, 2006). The nutrients that make their way into Lake Winnipeg originate from human and animal sewage, chemical fertilizers, detergents containing phosphates and natural processes (Roy *et al.*, 2007). It is estimated that over 45 per cent of nutrient loads that make their way into Lake Winnipeg originate from Manitoba and that agricultural runoff is a large contributor (Bourne, Armstrong, & Jones, 2002). Lake Winnipeg is now considered the most eutrophic among the 10 largest lakes in the world (Lake Winnipeg Stewardship Board, 2006). Similar to its water resources, the watershed's soil quality is eroding. Fifty per cent of croplands are threatened by erosion and 14 to 40 per cent of organic matter has been lost from Canadian prairie soils (Venema, 2006). This degradation is greatly impacting soil fertility and could potentially limit crop yields.



	Winnipeg	Erie
Watershed km ²	953 250	78 769
Lake km ²	24,387	25,821
WS / L	39.0	3.0
Length km	377	395
Residence T yrs	3.6	2.6
Secchi m	0.8-1.9	2.0-3.6

Figure 1. The Lake Winnipeg Watershed is significantly larger than the Lake Erie Watershed (WS/L = watershed to lake surface area, Residence T yrs = water residence time in years, Secchi m = a measure of eutrophication by light visibility depth in metres).

Landscape degradation has resulted in socio-ecological systems that are less resilient to environmental and economic pressures, such as climate change and trade liberalization (Venema, 2006). Natural climatic variations in temperature and precipitation, which result in floods and droughts, are not uncommon to the Canadian Prairies, but they are expected to increase with climate change. An unpredictable and unreliable climate regime will negatively impact the economic viability of agriculture in the region. In addition, globalization and international free trade agreements have increased competition, lowering the profit margins of agricultural producers (Venema, 2006). A mere 10 per cent of Canadian farming families generate enough revenue from their operations to sustain their households (Saskatchewan Agrivision Corporation Inc., 2007). The degradation and vulnerability of the Lake Winnipeg Watershed's socio-ecological system reflects the extent of human activities being carried out on its landscape and points to the vitality of its remaining ecosystems.

Addressing the eutrophication of Lake Winnipeg is a unique challenge due to the multitude of human activities influencing water and nutrient flows on its enormous multi-jurisdictional watershed. Nonpoint sources account for approximately 75 to 90 per cent of the nutrient loads that make their way into the lake (Lake Winnipeg Stewardship Board, 2006). In contrast, Lake Erie, which was declared a "dead lake" in the 1960s and 1970s, has a watershed approximately one-twelfth the size of the Lake Winnipeg Watershed. Nutrient loads dominated by point sources as opposed to nonpoint sources were largely responsible for its eutrophication (Great Lakes Information Network, 2006). Preventing further degradation of Lake Winnipeg will require novel approaches to influence landscape processes and mitigate nonpoint nutrient loading.

3. Environmental Assets and Ecosystem Services

Environmental assets are natural entities essential for well-being. They function as ecosystems to provide us with a number of services. For instance, environmental assets in the form of flowers, pollen and pollinators are required to perform the ecosystem service of pollination (Binning, Cork, Parry, & Shelton, 2001). The Millennium Ecosystem Assessment (2003) divides ecosystem services into four categories: provisioning services include the basic necessities we consume and require for our well-being; regulating services provide us with a habitable environment; cultural services benefit people in a nonmaterial manner; supporting services enable ecosystems to flourish (see **Figure 2**).

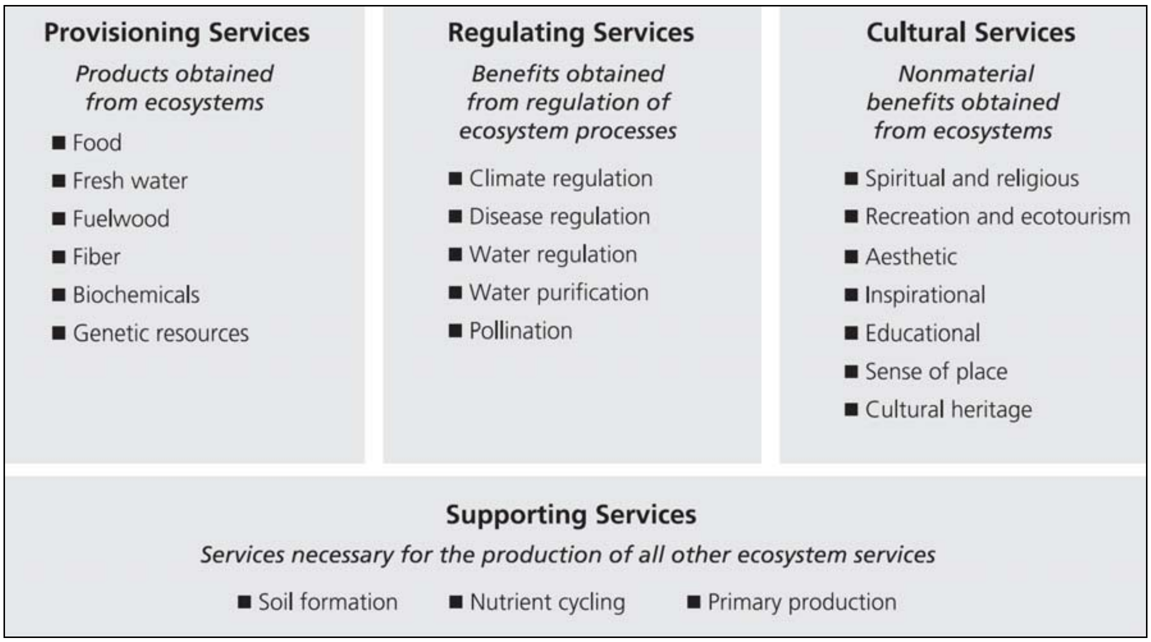


Figure 2. Ecosystem services are the benefits people obtain from ecosystems (Source: Millennium Ecosystem Assessment, 2003, p. 57).

An ecosystem's ability to provide services is improved when preserved, reconnected and restored and compromised when disturbed, fragmented and degraded (Aronson et al., 2006). **Figure 3** depicts the relation between environmental assets and their ecosystem services.

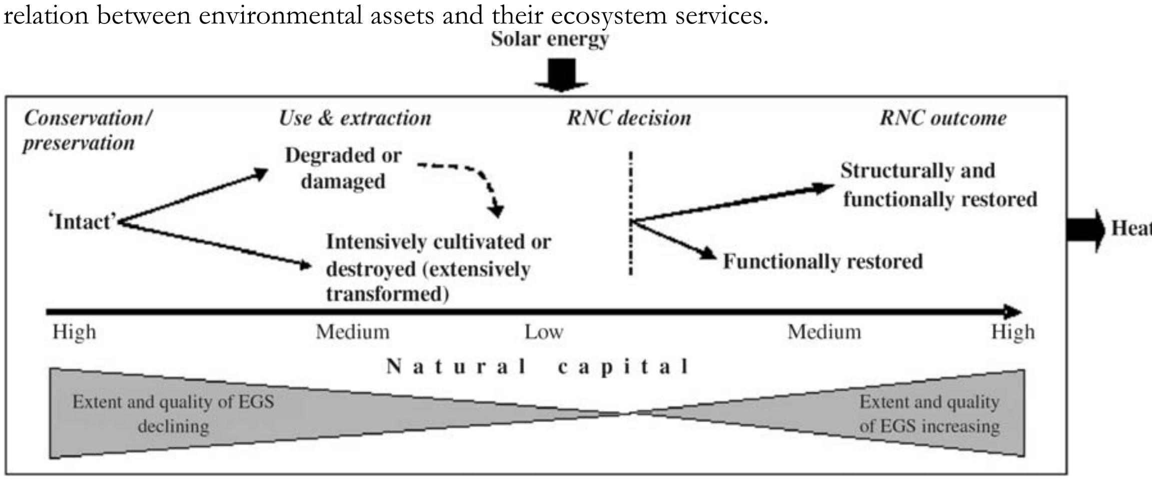


Figure 3. Environmental assets or natural capital provide ecosystem services (RNC = Restoration of Natural Capital, EGS = Ecosystem Goods and Services) (Source: Aronson *et al.*, 2006, p. 138).

Delineating, quantifying and valuing ecosystem services pose significant challenges. Ecosystem services emerge from whole and interconnected ecosystems that cannot truly be disaggregated (Straton, 2006). Furthermore, valuing ecosystem services cannot be based only on revealed preference methods as many ecosystem services are either not market-traded or not amenable to valuation through revealed preference methods. Nevertheless, this problem has been addressed by defining a generalized suite of ecosystem services and using a combination of revealed and stated preference valuation methods (see **Figure 4**).

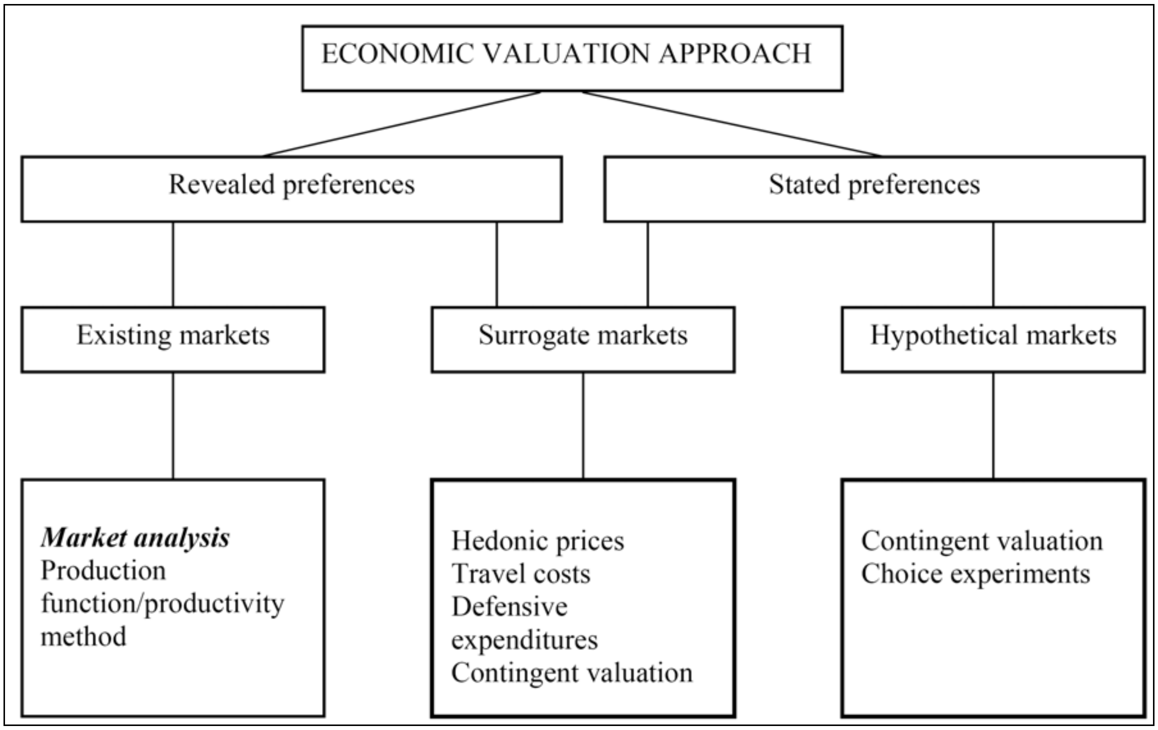


Figure 4. Valuation methodologies (Source: United Nations Economic and Social Council, 2006, p. 31).

Valuation approaches can be organized into revealed and stated preference methods. Revealed preference methods use data on actual behavior and consumption patterns while stated preference methods rely on responses to queries to estimate the willingness to pay for goods and services. The values of environmental assets traded in existing markets are determined by market prices driven by supply and demand and production costs. The productivity method is used to evaluate environmental quality impacts on a good's production costs. For example, water purification costs are compared to the cost of eliminating agricultural runoff. Revealed and stated preference methods within surrogate and hypothetical markets are used to capture values of ecosystem services that are not market-traded. The hedonic price method is used to determine the value of environmental assets via market-traded goods. For instance, houses located near natural environments are in greater demand. The travel cost method determines the value of environmental assets via travel expenditures for recreation. Defensive expenditures are estimated by evaluating the cost of avoiding damages as a result of adverse environmental impacts such as air pollution or flooding by maintaining or restoring environmental assets.

The contingent valuation method uses willingness to pay questions on hypothetical situations to determine the value of environmental assets and ecosystem services. It is the most widely used method for estimating non-use values. For example, people might be asked their willingness to pay for better air quality, biodiversity or aesthetically pleasing landscapes. The information collected using the contingent valuation method can be questioned as it consists of stated preferences based on hypothetical situations. Nevertheless, well conducted contingency valuation studies are being used to inform court rulings (Arrow, Solow, P., Learner, & Radner, 1993). “In the United States, contingent valuation is now a method many expert witnesses routinely rely on in court as a basis for their judgment ("British Columbia vs. Canadian Forest Products Ltd.," 2004, p. 9).” In addition, stated preference methods do not always generate marginal values for assessing tradeoffs at the margin. Choice experiments involve ranking and scoring selected environmental assets or ecosystem services and their estimated values allowing for the analysis of preferred environmental policy options. A comparing and ranking environmental asset restoration programs with different outcomes is an example of a choice experiment.

The suite of ecosystem services and revealed and stated preference valuation techniques have been widely used to conduct a number of global, national and regional ecosystem service valuation studies (Anielski & Wilson, 2007; Costanza et al., 1997; R. de Groot, 2006; R. S. de Groot et al., 2002). Costanza *et al.* (1997) evaluated 17 ecosystem services from 16 biomes to conservatively estimate that the natural world provides humanity with US$16 to $54 trillion in services annually. Anielski and Wilson (2007) used a similar ecosystem service framework to estimate that the Mackenzie River Basin provides CDN$448 billion in ecosystem services per year.

Table 1 presents the ecosystem services, widely applied, within the ecological economics literature, utilized to assess the environmental assets of southern Manitoba. The ecosystem services were organized into five categories based on their contextual relevance. For instance, ecosystem services that influence water quantity and quality were grouped together as they could play a role in improving the water quality of Lake Winnipeg.

Table 1. Ecosystem Services Examined		
Contextual Relevance	***Ecosystem Service***	***Description[a] – Function***
Water Quantity and Quality – Lake Winnipeg Eutrophication	Water Regulation	Regulation of water flows, which entrains pollutants and purifies water – Regulating.
	Water Supply	Filtering, retention and storage of fresh water – Provisioning.
	Erosion control and sediment retention	Maintains arable land and prevents water silting by lowering soil losses by wind and runoff – Regulating.
	Waste Treatment	Removal, breakdown or abatement of pollutants – Regulating.
Climate Change	Atmospheric Regulation	Regulation of atmospheric compositions by various processes such as carbon sequestration – Regulating.
	Climate Regulation	Influence of land covers on climate (temperature, precipitation, etc…) – Regulating.
Biodiversity	Biological Control	Control of populations, pests and diseases through trophic-dynamic processes – Regulating.
	Habitat/Refugia	Suitable living space for species to evolve and breed – Supporting.
Material Benefits	Food Production	The conversion of solar energy into edible plants and animals suitable for human consumption – Provisioning.
	Raw Materials	Conversion of solar energy into materials suitable for construction – Provisioning.
	Genetic Resources	Genetic evolution in plants and animals – Provisioning.
Social Well-being	Disturbance Prevention	Dampening of environmental disturbances such as storm protection and flood prevention – Regulating.
	Recreation	Opportunities for recreation, relaxation and refreshment – Cultural.
	Cultural	Spiritual, religious, historical and symbolic values – Cultural.
Environmental Integrity	Soil Formation	Rock weathering and organic matter accumulation leading to the formation of productive soils – Supporting.
	Nutrient Cycling	Storage processing and acquisition of nutrients within the biosphere – Supporting.
	Pollination	Movement of plant genes for reproduction –Supporting.

[a] All ecosystem services description were obtained from Anielski and Wilson (2007), de Groot (2006) and Farber *et al.* (2006).

4. An Environmental Assets Assessment of Southern Manitoba

The environmental asset assessment focused on Manitoba's portion of the Red, Assiniboine and Souris River Basin system, covering approximately 5.7 million hectares or 6 per cent of the Lake Winnipeg Watershed (see **Figure 5**). This landmass was selected as it accounts for over 70 per cent of the total Manitoban phosphorus load flowing into Lake Winnipeg (see **Figure 6**). In addition, land cover and soil data were limited to the southern and western parts of the province, which prevented extending the analysis to the rest of Manitoba's portion of the Lake Winnipeg Watershed. The City of Winnipeg area was excluded from the analysis due to a lack of soil data.

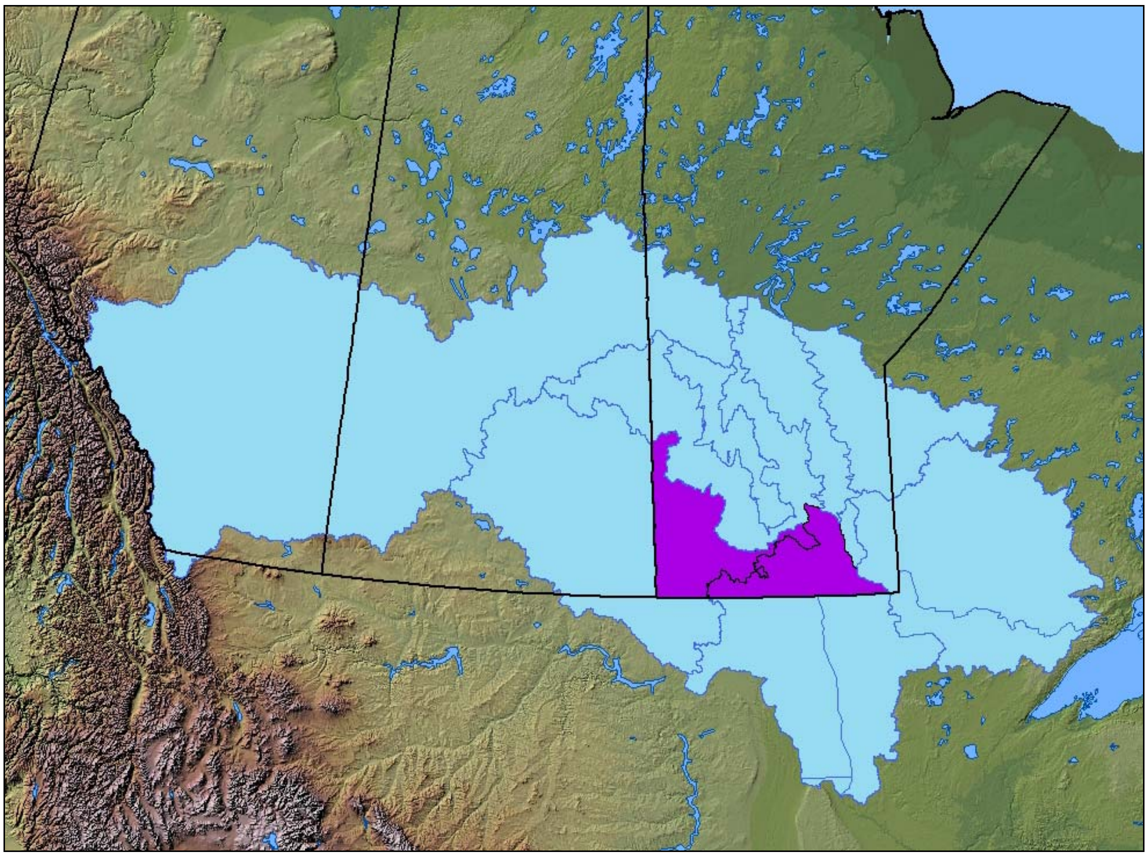


Figure 5. The southern Manitoba portion of the Red, Assiniboine and Souris River Basin system within the Lake Winnipeg Watershed.

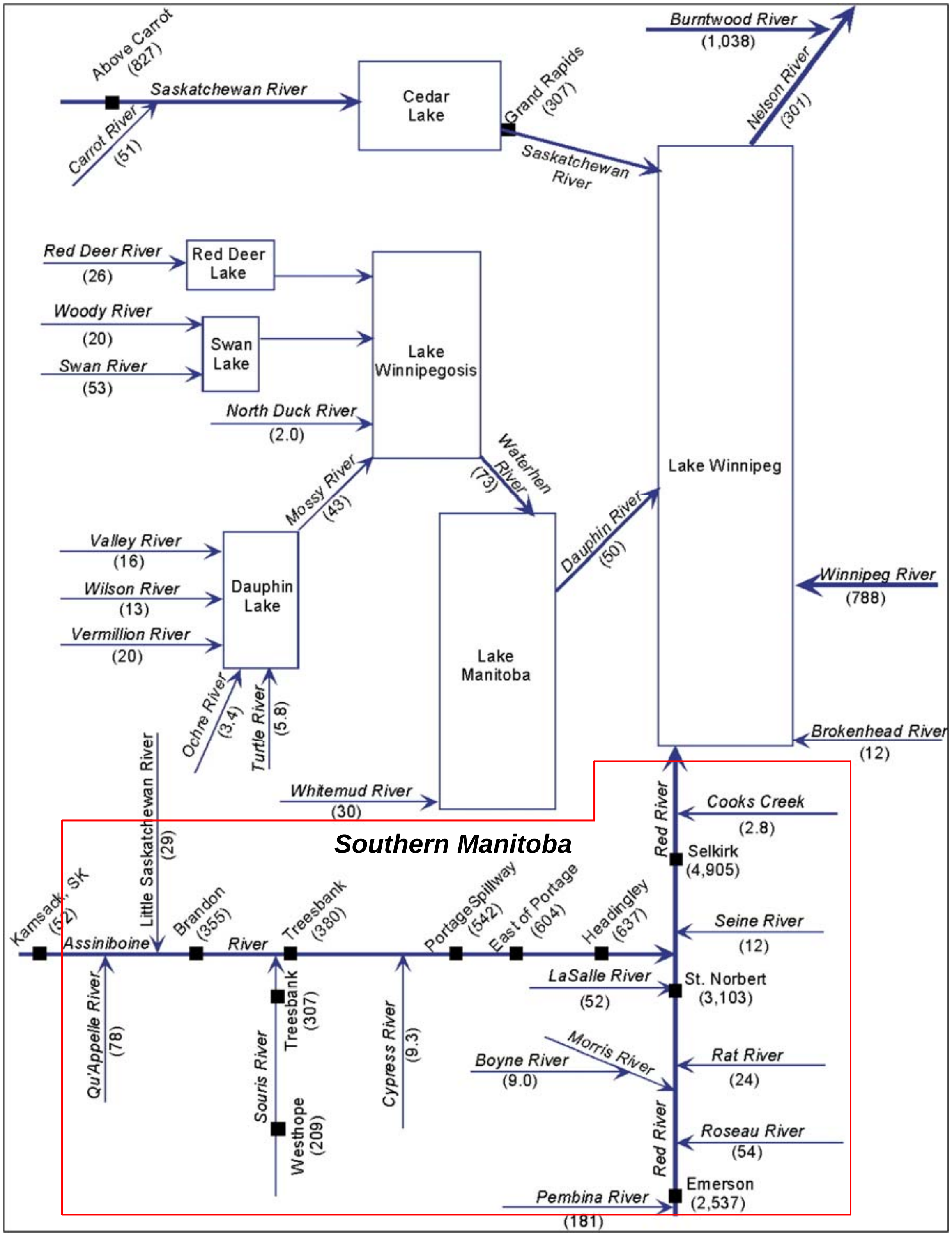


Figure 6. Total phosphorus loads in tonnes/year based on data obtained from long-term monitoring stations in Manitoba (1994 to 2001) (Source: Bourne *et al.*, 2002, p. 14). The study region of southern Manitoba is roughly delineated by the red box. The phosphorus loading per surface area (tonnes/km²) of southern Manitoba is five times greater than that of the Lake Winnipeg Watershed (Roy *et al.*, 2007).

A variety of data sources can be used to reconstruct landscapes (remote sensing data, land survey maps, biophysical information). Data availability, accuracy and accessibility will depend on the location and timeframe to be investigated, the acquisition methods used and the financial limitations of the project. The current and pre-settlement landscape provided logical time steps for assessing the ecosystem service potential of southern Manitoba. The environmental asset distribution used to estimate the ecosystem service flows of the current landscape were estimated based on 1999–2002 LandSat imagery. The soil composition of the landscape provided the required spatially grounded information to estimate the pre-settlement land cover composition (which dates back to the pre-1870s). Three pre-settlement landscapes were constructed based on matching soil types with land covers to estimate the ESV potential of the river basin system (see **Appendix A**). The surface areas for each land cover type on all four landscapes provided the biophysical basis to identify and quantify their respective environmental assets and ecosystem services.

The ESVs applied to the river basin system were estimated based on valuation data obtained from four Canadian studies. The studies were chosen primarily based on year of publication and geographical relevance to southern Manitoba (see **Appendix B**). All ESV estimates obtained from the studies were adjusted to account for inflation and assessed qualitatively to determine their relevance to the study site. In addition, the values used in the analysis were examined to estimate if they are total, average or marginal values based on the approach used to calculate them (see **Appendix C**). The valuation data compiled is conservative as economic values for each ecosystem service could not be obtained for the land covers assessed.

ESV ranges were compiled by estimating high and low economic values for each ecosystem service. The high and low values were generated by varying and/or omitting the economic values obtained from the valuation studies and used in the analysis. For instance, the carbon sequestration service provided by forests is reported by Anielski and Wilson (2007) to be worth CDN$616.11 per hectare, while Olewiler (2004) provides a lower estimate of CDN$15.00 per hectare. The variance in forest carbon sequestration service values published in the Canadian studies surveyed is reflected in the forest ESV range compiled. Furthermore, the ESV ranges also reflect inaccuracies associated with transferring ESVs derived for a given context to southern Manitoba. For instance, the economic values used to estimate a number of ecosystem services provided by wetlands (water supply, habitat/refugia and genetic resources) in the high estimate were omitted in the low estimate to reflect their questionable applicability to southern Manitoba.

Tables 2 and **3** summarize the ESVs that were applied to the study site organized by land cover types and contextual relevance. The ESVs applied to the Mackenzie region by Anielski and Wilson (2007), are significantly greater than the ESVs used for the analysis and are included in **Table 2** to provide a basis for comparison.

Table 2. Ecosystem Services Values in 2007 CDN$/hectare/year by Land Cover Type

Land Cover	**Low**	**High**	**Anielski and Wilson**[a]
Forests	$65.15	$677.43	$682.47
Prairies	$25.17	$50.61	$377.10
Wetlands	$939.10	$1,567.47	$5,441.29
Agricultural Land[b]	$12.59	$25.31	$304.34
Water Bodies	$0.00	$0.00	$12,792.67
Built-up	$0.00	$0.00	$1,489.95
Other	$0.00	$0.00	$0.00

[a] *Ecosystem Service Values of the Mackenzie Region* by Anielski and Wilson (2007).
[b] Agricultural land ESVs are assumed to be worth half prairie ESVs.

Assumptions were made to estimate the ESVs provided by agricultural lands, water bodies, built-up areas and lands classified as other. Due to variances in crop coverage, growth rates and varieties planted, agricultural land ESVs were assumed to be half that obtained from prairie grasses. Anielski and Wilson (2007) use a similar approach by estimating that ESVs provided by burned forested areas are worth half that of forests. Water Bodies were excluded from the analysis, as their surface area did not significantly change over time, its value is a function of changing water quality, requirements and availability and they can also be evaluated on a volumetric basis as opposed to a per hectare basis (Gardner Pinfold Consulting Economists Limited, 2006; Seyam, Hoekstra, & Savenije, 2003). Lands classified as **Built-up** (settled areas, roads and trails) and **Other** (wildfire areas, forest cut blocks, bare rock, sand and gravel) were excluded from the analysis due to a lack of reliable ESV data.

Table 3. Ecosystem Services Values in 2007 CDN$/hectare/year by Relevance to the Southern Manitoba Context

Contextual Relevance	Low	High
Water Quantity and Quality	$923.75	$985.23
Climate Change	$49.88	$662.26
Biodiversity	$27.29	$301.85
Material Benefits	$3.29	$323.29
Social Well-being	$37.80	$48.30
Environmental Integrity	$0	$0

Environmental Integrity ESVs, which are made up of supporting ecosystem services, could not be obtained from the Canadian studies surveyed. Supporting ecosystem services are invaluable as all ecosystem functions and services are dependant on them (Decaens, Jimenez, Measey, & Lavelle, 2006). Incorporating supporting service values would have increased the ESVs used in the analysis.

Two sets of calculations were carried out for each landscape to derive total annual ESVs by land cover type and contextual relevance. Land cover type surface areas and corresponding ESV ranges were multiplied together to give respective annual ESVs by land cover type (see Calculation 1). Ecosystem service values corresponding to a contextual relevance category were added together to give an overall ESV by contextual relevance (see Calculation 2).

Calculation 1. Current Landscape - Forest Land Cover Ecosystem Services

797,010 hectare (Forest Surface Area) x CDN$65.15/hectare/year (Forest Low ESV) = CDN$51,925,201/year

797,010 hectare (Forest Surface Area) x CDN$677.43/hectare/year (Forest High ESV) = CDN$539,918,484/year

Current Landscape Forest Land Cover Ecosystem Services annual ESV range = CDN$0.05 – 0.54 billion/year

Calculation 2. Pre-Settlement 1 – Water Quality and Quantity Ecosystem Services

1,782,300 hectare (Forest Surface Area) x CDN$0.11/hectare/year (Forest Water Quality and Quantity Low ESV) + 1,125,813 hectare (Wetland Surface Area) x CDN$920.20/hectare/year (Wetland Water Quality and Quantity Low ESV) + 2,203,950 hectare (Prairie Surface Area) x CDN$2.30/hectare/year (Prairie Water Quality and Quantity Low ESV) = CDN$1,041,230,969/year

1,782,300 hectare (Forest Surface Area) x CDN$0.11/hectare/year (Forest Water Quality and Quantity High ESV) + 1,125,813 hectare (Wetland Surface Area) x CDN$981.67/hectare/year (Wetland Water Quality and Quantity High ESV) + 2,203,950 hectare (Prairie Surface Area) x CDN$2.30/hectare/year (Prairie Water Quality and Quantity High ESV) = CDN$1,110,436,708/year

Pre-Settlement 1 Water Quality and Quantity Ecosystem Services annual ESV range = CDN$1.04 – 1.11 billion/year

The high and the low ESVs where each summed up to give an overall annual ESV range by land cover type and contextual relevance for all four landscapes. Detailed results are provided in the following subsections.

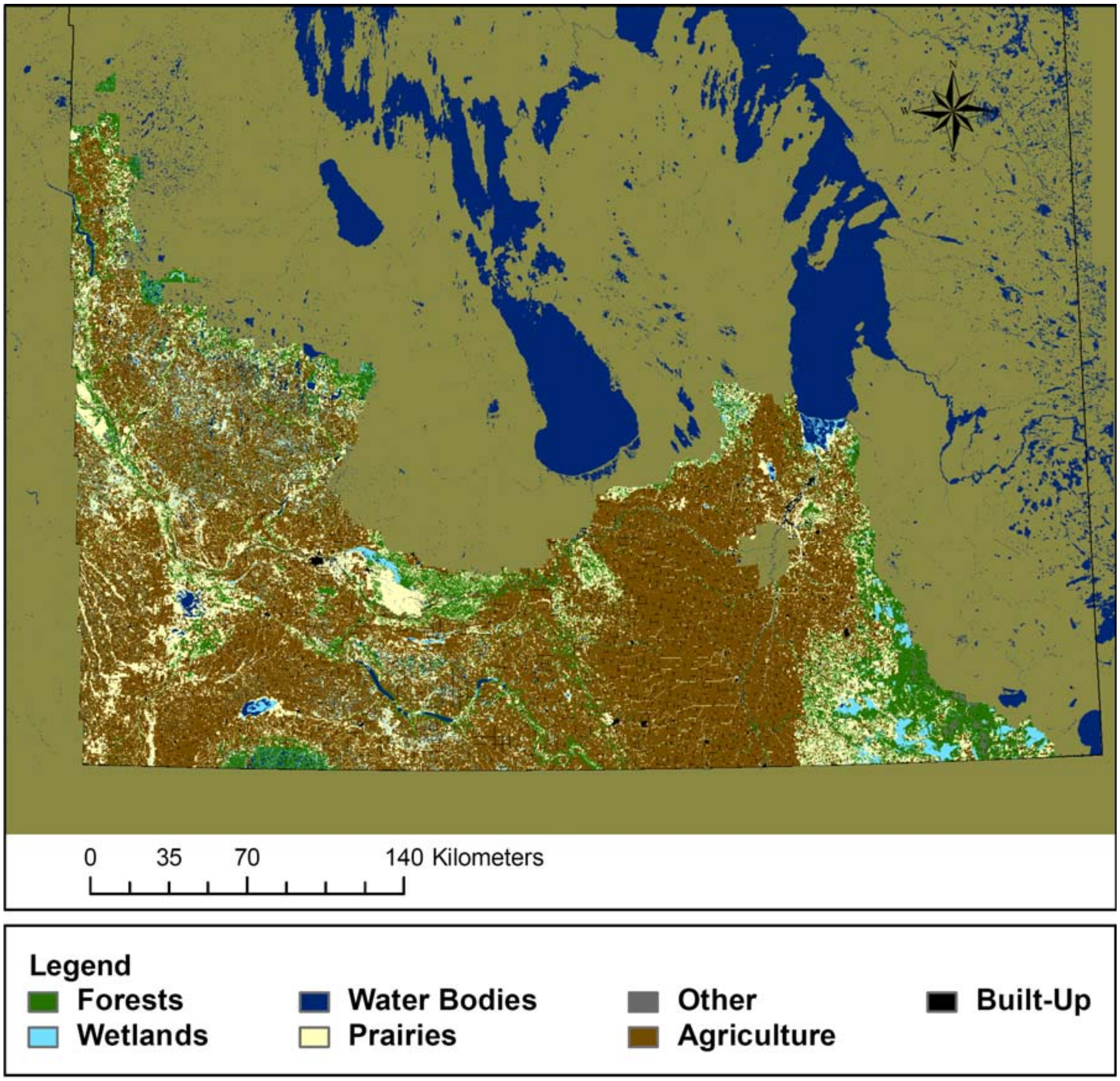
4.1. The Current Landscape

The current landscape was mapped based on 1999 to 2002 LandSat imagery. These images were interpreted by the Manitoba Conservation Remote Sensing department to derive land cover information categorized into 18 classes. The land cover information was simplified to seven classes (see **Appendix D**) to build the land cover map shown in **Figure 7**. Agricultural lands dominate the current landscape in southern Manitoba and approximately 60 per cent of the landscape has been human-altered. Remnant prairies, forests and wetlands provide a considerable amount of ecosystem services that can be translated in economic terms.

ESVs were estimated and presented by land cover types and contextual relevance to southern Manitoba context in **Figures 8** and **9**. The total ESVs calculated range from approximately 0.33 to 1.03 billion CDN$/year (see **Table 4**). Wetlands and forests account for 79 to 86 per cent of the total ESVs by land cover type, while prairie grasses account for 6 to 9 per cent, as its ESV per hectare is substantially lower. Ecosystem services influencing climate change and water quantity and quality represented 77 to 87 per cent of the total ESVs for the river basin system. These results highlight the importance of maintaining forests and wetlands to maximize ecosystem service benefits and of preserving environmental assets that provide ecosystem services influencing climate change and water quantity and quality.

Table 4. Summary of the current landscape ecosystem service values by land cover and contextual relevance

Land Cover and Contextual Relevance	**Area in Hectares**	**Ecosystem Service Values in 2007 billion CDN$/year**
Forests	797,010	0.05 – 0.54
Wetlands	223,547	0.21 – 0.35
Water Bodies	113,241	0.00
Prairies	1,153,347	0.03 – 0.06
Agricultural Land	3,245,733	0.04 – 0.08
Built-up	182,671	0.00
Other	18,519	0.00
Land Cover Type Total		**0.33 – 1.03**
Water Quantity and Quality		0.21 – 0.23
Climate Change		0.08 – 0.56
Biodiversity		0.02 – 0.08
Material Benefits		0.00 – 0.12
Social Wellbeing		0.02 – 0.04
Environmental Integrity		0..00
Contextual Relevance Total		**0.33 – 1.03**



Land Cover	AREA (ha)	Percentage (%)
Forests	797,010	13.90%
Wetlands	223,547	3.90%
Water Bodies	113,241	1.97%
Prairies	1,153,347	20.11%
Other	18,519	0.32%
Agriculture	3,245,733	56.60%
Built-Up	182,671	3.19%
TOTALS	5,734,068	100.00%

Figure 7. The current composition of the southern Manitoba landscape.

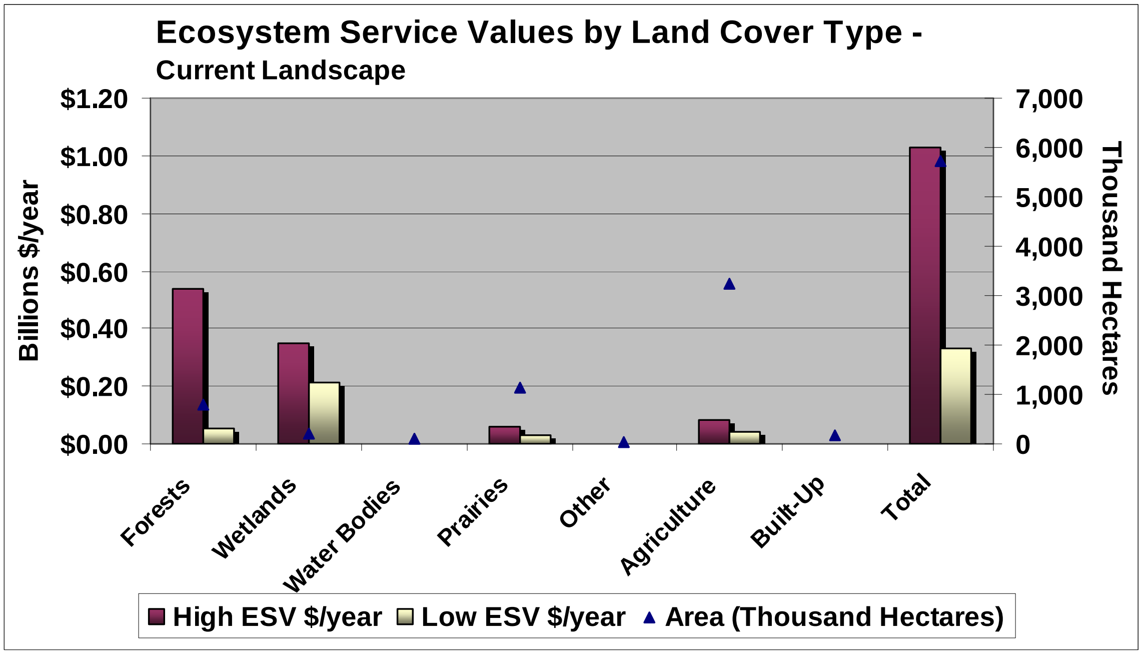


Figure 8. Ecosystem service values of the current landscape by land cover type.

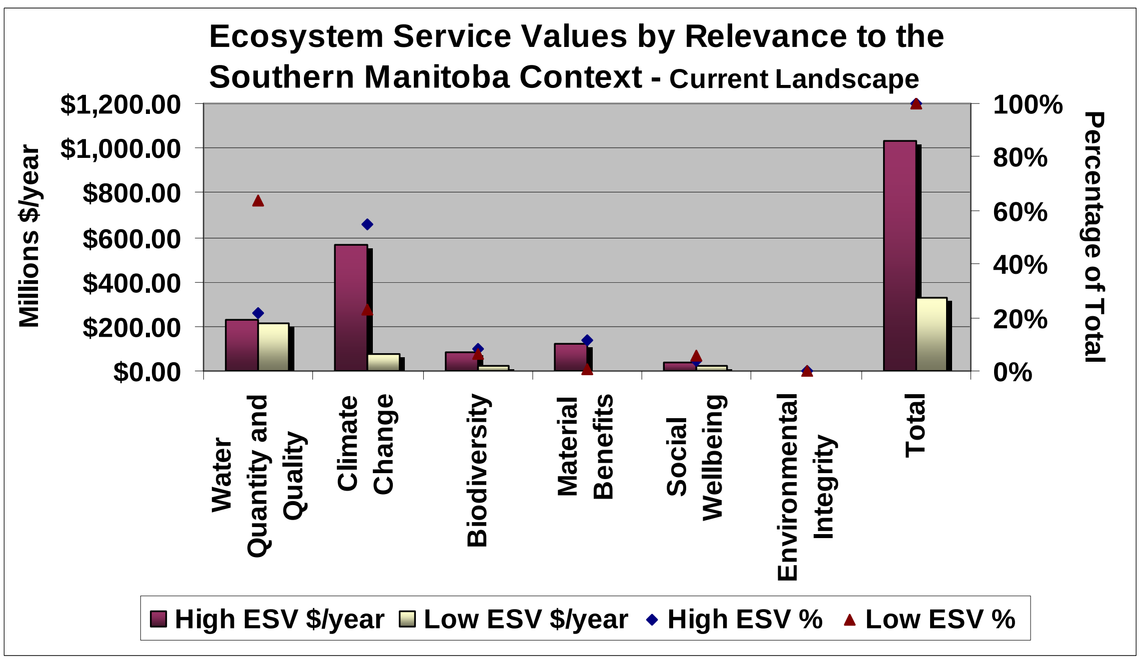


Figure 9. Ecosystem service values of the current landscape by contextual relevance to southern Manitoba.

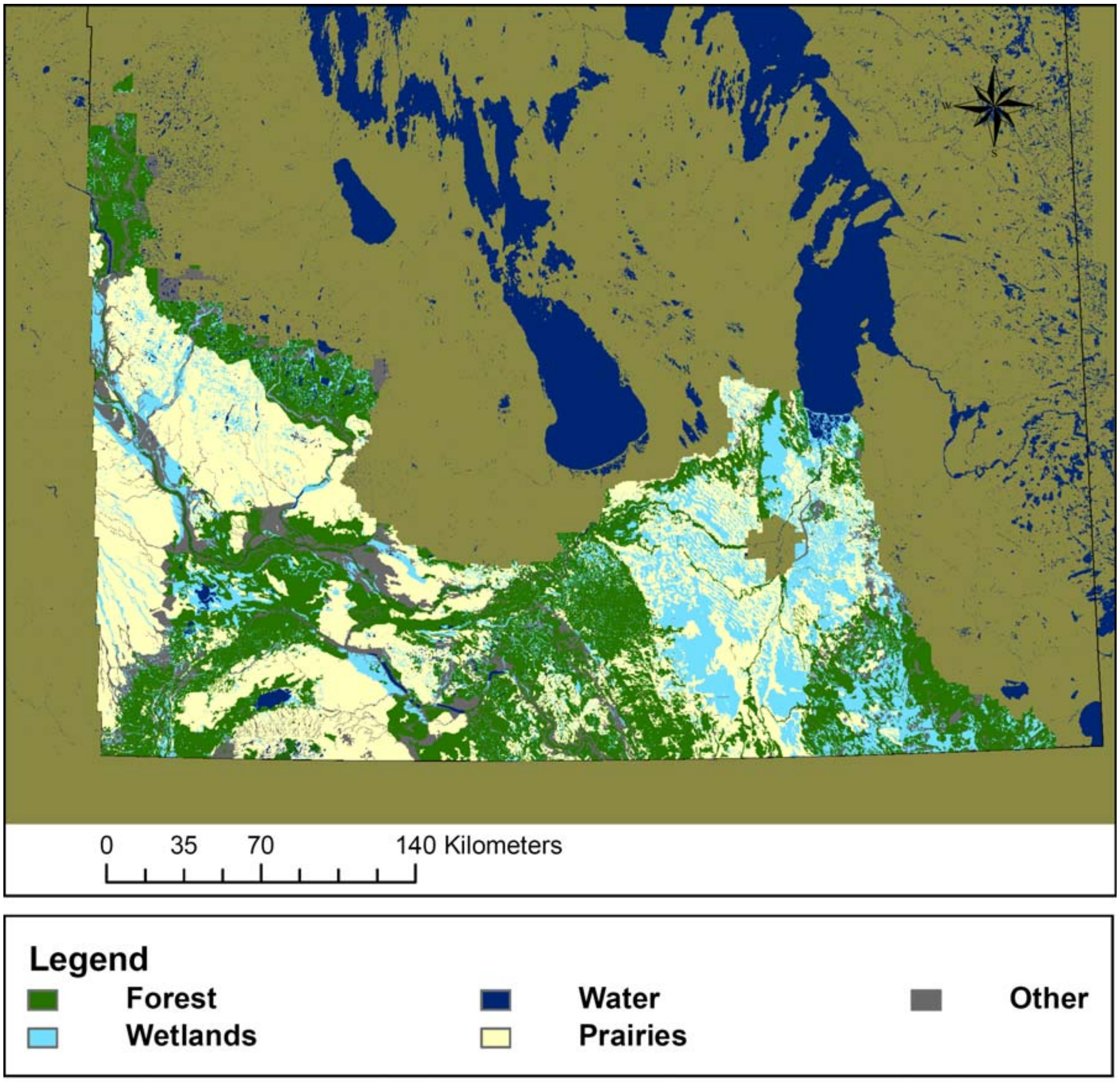
4.2. The Pre-settlement Landscape

Three pre-settlement landscapes were constructed based on soil genesis information (see **Figures 10**, **11** and **12**) which provided the basis for linking soil types with land covers. The existence of specific soils corresponds directly to particular land covers. For instance, the presence of chernozem soils implies the former existence of prairies as it is the periodic decomposition of grassland root structures that enable the formation of this soil type (Ellis, 1938). Gleysols require the presence of standing water for their formation, which implies that wetlands once covered these soils at some point in time (Ellis, 1938). While some soils form due to the presence of a particular land cover others do not. For instance, regosols can support prairie grasses as well as forests. The landscape was reconstructed based on GIS soil type information obtained from the Manitoban Land Inventory which was rasterized and reclassified into representative land covers using ArcGIS spatial analyst. This approach limited the accuracy of the reconstruction as each soil type could only be associated to one land cover type. To address this limitation three pre-settlement landscapes were constructed by varying the land covers on soils supporting various land covers. This gave a range of potential land cover distributions consisting of a wetland dominant (pre-settlement landscape 1), forest (deciduous, conifer and mixedwood) dominant (pre-settlement landscape 2) and prairie grass dominant (pre-settlement landscape 3) landscape (see **Appendix A**).

The pre-settlement landscapes were used to estimate the potential ESVs that could be provided by the southern Manitoba landscape if natural environments were to be completely restored (see **Figures 13** to **18**). The overall ESVs calculated for all three pre-settlement landscapes are summarized in **Table 5**. It must be noted that lands classed **Other** were not valued and that pre-settlement landscape 3 had approximately twice the surface area of this land class compared to the other pre-settlement landscapes. Forests and wetlands and ecosystem services that influence climate change and water quantity and quality provided the majority of ESVs. These results highlight the important benefits received from forests and wetlands and ecosystem services that influence water quantity and quality and climate change.

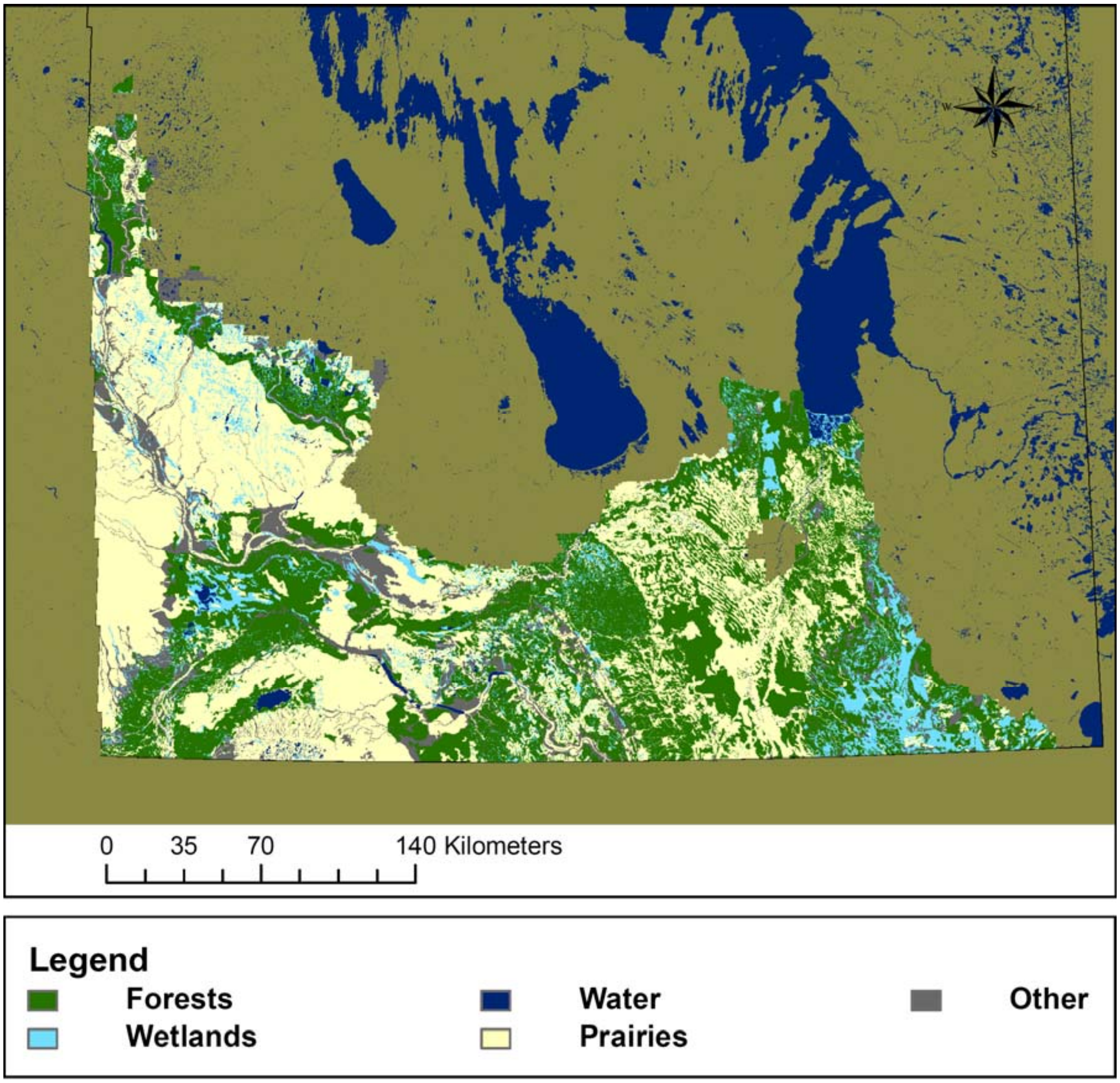
Table 4. Summary of the Pre-Settlement Landscapes Ecosystem Service Values by Land Cover and Contextual Relevance

Land Cover and Contextual Relevance	**Surface Areas in Hectares**			**Ecosystem Service Values in 2007 billion CDN$/year**		
	Land 1	Land 2	Land 3	Land 1	Land 2	Land 3
Forests	1,782,300	2,157,682	1,586,672	0.12 – 1.21	0.14 – 1.46	0.10 – 1.08
Wetlands	1,125,813	498,696	348,519	1.06 – 1.76	0.47 – 0.78	0.33 – 0.55
Water Bodies	89,113	89,113	89,113	0.00	0.00	0.00
Prairies	2,203,950	2,455,685	2,585,067	0.06 – 0.11	0.06 – 0.12	0.07 – 0.13
Agricultural Land	0	0	0	0.00	0.00	0.00
Built-up	0	0	0	0.00	0.00	0.00
Other	534,205	534,205	1,126,010	0.00	0.00	0.00
Land Cover Type Total				**1.23 – 3.08**	**0.67 – 2.37**	**0.50 – 1.75**
Water Quantity and Quality				1.04 – 1.11	0.46 – 0.49	0.33 – 0.35
Climate Change				0.08 – 1.17	0.09 – 1.41	0.08 – 1.05
Biodiversity				0.05 – 0.36	0.06 – 0.20	0.04 – 0.14
Material Benefits				0.01 – 0.37	0.01 – 0.20	0.01 - 0.15
Social Wellbeing				0.05 – 0.07	0.05 – 0.07	0.04 – 0.06
Environmental Integrity				0.00	0.00	0.00
Contextual Relevance Total				**1.23 – 3.08**	**0.67 – 2.37**	**0.50 – 1.75**



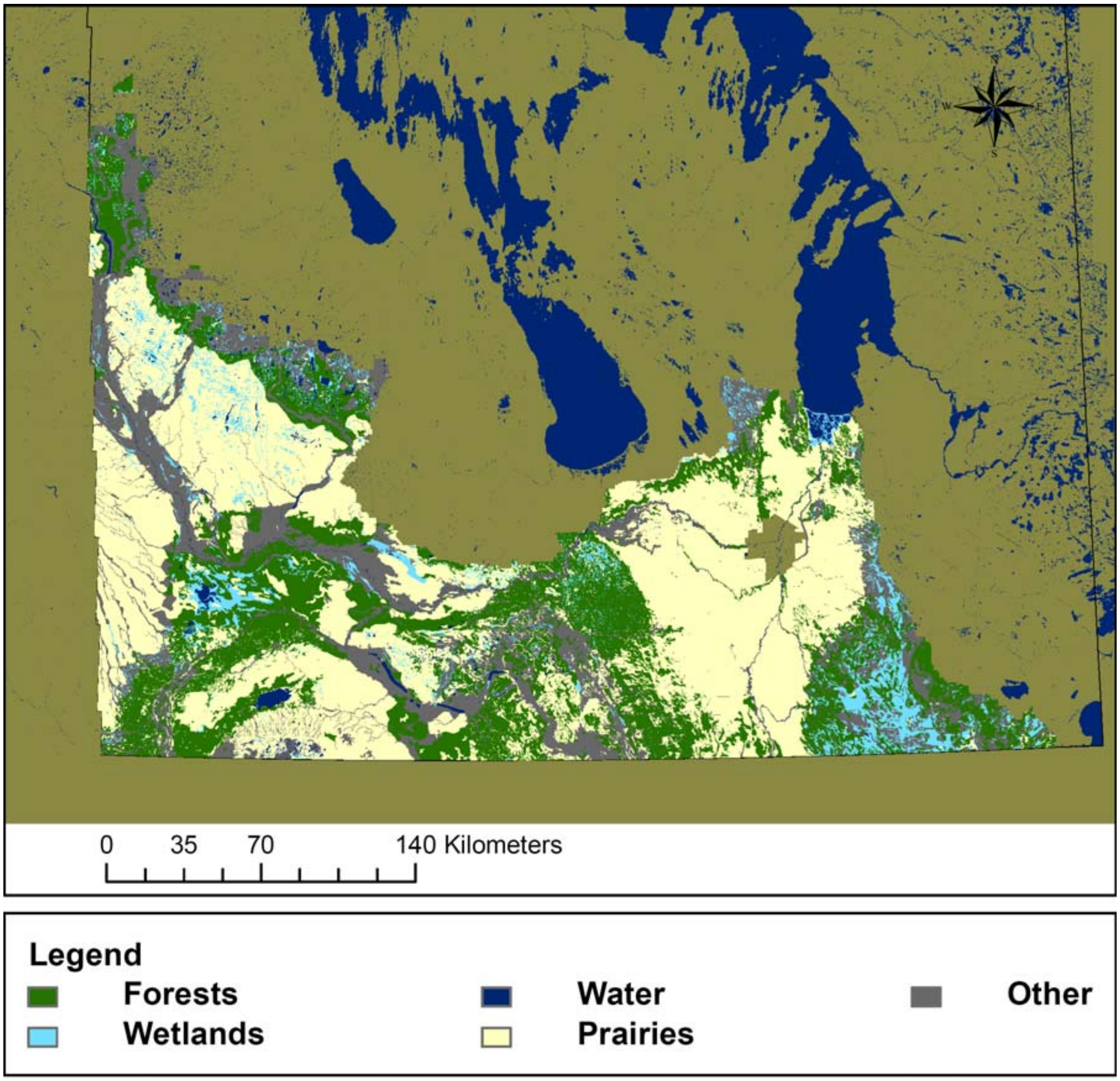
Land Cover	AREA (ha)	Percentage (%)
Forests	1,782,300	31%
Wetlands	1,125,813	20%
Water Bodies	89,113	2%
Prairies	2,203,950	38%
Other	534,205	9%
TOTALS	5,735,381	100%

Figure 10. A pre-settlement reconstruction of the southern Manitoban landscape based on soil types (Pre-settlement Landscape 1).



Land Cover	AREA (ha)	Percentage (%)
Forests	2,157,682	38%
Wetlands	498,696	9%
Water Bodies	89,113	2%
Prairies	2,455,685	43%
Other	534,205	9%
TOTALS	5,735,381	100%

Figure 11. A pre-settlement reconstruction of the southern Manitoban landscape based on soil types (Pre-settlement Landscape 2).



Land Cover	AREA (ha)	Percentage (%)
Forests	1,586,672	28%
Wetlands	348,519	6%
Water Bodies	89,113	2%
Prairies	2,585,067	45%
Other	1,126,010	20%
TOTALS	5,735,381	100%

Figure 12. A pre-settlement reconstruction of the southern Manitoban landscape based on soil types (Pre-settlement Landscape 3).

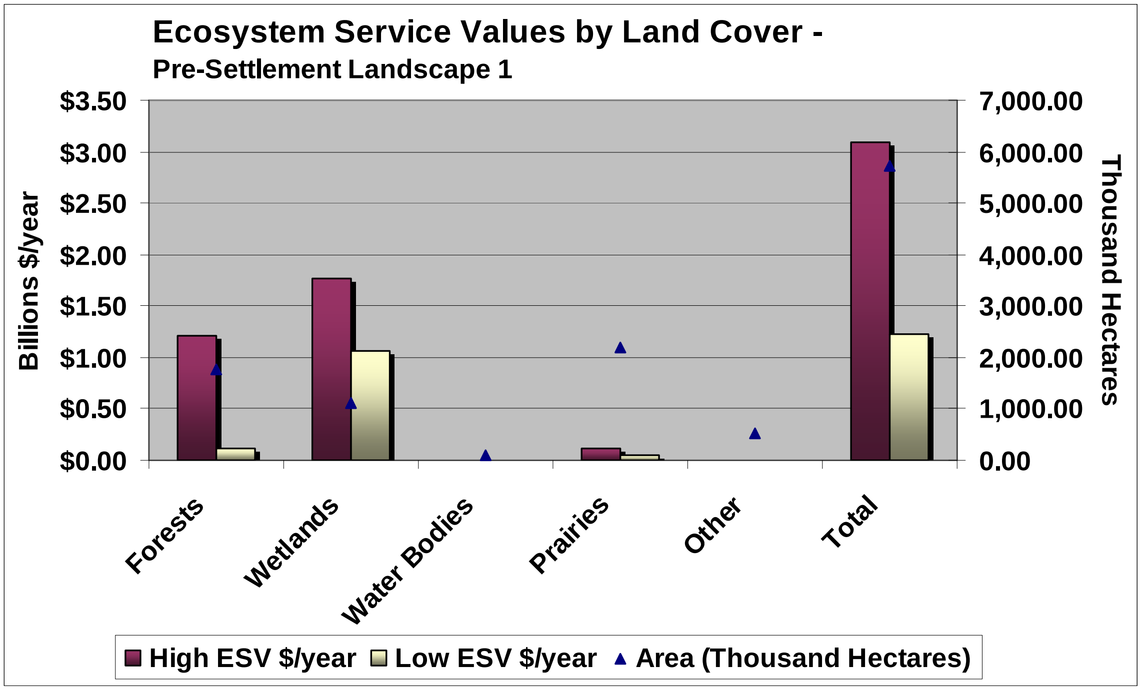


Figure 13. Ecosystem service values of pre-settlement landscape 1 by land cover type.

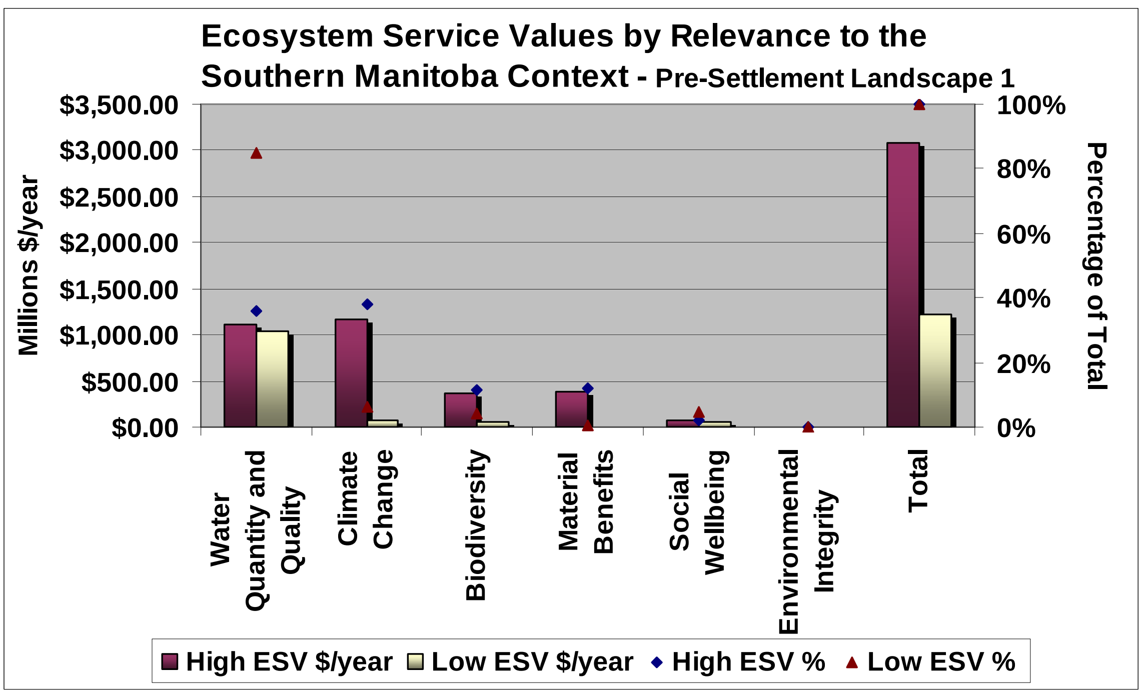


Figure 14. Ecosystem service values of the pre-settlement landscape 1 by contextual relevance to southern Manitoba.

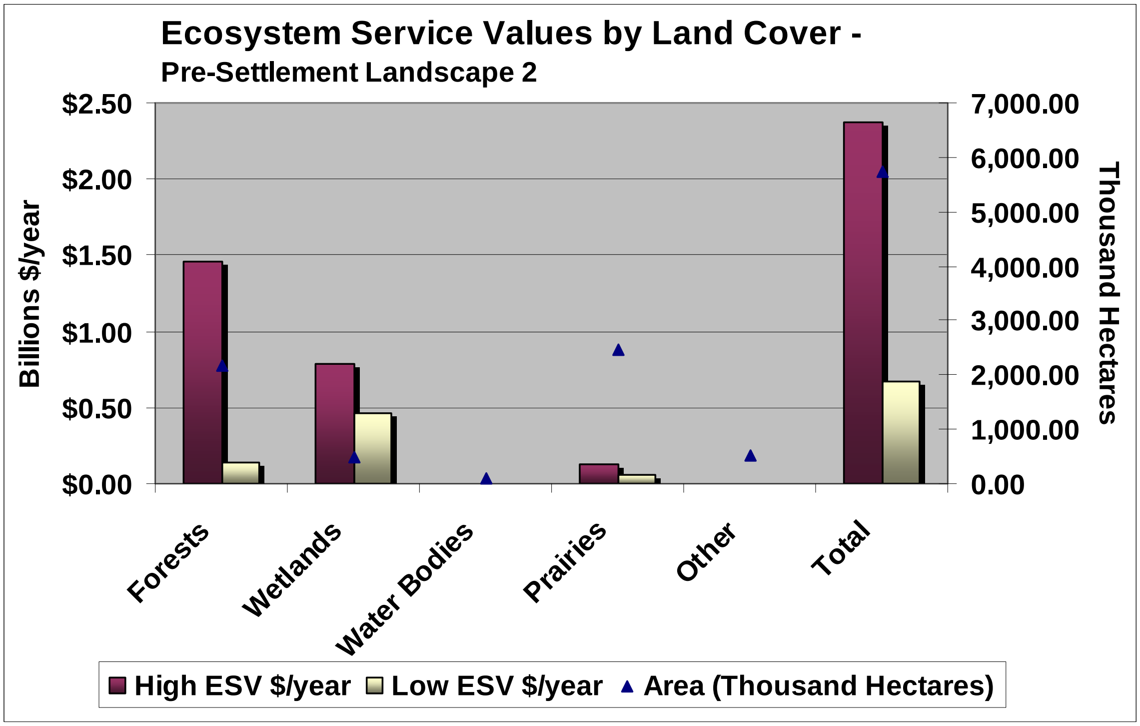


Figure 15. Ecosystem service values of the pre-settlement landscape 2 by land cover type.

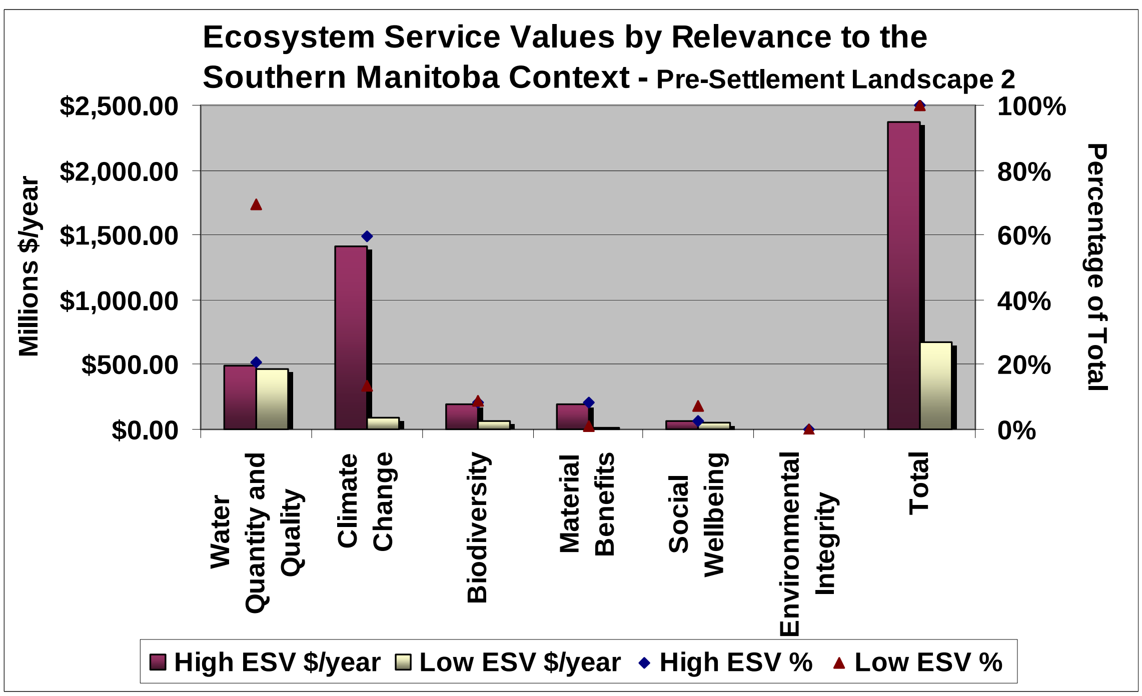


Figure 16. Ecosystem service values of the pre-settlement landscape 2 by relevance to the southern Manitoba context.

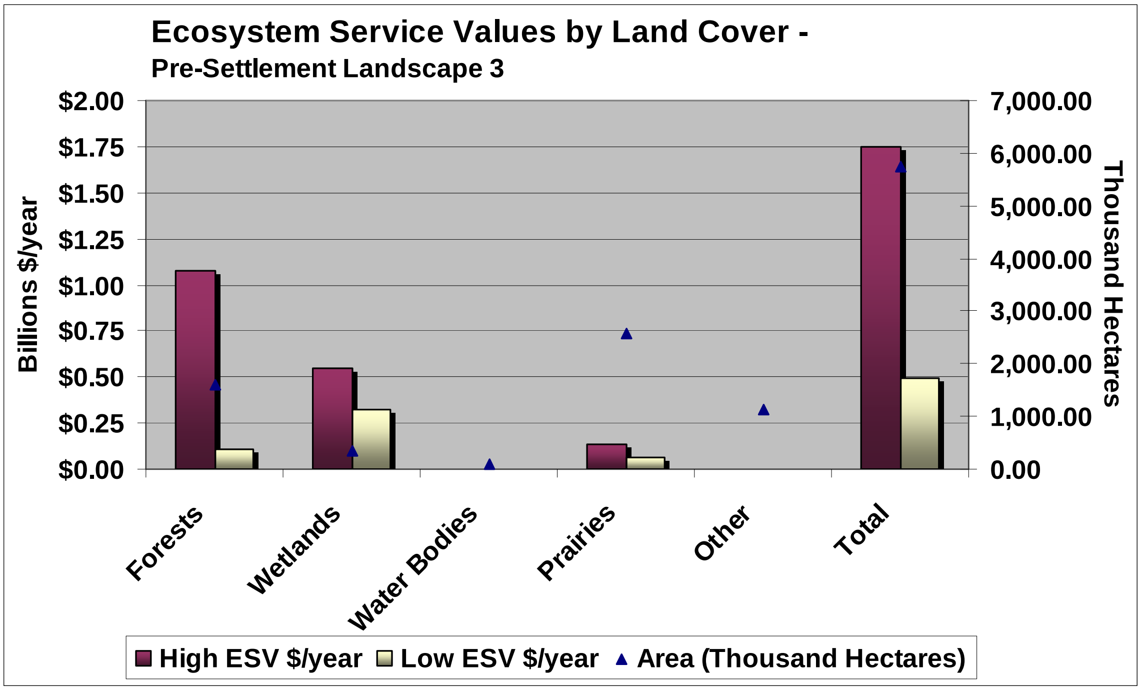


Figure 17. Ecosystem service values of the pre-settlement landscape 3 by land cover type.

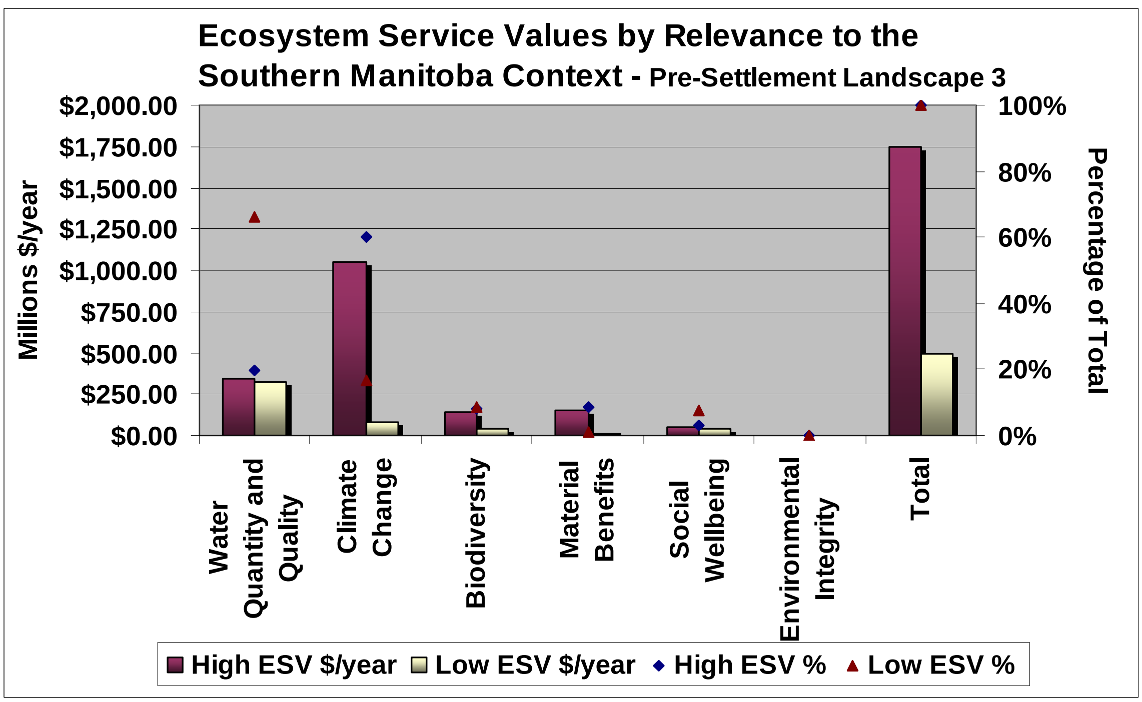


Figure 18. Ecosystem service values of the pre-settlement landscape 3 by contextual relevance to southern Manitoba.

4.3. Assessment Synthesis

Figure 19 summarizes total ESVs of the current and pre-settlement landscapes. To compare similar sets of ESVs, one must evaluate the high or low values between the current and pre-settlement landscapes. Comparing high ESVs with low ESVs between the different landscapes is not feasible, as they were compiled differently. When comparing the high or low values between the current and pre-settlement landscapes, the current landscape consistently provides lower ESVs, as there are substantially fewer forests, wetlands and prairies (see **Table 6**).

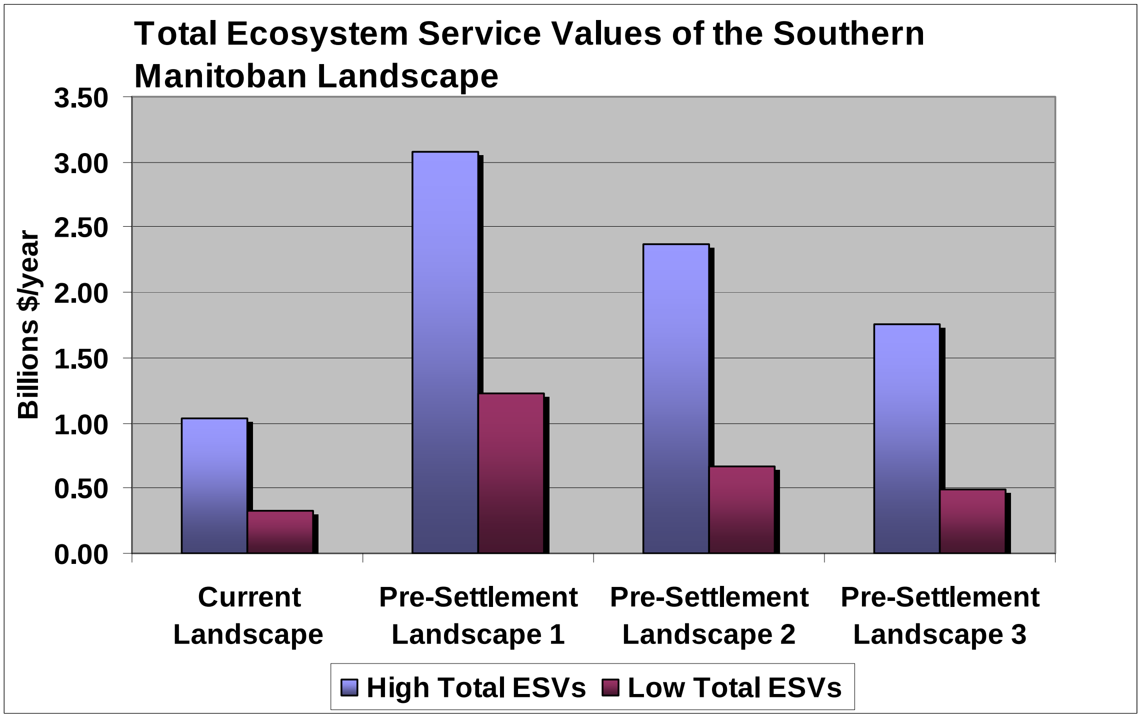


Figure 19. Total ecosystem service values of the current and pre-settlement southern Manitoban landscapes.

We observe that the majority of the ESVs are provided by forests and wetlands and ecosystem services related to water quantity and quality and climate change (see **Table 6**). As expected the current landscape had substantially less forests and wetlands compared to the pre-settlement landscapes. It must be noted that one fifth of pre-settlement landscape 3 surface area was classed **Other** which was not valued due to lack of information.

Table 5. Elements of the Pre-Settlement Landscapes Ecosystem Service Values Examined

Elements of the Results Examined	Current Landscape	Pre-settlement Landscape 1	Pre-settlement Landscape 2	Pre-settlement Landscape 3
Ecosystem Service Values in billion CDN$/year	0.33 - 1.03	1.23 - 3.08	0.67 - 2.37	0.50 - 1.75
Contribution of Forests and Wetlands ESVs to Total.	79% - 86%	95% - 96%	91% - 95%	86% - 93%
Contribution of Climate Change and Water Related ESVs to Total.	77% - 87%	74% - 91%	82% - 83%	80% - 83%
Forests and **Wetlands** Area	18%	51%	47%	34%
Other Surface Area	0.32%	9%	9%	20%

The reconstructions of the pre-settlement landscape provided a way to estimate the potential ESVs that could be derived from the landscape if natural environments were to be completely restored. These results point to a potential opportunity for optimizing the landscape to increase ecosystem services, which could enhance well-being and maintain livelihoods, via the preservation and restoration of environmental assets.

4.4. Critical Analysis of the Assessment

The methodology used for the environmental asset assessment is critically analyzed to gain insights for further research in the valuation of ecosystem services. The overall approach for the assessment was spatially grounded and was comprised of two main components; land cover distribution mapping and the valuation of ecosystem services. The rational for the spatially based approach and the methodological details of the assessment are examined in detail.

A spatially grounded approach was adopted for the assessment as remote sensing data provides accurate spatial biophysical information which can be used to assess the environmental assets of extensive areas in a cost effective manner. For instance, land cover maps for all of Canada can be produced from land cover information freely available through the Canadian Forestry Services. In addition, the National Land Water Inventory Service offers a number of agri-environmental spatial data sets such as soils and land cover data which are accessible via the internet. Land cover maps provide important biophysical information needed to evaluate the ecosystem services that can potentially flow from a landscape. The spatially grounded approach was also used as a number of ecosystem service values, such as the ones obtained from the valuation studies used in this analysis, were compiled based on surface area (Anielski & Wilson, 2005, 2007; Kulshreshtha & Pearson, 2006; McComb, Lantz, Nash, & Rittmaster, 2006; Olewiler, 2004). The spatial approach set the tone for the data requirements and methodology used to carry out the assessment which rested on generating land cover distribution maps at different time intervals.

The pre-settlement land cover maps generated for the analysis were based strictly on soil information while a number of other biophysical characteristics could greatly influence the types of ecosystems that can proliferate in a particular area. Additional biophysical information could have been included to improve the accuracy of the pre-settlement landscape reconstructions. Biophysical characteristics that change gradually over long periods of time such as soil composition and geomorphology are ideal for estimating land cover distributions of the distant past. Paleo-climatology data can also provide insights on past climate regimes. Combining geomorphology and climate data with soil information could assist in estimating with greater accuracy the pre-settlement land cover likelihood of a particular area. To address the imprecision associated with reconstructing a landscape based strictly on soil type three landscapes were reconstructed providing a range of potential pre-settlement land cover distributions.

Delineating, quantifying and valuing ecosystem services pose significant challenges. Conceptually, economically valuing ecosystems is not truly possible with current economic valuation methodologies as they emerge from interconnected, healthy and resilient ecosystems (Straton, 2006). Distinguishing one ecosystem service from another contradicts this reality. To address this challenge Boyd (2007) suggests that ecosystem services should be measured and valued strictly as "end products" similarly to human fabricated products. This can be problematic for the protection of natural environments as important ecological functions that contribute to the attainment of "end products" and are difficult to value may be neglected. Nevertheless, defining, delineating and valuing ecosystem services provide a way to measure and understand the important and valuable services we receive from the natural environment.

The valuation of ecosystem services is not an exact science but can provide valuable insights for managing ecosystems. Current economic valuation methodologies do not accurately capture the value of ecosystem services. Depending on the valuation method used, some types of economic valuation of ecosystem services can be considered less rigorous, or less amenable to decision-making, than others. Revealed preference methods which are typically based on marginal values are considered more relevant for decision making than values derived from stated preference methods, which tend to be total or average values better suited to assess all-or-nothing situations. Revealed economic valuation methods are limited to ecosystem services that are market traded while stated preference valuation methods are not considered to be rigorous. For example, a person's stated willingness to pay can be greatly influenced by the way that a question is posed and their frame of mind when answering the questions. Nevertheless, this problem has been partially addressed by using a combination of revealed and stated preference valuation methods and well structured surveys. As marginal/revealed valuation methodologies evolve and valuation studies continue to grow the accuracy of ecosystem service values will improve.

Conducting site specific economic valuation studies can be time consuming and expensive (McComb et al., 2006). Transferring ecosystem service valuation information from one context to another using benefit transfer techniques offers an economically viable approach to include ecosystem services values in decision making (Wilson & Hoehn, 2006). This approach also introduces error in the analysis as no two contexts will be similar. To minimize the error involved in transferring economic valuation data recent Canadian valuation studies that cover relevant geographic areas were used for the analysis.

Not all wetlands and forests provide the same amounts of ecosystem services and assessing their integrity informs their potential capacity to provide ecosystem services. Including a measure of ecosystem integrity in the economic valuation of ecosystem services is a major challenge as ecosystems are dynamic and constantly changing. The European Environment Agency accounts for ecosystem integrity by measuring ecosystem distress signals such as water quality and shortage, structure and morphology changes, fragmentation, nutrient cycling pattern disruptions, chemical distress and biodiversity (Weber, 2006). Anielski and Wilson (2005) identify ecosystem integrity as being of great importance to properly assess the value of natural environments. They discuss Dr. James Karr's Index for Biological Integrity which measures human disturbances, biological condition and thresholds as a potential way to address this shortfall (Anielski & Wilson, 2005). Walker and Pearson (2007) suggest the measuring ecosystem resilience as a way to include ecosystem integrity considerations when assessing natural environments. For instance, they propose measuring water table depth to assess soil resilience as groundwater can impact soil salinity rendering it unfertile. Including ecosystem integrity measures such as habitat fragmentation and biodiversity would greatly enhance the accuracy of ecosystem service valuation studies.

To account for the data limitations and methodological shortfalls associated with valuing ecosystem services, ESV ranges were used in the analysis. High and low ESV estimates were generated for every ecosystem service evaluated. The extent of the ESV ranges compiled reflected the diversity of the ESVs reported in the valuation studies examined. Furthermore, the ESV ranges also reflect inaccuracies associated with transferring ESVs derived for a given context to southern Manitoba. For instance, the economic values used to estimate a number of ecosystem services provided by wetlands (water supply, habitat/refugia and genetic resources) in the high estimate were omitted in the low estimate to reflect their questionable applicability to southern Manitoba. The use of ranges attempts to account for the uncertainties and variances associated with ecosystem valuation methods and available information.

It must be noted that the ESV ranges used in this study were derived by aggregating total, average and marginal values. According to conventional economics these aggregated values should not be used for decision making as they cannot be compared to measures of economic values expressed in market exchanges (Daly, 1998). Although this may be true within the current economic context, some economists argue that strictly basing decision making on marginal values has lead to the unimpeded loss of environmental assets (Ayres, 1998; Costanza et al., 1998; Daly, 1998; Pearce, 1998). "If economics can only deal with small increments and decrements in our natural capital won't the willingness to pay criterion justify one loss after another until there are non left (Pearce, 1998, p. 28)" Using Lauderdale's Paradox (scarcity is necessary for something to have an exchange value which has lead to the expansion of private riches at the expense of public wealth), Daly (1998) contends that aggregated values should be viewed as a useful index to measure how far we have moved away from an historical base period. Although marginal values may provide for more reliable decision making at the micro scale within our current economic context, aggregate values provide a useful coarse measure at the macro scale for the loss or gain of environmental assets from a given baseline (Daly, 1998). Consequently, it can be argued that decision making based on marginal and aggregated values may lead to more sustainable outcomes. Clearly, ecosystem services valuation methods need to evolve to enhance our ability to determine the short and long term gains and impacts that our choices will have on our wellbeing and natural environments.

Despite land cover mapping challenges and the limitations of economically valuing ecosystem services they provide useful information. Land cover mapping provides a means for assessing landscape changes over time which can be useful for estimating ecosystem services flows. Ecosystem service valuation studies enable comparative analyses to similar studies and most importantly, they draw attention to the valuable services we receive from natural environments even when they do not generate market-based economic activity.

5. Drivers of Landscape Transformation

A landscape is an expression of its ecological and social history (Antrop, 2005; Leach, Mearns, & Scoones, 1999). A historical analysis of the policies and institutional arrangements that have shaped southern Manitoba into an intensive agro-ecosystem provides a point of entry for understanding the underlying causes that have resulted in environmental asset losses (Leach *et al.*, 1999). Consequently, a biophysical, socio-political and economic lens was used to identify a number of driving forces that have transformed the southern Manitoban landscape over time.

The biophysical characteristics of southern Manitoba facilitated the establishment of agriculture as the main economic activity in the region for over a century. Manitoba was once covered by an enormous glacier that moved southward from Hudson Bay, flattening the landscape until its southern edge began melting faster than its advancement due to an increase in ambient temperature (Buckner, 1990). Meltwater from the glacier formed glacial Lake Agassiz, which over time drained northwards and eastwards, leaving behind a number of lakes approximately 8,000 years ago. Glacier movements and glacial lake submergence shaped the province's soils and topography. Southern Manitoba is characterized by an even terrain with the majority of the landscape not exceeding a five per cent slope, and soils that are mixed and fairly uniform, which are attributes well-suited for agriculture (Ellis, 1938). A reconstruction of the southern Manitoban landscape based on 1871 to 1877 dominion survey maps indicates that this area was covered in prairie grasses, large forests and wetlands (Hanuta, 2006). The landscape is now marked by a dramatic loss of environmental assets dominated by agricultural lands. The remnant natural vegetation presently found in southern Manitoba is comprised of tall and mixed prairie grasses with narrow forests (100 to 200 metres), mostly bordering rivers and streams (St. George & Nielsen, 2002).

Southern Manitoba experiences a semi-arid climate with precipitation variability ranging from 20 to 25 per cent based on 1960 to 2002 precipitation data (Venema, 2006). St. George and Nielsen (2002) conclude, based on hydro-climate data inferred from tree rings, that the mean precipitation received in southern Manitoba has been relatively stable over the last 200 years. Between 1775 and 1998, southern Manitoba has received a mean annual precipitation of approximately 590 mm, which is comparable to the mean annual precipitation of 598 mm received between 1961 and 1990 (St. George & Nielsen, 2002). They further state that "prior to the 20th century, southern Manitoba's climate was more extreme and variable, with prolonged intervals that were wetter and drier than any time following permanent Euro-Canadian settlement (St. George & Nielsen, 2002, p. 110)." Regional climate studies for flooding and drought planning based on 20th century data underestimate worst-case scenarios as long-term climate records in the Northern Great Plains infer that natural variations can cause substantial shifts in precipitation regimes, which can last for decades and impact several thousand kilometres (St. George & Nielsen, 2002). These findings do not bode well for the agricultural industry, as natural climatic variations may be substantially exacerbated by the effects of climate change. In the last century, southern Manitoba has already experienced a number of climatic fluctuations that have resulted in substantial losses in agricultural production. The drought of 1988 resulted in a 50 per cent drop in net farm incomes; more recently, the flooding of 2005 significantly reduced yields in Manitoba (Venema, 2006). These events serve as a reminder to the potentially devastating effects of climate on the agricultural industry and its vulnerability to climate change.

Federal government policies, which initially encouraged settlement and the establishment of agriculture in southern Manitoba, were instrumental in molding the landscape (see **Figure 20** and **Appendix E**). Policies developed from 1870 to 1914 were guided by the desire to settle the west and establish a resource-based economy primarily driven by agriculture. The First World War prompted the federal government to establish the Board of Grain Supervisors as the demand for wheat increased substantially to support the allied forces. The wheat boom continued beyond World War

One until the Great Depression from 1929 to 1939, which saw the collapse of wheat market prices and a prolonged drought. This impelled the federal government to establish policies to protect agricultural producers from economic and environmental impacts. The Second World War led to the diversification of agricultural production in the Canadian prairies and coincided with the rapid mechanization of farming operations. Rural development was initiated in the early 1960s to raise incomes and the quality of life of rural residents primarily through agricultural expansion, diversification and intensification.

Comprehensive land-use planning in Manitoba has been slow to develop, which may be attributed to the apparent abundance of natural resources within the province (Todd, 1982). Issues such as soil and water conservation, wildlife preservation and environmental pollution began to gain some importance in the 1950s (Todd, 1982). As the population expanded and demands for resources increased and diversified, the provincial government started paying more attention to the finite nature of its resource base. Throughout the 1960s and 1970s, land-use planning made inroads and eventually was entirely integrated within provincial government policy. The first comprehensive land-use plan under the name of "Guidelines for the Seventies" made its appearance in Manitoba in the mid-1970s.

Prairie agriculture started a restructuring process in the late 1980s due to trade liberalization and efforts to meet the North American Free Trade Agreement and World Trade Organization Compliances (Venema, 2006). Environmental protection and sustainable development movements started gaining momentum and public awareness in the early 1990s. As a result, the importance of healthy functioning ecosystems and their services for human well-being has started gaining credence and attention within government over the last two decades.

To summarize, the biophysical characteristics of southern Manitoba have made it amenable to agriculture. Socio-political and economic drivers have shaped the southern Manitoban landscape by establishing, maintaining and expanding agricultural practices for over a century. With the exception of the last three decades, most government policies have been geared towards upholding agriculture as the main form of economic activity in the area. Trade liberalization and climate change are now challenging the economic viability of farming in Manitoba. Agricultural impacts on natural environments are no longer being ignored by the public and in response governments have instituted a number of environmental protection policies to remedy the situation (see **Appendix E**).

The biophysical and socio-political influences that have shaped southern Manitoba are synthesized and presented chronologically by time periods in **Figure 20**. The socio-economic systems that are dependant on agriculture in southern Manitoba are now more vulnerable to natural and economic shocks and stresses. Environmental asset preservation and restoration may offer a means to effectively cope with change by absorbing these shocks and stresses. Identifying and linking the drivers of landscape transformations qualitatively to the state of the environment provides a basis for formulating effective environmental asset preservation and restoration policies.

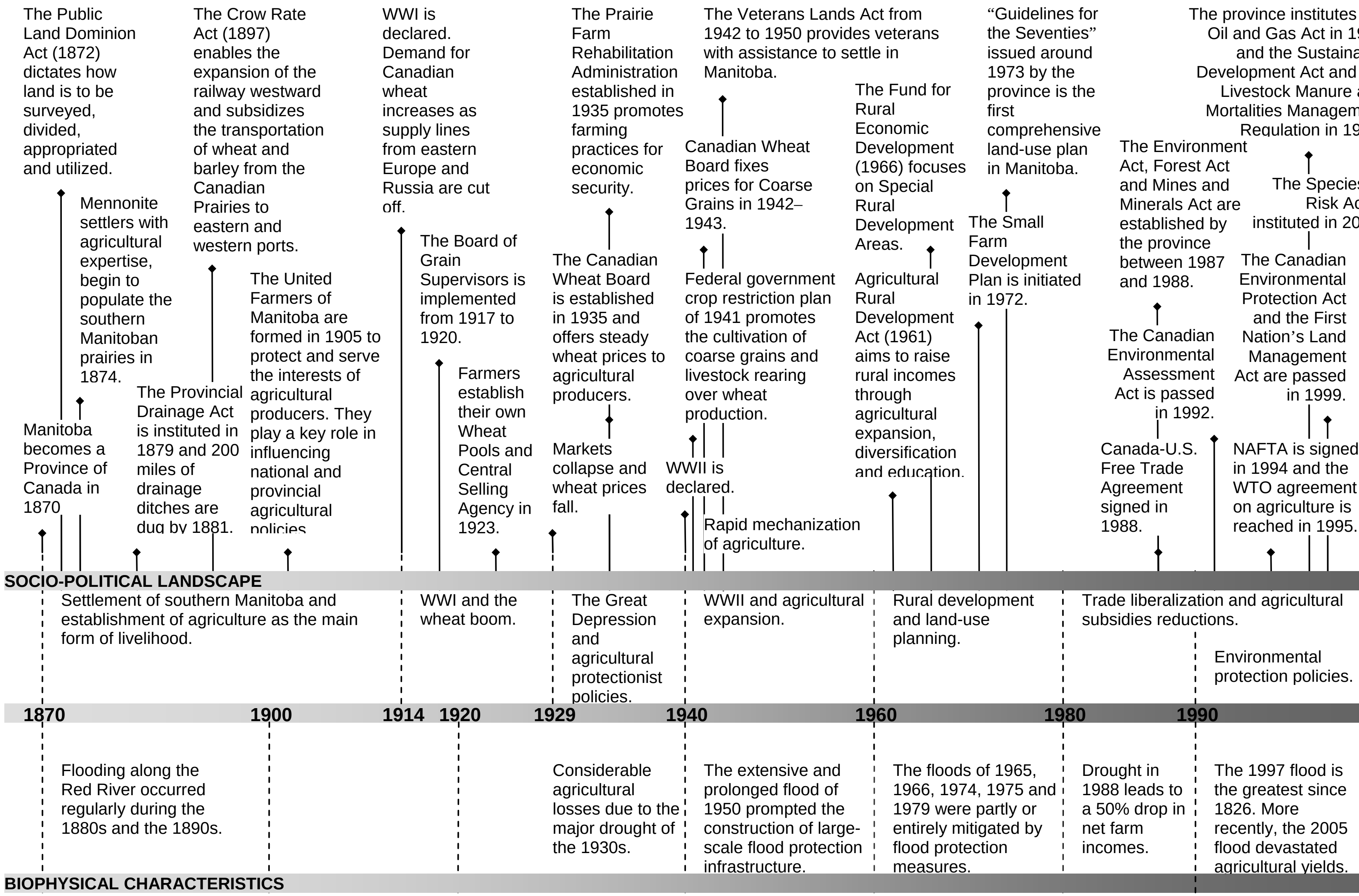


Figure 20. Timeline presentation of the drivers of landscape transformation in southern Manitoba.

6. Policy Relevance of the Ecological Services Assessment

A retrospective analysis of the environmental assets on the landscape provided two important policy insights. The first being the influence of past policies on the distribution and quantity of ecosystem services and the second being the economic value of ecosystem services lost or gained. It also informs the development of effective strategies and a financial case for preserving and restoring ecosystems. A good understanding of the landscape's transformation, dynamics and responses to various policies will facilitate the implementation of an effective environmental asset preservation and restoration program. Quantifying and valuing ecosystem service losses or gains provide an economic rationale for their preservation and restoration. **Figure 21** depicts the approach suggested to develop effective environmental asset preservation and restoration programs.

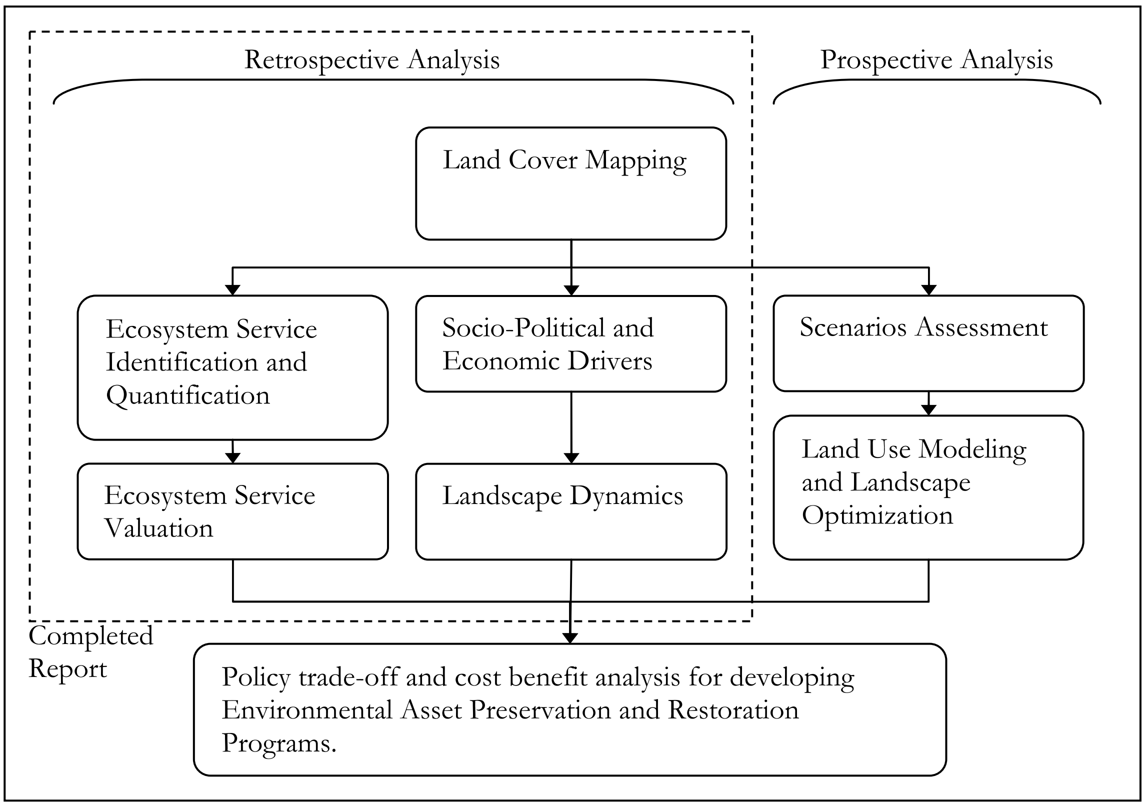


Figure 21. A retrospective and prospective analysis of a landscape's environmental assets will inform the development of effective environmental asset preservation and restoration programs.

The physical transformation of the landscape is required to gauge the ecosystem services potential that could be provided if natural environment were restored. It also provides a general picture of the former physical layout of the natural environments on the landscape so that environmental asset restoration can be spatially targeted more effectively to improve wellbeing. Understanding landscape dynamics is primordial for developing effective environmental asset preservation and restoration programs. A landscape is a reflection of its ecological and social history. Therefore, a retrospective understanding of how and why the landscape has transformed provides useful landscape dynamic insights for a given context. These insights can then be used to effectively guide change leading to a desired outcome. For instance, intervening effectively in a large and complex landscape, such as the Lake Winnipeg Watershed, in an effective manner requires an understanding of how the landscape has responded to past changes.

A historical understanding of the socio-political drivers that have transformed the landscape informs which key political levers can be influenced for a desired change. In addition, a retrospective look at the drivers of landscape transformation may assist in avoiding past mistakes. For example, the over-exploitation of agricultural land which led to the 1930s dust bowl in the United States could repeat itself if too much land is taken out conservation reserve programs to cultivate biofuels. Furthermore, the agricultural practices and policies of the United States which have led to the hypoxia of the Gulf of Mexico are being repeated in the Canadian prairies leading to the eutrophication of Lake Winnipeg. Clearly, lessons learned from the past can inform the development of effective policies for a sustainable future.

Preserving and restoring environmental assets or ecological infrastructure can provide important services in a cost effective manner when compared to expensive hard infrastructure. Environmental assets or ecological infrastructure also supplies numerous co-benefits above and beyond economically valued services. For example, forested watersheds provide clean water by retaining and filtering precipitation, filter air pollutants, sequester carbon and provide wildlife habitat. Conversely, hard infrastructure facilities typically supply one service such as clean water or recreation. The economic valuation of ecosystem services can help justify expenditures in maintaining and building ecological infrastructure when measured against hard infrastructure investments.

The economic valuation of ecosystem services reveals to policy makers the important benefits we receive from functioning ecosystems, thus establishing a rationale for their preservation and restoration. Furthermore, policy impacts on ecosystem services can only be assessed if ecosystem services are tracked and evaluated (Boyd, 2007). Overall, assessing, quantifying and economically valuing ecosystem services allows for a more rigorous policy trade-off and cost benefit analysis.

7. Future Directions

Potential future directions for this research include the development of an IMEA information architecture and scenarios work to explore the potential benefits of environmental asset restoration. An IMEA information architecture is required to inform high-level environmental asset strategic planning as well as guide local or regional environmental asset management. Scenarios work would complement the development of the IMEA architecture by enabling the exploration of land uses that could address environmental and socio-economic issues.

An IMEA information architecture which can inform national, regional and local efforts to sustainably manage natural environments could facilitate the implementation of effective land use and environmental management policies. The IMEA information architecture would build on Statistics Canada's Canadian System of Environmental and Resource Accounts and would provide additional information required to properly manage and value natural environments. For example, examining the time lag between the implementation of a policy and its influence on the landscape can provide insights into the effectiveness an implemented policy for a desired outcome.

Exploring land use scenarios that protect the natural environment and improve the well-being of Canadians can be achieved by using landscape simulation models. For example, the landscape could be optimized to address the eutrophication of Lake Winnipeg by mitigating the nutrient loading of water bodies through environmental asset restoration. The potential advantages of restoring riparian areas or wetlands to absorb nutrient loads could be investigated with a landscape simulation model. A retrospective and prospective understanding of past, current and potential future landscape dynamics provides a sound basis for developing environmental asset preservation and restoration programs.

7.1. IMEA Information Architecture

Building on Statistics Canada's Canadian System of Environmental and Resource Accounts, an IMEA information architecture could inform the development of effective land use and environmental management policies. The IMEA information architecture would provide additional information required to properly manage and value natural environments.

Current Environment Canada programs will facilitate the development of the IMEA information architecture. The Canadian wetlands classification system will lead to a better interpretation of remote sensing data so that wetlands can be economically valued more accurately. The Canadian Wildlife Service species at risk program could guide the development of an ecosystem integrity measure to enhance the economic valuation of ecosystem services. The Environmental Valuation Resource Inventory provides important peer-reviewed environmental valuation information. These Environment Canada programs will be instrumental in shaping and developing an effective IMEA information architecture for environmental management planning and policy-making.

In addition to the valuable work being carried out by governments a number of leading edge academic research endeavours will also enhance the development of the IMEA information architecture. For example, linking drivers and rates of landscape transformation can provide insights on their interactions. Schneeberger *et al.* (2007) used consistent high resolution land-use data and the methodology depicted in **Figure 22** to examine landscape transformation rates in Switzerland. Their research provides the following insights:

- measures time lags between the implementation of policies and observable changes on the landscape;

- identifies drivers that counteract or slow landscape transformation changes;
- shows relationships between drivers of landscape transformation, such as political influences, and biophysical characteristics; and
- measures the contributions and effectiveness of actors/institutions attempting to influence landscape transformations.

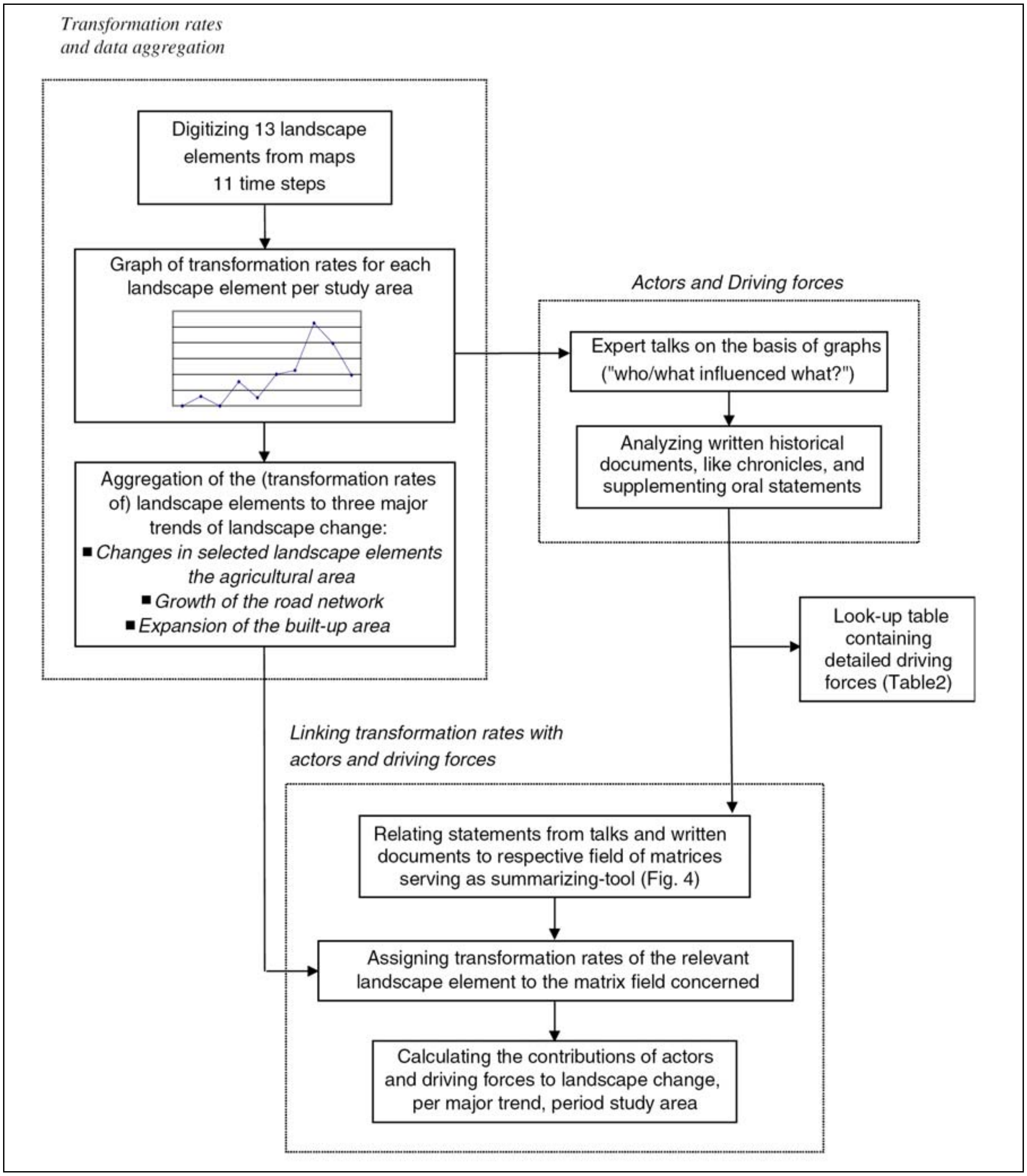


Figure 22. Methodology for linking drivers and rates of landscape transformations (Source: Schneeberger *et al.*, 2007, p. 352).

This area of research offers great promise in understanding why landscapes transform at a particular pace, which can be useful for developing effective land-use policies. For example, linking the drivers of landscape transformation presented in Section 5 to a time series of agricultural land-use data can be useful for understanding the impact and effectiveness of various land-use policies. A number of relevant advances in academia will be explored to develop the IMEA information architecture.

The IMEA information architecture will aim to guide effective environmental policy making and will be shaped by Statistics Canada's CSERA, existing Environment Canada programs and advances in academia.

7.2. Scenarios for Maximizing Ecosystem Service Benefits

A prospective look at maximizing ecosystem service benefits from the landscape can be achieved by exploring various land use scenarios. Optimizing the landscape for human well-being can be achieved by balancing human-altered landscapes and natural environments. Comparing and valuing land use scenarios using landscape models and relevant valuation techniques can provide valuable insights for decision making. For example, restoring wetlands can lower nutrient flows into water bodies and flood events. Exploring the potential benefits gained from restoring environmental assets can be achieved by using landscape models that simulate nutrient flows based on land cover configurations. The Surface Water Assessment Tool (SWAT), a model developed by the United States Agricultural Society, can be used for this purpose (Gassman, Reyes, Green, & Arnold, 2007). A number of studies have been completed using SWAT in various parts of the world to simulate nitrogen and phosphorus flows with varying levels of success (Gassman *et al.*, 2007). Building on this body of knowledge, a similar study could be applied to southern Manitoba. This work would assist with the development of an environmental asset restoration approach to optimize the landscape for the protection of the environment and the well-being of its citizens.

The restoration of natural environments may also provide a cost-effective alternative to large and expensive infrastructure projects that aim to provide a variety of services. For example, New York City saved approximately US$6 billion by preserving and restoring natural environments to improve its water supply instead of building a water filtration plant (Venema, 2007). The City of Winnipeg is currently planning on spending CDN$1.2 – $2.0 billion to upgrade its wastewater treatment plants and lower its contribution of total phosphorus into the Red River (Holle, 2007). The city is responsible for approximately 5 per cent of the total phosphorus load that makes its way into Lake Winnipeg (Roy *et al.*, 2007). In contrast, the Province of Manitoba contributes over 40 per cent of the load through natural and human-induced landscape processes (Roy *et al.*, 2007). Environmental asset preservation and restoration offers a potentially cost effective means of addressing environmental issues and improving wellbeing.

8. Conclusion

An Integrated Management of Environmental Assets (IMEA) Approach was applied to the Manitoban portion of the Red, Assiniboine and Souris River Basin system to evaluate the ecosystem services that are currently and were formerly flowing from this landscape. The assessment determined that the current landscape provides ESVs ranging from CDN$0.33 to $1.30 billion/year, while three pre-settlement landscape estimates provide ESVs ranging from CDN$0.5 to $3.02 billion/year. Forests and wetlands accounted for 80 per cent to 96 per cent of the total ESVs while ecosystem services influencing climate change and water quantity and quality accounted for 70 per cent to 91 per cent of the total ESVs for all landscapes evaluated. The valuable benefits received from forests and wetlands and ecosystem services influencing climate change and water quantity and quality point to the potential opportunity for mitigating environmental issues, such as the degradation of Lake Winnipeg's water quality, by preserving and restoring environmental assets on the landscape.

The methodological shortfalls of the assessment were the pre-settlement reconstruction approach and the limitations of economically valuing ecosystem services. The pre-settlement land cover maps generated for the analysis were based strictly on soil information. A number of other biophysical characteristics such as geomorphology and climate could greatly influence the proliferation of ecosystems. To address the imprecision associated with the reconstruction approach a range of potential pre-settlement land cover distributions were mapped. Current economic valuation methodologies do not accurately capture the value of ecosystem services. In addition, transferring ecosystem service valuation information from one context to another introduces error as no two contexts are similar. To account for the data limitations and methodological shortfalls associated with valuing ecosystem services, ESV ranges were compiled and used for the analysis which reflected the diversity of ESVs reported in the valuation studies examined. It must be noted that the ESV ranges were derived by aggregating total, average and marginal values which does not lend itself well for decision making based on conventional economics as they cannot be compared to marginal values. Nevertheless, aggregate values provide a useful coarse measure at the macro scale to assess the loss or gain of environmental assets from a given baseline (Daly, 1998). Consequently, decision making based on marginal and aggregated values may lead to more sustainable outcomes. Despite the limitations of economically valuing ecosystem services, they draw attention to the valuable services we receive from natural environments.

Southern Manitoba is a landscape that has biophysical characteristics conducive for agriculture. For this reason, the socio-political drivers that have transformed the landscape have been directed towards establishing, maintaining and expanding agriculture as the main economic activity for over a century. The landscape, once covered in prairies, forests and wetlands, is now an intensive agricultural landscape. Trade liberalization, climate change and environmental concerns, such as the eutrophication of Lake Winnipeg, are undermining the economic viability of current agricultural practices within the region, lowering the resilience of its socio-economic systems. Restoring natural environments may provide a cost-effective way to build resiliency within socio-economic and ecological systems. A restoration agenda would require some co-optimization of agricultural and ecosystem services production. For example, finding the right balance between human altered landscapes such as agricultural land and natural environments such as riparian areas, wetlands and forests can lower nutrient loads into water bodies and attenuate climate change thus ensuring the long-term viability of local livelihoods. This analysis provides a preliminary look into the potential ecosystem services available for restoration programs within a critical portion of the Lake Winnipeg Watershed.

A retrospective analysis of the environmental assets on the landscape provided two important policy insights. The first being the influence of past policies on the distribution and quantity of ecosystem services and the second being the economic value of ecosystem services lost or gained. It also informs the development of effective strategies and a financial case for preserving and restoring ecosystems. A good understanding of the landscape's transformation, dynamics and responses to various policies will facilitate the implementation of an effective environmental asset preservation and restoration program. Quantifying and valuing ecosystem service losses or gains provides an economic rational for their preservation and restoration. Overall, the economic valuation of ecosystem services allows for a more objective and rigorous policy trade-off and cost benefit analysis.

Potential future directions for this research include the development of an IMEA information architecture and scenarios work to explore the potential benefits of environmental asset restoration. An IMEA information architecture is required to inform high-level environmental asset strategic planning as well as guide local or regional environmental asset management. For instance, examining the relationship between drivers and rates of landscape transformation could inform the development of effective environmental planning and management approaches. Scenarios work would complement the development of the IMEA architecture by enabling the exploration of land uses that could address environmental and socio-economic issues such as the eutrophication of Lake Winnipeg. In addition, valuation methodologies providing comparable values that can be aggregated are required to evaluate various land use scenarios and inform decision making.

A retrospective (understanding the past and present) and prospective (looking to the future) look at the ecosystem services that originate from environmental assets provides a sound basis for developing an effective environmental asset restoration programs. This report imparts the retrospective element required for developing an IMEA information architecture to better manage, preserve and restore environmental assets and in doing so address ecological and socio-economic challenges.

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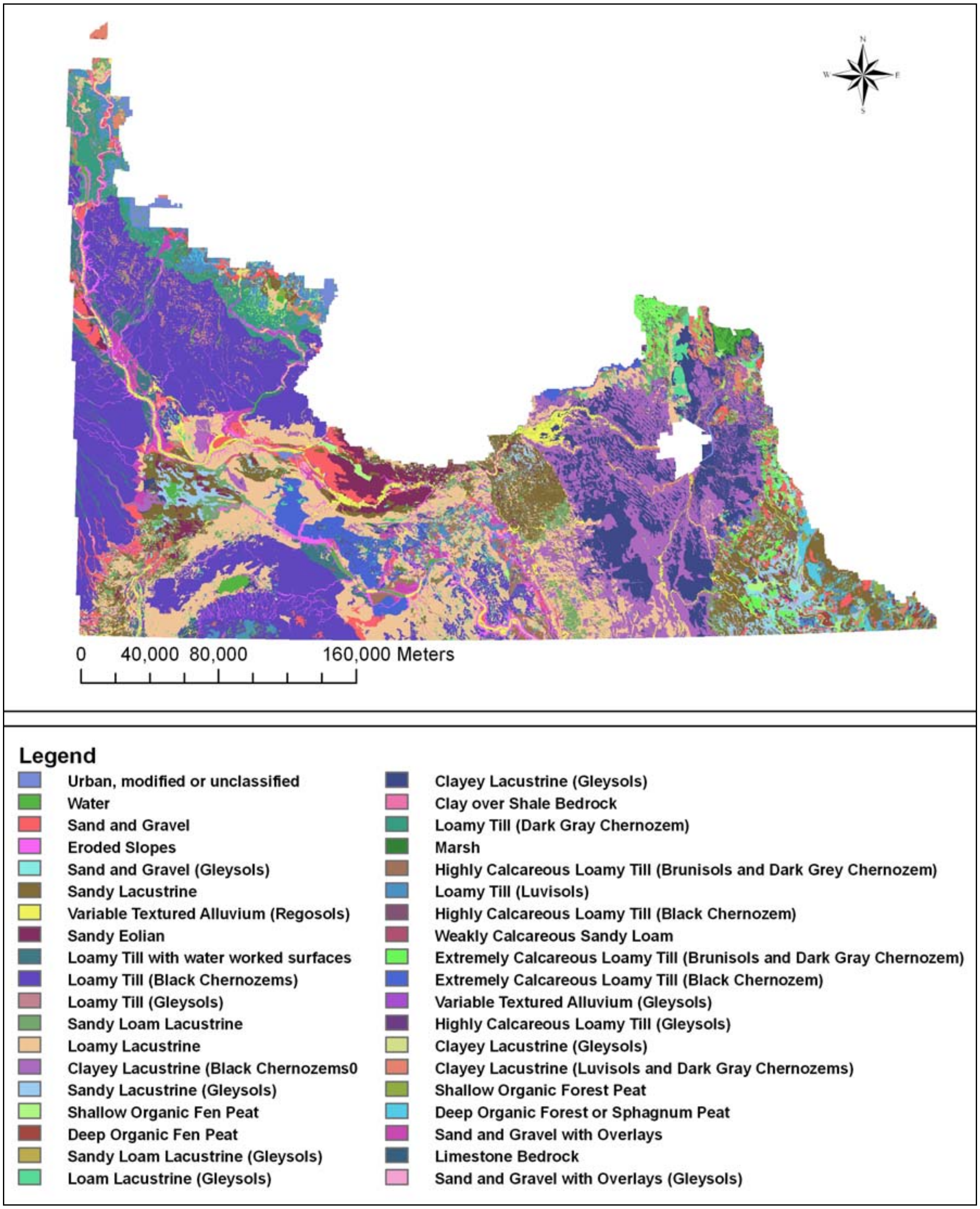
Appendix A – Soil Composition Map



Soil and Land Cover Associations

Soil Class	Pre-settlement 1	Pre-settlement 2	Pre-settlement 3
Loamy Till (Black Chernozem)	Prairies	Prairies	Prairies
Loamy Lacustrine	Forest	Forest	Forest
Clayey Lacustrine (Black Chernozem)	Prairies	Prairies	Prairies
Clayey Lacustrine (Gleysols)	Wetlands	Wetlands	Wetlands
Sandy Lacustrine	Forest	Forest	Forest
Sand and Gravel	Other	Other	Other
Eroded Slopes	Other	Other	Other
Loamy Till (Dark Gray Chernozem)	Forest	Forest	Forest
Variable Textured Alluvium (Regosols)	Forest	Prairies	Other
Loamy Till (Luvisols)	Forest	Prairies	Other
Extremely Calcareous Loamy Till (Black Chernozem)	Prairies	Prairies	Prairies
Sandy Lacustrine (Gleysols)	Wetlands	Wetlands	Wetlands
Sandy Eolian	Prairies	Prairies	Prairies
Sandy Loam Lacustrine	Forest	Forest	Forest
Loamy Till with water worked surfaces	Wetlands	Prairies	Other
Sand and Gravel with Overlays	Other	Other	Other
Loam Lacustrine (Gleysols)	Wetlands	Wetlands	Wetlands
Water	Water	Water	Water
Extremely Calcareous Loamy Till (Brunisols and Dark Gray Chernozem)	Prairies	Forest	Other
Loamy Till (Gleysols)	Wetlands	Wetlands	Wetlands
Clayey Lacustrine (Luvisols and Dark Gray Chernozems)	Forest	Forest	Forest
Shallow Organic Fen Peat	Wetlands	Wetlands	Wetlands
Highly Calcareous Loamy Till (Brunisols and Dark Grey Chernozem)	Prairies	Forest	Other
Urban, Modified or Unclassified	Other	Other	Other
Deep Organic Forest or Sphagnum Peat	Forest	Wetlands	Other
Shallow Organic Forest Peat	Forest	Forest	Forest
Deep Organic Fen Peat	Wetlands	Wetlands	Wetlands
Sand and Gravel (Gleysols)	Wetlands	Wetlands	Wetlands
Highly Calcareous Loamy Till (Gleysols)	Wetlands	Wetlands	Wetlands
Variable Textured Alluvium (Gleysols)	Prairies	Wetlands	Other
Sand and Gravel with Overlays (Gleysols)	Wetlands	Wetlands	Wetlands
Marsh	Wetlands	Wetlands	Wetlands
Sandy Loam Lacustrine (Gleysols)	Prairies	Wetlands	Other
Limestone Bedrock	Other	Other	Other
Clay over Shale Bedrock	Forest	Prairies	Other
Highly Calcareous Loamy Till (Black Chernozem)	Prairies	Prairies	Prairies
Weakly Calcareous Sandy Loamy Till	Forest	Other	Other
Clayey Lacustrine (Gleysols)	Wetlands	Forest	Prairies

Appendix B – Ecosystem Services Values

Ecosystem Services Valuation Information Sources and Context Comparability						
Publication			**Context Comparability**			
Author and Year	**Title**	**Publisher**	**Land Cover**	**Area**	**Benefit Data**	**Overall Quality**
Kulshreshtha Suren N. and George G. Pearson, 2006	An Update on Determination of a Cost Recovery Framework and Fee Schedule Formula for the Agriculture and Agri-Food Canada – Prairie Farm Rehabilitation Administration Community Pasture Program	Government Document – Agriculture and Agri-Food Canada	Prairies	Saskatchewan; Manitoba	Community Pasture Program benefits reported in 2006 CDN$/total community pasture area	Canadian Prairie context applied to the southern Manitoba context. Demographics and benefits should be very similar. Overall, excellent transferability of data.
Anielski, Mark and Sara Wilson, 2005	Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems.	Canadian Boreal Initiative Pembina Institute	Wetland	Canadian Boreal Region	Canadian Boreal Region (wetlands) ecosystem goods and services benefits reported in 2002 CDN$/ha/year	Vast Canadian Boreal Region context applied to the southern Manitoba context. Demographics and benefits somewhat similar. Overall good transferability of data.
Anielski, Mark and Sara Wilson, 2007	The Real Wealth of the Mackenzie Region	Canadian Boreal Initiative	Forest	Mackenzie watershed, portion of the Canadian Boreal Region.	Mackenzie watershed portion of the Canadian Boreal Region (forests) ecosystem goods and services benefits reported in 2006 CDN$/ha/year	Mackenzie watershed portion of the Canadian Boreal Region applied to the southern Manitoba context. Overall good transferability of data.
Nancy Olewiler, 2004	The Value of Natural Capital in Settled Areas of Canada	Duck Unlimited, Nature Conservancy Canada	Wetland	Fraser River Valley	Fraser River Valley (wetlands) ecosystem goods and services benefits reported in 2004 CDN$/ha/year	Fraser River Valley context applied to the southern Manitoba context. Demographics and benefits are somewhat similar. Time lapse of 3 years. Overall good transferability of data.

Land Cover: Forests – High and Low Values for Ecosystem Services (Used for High and Low Estimates = Normal***; Used only for High Estimates*** = **Bold*****: Used only for Low Estimates*** = *Italics****).*** All values reported in CDN$/ha/year.

Ecosystem Service	**ESV Reported**	**ESV 2007 adjusted**	**Methodology and Applicability to the Southern Manitoban Context (Good/Medium/Poor)**	**Source**
1. Atmospheric Regulations	-	-		
2. Climate Regulation	**$616.11** *$15.00*	**$628.43** *$16.05*	**Good: Stern (2007) assumes a social cost of CDN$38.60/tonne of carbon under the A2 emissions scenario (3.9°C warming pre-industrial to 2100).** *Medium: Based on the total amount of carbon stored, valued at $150 per hectare at a discount rate of 10%. This estimate assumes that the forest is preserved indefinitely.*	**Anielski & Wilson, 2007** *Olewiler, 2004*
3. Disturbance Avoidance	-	-		
4. Water Stabilization and Regulation	-	-		
5. Water Supply	$0.11	$0.11	Medium: The value was derived based on the replacement cost of forest water supply and filtration services using the US Forest Service estimate of CDN$0.05/$m^3$.	Anielski & Wilson, 2007
6. Erosion Control and Sediment Retention	-	-		
7. Soil Formation	-	-		
8. Nutrient Cycling	-	-		
9. Waste Treatment	-	-		
10. Pollination	-	-		
11. Biological Control	$25.97	$26.49	Medium: The value was derived by using the US Forest Service estimate of USD$7/acre to replace bird pest control with chemical pesticides or genetic engineering.	Anielski & Wilson, 2007
12. Habitat/Refugia	$0.63	$0.64	Good: The value was calculated based on a willingness to pay study for Maintaining natural habitat for Woodland Caribou in Saskatchewan.	Anielski & Wilson, 2007
13. Food Production	$2.55	$2.60	Good: The estimate was derived based on market values for food obtained from forests such as berries, mushrooms, waterfowl and animals.	Anielski & Wilson, 2007
14. Raw Materials	$0.35	$0.36	Good: The value was estimated from Non-timber Forest Product market values, which include ornaments, raw materials and medicines.	Anielski & Wilson, 2005
15. Genetic Resources	-	-		
16. Recreation	$18.53	$18.90	Good: The value was derived from a national study on travel costs and related expenditures for outdoor trips.	Anielski & Wilson, 2007
17. Culture	-	-		
TOTALS	**$665.85** *$63.14*	**$677.54** *$65.15*		

***Land Cover: Prairies – High and Low Ecosystem Service Values (Used for High and Low Estimates** = Normal**, Used only for High Estimates** = **Bold, Used only for Low Estimates** = *Italics*).* All values reported in CDN$/ha/year.

Ecosystem Service	ESV Reported	ESV 2007 adjusted	Methodology and Applicability to the Southern Manitoban Context (Good/Medium/Poor)	Source
1. Atmospheric Regulations	-	-		
2. Climate Regulation	$22.11	$22.55	Good: The value of CDN$15/tonne of stored carbon based on sustained vegetative production on the pastures.	Kulshreshtha & Pearson, 2006
3. Disturbance Avoidance	-	-		
4. Water Stabilization and Regulation	-	-		
5. Water Supply	-	-		
6. Erosion Control and Sediment Retention	$2.25	$2.30	Good: Damage cost avoided to water quality based on a study by Belcher *et al.* (2001) for the Upper Assiniboine River Basin.	Kulshreshtha & Pearson, 2006
7. Soil Formation	-	-		
8. Nutrient Cycling	-	-		
9. Waste Treatment	-	-		
10. Pollination	-	-		
11. Biological Control	-	-		
12. Habitat/Refugia	$0.10	$0.10	Good: Willingness to pay for preserving wetlands within Saskatchewan households.	Kulshreshtha & Pearson, 2006
13. Food Production	**$18.08**	**$18.44**	**Good: Market value for grazing on private lands in the Canadian Prairies.**	**Kulshreshtha & Pearson, 2006**
14. Raw Materials	-	-		
15. Genetic Resources	$0.22	$0.22	Medium: Willingness to pay for preserving biodiversity derived from Kulshreshtha & Pearson (2002).	Kulshreshtha & Pearson, 2006
16. Recreation	**$6.86**	**$7.00**	**Good: Study conducted by the Federal, Provincial, Territorial Task Force for Manitoba and Saskatchewan based on travel costs and related expenditures for outdoor recreation.**	**Kulshreshtha & Pearson, 2006**
17. Culture	-	-		
TOTALS	**$49.62** *$24.68*	**$50.61** *$25.17*		

Land Cover: Wetlands – High and Low Ecosystem Service Values (Used for High and Low Estimates = Normal***, Used only for High Estimates*** = **Bold*****, Used only for Low Estimates*** = *Italics****).*** All values reported in CDN$/ha/year.

Ecosystem Service	ESV Reported	ESV 2007 adjusted	Methodology and Applicability to the Southern Manitoban Context (Good/Medium/Poor)	Source
1. Atmospheric Regulations	-	-		
2. Climate Regulation	-	-		
3. Disturbance Avoidance	-	-		
4. Water Stabilization and Regulation	$408.00	$436.56	Medium: The value was obtained from Leschine *et al.* (1997), who calculated the replacement cost of wetland flow reduction capacity by water detention facilities.	Olewiler, 2004
5. Water Supply	**$55.38**	**$61.47**	**Medium: Global average value based on 89 valuation studies compiled by Schuyt and Brander (2004), which incorporates various types of wetlands from every part of the world. Wetlands help recharge groundwater by slowing runoff and storing water, which is important for rural Manitobans.**	**Anielski & Wilson, 2005**
6. Erosion Control and Sediment Retention	-	-		
7. Soil Formation	-	-		
8. Nutrient Cycling	-	-		
9. Waste Treatment	$452.00	$483.64	Good: Value derived from a conservative estimate of phosphorus and nitrogen-removal capacity of wetlands and the cost of treating phosphorus and nitrogen at the Vancouver wastewater treatment plant.	Olewiler, 2004
10. Pollination	-	-		
11. Biological Control	-	-		
12. Habitat/Refugia	**$247.36**	**$274.57**	**Medium: Global average value based on 89 valuation studies compiled by Schuyt and Brander (2004), which incorporates various types of wetlands numerous parts of the world. Wetlands in Manitoba provide important habitat for waterfowl.**	**Anielski & Wilson, 2005**
13. Food Production	-	-		
14. Raw Materials	-	-		
15. Genetic Resources	**$263.36**	**$292.33**	**Poor: Global average value based on 89 valuation studies compiled by Schuyt and Brander (2004), which incorporates various types of wetlands from every part of the world. Global average may not be applicable to the Manitoban context.**	**Anielski & Wilson, 2005**
16. Recreation	$18.53	$18.90	Good: The data was derived from a national study on travel costs and related expenditures for outdoor trips.	Anielski & Wilson, 2007
17. Culture	-	-		
TOTALS	**$1,444.63** *$878.53*	**$1,567.47** *$939.10*		

Appendix C - Derivation of Ecosystem Service Values

Detailed Methodology Used to Derive Ecosystem Services Values Used in the Analysis			
Land Cover	Ecosystem Service	Obtained From	Value Type Estimate (Total, Average or Marginal) based on Original Valuation Source Description.
Forest	Climate Regulation	Anielski & Wilson, 2007	Stern (2007) derives a social carbon cost (an estimation of the economic impacts of climate change) of $85/tonne of CO_2 (year 2000 prices) based on the A2 emissions scenario with a mean warming of 3.9^{o}C relative to pre-industrial in 2100. This value was then converted to $38.60/tonne of C and then multiplied with the Canada's forest average carbon sequestration rate from 1920 and 1994 calculated by Kurz and Apps (1999) which was 0.428 tonnes of C/ha/year. (**Marginal Value**)
		Olewiler, 2004	This carbon sequestration value was derived from van Kooten and Bulte (1998) and is based on calculating the value of carbon that escapes back into the atmosphere from deforestation followed by replanting. The following equation was used for the calculation: Total Carbon Release=$[\delta\varrho/(1+r-\delta) + (1-\varrho)]C$ ϱ=proportion of C that gets captured in wood products that decay (ranges from 0 to 1) = 0.6 δ=rate of decay=0.02 r=discount rate=0.04 C=carbon stored in trees harvested on the coast of British Columbia=182.4 kg of C/m^3 The value calculated was then multiplied by an estimated standing inventory of commercial timber on the coast of British Columbia and a shadow price of $20/tonne of C. This gave a value of $150/ha which was then converted into an annual flow of $15/ha/year by assuming a discount rate of 10%. (**Average Value**)
	Water Supply	Anielski & Wilson, 2007	Sedell et al. (2000) determined a marginal value of $40/acre-foot based on economic studies and transaction evidence for offstream uses in areas without ample water supply. The marginal value of streamflow for recreation was determined to be below $10/acre-foot. Anielski and Wilson (2005) apply these values to determine the water supply service provided by forested areas in Canada's Boreal Region. (**Marginal Value**)
	Biological Control	Anielski & Wilson, 2007	The US Forest Service estimated the replacement cost of bird pest control services through the use of chemical pesticides and genetic engineering to be more than USD$7/acre. (**Marginal Value**)
	Habitat/Refugia	Anielski & Wilson, 2007	The willingness to pay for maintaining habitat for Woodland Caribou in Northern Saskatchewan was determined by Tanguay et al. (1993) by posing the following question to Saskatchewan households: "It is possible that by the year 2002 there will be 1,800 Woodland Caribou in Northwestern Saskatchewan. A Woodland Caribou Maintenance program could be developed and implemented to ensure that Caribou maintain

			their current numbers at approximately 3,600 and their range within Northwestern Saskatchewan. What is the maximum amount you would be willing to pay annually for the next ten years into a trust fund run by an idependant foundation for this Caribou Maintanance Program? (fill in amount) $______." The survey results were then converted into converted into an average willingness to pay per household for preserving biodiversity and applied to 50% of the households in the Boreal Forest. The per hectare value that was estimated was CDN$0.67/ha. (**Average Value**)
	Food Production	Anielski & Wilson, 2007	Hanaer and Adamowicz (2000) determined that communities inhabiting the Alberta's boreal region rely on forests to provide them with subsistence food valued at CDN$5,000 to 11,000/household based on the market values of replacing these products with the closest substitutes to harvest products. These numbers were then applied to the number of aboriginal households in the Boreal Region to estimate a total food production value for the area. (**Total Value**)
	Raw Materials	Anielski & Wilson, 2005	The Canadian Forestry Service (2005) estimated in 2004-2005 that non-timber forest products had a market value of CDN$725 million to 1.33 billion. Anielski and Wilson (2005) estimated that the non-timber forest products that provide raw materials represented 60% of the value obtained by the Canadian Forest Service which gave a value of $0.35/ha. (**Average Value**)
	Recreation	Anielski & Wilson, 2007	Based on a 1996 survey carried out by Environment Canada (2000) on the economic significance of nature related activities Canadians reported a willingness to pay an additional CDN$ 2 billion for nature related activities. Since 30.2% of the survey participants reported the Boreal Region as a recreational destination, Anielski and Wilson estimate that the marginal value of nature based recreational activities is worth CDN$654.7 million/year for the Boreal Region. (**Marginal Value**)
Prairies	Climate Regulation	Kulshreshtha & Pearson, 2006	The value was calculated based on greenhouse gas emissions data obtained from the Canadian Agricultural Model. Model details can be obtained from Sobool and Kulshreshtha (2005). A value of $15/tonne of Carbon was assumed based on sustained vegetative production on the pastures. This value is based on a domestic emission trading system and the estimated cost of mitigating Large Final Emitters. (**Marginal Value**)
	Erosion Control and Sediment Retention	Kulshreshtha & Pearson, 2006	Belcher (2001) estimates the erosion and control and sediment retention values of permanent vegetation cover in the Upper Assiniboine River basin by using Ribaudo's (1989) wind erosion damage estimate in New Mexico which amounts to USD$42.11/ha/year. This figure was then adjusted to reflect the population differences between New Mexico and the Upper Assiniboine River Basin which gave a value of $2.31/ha/year. (**Marginal Value**)
	Habitat/Refugia	Kulshreshtha & Pearson, 2006	Willingness to pay for preserving wetlands was used as proxy valuing habitat/refugia ecosystem services on the prairie grasslands. The values were obtained from Young and Thompson (1990) who estimated an average willingness to pay of $58.64/household/year for three regions in the agricultural belt of southern Saskatchewan. This figure was adjusted by Kulshreshtha and Pearson (2006) and estimated

			to be worth approximately CDN$92,000 for Community Pastures Program which covers a surface area of 929,357 hectares. When broken down on a per hectare basis this gives CDN$0.10/ha/year (**Average Value**).
	Food Production	Kulshreshtha & Pearson, 2006	Kulshreshtha and Pearson (2006) estimated the replacement cost of grazing on the community pastures was estimated based on the market value of grazing on private land was. The data for grazing costs on private pastures was obtained from the cost of production for cow-calf operations published by the agricultural departments within the provinces of Alberta, Saskatchewan and Manitoba. (**Marginal Value**)
	Genetic Resources	Kulshreshtha & Pearson, 2006	van Kooten (1994) derives a biodiversity value of CDN$2.53/ha by using contingent valuation information which provides willingness to pay values for recreational activities related to "nature study, fishing, hiking/skiing and hunting" and dividing these values by the total the total land area of mature and over-mature forests in British Columbia (28.36 million hectares) excluding parks and ecological reserves. (**Average Value**)
	Recreation	Kulshreshtha & Pearson, 2006	The Federal-Provincial-Territorial Task Force on the Importance of Nature to Canadians (2000) estimate that estimate the willingness to pay for nature related activities such as fishing, nature walks, cross country skiing, snowmobiling, camping, trail riding, berry picking and non-consumptive wildlife/waterfowl related activities. This value was estimated to be $10.09/day for Manitoba and $10.56/day for Saskatchewan. (**Average Value**)
Wetlands	Water Stabilization and Regulation	Olewiler, 2004	Leschine et al. (1997) estimate that the replacement cost of the North Scriber Creek Wetlands of the City of Lynnwood, in Western Washington by estimating their flow retention capacities and then estimating the cost of a water detention facility with the same capacity. (**Average Value**)
	Water Supply	Anielski & Wilson, 2005	Schuyt and Brander (2004) compiled a various wetland ecosystem service values based on a meta-analysis of 89 wetland valuation studies which examined various types of wetlands (unvegetated sediment, freshwater wood, salt/brackish marsh, freshwater marsh, mangrove) from all over the world (North America, South America, Europe, Africa, Asia and Oceania). They derived a median value for the water supply service provided by wetlands. (**Average Value**)
	Waste Treatment	Olewiler, 2004	Olewiler (2004) derives the waste treatment service value for wetlands in the Lower Fraser Valley by using a conservative estimate for the absorption of nutrient by wetland from a North American database (80.3 kg/ha/year of phosphorus and 547.5 kg/ha/year of nitrogen) and a conservative cost estimate of removing phosphorus and nitrogen from Vancouver's primary and secondary treatment facilities (CDN$21.85/kg of phosphorus and CDN$3.04/kg of nitrogen). (**Marginal Value**)
	Habitat/Refugia	Anielski & Wilson, 2005	Schuyt and Brander (2004) compiled a various wetland ecosystem service values based on a meta-analysis of 89 wetland valuation studies which examined various types of wetlands (unvegetated sediment, freshwater wood, salt/brackish marsh, freshwater marsh, mangrove) from all over the world (North America, South America, Europe, Africa, Asia and Oceania). They derived a median value for the habitat/refugia service provided by wetlands. (**Average**

			Value)
	Genetic Resources	Anielski & Wilson, 2005	Schuyt and Brander (2004) compiled a various wetland ecosystem service values based on a meta-analysis of 89 wetland valuation studies which examined various types of wetlands (unvegetated sediment, freshwater wood, salt/brackish marsh, freshwater marsh, mangrove) from all over the world (North America, South America, Europe, Africa, Asia and Oceania). They derived a median value for the genetic resources service provided by wetlands. (**Average Value**)
	Recreation	Anielski & Wilson, 2007	Based on a 1996 survey carried out by Environment Canada (2000) on the economic significance of nature related activities Canadians reported a willingness to pay an additional CDN$ 2 billion for nature related activities. Since 30.2% of the survey participants reported the Boreal Region as a recreational destination, Anielski and Wilson estimate that the marginal value of nature based recreational activities is worth CDN$654.7 million/year for the Boreal Region. (**Marginal Value**)

Appendix D – Land Cover Typology

MANITOBA LAND USE INVENTORY - Land Use / Land Cover Classes for Manitoba
(Source: Province of Manitoba, 2004)

Agricultural/Cropland = Agriculture	Lands dedicated to the production of annual cereal, seed and specialty crops. These lands would normally be cultivated on an annual basis.
Deciduous Forest = Forests	Forest lands where 75% to 100% of the tree canopy is deciduous. Dominant species include trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and white birch (*Betula papyrifera*). May encompass small patches of grassland, marsh or fens less than two hectares in size. Dense forest canopy (>60%), open canopy (26–60%), sparse canopy (10–25%).
Water Bodies = Water Bodies	Consists of all open water—lakes, rivers, streams, ponds and lagoons.
Grasslands/ Rangelands = Prairies	Lands of mixed native and/or tame prairie grasses and herbaceous vegetation. May also include scattered stands of shrub such as willow (*Salix spp.*), choke-cherry (*Prunus spp.*), saskatoon (*Amelanchier spp.*) and pincherry (*Prunus spp.*). Lands may be used for the harvesting of hay while others may be grazed. Both upland and lowland meadows fall into this class. There is normally (<10%) shrub or tree canopy.
Mixedwood Forest = Forests	Forest lands where 26% to 74% of the tree canopy is coniferous. May encompass treed bogs, marsh or fens less than two hectares in size. Dense forest canopy (>60%), open canopy (26–60%), sparse canopy (<26%).
Marsh = Wetlands	Wetlands comprised of various herbaceous species. Wetlands range from intermittent inundated (temporary, seasonal and semi-permanent) to permanent depending on the current annual precipitation. Common vegetation species include: sedge (*Carex spp.*), whitetop (*Scolochloa festucacea*), giant reed grass (*Phragmites australis*), prairie cordgrass (*Spartina pectinata*), mannagrass (*Glyceria spp.*), slough grass (*Beckmannia spp.*), cattail (*Typha spp.*), and bulrush (*Scirpus spp.*).
Bogs = Wetlands	Wetlands dominated by bryoid-mosses (i.e., *Spaghnum spp.*) and ericaceous shrubs such as labrador tea (*Ledum spp.*). Tamarack (*Larix larcina*) and black spruce (*Picea mariana*) are also found with a sparse to dense (10–100%) canopy.
Treed Rock = Other	Lands of exposed bedrock with less than 60% tree canopy. The dominant tree species include jack pine (*Pinus banksiana*), and/or black spruce (*Picea mariana*) with shrub cover such as alder (*Alnus spp.*). Open canopy (26–60%), sparse canopy (10–25%).
Coniferous Forest = Forests	Forest lands where 75% to 100% of the tree canopy is coniferous. Jack Pine, white spruce (*Picea glauca*) and black spruce are the dominant species in this class. May include patches of treed bog, marsh and/or fens less than two hectares in size. Dense forest canopy (>60%), open canopy (26–60%), sparse canopy (10–25%).
Wildfire Areas = Other	Forest lands that have been recently burnt (<5 years) with sporadic regeneration and can include pockets of unburned trees.

Open Deciduous Forest/Shrub = Forests	Lands characterized by shallow soils and/or poor drainage, which support mainly a cover of shrubs such as willow (*Salix spp.*), alder (*Alnus spp.*), saskatoon (*Amelanchier spp.*) and/or stunted trees such as trembling aspen, balsam poplar and birch with a sparse (10–25%) to open canopy (26–60%).
Forage Crops = Agriculture	Agricultural lands used in the production of forage such as alfalfa and clover or blends of these with tame species of grass. Fall seeded crops such as winter wheat or fall rye may be included here.
Cultural Features = Built-up	Cities, towns, villages and communities with place names. Also includes: cemeteries, shopping centres, large recreation sites, autowreck yards, airports, cottage areas, race tracks and rural residential.
Forest Cutovers = Other	Forest lands where commercial timber have been completely or partially removed by logging operations.
Bare Rock/Gravel/Sand = Other	Lands of exposed bedrock, gravel and/or sand dunes and beaches with less than 10% vegetation. Also includes gravel quarry/pit operations, mine tailings, borrow pits and rock quarries.
Roads/Trails = Built-up	Highways, secondary roads, trails and cut survey lines or right-of-ways such as railways and transmission lines.
Fen = Wetlands	Wetlands with nutrient-rich, minerotrophic water, and organic soils composed of the remains of sedges (*Carex spp.*) and/or mosses (*Drepanocladus spp.*), where sedges, grasses, reeds and moss predominate but could include shrub and sparse tree canopy of black spruce and/or tamarack. Much of the vegetative cover of fens would be similar to the vegetation zones of marshes.
Lichen Heath = Other	Lands characterized by an abundance of lichen (*C. alprestris*, *C. mitis*, *C. rangerferina*) and health vegetation (*L. decumbens*, *V. vitis-idaea*, *V. uglinosum*, *E. nigrum*) located on well-drained summits and upper slopes. The forest canopy is sparse (<10%) with the dominant tree being black spruce. Lichen heath is found in the taiga shield ecozone.

Appendix E – Land Use Regulations

Table 6 – Land Use Related Policies		
Policies and Programs	**Description**	**Year of Implementation**
National		
The Public Land Dominion Act	Described how the land was to be surveyed, divided, appropriated and utilized (Dominion of Canada, 1872).	1872
Crow Rate and the Western Grain Transportation Act	The Crow Rate Act and the WGTA provided transportation subsidies for shipping wheat and other grains from agricultural producers of the Canadian Prairies (Swanson & Venema, 2006).	1897–1996
Prairie Farm Rehabilitation Act	The Prairie Rehabilitation Act was instituted to "secure the rehabilitation of the drought and soil drifting in the provinces of Manitoba, Saskatchewan and Alberta, and to develop and promote within those areas, systems of farm practices, tree culture, water supply, land utilization and land settlement that will afford greater economic security (Agriculture and Agri-Food Canada, 2005)."	1935–Present
Canadian Wheat Board Act	The Canadian Wheat Board Act was implemented to buffer farmers against fluctuating market prices. The Canadian Wheat Board is now the largest seller of wheat and barley in the world representing more than 20 per cent of the international market (Canadian Wheat Board, 2007).	1935–Present
Veterans Lands Act	Provides incentives for veterans to settle in the Canadian Prairies and in four specific locations in Manitoba.	1942–1950
Agricultural and Rural Development Act	The Agricultural and Rural Development Act (ARDA) was established to raise the level of income and standard of living of rural areas. Initially, the ARDA focused on researching land use and farm adjustment, soil and water conservation and rural development but evolved over time to include staff and training services and public information services and special rural development areas (Todd, 1982).	1961–Present
Fund for Rural Economic Development	The goal of the Fund for Rural Economic Development was to establish economically viable farming operations through the effective and improved use of land, which focused on pasture and forage crops for cattle production, and resource management and control (Todd, 1982).	1967
Small Farm Development Program	The Farming for Rural Economic Development Act evolved out of the need to raise the level of income and standard of living of rural areas (Todd, 1982).	1971
Canadian Environmental Assessment Act	The *Canadian Environmental Assessment Act* (the Act) is a federal statute that requires federal departments to conduct environmental assessments for projects and	1992–Present

	activities in order to obtain federal approval of financial support (Western Economic Diversification Canada, 2006).	
First Nations Land Management Act	*The First Nations Land Management Act* provides First Nations with the power to institute environmental laws for the development and conservation of natural resources and ecosystems and to improve their capacities and opportunities for economic development (Indian and Northern Affairs Canada, 2004).	1999–Present
Canadian Environmental Protection Act	"An Act respecting pollution prevention and the protection of the environment and human health in order to contribute to sustainable development" (Environment Canada, 2007).	1999–Present
Species at Risk Act	"To prevent endangered or threatened species from becoming extinct or extirpated; To help in the recovery of endangered, threatened and extirpated species; and To manage species of special concern to help prevent them from becoming endangered or threatened" (Parks Canada, 2005).	2002–Present
Provincial		
Provincial Drainage Act	This Act initiated a survey of wet areas and the creation of drainage districts and ditches.	1879
Guidelines for the Seventies	The "Guidelines for the Seventies" articulates a vision for the development and land use of the Province of Manitoba. The document rested on four basic principles: • maximization of the well-being of all Manitobans; • equality of all residents through the equitable distribution of development benefits; • implementation of policies and programs that allow Manitobans to remain where they prefer to live (a "stay option"); and • promotion of public participation in development decisions that will affect their future (Todd, 1982).	~1975
Environment Act	The intent of this Act is to develop and maintain an environmental management system in Manitoba which will ensure that the environment is maintained in such a manner as to sustain a high quality of life, including social and economic development, recreation and leisure for this and future generations (Province of Manitoba, 1988).	1987–Present
Livestock Manure and Mortalities Management Regulation	"The purpose of this regulation is to prescribe requirements for the use, management and storage of livestock manure and mortalities in agricultural operations so that livestock manure and mortalities are handled in an environmentally sound manner" (Province of Manitoba, 1998a)	1998–Present
Sustainable Development Act	"The purpose of this Act is to create a framework through which sustainable development will be implemented in the provincial public sector and promoted in private industry and in society generally" (Province of Manitoba, 1998b).	1998–Present
Forest Act	The Forest Act restricts the forestry industry to allowable cuts and provides guidelines for forest	1988–Present

	stewardship practices.	
Mines and Minerals Act	The Mines and Minerals Act guides industry to develop mining projects in accordance with the principles outlined in the Sustainable Development Act.	1987–Present
Oil and Gas Act	The Oil and Gas Act guides industry to develop oil and gas development projects in accordance with the principles outlined in the Sustainable Development Act.	1994–Present