**A Business Case for Wetland Conservation and Restoration in the Settled Areas of Alberta**
**Vermilion River Subwatershed Case Study**

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## Acknowledgements

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## About this Report

The Business Case for Wetland Conservation in the province of Alberta was commissioned by the Ducks Unlimited Canada (DUC) Institute for Waterfowl and Wetland Research (IWWR). For several years DUC has recognized the value of economic information to inform environmental policy and decision-making.

This document is not meant to provide any primary economic research. Rather, it is a concise summary of the wetland valuation and restoration cost literature conducted in the white zone of the province framed within the context of some pressing environmental issues. This information is intended to inform wetland stakeholders across the province of not only the value of wetland ecosystems but of the financial legitimacy of retaining these ecosystems on the landscape.

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## Glossary of Terms

**Benefit transfer:** the process by which the estimated benefit for one or more sites or policy proposals is used to assign benefit or value to other, comparable sites or policy proposals.

**Beneficial Management Practice (BMP):** any agricultural management practice that mitigates or minimizes negative impacts and risk to the environment, ensures the long term health of land-related resources used for agriculture and does not negatively impact the long term economic viability of producers.

**Business case:** document that provides rationale for a given project through the presentation of relevant material, including background information, expected benefits of the project, expected costs of the project, and consideration of risk.

**Cost-benefit analysis:** a tool for comparing the benefit to society and/or government with the costs to society and/or government for making a particular policy or management decision.

**Environmental services:** the goods and services provided by ecosystems and their functions (often used interchangeably with ecological services or ecosystem services).

**Natural capital:** the amount of natural ecosystems that yields a flow of valuable ecosystem goods and services into the future

**Social return on investment method:** method for measuring extra-financial value (i.e. environmental and social value not currently reflected in conventional financial accounts) relative to resources invested.

**Social return on investment ratio (SROI):** the social benefits of a proposed project divided by the costs.  A social return ratio >1 indicates the benefits are greater than costs.

**Executive Summary**

Conversion of natural ecosystems is evident across Alberta, but is demonstrated most clearly in the settled southern regions. In the Vermilion River subwatershed of the east-central parkland, agricultural conversion and development of transportation routes has significantly altered the historic natural landscape. While this development has contributed to economic growth and prosperity for local residents, this alteration has also led to significant environmental degradation. Water quality issues from nutrient loading and quantity issues from flooding are a particular concern here and across the province.

Wetlands are natural ecosystems that have been significantly converted and degraded in this area. The Alberta Wetland Inventory (GOA 2012) indicates that up to 64 per cent of wetlands in this region have been lost since settlement, and that this loss is continuing today at 0.3-0.5% annually despite a growing awareness among scientific and government communities regarding the benefits of wetland ecosystems. Ducks Unlimited Canada believes that conservation and restoration of wetland ecosystems in this area has the potential to assist in minimizing the water quality degradation of Vermilion River.

Research into the water quantity function of wetlands in the Vermilion River subwatershed and transferring estimates from comparable watersheds in the prairie pothole region of Canada indicate that with the existing level of wetlands, Vermilion River has an annual flow of 562,252m$^3$, sequesters 152 tons of $CO_2$e, retains 2,344 tons of nitrogen and 469 tons of phosphorous and provides $1.2 million in recreation value annually. This information allows approximation of the economic value of these wetland services to humans

The benefit-cost analysis discounted at 10 years for nutrient retention (P&N) alone indicates that the annual benefit is approximately $315 million ($390 million for full restoration), while the opportunity cost to retain all the current wetlands is $50 million annually ($175 million for full restoration). This provides a benefit-cost ratio of approximately 6.31 for wetland retention (1.36 for full restoration), indicating that nutrient reduction potential provides a

desirable return on investment. When other services[1] are included in a partial social return on investment framework over the same ten-year period, a 6.91 return ratio is estimated for retention, and a 3.32 ratio for 25 per cent restoration. These results should be considered conservative estimates, as services without an easy dollar approximation - such as groundwater recharge, sediment and flood control - were not included in the analysis.

The general results from this business case are as follows:

- Wetlands in the Vermilion River subwatershed are preventing nutrients from entering the Vermilion River and controlling the peak discharge of water, which demonstrates that wetland retention and restoration will assist industry in controlling nutrient loss on the landscape.
- Nutrient removal currently provided by Vermilion River wetlands is valued at $36.9 million annually, based upon average phosphorous and nitrogen removal rates and local filtration costs.
- When nutrient removal, carbon sequestration and recreation benefits are included in a partial social return on investment, investment in wetland conservation and restoration yields a substantial return on investment. Investment remains a financially sound decision even when nutrients retention alone is considered under retention and low restoration scenarios.
- Wetland retention provides the highest social return on investment. As the full cost of wetland restoration, including securement, restoration and monitoring amount to an average cost of approximately $10,000 per hectare, high levels of restoration can be prohibitively expensive, however low to moderate levels of restoration demonstrate a significant social return on investment..

Wetland conservation is an effective means to meet Alberta's water quality and quantity needs – domestically and internationally – in an environmentally credible and often economically viable means. The public needs to be made aware of this net benefit to assist in driving policy change towards the maintenance and restoration of these ecosystems.

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[1] Carbon sequestration and recreation.

[2] This scrutiny led to the creation of a working group and the resultant formation of an Environmental

## 1.0 Introduction

Alberta is endowed with natural resources that provide a significant contribution to the provincial and local economies (GOA 2012; GOA 2011). As a result of this importance and rising environmental awareness domestically and internationally, natural resource management in this province is under increasing scrutiny[2]. The recent Cabinet Mandate under Premier Redford administration recognizes this importance by advocating an *Integrated Resource System* that achieves the environmental, economic and social outcomes favorable to Albertans (GOA 2012) over time[3] to achieve world-class environmental outcomes.

The Alberta government recognizes that in addition to the direct financial benefit from the extraction and marketing of natural resources, the ecosystems where they are located provide additional indirect benefit to society and environment. These benefits can be in the form of ecological services (ES)[4], including: improved surface water quality, ensuring sustainable surface water storage and supply, mitigating the impacts of climate change, mitigating the impacts of drought and floods, sequestering carbon, providing habitat for wildlife and maintaining and enhancing biodiversity. While this provision of natural capital is increasingly recognized by the public and policy makers[5] (GOA 2011; Pattison et al 2011; Barbier et al 1997), it remains undervalued in the marketplace – and therefore the extraction and development of natural resources can take economic and political priority. As a result the Millennium Ecosystem Assessment estimates that 60% of global ecosystems are being used at an unsustainable rate (MEA 2005).

Wetlands have been identified as one of the most valuable ecosystems in the provision of ES (GOA 2011; MEA 2005). Unfortunately the loss and degradation of wetlands is a growing

[2] This scrutiny led to the creation of a working group and the resultant formation of an Environmental Monitoring Agency in the province.
[3] Also known as cumulative effects management (ESRD 2012).
[4] Ecological services is commonly used in the literature; it can also be considered ecological goods and services, natural capital or environmental and economic benefits.
[5] Canada formalized a national wetland policy in 1991, and progressive policies have recently been enacted in Nova Scotia, New Brunswick, and Prince Edward Island.

ecological concern. In southern Alberta 64% of historical wetlands have been lost, and continues at 0.3-0.5% annually[6] (AESRD 2012) with subsequent loss of ecological function. As a result, the natural controls on nutrient loading have been compromised, resulting in decreased water quality and less attractive recreational activities. In addition, natural balancing of flooding and drought situations is compromised (Pomeroy et al 2012).

The purpose of this report is to provide a business case for wetland retention and restoration in the White Zone of Alberta. Applicable wetland research from Alberta where possible, and comparable regions where necessary, will be employed to properly frame the issue. Background information will be provided on the current status of wetlands in the province, including current conservation efforts, framed within the context of environmental degradation. Building upon available biophysical and related ES data, wetland benefits and costs will be discussed and economic estimates of both will be provided in the context of the Vermilion River subwatershed. A benefit cost analysis of the ES related to nutrient retention will be presented, and then expanded to include additional estimates of wetland benefits within a partial social return on investment (SROI) framework. Extrapolations will be made to the entire Alberta prairie pothole region, conclusions will be drawn and recommendations made.

## 2.0 Background

Canada formally acknowledged the value of wetland ecosystems when it signed the Ramsar Convention on Wetlands in 1971. It was also the first national government to enact a wetland policy in 1991 (Environment Canada 1991). Despite this action, nearly 20 million hectares of wetland have been drained for agricultural purposes alone; and this continues today, having a negative impact on the natural environment and quality of human life (Environment Canada 2009).

Dramatic wetland conversion occurred because natural ecosystems such as wetlands are not currently valued by the market system and few financial incentives exist for landowners to maintain them. Wetlands can be costly for agricultural producers to maintain in terms of increased fuel and time taken to manoeuvre machinery around them during seeding and harvesting, and can lead to double application of seeds or fertilizers resulting in higher input

[6] Compounding rate

costs (Packman 2010). In urban or industrial development, filling and draining wetlands allows the outward expansion of city limits. In suburban developments, filling in a wetland creates space for privacy and independence from urban sprawl. In almost all situations the value of the land is determined by its productive capacity to supply human needs.

### *2.1Wetland Inventory*

To determine the extent of existing and lost wetlands several provincial wetland inventories were combined and enhanced into one database; this integration has been the focus of the Alberta Wetland Inventory Project led by the Alberta Ministry of Environment and Sustainable Resource Development (AESRD) under the Water for Life Strategy. The Wetland Inventory has classified 18.7 million hectares and determined that 64% of wetlands in southern Alberta have disappeared since settlement; loss continues at a rate of 0.3-0.5% annually[7]. Identified causes for wetland loss include population growth, industrial development, land use changes, management practices and policies[8] (AESRD 2012).

### *2.2 Policy*

The Alberta government has formally recognized the importance of wetland conservation in several ways: the interim policy Wetland Management in the Settled Areas of Alberta: an Interim Policy (AWRC 1993), the Water Act (GOA 2000), and the Water for Life Strategy (GOA 2003; GOA 2007; GOA 2009). A key action of the Water for Life Strategy is the completion of a wetland policy and corresponding implementation plan. Consultative processes (AWC 2008) and research projects on wetland ecosystem services (GOA 2011) within government to inform and implement the policy are ongoing, to date no legislative action has been taken.

However, there is currently an opportunity for such action to occur. A complete and legislated wetland policy will directly relate within the current mandate outlined by the Redford

[7] Further research and refinement of the wetland inventory is being completed by Irena Creed's lab from Western University.
[8] While drought is often cited as a reason for wetland loss, certain wetland functions such as flood attenuation remain in drought conditions and full function is restored once water returns. Rather, it is the ease of drainage associated with drought conditions and not drought itself that causes wetland loss.

government (GOA 2012). Priority Initiative #4 demands an Integrated Resource System that "sets and achieves the environmental, economic and social outcomes Albertans expect from resource development and maintains the social licence to develop resources" (GOA 2012). A comprehensive wetland policy that recognizes the social, environmental and economic values of wetlands and that has the ability to balance and enforce wetland conservation will meet this objective.

Within the Interim Policy, the province does address wetland loss through the Provincial Wetland Restoration/Compensation Guide (AE 2007). Under this guide, developers are to follow the process of avoidance, minimization, and compensation. First, all possible effort should be made to avoid wetland alteration. If avoidance is impossible, then minimization of loss should be the objective, and if the first two options are exhausted then the developer must compensate for the lost wetland at a 3:1 area ratio. Compensation must be paid to a recognized Wetland Restoration Agency[9] that will then restore a similar wetland elsewhere – preferably nearby.

In addition to the provincial level policy research, environmental organizations have partnered with landowners, government and academic institutions to research the environmental services provided by wetlands, stop wetland loss, raise public awareness and in some cases become involved in restoration activities. A complete list of these research initiatives can be found in Alberta Environment Ecosystem Goods and Services Assessment (AE 2007), and an updated version is currently in progress. These organizations include Ducks Unlimited Canada, Delta Waterfowl, the Nature Conservancy of Canada, the David Suzuki Foundation and World Wildlife Fund[10].

## 3.0 Environmental Issue: Water Quality

Concern over the abundance and quality of surface water is becoming a major environmental issue in Alberta (GOA 2011). Water quality in particular has two major implications to the province: *domestically*, in terms of public health risks associated with blue-green algae blooms in

[9] Ducks Unlimited Canada is currently the only Wetland Restoration Agency in the province.
[10] Among others

Alberta lakes, and *internationally*, in terms of international perceptions on pollution due to oil and gas extraction. Support for water quality monitoring and enhancement is strong, as indicated by the recent recommendation to establish an independent environmental monitoring agency in the province (AEMGW 2012).

Nutrient loading is of particular concern in the settled areas of the province. Howard et al. (1999; 2006) reported major concerns over nutrient loading in surface water quality from agricultural and industrial sources, and that future action would needed to address these concerns. Specifically, they recommend that a

> *desirable long-range goal for Alberta is a balanced nutrient management approach to land application of nutrient-bearing materials, but a site specific approach to soil phosphorus management would be suitable for addressing the more immediate need to protect water quality*

A number of initiatives are beginning to address this concern. The Alberta Soil Phosphorous Limits Project was initiated under the Agricultural Operations Practices Act to increase understanding of phosphorous levels in the province to protect soil and water quality (Little et al 2007). The Final Report emphasized the importance of exploring the use of beneficial management practices that work in Alberta. Miller et al (2011) researched nutrient run-off from agriculture in southern Alberta under the Watershed Evaluation of Beneficial Management Practices (WEBs) program. A group of stakeholders in southern Alberta have formed to create the Bow River Phosphorous Management Plan that will address the issues of phosphorous pollution in the face of increased population pressures and development in the watershed. This Plan is collaborative and innovative. Using the concept of cumulative effects management it attempts to promote environmental beneficial management practices in the watershed to prevent phosphorous loading and the resultant negative effects downstream (BRPMP 2012).

**4.0 Vermilion River Subwatershed**

This report will use the Vermilion River subwatershed as a case study to determine whether wetland conservation – both retention and restoration as a BMP - is an effective means to meet Alberta's water quality and quantity needs in an environmentally credible and economically viable manner. Research conducted by the Cold Water Research Institute from the University of

Saskatchewan and the Vermilion River Watershed Management Plan provides the foundation of this comparison.

The Vermilion River subwatershed is located in east-central Alberta, and is part of the larger North Saskatchewan watershed. It is located in the parkland region of east central Alberta, and is primarily agriculturally based. Therefore significant conversion of the landscape has occurred here since settlement.

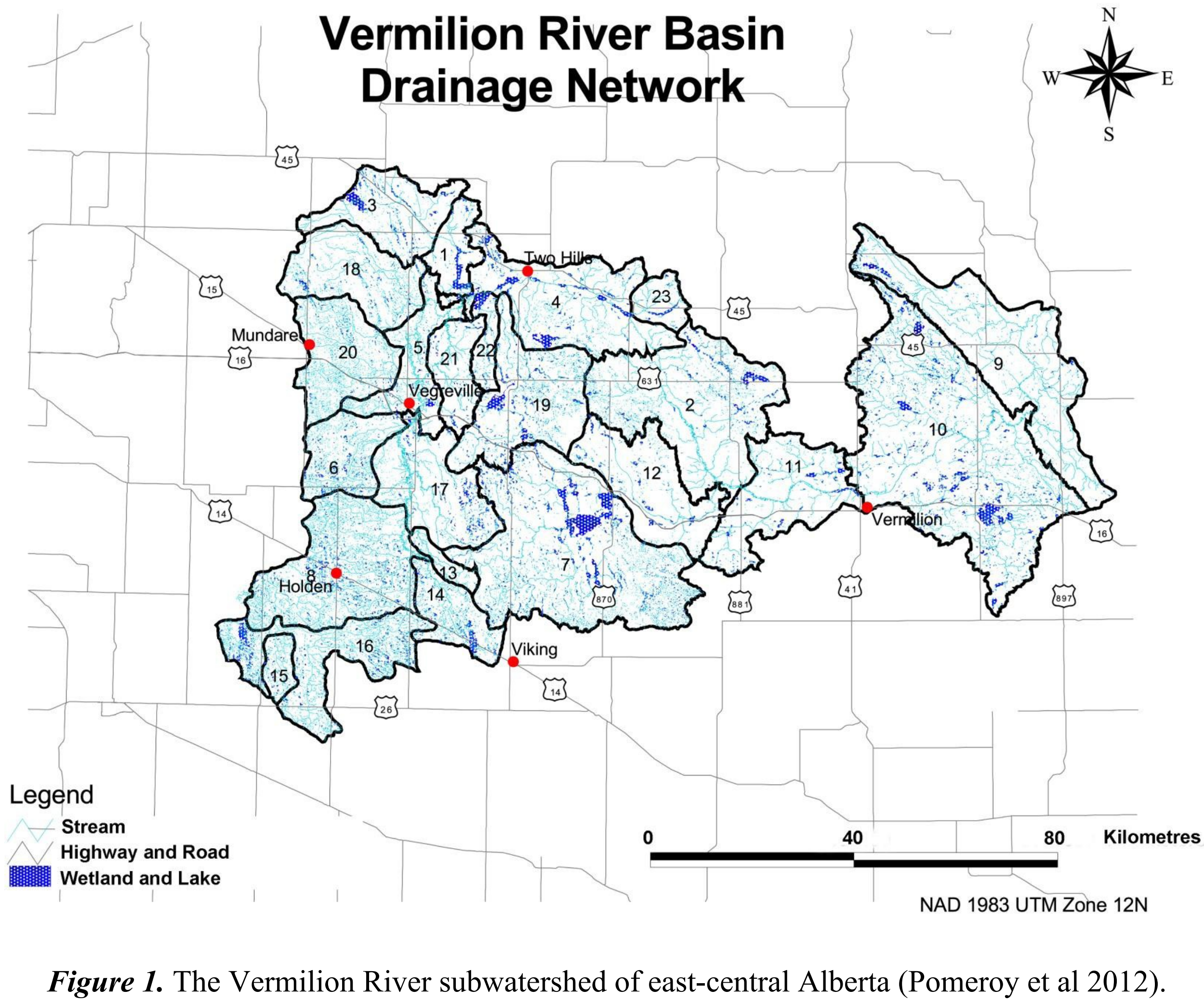


***Figure 1.*** The Vermilion River subwatershed of east-central Alberta (Pomeroy et al 2012).

In order to understand the landscape conversion and wetland loss that has occurred, Ducks Unlimited Canada[11] extensively mapped the subwatershed and created a drained wetland inventory. Their results indicate that in 1949 an estimated 58,010 hectares of wetlands existed on the landscape. Fifty-five years later (2004) that area has dropped to 46,890 hectares - primarily due to agricultural drainage and transportation infrastructure development (Pomeroy et al 2012).

Pomeroy et al (2012) developed several wetland loss and restoration scenarios based upon these numbers that are provided in Table 1 below. Restoration scenarios of 25%, 50% and 100% of the total wetlands that have been lost since 1949. Loss scenarios are 25%, 50% and 100% of the existing wetlands on the landscape. These scenarios will be used to relate the benefits and costs of wetlands in the following section.

**Table 1.** Wetland restoration and loss scenarios in the Vermilion River subwatershed.

| Scenario | Wetland area | |
|---|---|---|
| | Hectares | Change |
| Rest100 | 58,010 | 11,120 |
| Rest50 | 52,450 | 5,560 |
| Rest25 | 49,670 | 2,780 |
| Existing | 46,890 | 0 |
| Loss25 | 35,170 | - 11,720 |
| Loss50 | 23,450 | - 23,440 |
| Loss100 | 0 | - 46,890 |

## 5.0 Benefits of Wetlands

Qualitative estimations of the contribution of wetlands to ecosystem health are commonly cited in conservation literature (Environment Canada 1991; MEA 2005). These benefits include biodiversity enhancement, flood water control, erosion control, groundwater recharge, surface water quality improvements (reduction of nitrogen and phosphorous in particular), and carbon sequestration (Environment Canada 2009). While these benefits are existent for most wetlands, they occur in varying degrees across regions and wetland classifications; coastal wetlands are not the same as boreal or prairie pothole wetlands. Due to heterogeneity between wetlands and

[11] Under an AESRD contract for the Drained Wetland Inventory

financial constraints for research, precise estimates of the biophysical benefits of specific wetland ecosystem functions are often limited, relying on techniques such as benefit transfers[12].

Pomeroy et al (2012) has specifically researched the water quantity estimates under the current level and several loss and restoration scenarios. This information allows for greater precision when estimating economic values provided from these ecosystems. However, the data regarding phosphorous, nitrogen, sediment load, water flow and groundwater recharge capacity of wetlands in this watershed are not available[13]. Therefore benefit estimates from similar watersheds in Alberta and the prairie pothole region are employed. The following sections look at each service provision in detail.

*5.1 Flood Control*

Wetlands help to control flooding by regulating the flow of water during spring snowmelt and periods of high rainfall. With the current inventory of wetlands and open water, Vermilion River subwatershed has an annual discharge of 562,258 cubic meters. This flow would decrease by 3.4% per cent if all historic wetlands were restored, and would increase by 3.5% per cent if all existing wetlands were lost (Pomeroy et al 2012)[14]. Although flood control benefit estimates are cited (Wilson 2008; Olewiler 2004) the estimates are not easily related to human demands in the Vermilion River subwatershed and so are not presented here. This benefit clearly exists, but its quantification is beyond the scope of this report.

**Table 2.** A summary of annual water quantity retention capacity of several wetland retention and restoration scenarios in the Vermilion River subwatershed.

| Scenario | Wetland area | | Total Flow* m3/year | Change in Flow (m3/year) |
|---|---|---|---|---|
| | Hectares | Change | | |
| Rest100 | 58,010 | 11,120 | 543,060 | -19,198 |
| Rest50 | 52,450 | 5,560 | 551,707 | -10,551 |
| Rest25 | 49,670 | 2,780 | 557,418 | -4,840 |
| Existing | 46,890 | 0 | 562,258 | - |
| Loss25 | 35,170 | - 11,720 | 566,944 | 4,686 |
| Loss50 | 23,450 | - 23,440 | 571,253 | 8,995 |
| Loss100 | 0 | - 46,890 | 582,100 | 19,842 |

*average from 2005-2009

[12] Functions from a one area are applied elsewhere (see Glossary).
[13] Primary data collection of ecosystem services is costly and time consuming.
[14] This is lower than described in the Black River (Pattison et al 2011) and Broughtons Creek (Yang et al 2008).

*5.2 Phosphorous Removal*

Wetlands have the ability to store phosphorous in sediment layers which can be used by aquatic vegetation. Richardson and Quian (1999) in a review of North American wetlands estimate that wetlands can store 10 kg/ha/yr[15]. When this removal rate is applied to the scenarios in the Vermilion River subwatershed there is an increase in the phosphorous loading to the watershed of 117,200 kg under 25% loss to 468,900 kg under complete loss. Alternatively, restoring all wetlands in the subwatershed would retain an additional 27,800 kg of phosphorous in 25% restoration to 111,200 kg under full restoration (Table 3). Using a $50 per kg phosphorous removal cost (Olewiler 2004), these figures equate to an increase of $5.6 million in benefits from full restoration to a decrease of $23.4 million under complete loss.

The phosphorous removal capacity of wetlands is a key benefit in terms of water quality concerns from agricultural run-off. When landowners drain wetlands the water and associated nutrients move off the landscape and into watercourses. If producers manage the movement of water by retaining wetlands, they also manage the movement of nutrients. Water quality concerns both locally and downstream from nutrient run-off can be stopped by retaining wetlands on the landscape.

**Table 3.** A summary of the annual phosphorous retention capacity of Vermilion River subwatershed wetlands and the associated economic benefit.

| Scenario | Wetland area | | Total P Kg/y | Change in P Kg/y | Total Value $/y | Change in Value $/y |
|---|---|---|---|---|---|---|
| | Hectares | Change | | | | |
| Rest100 | 58,010 | 11,120 | 580,100 | 111,200 | 29,005,000 | 5,560,000 |
| Rest50 | 52,450 | 5,560 | 524,500 | 55,600 | 26,225,000 | 2,780,000 |
| Rest25 | 49,670 | 2,780 | 496,700 | 27,800 | 24,835,000 | 1,390,000 |
| Existing | 46,890 | 0 | 468,900 | - | 23,445,000 | - |
| Loss25 | 35,170 | - 11,720 | 351,700 | -117,200 | 17,585,000 | - 5,860,000 |
| Loss50 | 23,450 | - 23,440 | 234,500 | -234,400 | 11,725,000 | - 11,720,000 |
| Loss100 | 0 | - 46,890 | - | - 468,900 | - | -23,445,000 |

[15] This number is similar to the 6.4 kg/ha/yr estimated by White et al (2000) and much more conservative than the 80.3 kg/ha/yr used in GOA (2011) in the Shephard Slough study.

*5.3 Nitrogen Removal*

In an analysis of nitrogen retention in a comparable watershed in Manitoba, Yang et al (2008) conservatively estimates that a wetland hectare can retain 50 kg of nitrogen annually. When linked with a $5.75 per kilogram removal cost (Olewiler 2004) this increases the nitrogen retention capacity from existing levels by 556,000 kilograms under full restoration, and increases loading by 2.3 million kilograms under complete wetland loss. These numbers equate to an increase in value of approximately $3.2 million annually under full restoration and a loss of $13.5 million under complete loss (Table 4).

**Table 4.** A summary of the annual nitrogen retention capacity of Vermilion River subwatershed wetlands and the associated economic benefit.

| Scenario | Wetland area | | Total N Kg/y | Change in N Kg/y | Total Value $/y | Change in Value $/y |
|---|---|---|---|---|---|---|
| | Hectares | Change | | | | |
| Rest100 | 58,010 | 11,120 | 2,900,500 | 556,000 | 16,677,875 | 3,197,000 |
| Rest50 | 52,450 | 5,560 | 2,622,500 | 278,000 | 15,079,375 | 1,598,500 |
| Rest25 | 49,670 | 2,780 | 2,483,500 | 139,000 | 14,280,125 | 799,250 |
| Existing | 46,890 | 0 | 2,344,500 | - | 13,480,875 | - |
| Loss25 | 35,170 | - 11,720 | 1,758,500 | - 586,000 | 10,111,375 | - 3,369,500 |
| Loss50 | 23,450 | - 23,440 | 1,172,500 | -1,172,000 | 6,741,875 | - 6,739,000 |
| Loss100 | 0 | - 46,890 | - | - 2,344,500 | - | - 13,480,875 |

*5.4 Recreation Value*

A challenge when determining the recreation value of wetlands in the high degree of local variation – such as proximity to urban areas, numbers of waterfowl, demographics of the local population, etc. While no specific study in the Vermilion River subwatershed on the recreation value of wetlands has been conducted, there is a significant amount of waterfowl hunting and other recreation activities that are enjoyed by local community members and visitors and the Vermilion River Subwatershed Management plan identifies action plans to explore and expand tourist potential for the area. Based upon results from Olewiler (2004)[16] and Wilson

[16] Olewiler (2004) reports a willingness to pay of $3.17/ha/yr for recreational fishing, $12.50/ha/yr for recreational hunting, $57.65/ha/yr for wildlife viewing and $44.65/ha/yr for recreational activities such as camping and hiking.

(2008) the range of recreation values of wetlands across Canada is between $25.27/ha/yr to $138.37/ha/yr, with a median value of $82.15/ha/yr (DUC 2012). Considering the distance to large urban centers and agricultural rental rates in the Vermilion River subwatershed, the conservative $25.71/ha/yr was applied to the scenarios, resulting in an increased recreation value of $281,002 annually under full restoration and a decrease of $1.2 million annually under complete loss.

**Table 5.** A summary of the annual recreation values of Vermilion River subwatershed wetlands under several restoration and loss scenarios.

| Scenario | Wetland area Hectares | Change | Total Benefit $/y | Change in Benefit $/y |
|---|---|---|---|---|
| Rest100 | 58,010 | 11,120 | 1,465,913 | 281,002 |
| Rest50 | 52,450 | 5,560 | 1,325,412 | 140,501 |
| Rest25 | 49,670 | 2,780 | 1,255,161 | 70,251 |
| Existing | 46,890 | 0 | 1,184,910 | - |
| Loss25 | 35,170 | - 11,720 | 888,746 | - 296,164 |
| Loss50 | 23,450 | - 23,440 | 592,582 | - 592,329 |
| Loss100 | 0 | - 46,890 | - | -1,184,910 |

*based upon $25.27 ha/annually

*5.5 Carbon Sequestration*

The Alberta Tech Fund estimates the value of carbon sequestration to be worth $15 per tonne $CO_2e$. (GOA 2011). According to Badiou et al (2011) the annual per hectare storage of $CO_2e$. varies between drainage and restoration due to release of stored carbon. Therefore it is estimated that 326 tonne of $CO_2e$ per hectare would be released under drainage scenarios and 3.25 tonnes would be stored under restoration scenarios (Badiou et al 2011). Full restoration of wetlands leads to an increase of 36,140 tonnes stored annually with a monetary benefit of $542,100, and full loss of wetlands would lead to a release of $15.3million T/yr with a related monetary loss of $229.3 million annually. This information strongly supports the retention of wetlands due to the resultant increased cost of the released carbon currently stored in the wetlands.

**Table 6.** A summary of the annual carbon sequestration capacity of Vermilion River subwatershed wetlands and the associated economic benefit.

| Scenario | Wetland area | | Total C T/y | Change in C T/y | Total Value $/y | Change in Value $/y |
|---|---|---|---|---|---|---|
| | Hectares | Change | | | | |
| Rest100 | 58,010 | 11,120 | 188,533 | 36,140 | 2,827,988 | 542,100 |
| Rest50 | 52,450 | 5,560 | 170,463 | 18,070 | 2,556,938 | 271,050 |
| Rest25 | 49,670 | 2,780 | 161,428 | 9,035 | 2,421,413 | 135,525 |
| Existing | 46,890 | 0 | 152,393 | - | 2,285,888 | - |
| Loss25 | 35,170 | - 11,720 | 114,303 | - 3,820,720 | 1,714,538 | -57,310,800 |
| Loss50 | 23,450 | - 23,440 | 76,213 | - 7,641,440 | 1,143,188 | -114,621,600 |
| Loss100 | 0 | - 46,890 | - | - 15,286,140 | - | - 229,292,100 |

*5.6 Other Services*

Wetlands provide many more services than the five services described above. These benefits include groundwater recharge, sediment control, decreased flood risk, increased property value for houses and intrinsic biodiversity values. However, there is currently an absence of primary research on these services in the Vermilion River subwatershed specifically and Alberta generally. Consequently, these services are left out of the analysis. Their absence is an indication that the wetlands values described in the analysis can be considered very conservative and the net benefit is likely higher than described.

# 6.0 Costs of Wetland Restoration and Retention

While specific costs of wetland restoration and retention can be difficult to gauge[17], for the purposes of this report the costs associated with retention and restoration activity are divided into two general categories[18]: fixed costs to restore wetlands and opportunity costs to keep wetlands from an alternative land use.

Fixed costs are the specific financial requirements to physically restore a drained or degraded wetland. For example, removing soil from a filled wetland requires machinery and administrative costs; a drainage ditch only needs to be plugged. DUC is currently the only recognized wetland restoration agency in Alberta (Alberta Environment 2007) and therefore has detailed restoration cost estimates. Based upon mitigation guidelines and compensation rates, DUC (2012) estimates the per hectare cost of wetland restoration to be approximately $10,000 in the prairie parkland; this includes land securement, physical restoration and future management costs.

Opportunity costs are financial returns that accrue from the next most profitable alternative. For example, keeping wetlands in their natural state forgoes the financial opportunity that could results from agricultural production or acreage development; the change in land use represents a resource cost in terms of foregone land rent. Accurate knowledge of opportunity costs is important for long term wetland retention, as the majority of wetland area in southern Alberta is on private land. If development pressure is exerted from agricultural sources, then the opportunity cost is related to commodity prices and expected crop yields. If pressure is exerted by urban expansion, then opportunity costs are related to returns from housing, retail, or industrial prices.

Table 7 provides estimates of the cost of wetland restoration and retention that corresponds to the various scenarios. Restoration costs are considered an up-front expenditure of $10,000 per hectare restored, and opportunity costs are based upon Alberta Agriculture and

[17] No rigorous economic cost estimates of wetland retention and restoration currently exist in Alberta, although reverse auctions and other economic studies are being explored by the University of Alberta.
[18] Nuisance costs are a third category described in the literature (Packman 2010; Cortus 2005) but are not considered in this analysis due to limited availability of Alberta estimates.

Rural Development (AARD) estimates for agricultural land rent in central Alberta, estimated at $124.71 per hectare annually (AARD 2011).

**Table 7.** A summary of annual cost estimates of wetland conservation in the Vermilion River watershed under several loss and restoration scenarios.

| Scenario | Wetland area | | Restoration Cost | Opportunity Cost | Total Cost |
|---|---|---|---|---|---|
| | Hectares | Change | $ | $ | $ |
| Rest100 | 58,010 | 11,120 | 111,200,000 | 7,234,445 | 118,434,445 |
| Rest50 | 52,450 | 5,560 | 55,600,000 | 6,541,055 | 62,141,055 |
| Rest25 | 49,670 | 2,780 | 27,800,000 | 6,194,361 | 33,994,361 |
| Existing | 46,890 | 0 | | 5,847,666 | 5,847,666 |
| Loss25 | 35,170 | - 11,720 | | 4,386,061 | 4,386,061 |
| Loss50 | 23,450 | - 23,440 | | 2,924,457 | 2,924,457 |
| Loss100 | 0 | - 46,890 | | - | - |

# 7.0 Benefit Cost Analysis

This section analyzes the economic feasibility of wetland conservation in two components: a benefit cost comparison specifically for nutrient removal in the watershed, and a partial social return on investment (SROI) analysis that incorporates additional values provided by wetlands. Biophysical results from the Vermilion River watershed inform this section where possible, supplemented in part by other wetland studies in Alberta. However, some estimates are not included in this analysis due to lack of credible proxy data, such as sediment control and groundwater recharge. Therefore all estimates should be considered conservative.

The net present value and benefit cost (and SROI) ratio for each scenario is provided for three time periods: the initial year, 10 years and 30 years[19]. The annual costs and benefits over the retention time were discounted and summed for the present value using the following formula:

$$PV = \sum_{t=1}^{T} \frac{TC_i^t}{(1+r)^t}$$

where *TC* is the total cost (or benefit), *r* is the discount rate and *t* is the time period summed over the total time period *T*. The fixed costs for wetland restoration were incorporated as an up-front cost in the initial year. This calculation is used for both the costs and the benefits, which are subtracted from each other to determine the net present value (NPV) in 2011 dollars using a 3 per cent discount rate[20]. The SROI ratio is calculated by dividing the present value benefits by the present value costs; a ratio >1 indicates that benefits exceed the costs, and vice versa.

*7.1 Nutrient Reduction Potential*

As identified in the AB Phosphorous reduction strategy and Bow River Phosphorous management plan, the capacity of wetlands to remove nutrients such as phosphorous and nitrogen from surface water is very important in this province. As such, a separate comparison is made between the estimated financial benefits of nutrient removal with the costs of retention and restoration.

*7.1.1 Baseline and Loss Scenarios*

Prior to retention and restoration analyses, it is important to consider the financial implications of no wetland conservation initiatives in the watershed. Using the drainage or loss scenarios and estimated per hectare removal rates by wetlands and comparative costs from water treatment facilities, it is estimated that complete drainage of Vermilion wetlands would equate to a $37 million annual financial loss.

**Table 8.** A comparison of the total loss of wetland nutrient removal benefits

[20] Stern (2005) suggests that traditional measures of discount rates are often too high when applied to the environment, and that environmental services value may in fact increase into the future as they become more scarce. Therefore lower discount rates should be considered.

annually in the Vermilion River subwatershed under several loss scenarios

| Loss Scenario | Lost Benefit per Year ($) |
|---|---|
| 25% | - 9,229,500 |
| 50% | - 18,459,000 |
| 100% | - 36,925,875 |

### *7.1.2 Wetland Retention and Restoration Scenarios*

A comparison of the benefits and costs of retaining and restoring wetlands in the Vermilion subwatershed is provided in Table 9. The nutrient filtration benefit from the existing wetlands was a summation of the phosphorous and nitrogen removal capacity, determined by multiplying the total number of wetland hectares by the annual per hectare removal rate[21]. Costs were determined by multiplying opportunity cost ($124.71/ha) by the total number of wetland hectares retained or restored, and when wetlands were restored, the additional up-front restoration cost ($10,000/ha). The present value of benefits and total costs were added and discounted for the various time frames, present values were subtracted to determine the net present value, and then divided to determine the return on investment ratio.

As restoration activities are assumed to occur during the first year, costs are greater than benefits at that time across all restoration scenarios. However, results indicate that over longer time horizons (10 and 30 years) the nutrient removal benefits of these wetlands are greater than the costs of restoration and retention. However, a decreasing ratio is observed as larger numbers of wetlands are restored – directly related to the restoration costs of such a large number of wetland hectares. Over a ten year time horizon ratios range from 6.31 (retention) to 1.36 (100% restoration).

**Table 9.** Comparison of the benefits and costs of wetlands for nutrient retention in the Vermilion River subwatershed under several wetland restoration scenarios over 1, 10 and 30 years

[21] Phosphorous removal rate of 10 kg/ha/yr multiplied by the cost of mechanical phosphorous filtration of $50 per kg; nitrogen removal rate of 50kg/ha/yr multiplied by the cost of mechanical nitrogen filtration of $5.75 per kg.

| Scenario | Options | Total Benefits | Total Costs | Net Present Value | SROI |
|---|---|---|---|---|---|
| 100% Restoration | Initial Year | 45,682,875 | 118,434,427 | - 72,751,552 | **0.39** |
| | 10 years | 389,684,190 | 174,762,464 | 103,721,725 | **1.36** |
| | 30 years | 895,404,512 | 257,251,903 | 526,952,609 | **2.43** |
| 50% Restoration | Initial Year | 41,304,375 | 62,141,040 | -20,836,665 | **0.66** |
| | 10 years | 352,334,697 | 113,070,286 | 183,664,411 | **2.09** |
| | 30 years | 809,583,980 | 187,653,479 | 566,330,501 | **3.33** |
| 25% Restoration | Initial Year | 39,115,125 | 33,994,346 | 5,120,779 | **1.15** |
| | 10 years | 333,659,950 | 82,224,196 | 223,635,754 | **3.03** |
| | 30 years | 766,673,713 | 152,854,267 | 586,019,447 | **4.24** |
| Retention | Initial Year | 36,925,875 | 5,847,652 | 31,078,223 | **6.31** |
| | 10 years | 314,985,204 | 49,881,657 | 265,103,547 | **6.31** |
| | 30 years | 723,763,447 | 114,616,558 | 609,146,889 | **6.31** |

*7.2 Partial Social Return on Investment (SROI)*

The SROI builds on the principles of the traditional cost benefit analysis, but is specifically intended to incorporate social and environmental values into an economic analysis[22]. As such, it can be considered an appropriate framework for wetland retention and restoration comparisons. However, the missing market and lack of defensible approximations for these services renders this a partial, and therefore conservative, estimate of the social return on investment provided by wetlands in the Vermilion watershed.

The partial SROI analysis is structured in the same manner as the previous section: a baseline and loss section, a retention and restoration section, and general conclusions. Costs provided in the analysis are again based upon agricultural opportunity costs for wetland retention and fixed costs for wetland restoration[23]. The wetland hydrology benefit provided in the analysis is based upon Vermilion River data, while other benefits are based upon relevant Alberta estimates where possible[24]. These include phosphorous and nitrogen removal, recreation and carbon sequestration values.

### *7.2.1 Baseline and Wetland Loss Scenarios*

When additional wetland benefits are included in the analysis, the financial loss from wetland drainage is even higher than when considering the nutrient removal capacity alone. Complete loss of wetlands would result in $40.4 million in lost benefits.

**Table 10.** A comparison of the total loss of wetland benefits annually in the

[22] SROI has been used effectively by various organizations, including the city of Calgary, the New Economics Foundation in the United Kingdom, the Rotman School of Management at the University of Toronto, Carleton University, etc.
[23] Restoration costs for wetlands drained for urban or housing development were not included in the analysis.
[24] There are gaps in primary Alberta ES numbers, requiring the use of benefit transfers.

Vermilion River subwatershed under several loss scenarios

| Loss Scenario | Lost Benefit per Year ($) |
|---|---|
| 25% | - 10,097,014 |
| 50% | - 20,194,029 |
| 100% | - 40,396,673 |

*7.2.2 Wetland Retention and Restoration Scenarios*

The economic feasibility of restoring wetlands to provide additional societal benefit is presented in Table 11. The benefits were determined by multiplying the total number of wetland hectares in each scenario by the per hectare benefits. Costs were determined by multiplying opportunity cost ($124.71/ha) by the total number of wetland hectares retained and when wetlands were restored, the additional up-front restoration cost ($10,000/ha). Total benefits and total costs were subtracted to determine the net present value.

Retention of existing wetlands in the Vermilion subwatershed provides a net benefit of $34.5 million within the first year; $294.7 million over 10 years; and $677.2 million over 30 years (Table 11). Retention, therefore, provides a social return on investment of 6.91, indicating that for every $1 spent on wetland retention society receives $6.91 in benefit.

The wetland restoration scenarios assume that the existing wetland base will be maintained, and that restoration costs will occur in the first year. The restoration of 25 per cent, or 2,780 hectares of wetlands, generates a net benefit of approximately $8.8 million in the first year, $255 million over 10 years, and $658 million over 30 years. The SROI is initially at 1.26, but increases to 4.64 over 30 years because restoration costs are incurred in the first year.

Complete restoration of 100% of historical wetlands is unlikely to occur but provides an interesting perspective. The restoration of all historic wetlands (11,120 hectares) generates a net loss of approximately $68.5 million in the first year due to initial restoration costs; but moves to a net benefit of $140 million over 10 years, and $611 million over 30 years (Table 11). The benefits derived from this scenario do not justify the cost at the first year, yet the SROI does increase to 2.66 over 30 years.

**Table 11.** Comparison of the benefits and costs of wetlands in the Vermilion River subwatershed under several wetland restoration scenarios over 1, 10 and 30 years.

| **Scenario** | **Options** | **Total Benefits** | **Total Costs** | **Net Present Value** | **SROI** |
|---|---|---|---|---|---|
| 100% Restoration | Initial Year | 49,976,775 | 118,434,427 | - 68,457,652 | **0.42** |
| | 10 years | 426,312,030 | 174,762,464 | 140,349,565 | **1.49** |
| | 30 years | 979,566,851 | 257,251,903 | 611,114,948 | **2.66** |
| 50% Restoration | Initial Year | 45,186,724 | 62,141,040 | -16,954,316 | **0.73** |
| | 10 years | 385,451,921 | 113,070,286 | 216,781,636 | **2.29** |
| | 30 years | 885,679,734 | 187,653,479 | 642,426,255 | **3.64** |
| 25% Restoration | Initial Year | 42,791,698 | 33,994,346 | 8,797,353 | **1.26** |
| | 10 years | 365,021,867 | 82,224,196 | 254,997,671 | **3.32** |
| | 30 years | 838,736,175 | 152,854,267 | 658,081,908 | **4.64** |
| Retention | Initial Year | 40,396,673 | 5,847,652 | 34,549,021 | **6.91** |
| | 10 years | 344,591,813 | 49,881,657 | 294,710,156 | **6.91** |
| | 30 years | 791,792,616 | 114,616,558 | 677,176,058 | **6.91** |

*7.2.3 Analysis*

The results from this section indicate that retention and moderate levels of restoration present the highest return on investment. Having a return of $6.91 dollars for every $1 invested is an excellent investment option, and even 50% of wetland restoration over 30 years provides an attractive alternative. Further, this estimate can be considered conservative as services like groundwater recharge and erosion control are not included in these calculations. In regions upstream of Edmonton or Calgary or in areas nearer large urban centers the SROI ratio can easily be assumed much higher.

*7.3 Sensitivity Analysis*

A sensitivity analysis determines how responsive the analysis is to changes in the input variables (benefit estimates, opportunity costs and restoration costs). It is of particular importance when the SROI ratio is nearing 1:1, as slight miscalculations in the analysis could alter the conclusion. However, the high ratios observed in this calculation indicate that retention and restoration of wetlands will be financially viable even with much higher restoration and opportunity costs, and much lower wetland benefits.

## 8.0 Extrapolation

The conclusions from the Vermilion case study can be extended to other regions in the settled areas of Alberta. The Vermilion watershed is characteristic in terms of function to many watersheds in the parkland and central Alberta region. Therefore conclusions from this study can be considered relevant to other parts of Alberta – that wetland retention in particular and some levels of restoration are a financially sound investment.

In addition, Vermilion River is downstream of Edmonton and far from urban centers. Therefore while costs of restoration and retention may be lower than in some other areas, the benefits associated with recreation, property prices and even nutrient removal are lower than may be found elsewhere in the settled area of the province.

## 9.0 Public Demand

As scientific understanding of the value of wetlands to society increases, so does the demand of the public to see action taken to maintain this benefit. In a 2012 Alberta wide survey, Krogman et al (2012) determined that 85% of Albertan's are "concerned" to "very concerned" about wetland loss, while 79% of respondents indicated that the Alberta government should do more to protect the natural environment. Furthermore, Albertans overall concern for the natural environment is related to wetland health: the primary environmental concerns are chemical pollutants in lakes and rivers (91%), water availability (79%), manure and water quality (78%).

The current Alberta government has often stated their commitment to listen to Albertans. The health of aquatic ecosystems is clearly in the minds of the Alberta public, and therefore there is a responsibility on the part of Alberta legislators to address that concern.

## 10.0 Conclusions and Recommendations

Alberta is a province richly endowed with natural resources that are the foundation of the economy. Yet in an era of global economic uncertainty and environmental awareness, this resource based economy faces increased global scrutiny. The ability of Alberta to enjoy sustained economic growth and environmental prosperity is in question, and therefore investment alternatives that meet the Ministerial Mandate for Integrated Resources Systems should be considered in a favorable manner.

This report presents a strong financial case for the retention and restoration of wetland ecosystems in the Vermilion River subwatershed and, by extension, the settled areas of Alberta. Investment in wetland conservation provides a positive social return on investment: every $1 invested in retention yields $6.91 in nutrient removal, recreation and carbon sequestration; and every $1 invested in 25% restoration of lost wetlands yields $3.32 over a 10 year time frame. Major environmental concerns in the province, such as water quality, are addressed by having wetlands on the landscape. Direct comparison of the costs of retention and restoration with the benefits indicate high returns on investment dollars, leading to positive social, environmental and economic outcomes. These positive outcomes create a strong case for an effective and enforced wetland policy in Alberta.  It is possible for this policy to yield positive economic growth, environmental stewardship, and a positive political outcome. It is in the provinces best interest to develop and implement a policy that halts further loss of Alberta's wetlands, restores those that have been lost, and maintains natural habitat and clean water for future generations of Albertans.

## References


Alberta Agriculture and Rural Development (AARD). 2011. Custom Rates 2011 – Land Leasing. Retrieved from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd13852 on December 15, 2012.

Alberta Environment and Sustainable Resource Development (AESRD). 2012. Wetlands Inventory Project. Retrieved from http://www.waterforlife.alberta.ca/01519.html on July 04, 2012.

Alberta Environment Monitoring Working Group (AEMGW). 2012. Implementing a World Class Environmental Monitoring, Evaluation and Reporting System for Alberta. Report of the Working Group on Environmental Monitoring, Evaluation and Reporting.

Alberta Environment. 2007. Ecosystem Goods and Services Assessment - Southern Alberta. Phase I Report: Key Actors and Initiatives. Presented by Integrated Environments (2006) Ltd. and O2 Planning + Design Inc.

Alberta Environment. 2007. Provincial Wetland Restoration/Compensation Guide. URL: [http://www.environment.alberta.ca/documents/. Prepared with the Alberta NAWMP Partnership.

Alberta Water Council (AWC). 2008. Recommendations for a new Alberta Wetland Policy. Alberta Water Council Working Group Recommendations.

Alberta Water Resources Commission (AWRC). 1993. Wetland Management in the Settled Area of Alberta: An Interim Policy. The Government of Alberta.

Anielski, M. and S. Wilson. 2007 (updated 2009). *The Real Wealth of the Mackenzie Region*. Study prepared for the Canadian Boreal Initiative. Updated January 2009

Badiou, Pascal, Rhonda, McDougal, Dan Pennock and Bob Clark. 2011. Greenhouse gas emissions and carbon sequestration potential in restored wetlands of the Canadian prairie pothole region. *Wetlands Ecol. Management* 19:237–256

Barbier, E. B., Acreman, M. C. and Knowler, D. 1997. *Economic valuation of wetlands: A guide for policy makers and planners.* Ramsar Convention Bureau, Gland, Switzerland.

Bow River Phosphorous Management Plan (BRPMP). 2012. Overview of the Bow River Phosphorous Management Plan. Presentation by A. Neupane.

Ducks Unlimited Canada (DUC). 2012. Wetland compensation rates in the province of Alberta by region. Unpublished data.

Ducks Unlimited Canada (DUC). 2012. Recreation values associated with wetlands and natural areas in Canada. Unpublished data.

Environment Canada. 1991. The Federal Policy on Wetland Conservation, Government of Canada, Ottawa, Ontario.

Environment Canada. 2009. Bardecki, M.J., K. Rollins and B. Cundiff. Putting an Economic Value on Wetlands—Concepts, Methods and Considerations. Great Lakes Fact Sheet. Environment Canada, Ottawa. Retrieved from: http://www.on.ec.gc.ca/ wildlife/factsheets/fs_wetlands-e.html on January 26, 2009.

Government of Alberta (GOA). 2003. Water for Life: Alberta's Strategy for Sustainability. Retrieved from http://www.waterforlife.alberta.ca/ on August 02, 2012.

Government of Alberta (GOA). 2007. Water for Life: Renewal Strategy. Retrieved from http://www.waterforlife.alberta.ca/ on August 02, 2012.

Government of Alberta (GOA). 2009. Water for Life: Action Plan. Retrieved from http://www.waterforlife.alberta.ca/ on August 02, 2012.

Government of Alberta (GOA). 2011. Ecosystem Services Approach Pilot on Wetlands: Integrated Assessment Report.

Government of Alberta (GOA). 2012. Cabinet Mandate. Retrieved from http://alberta.ca/mandate.cfm on July 20, 2012.

Government of Alberta (GOA). 2012. Highlights of the Alberta Economy 2012. Retrieved from http://www.albertacanada.com/business/statistics/economic-highlights.aspx on December 02, 2012.

Government of Alberta. 2000. Water Act. Revised Statutes of Alberta 2000 Chapter W-3. Current as of November 01, 2010.

Howard, A., Olson B., and S. Cooke. 1999. Impact of Soil Phosphorous Loading on Water Quality in Alberta: A Review. Submitted to Alberta Agriculture and Rural Development.

Howard, A.E., Olson, B.M., and Cooke. S.E. 2006. Impact of soil phosphorus loading on water Lethbridge, Alberta, Canada. Alberta Soil Phosphorus Limits Project. Volume 5: 41 pp.

Krogman, N, Huddart, K. and A. Krahn. 2011. Alberta-wide random sample survey. Population Laboratory, University of Alberta. Unpublished data.

Little, J.J., Nolan, S.C., Casson, J.P., and B.M. Olson . 2007. Relationships between soil and runoff phosphorus in small Alberta watersheds. *Journal of Environmental Quality* 36:1289-1300.

Locky, D. 2011. Wetlands, Land Use, and Policy: Alberta's Keystone Ecosystem at a Crossroads. Green Paper Presented at Alberta Institute of Agrologists 2011 Conference.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington DC.

Miller, J., Chanasyk, D., Curtis, T., and B. Olson. 2011. Phosphorus and nitrogen in runoff after phosphorus- or nitrogen-based manure applications. *Journal of Environmental Quality, 40*(3), pp. 949-958.

Olewiler, N. 2004. The Value of Natural Capital in Settled Areas of Canada. Published by Ducks Unlimited Canada and the Nature Conservancy of Canada. 36 pp.

Packman, K. 2010. Investigation of Reverse Auctions for Wetland Restoration in Manitoba. Unpubl. MSc Thesis, University of Alberta.

Pattison, J., Boxall, P. C. and Adamowicz, W. L. 2011. The Economic Benefits of Wetland Retention and Restoration in Manitoba. *Canadian Journal of Agricultural Economics.* no. doi: 10.1111/j.1744-7976.2010.01217.x

Pomeroy, J., Fang, X., Shook, K., and C. Westbrook. 2012. Informing the Vermilion River Watershed Plan through Application of the Cold Regions Hydrological Model Platform. Center for Hydrology, University of Saskatchewan.

Richardson C., and S. Quian. 1999. Long-Term Phosphorus Assimilative Capacity in Freshwater Wetlands: A New Paradigm for Sustaining Ecosystem Structure and Function. *Environmental Science and Technology.* 33 (10).

Stern, N. 2005. The Economics of Climate Change: The Stern Review. Cambridge University Press.

White, J., Bayley, S., and P. Curtis. 2000. Sediment Storage of Phosphorous in a Northern Prairie Wetland Receiving Municipal and Agro-industrial Wastewater. *Ecological Engineering* 14: 127-138.

Yang, W., X. Wang, T.S. Gabor, L. Boychuk, and P. Badiou. 2008. Water Quantity and Quality Benefits from Wetland Conservation and Restoration in the Broughton's Creek Watershed. Ducks Unlimited Canada publication. 48 pp.