

Credit Valley Conservation

Valuing Wetlands in Southern Ontario's Credit River Watershed



Phase I Wetland Ecosystem Services Characterization
and Literature Review - May 2009

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Valuing Wetland Ecosystem Services in the Credit River Watershed, Ontario: Phase 1 Report
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May 2009

2009 The Pembina Institute and Credit Valley Conservation

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About Credit Valley Conservation

Credit Valley Conservation (CVC) was formed on May 13, 1954, and has been working for over 50 years to protect the natural environment. CVC is one of 36 conservation authorities operating in Ontario and is a partnership of the municipalities within the Credit River Watershed. CVC is a community-based environmental organization originally formed by an Act of provincial government and dedicated to conserving, restoring, developing and managing natural resources on a watershed basis. More information about CVC is available at www.creditvalleyca.ca.



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Valuing Wetlands in Southern Ontario's Credit River Watershed

Wetland Ecosystem Services Characterization and Literature Review

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1. Introduction

Wetlands are now recognized as the most productive natural areas in the world.¹ They are estimated to provide up to 40% of all ecosystem services worldwide, despite covering only 1.5% of the Earth's surface.²

In spite of their significance, approximately 70% of Prairie and southern Ontario wetlands have been converted for alternative land uses since European settlement. Agricultural reclamation represents 85% of Canada's total wetland losses.³ The Credit River Conservation Authority estimates that approximately 75% of natural wetlands within the Credit River watershed have been lost due to land use conversion.⁴

The south Credit River watershed's relatively rapid shift from agricultural, pasture or forest land use to an urban landscape is also creating issues related to surface and groundwater quality and quantity, streamflow, erosion and wildlife habitat.⁵ Effects of urbanization have included increased area of impervious soils, reduced amount of available wildlife habitat, decreased surface water infiltration and increased soil erosion. Credit Valley Conservation (2005) also noted an overall decline in the amount of groundwater recharge during the period from 2000 to 2003.⁶ Annual precipitation and streamflow declined by approximately 7% and 17%, respectively, over the same time period.⁷

The Credit River receives treated wastewater effluent from four wastewater treatment facilities equipped with tertiary treatment.^{8,9} Surface water in the Credit River consists of roughly 50% treated effluent in headwater areas.¹⁰ Analysis of surface water quality data from 1995 to 2005 revealed "good" to "fair" water quality in the Credit River and "marginal" to "poor" water quality in its tributaries, due to decreased buffering capacity.¹¹ Communities of benthic invertebrates at monitoring stations throughout the Credit River watershed were either "impaired" or "possibly impaired."¹² These invertebrates are used to indicate ecosystem aquatic health. Monitoring of fish health completed at 36 field stations revealed 16 stations where health was "excellent" or "good," 11 where health was "fair" and 10 where health was "poor."¹³

This report details the 1st of a 2-phase research project focused on valuing wetland ecosystem services in the Credit River Watershed, in Ontario. Below, we provide a summary of the literature that has focused on: (i) identifying/quantifying wetland ecosystem services; (ii) assessing the impact that human activities/actions have on these services; and (iii) estimating the economic value provided by these services. We then determine the method that will be employed in Phase 2 of this research that will assess the value of ecosystem services provided by the wetlands in the watershed.

The specific approach taken in our review of the literature is to highlight the established links that exist between wetland ecological service indicators and their associated inputs (i.e., actions/activity indicators that occur on the land base) and outcomes (i.e., economic value). Figure 1 illustrates these relationships.

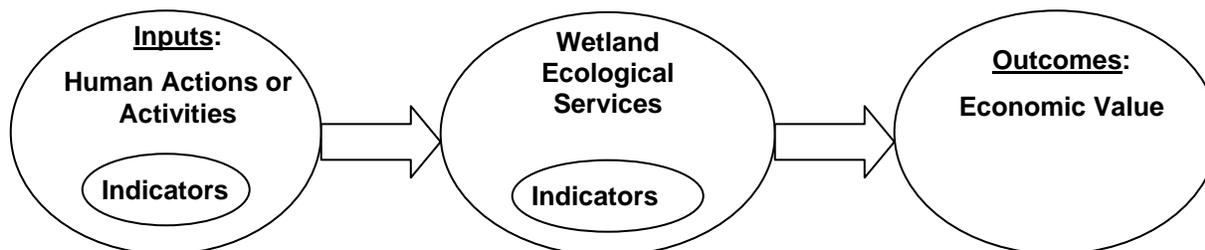


Figure 1. Approach taken in our summary of the literature

The process of establishing the links in Figure 1 involves the following critical elements:

- Identification of key ecological services provided by wetlands (**Example:** Flood protection - wetlands buffer outlying areas from flooding by slowing and retaining water run-off).
- Identification of indicators that represent the key ecological services (**Example:** Frequency of flood events in the watershed).
- Assessment of current ecological service indicator condition. This can be assessed quantitatively (**Example:** Flooding events of 3 meters above peak water flow occur once every 5 years), or qualitatively (**Example:** Flooding events occur often).
- Identification of the manner in which human actions/activities affect ecological service indicators (**Example:** Establishing forest cover on adjacent lands results in more regular and lower velocity water run-off which improve the wetlands ability to provide flood protection).
- Identification of indicators that represent the human actions/activities affecting ecological service indicators (**Example:** Conversion of land-use from agriculture to forest within 10 hectares of the riparian area of the wetland).
- Assessment of the impact that the human action/activity indicators have on wetland ecological service indicators (**Example:** Conversion of agricultural land to forestland within 10 hectares of the riparian area of the wetland causes flooding events of 3 meters above peak water flow to occur once in every 50 years instead of ever 5 years).
- Assessment of the impact that the change in wetland ecological services have on economic values (**Example:** Reducing frequency of flooding events from once every 5 years to once every 50 years will cause a reduction in property damage of \$1.5 million).

Once the key ecological services, human actions, and economic value methods for wetland analysis are identified and linked, they will provide some insight into the required inputs and range of outcomes that can be produced when valuing wetlands.

2. Identifying Wetland Ecological Services

2.1 Types of Wetlands

The Canadian Wetland Classification System (CWCS) categorizes wetlands into classes based on morphology and habitat characteristics¹⁴. The CWCS recognizes the following five classes of wetlands: (i) bogs; (ii) fens; (iii) swamps; (iv) marshes; and (v) shallow water. Table 1 describes the characteristics of each wetland class.

Table 1. Classification of Canadian wetlands

(Source: Environment Canada, *The Canadian Wetland Classification System 2009*)¹⁵

Type of Wetland	Description
Bogs	Bogs are characterized by peat accumulation to a depth of 3-5 m. The water table is located at or below the surface of the peat layer and is recharged by fog and snow. Consequently, bogs are low in minerals. Bogs typically occur in polar and sub-arctic regions of northern Canada. They are commonly acidic (pH 4 to 4.8) due to the creation of organic acids during peat decomposition. Bogs can be treed or treeless, but are colonized by vegetation tolerant of humidity, acidity and nutrient-poor conditions. Flora may include wild flowers, such as orchids.
Fens	Fens are also characterized by the presence of peat; however, they feature a greater number and diversity of marshy plants than bogs. The water table of a fen fluctuates at the surface; water seeps through the peat or flows through open channels in the vegetation. The water table is fed by groundwater which has leached through mineral soil which release moderate amounts of nutrients into the water. The pH of fen water is site-specific but generally higher than that of bogs. Vegetation varies with water table depth and chemistry but commonly includes moderately decomposed sedges, rushes, grasses and mosses. Shrubs or trees may be present in drier areas. "Poor fens" have with low mineral content in the water table and are dominated by peat and shrubs; "rich fens" have higher mineral content and are dominated by sedges and brown mosses.
Swamps	Swamps generally occur near rivers, lakes and other waterways and are distinguished by the dominance of trees or tall shrubs. Swamps are drier than marshes and fens because of the presence of organic matter above the water table, but are likened to treed bogs. They may be permanently or seasonally flooded. Swamps can develop directly on mineral soils or on peat. Swamps which develop on top of sandy soils may develop a layer impermeable to water drainage. There are three main types of swamps: shrub swamps, coniferous swamps and deciduous swamps. Mixed swamps show characteristics of more than one type of swamp. Swamps act as water reservoirs during drought and are valued as habitat for a diversity of plant and wildlife species.
Marshes	Marshes are the most common wetlands in North America. They are wetter than swamps and support fewer trees and tall shrubs. The fluctuating water table of marshes leads to periodic saturation by surface water. The root zone remains wet year-round, except during drought. Marshes may be permanent, semi-permanent or

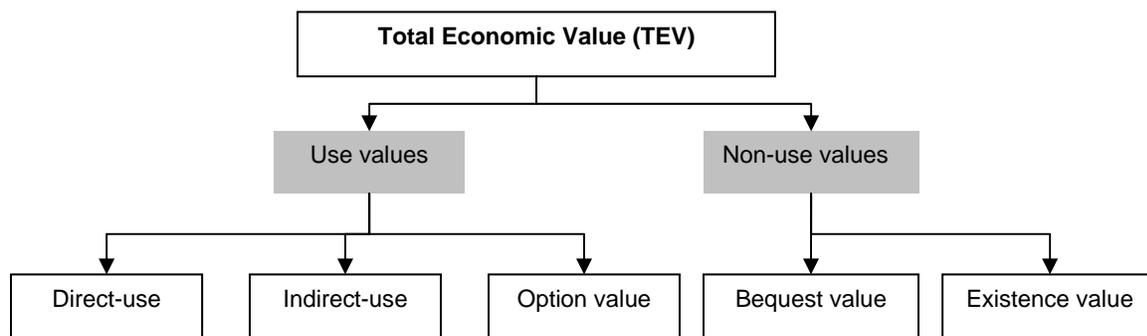
	temporary and can contain fresh or saline water. The water table may be fed by local streams, precipitation, groundwater discharges and/or tidal action. Many freshwater marshes are alkaline due to the presence of dissolved oxygen. Marshes often consist of a mosaic of vegetation and mudflats, dominated by rushes, reeds, grasses and sedges, shrubs and other herbaceous species. Floating-leaved and submergent plants, brown mosses and macroscopic algae may also be present. Marshes are a key source of food for wildlife.
Shallow Water	Shallow water wetlands occur in transitional areas between bogs, fens, marshes or swamps and waterbodies such as lakes. Nutrient and gas exchange, oxidation and decomposition frequently occur in this type of wetland. Nutrient and mineral composition are site-specific. Peat, organic and mineral materials and marl accumulate in slow-moving pools and provide a substrate for rooted, submerged and floating vegetation and algae and aquatic mosses. Rooted emergent vegetation, such as trees, can occupy up to 1/4 total area, but are generally relegated to the periphery.

Each of the wetland classes outlined in Table 1 provides a different set of EG&S for human use. Natural variation within each wetland class will result in variations in EG&S provision even within the classes themselves. More specifically, EG&S provision within a wetland varies with a number of biogeochemical factors such as season, temperature, precipitation, size, flow rate, flow volume, and many others. It is important to note that this study is based on general patterns of wetland function; accuracy and reliability of the results improve with data quality and availability.

2.2 Ecological Services Provided by Wetlands

Ecosystem service valuation is often framed within the concept of total economic value (TEV). In our context, TEV can be interpreted as the total of all values derived from a wetland. This framework has been discussed extensively in the literature.^{16,17} The TEV framework is illustrated in Figure 2.

Figure 2. Total economic value framework for environmental valuation.



As Figure 2 depicts, the services afforded to society by ecosystems are categorized into two main values: use values and non-use values. Use values reflect the benefits derived by humans from consuming (either directly or indirectly) or from the option of consuming ecological services. Non-use values, in contrast, are derived without consumption taking place. There are three types of use values:

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- **Direct use value** – the value derived from the direct use of the ecosystem or resource, such as the value of water for drinking.
- **Indirect use value** - the value derived from the indirect use of the ecosystem or resource, such as the value of a wetland in flood control.
- **Option value** - the value derived from preserving a use value of water today for the option of using it in the future (e.g. preserving the flow of a stream today so that it may be used in the future).

The second component of TEV is non-use values. There are two types of non-use values¹⁸ (also referred to as inherent values):

- **Bequest value** - the satisfaction that individuals derive from the knowledge that water, at a particular supply or quality level, exists for future generations.
- **Existence value** - the satisfaction that individuals derive from the knowledge that water, at a particular supply or quality level, exists today even though they do not use it.

Tables 2 to 5 provide a summary of the direct, indirect, option-use, and non-use ecological service values that characterize wetlands. Each service is allocated to its particular economic value classification.

Table 2. Summary of direct use values of wetlands¹⁹

Ecological Service	Range of Services	Description
Raw materials	Fisheries	Wetlands provide spawning and feeding habitat for several commercial fish species in Canada. The Credit River alone hosts 45 fish species, including: brook, brown and rainbow trout; smallmouth and largemouth bass; northern pike and carp.
	Agriculture Products	Agricultural uses for wetlands in Canada are generally limited to cultivation of wild rice, cranberries and wild blueberries ²⁰ Agriculture has primarily focused on drainage of wetlands for access to highly productive soils. Harvesting of peat and hardwood also contribute hundreds of millions of dollars to the Canadian economy each year ²¹
Recreation	Hunting/ Fishing	Many wetlands provide known recreational benefits due to their aesthetic qualities and high degree of biodiversity ²²
	Bird watching/ Hiking	
Information	Education	Due to their significant biodiversity, wetlands provide a unique opportunity for environmental education. The Credit Valley Conservation Authority runs educational programs throughout the year, with a focus on summer programs for youth.

Table 3. Summary of indirect use values of wetlands

Ecological Service	Range of services	Description
Nutrient Retention	Phosphorous attenuation	Wetlands play an important role in nitrogen, phosphorus and sulfur retention, particularly in agricultural areas. ²³ Wetland vegetation enhances microbial activity in soil and root zones. ²⁴ Plant matter, including root and leaf tissue, promotes growth of bacterial 'biofilms' which trap and metabolize nutrients, such as nitrates and phosphates, and
	Nitrogen attenuation	

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		elevate dissolved oxygen levels. ²⁵ Increased oxygen availability enables more rapid decomposition of organic matter, and further nutrient uptake, in wetlands than other land uses.
Waste treatment	Pollution abatement	Wetlands improve water quality by trapping sediments, slowing water flows and accumulating peat deposits. ²⁶ Surface water is generally much cleaner after flowing through a wetland. Wetland biophysical processes including denitrification, sedimentation and assimilation act to diminish nitrogen concentration in agricultural runoff.
Flood Control	Water Retention	Wetlands, specifically floodplain wetlands, often provide critical water storage during extreme weather events, including both heavy rainfall and drought. Peak flows are reduced and/or delayed by the presence of wetlands. Water is released slowly by wetlands over a longer span of time than other land uses. Wetlands thereby moderate water balance. In wetlands with high evapo-transpiration rates, downstream river flow may be significantly reduced during dry periods. Evaporation from wetlands has been observed to be consistently higher than from non-wetland areas.
	Erosion Control	
Groundwater Recharge	Groundwater Recharge	Groundwater aquifers are often replenished through wetlands, or vice versa. ²⁷ However, wetlands which overlie impermeable materials may have little or no interaction with local groundwater aquifers. ²⁸
Climate Regulation	Carbon Storage	Wetlands play a key role in the global carbon cycle by sequestering and releasing significant amounts of carbon. ²⁹ Carbon is also stored in wetland sediments and carried between ecosystems (i.e. from rivers to lakes) during water movement. ³⁰
	Evapo-transpiration	Wetlands equalize the local climate, primarily through moderation of rainfall and temperature. ³¹
Biodiversity	Plant & Wildlife species diversity	Protect native plant and wildlife species, provide habitat for natural reproduction, and protect genetic diversity by acting as gene banks.
Biological control	Pest management	Natural biological control of pest populations and diseases occurs due to predation by other species within wetland habitats. For example, young fish consume mosquito larvae, thereby controlling the population of mosquitoes. Only a healthy wetland ecosystem can support fish species, thus maintaining a healthy wetland ecosystem is essential to controlling mosquito populations.
Pollination	Maintaining pollinating invertebrate species	Wetlands are critical habitat areas for pollinating species of insects. Clean surface water is required for reproduction and early survival of invertebrate species. These invertebrates become important pollinators during their adult phase.

Table 4. Summary of option values of wetlands

Ecological Service	Range of services	Description
Future Use Value	Future Direct Use	As long as wetlands are preserved, they offer future uses for humans. Wetlands may be preserved to ensure that their services can be used in the future.
	Future Indirect Use	
Future Information Value	Future Education	Human knowledge of wetland values and characteristics is far from complete. By preserving wetlands, humans have the ability to continue learning about them and using them to teach others about their functions.

Table 5. Summary of existence values of wetlands

Ecological Service	Description
Biodiversity Protection	One third of Canada's Species At Risk rely on wetland habitat for survival. ³² In Ontario alone, almost 90% of endangered species rely on wetlands for feeding, reproduction or habitat. ³³ This service will become increasingly important in the future.
Cultural	Wetland ecosystems figure prominently in our natural heritage. Wetlands' life-sustaining services featured prominently in our ancestors' survival and continue to play a vital role in our society. Wetlands also provide spiritual benefits by offering a place of serenity and communion with nature.
Aesthetics	Canadian artists like Robert Bateman have depicted the aesthetic value of wetlands in numerous works of art. Indeed, entire Canadian art exhibits have been devoted to the inspirational beauty of wetlands.
Bequest value	Bequest value refers to the benefit humans derive from knowing that a wetland resource is available for future generations. ³⁴ Bequest values are similar to existence values, but are protected for future generations rather than peace of mind in the present.

Note that multiple wetland values often coexist. These values may be complimentary, and increase similarly with alterations to biophysical wetland components. For example, a wetland with high biodiversity protection value may have high recreation value (i.e. to birdwatchers). As wetland structural heterogeneity increases, both biodiversity protection value and recreation value may increase similarly.

However, some wetland values may have an inverse relationship. For example, a wetland which has high nutrient retention value may have low biodiversity protection value. By acting to improve the nutrient retention value of the wetland, it is possible that the biodiversity protection value may be negatively impacted.

For this reason, it is necessary to prioritize wetland values when developing a management strategy. CVC will need to identify the values on which they wish to focus their conservation and/or restoration efforts in order to ensure that high priority values are maintained or enhanced.

3. Biophysical Characteristics of Wetland Ecological Services

The Millennium Ecosystem Assessment (2005) states that hydrological regime (flow rate, volume, and water velocity) and topography (size, aspect and shape) are often the most important factors affecting provision of wetland services.³⁵ Physicochemical conditions make services of each type of wetland unique. Hydrological conditions influence numerous abiotic factors, including nutrient availability, soil anerobiosis and salinity in both coastal and inland wetlands.³⁶ These factors determine the types of ecological communities present in a given wetland. Ecological communities, in turn, influence wetland hydrology and physicochemical characteristics.

What is most clear is that past practices of land use, including wetland conversion to agriculture and urban use, has been the most pertinent action that has degraded the functioning of wetlands and subsequently the provision of wetland ecological services.

3.1 Biophysical Functions

To assess the factors that influence a wetland's ability to provide key ecological services, we conducted a review of biophysical studies focused on wetlands and environmental impacts. The literature review revealed six key biophysical wetland services which can be broadly categorized as follows: (i) waste treatment; (ii) biodiversity; (iii) climate regulation; (iv) flood control; (v) recreation benefits; and (vi) aesthetic benefits. The following describes each service in more detail.

3.1.1 Waste Treatment

Zedler (2003) states that conserving downstream wetlands, where water quality is diminished due to pollutant loading, can maximize treatment benefits and has been observed to reduce nitrate concentrations by up to 80%.³⁷

L.-A. Hansson et. al. (2005) found a positive relationship between wetland depth and phosphorus retention and a negative relationship between phosphorus retention and wetland surface area.³⁸ They postulated that this was likely due to re-suspension of phosphate-bound sediment particles by the action of wind in shallow wetlands with greater surface area.³⁹ They reported that wetlands designed to encourage phosphorus should be small and deep to promote particle sedimentation and that wetlands designed to encourage nitrogen retention should be constructed to have a larger surface area.⁴⁰ The researchers proposed that, in order to balance these opposing design features and provide nitrate- and phosphate-removal benefits, large wetlands should be designed to feature both deep and shallow areas. Incorporating

islands or gravel bars into wetland design can promote growth of emergent and riparian vegetation to reduce wind effects and flow speed.⁴¹

Moreno-Mateos *et. al.* (2008) indicated that the ability of wetlands to improve water quality is related to a variety of parameters including, but not limited to: Vegetation cover or type; depth; water retention time; soil type; particle size; and regional climate.⁴² They also determined that wetlands should occupy least 2.83% of agricultural catchments in order to maintain good water quality in areas with highly saline soils.⁴³ Specifically, wetlands characterized by dense vegetation and flat bottoms were favoured to promote denitrification.⁴⁴ Zedler (2003) reports that a wetland's capacity for denitrification is related to the amount of nitrogen in inflowing water, water flow rate, the amount of solid organic matter, residence time and the availability of plant surface area for proliferation of nitrogen-fixing bacteria.⁴⁵ The effect of dilution in large wetlands to increase water quality was also noted, as was the benefit of protecting several "scattered and numerous wetlands", as opposed to a few and large wetland complexes, in order to increase landscape complexity (patch density and heterogeneity). This was found to reduce the amount of total dissolved solids in surface water.⁴⁶ Zedler indicates that wetlands in agricultural watersheds with areas as little as 1% of the total watershed area can effectively remove nutrients.⁴⁷ Wetlands have been reported to remove approximately 77% of total nitrogen in surface inflows.⁴⁸

The spatial arrangement of pollution sources and sinks have a significant impact on the ability of wetlands to act as a pollution sink.⁴⁹ They report that the ability to mitigate the impacts of point and non-point source pollution including agricultural run-off, pesticides, fertilizers, oil, metals (e.g. copper, nickel, cadmium, zinc and lead) and polycyclic aromatic hydrocarbons is significantly reduced the sources cover a land area exceeding 65% of the watershed.⁵⁰

Further, in order for wetlands to have an impact on overall watershed hydrology, they must occupy at least 2%–7% of the total watershed area.⁵¹

3.1.2 Biodiversity

The term "biodiversity" encompasses three types of diversity: genetic diversity, species diversity and ecosystem diversity.⁵² Genetic diversity is the genetic variability between individuals of the same species. Species diversity refers to the number of different species within an area. Ecosystem diversity encompasses the variety of habitats, communities and ecological processes within an area.

Increased genetic diversity creates increased resilience of wildlife populations in the face of habitat changes or disease. For example, increased genetic diversity can be what enables some members of a wildlife population to survive an outbreak of disease, because some individuals are genetically resistant to its effects. Genetic variability can also reduce or mask the effects of harmful genetic mutations.

Increased species and ecosystem diversity lead to greater wildlife protection by ensuring that a greater number of species can make use of an area. For example, if only three plant species are present in a given wetland, then only wildlife species that can consume those three plant species will be able to make use of that wetland for food. If, on the other hand, 23 plant species are present in another wetland, then a greater number of wildlife species will be able to use the wetland because that wetland provides a more diverse food source.

Unfortunately, wetlands which effectively remove significant amounts of nutrients and sediments are not necessarily high-quality wildlife habitats because they are more likely to develop monocultures of hardy, nutrient-loving plant species such as cattails (*Typha* sp.).⁵³ Zedler (2003) reports that large wetlands are more valuable for preserving avian biodiversity than smaller wetlands, especially when they are located next to large tracts of upland habitat;

however, biodiversity may be equalled in small wetlands with significant structural diversity, canopy layering or productivity.⁵⁴ Conversely, smaller wetland areas may act as refugia for rare plant species.⁵⁵ Zedler refers to the Nature Conservancy's guideline that 15-25% of an area must be conserved in order to protect biodiversity.⁵⁶ Further, the following attributes characterize ecosystem functioning relative to wetland biodiversity:

- Habitat connectivity and structural diversity are significant factors required to enhance biodiversity.⁵⁷
- Periodic natural disturbance within a normal disturbance pattern due to events such as flooding is also required to maintain biodiversity.⁵⁸
- Fragments of natural habitats provide the best opportunity to stimulate biodiversity.⁵⁹
- Restored wetlands commonly fail in the areas of water balance, revegetation, wildlife rejection of habitat and introduction of invasive species, exacerbating vegetation damage.⁶⁰

Biophysical factors which impact species biodiversity vary with regional species composition and the type of species using the wetland. With respect to duck populations, wetland value is related to availability, depth, temperature, quality and presence of open water; presence or absence of vegetation; type and growth patterns (patchy vs. open) of vegetation; water chemistry; soil type; and geographic or topographic location.⁶¹ Colder surface waters may not be hospitable to some duck species, whereas warmer surface water may not permit growth of food for ducks. Presence of some duck species which use trees for food or nesting may be influenced by tree cover.⁶² Nutrient loading in wetlands often leads to increased algal bloom, decreased invertebrate populations, and subsequent decreases in duck populations.

3.1.3 Climate Regulation

Since uptake of carbon dioxide is required for plant growth, climate regulation is commonly estimated in terms of total biomass within a wetland. Carbon comprises roughly 50% of plant biomass. Therefore, carbon storage is proportionate to the amount of plant biomass, which can be calculated as the density of plant vegetation multiplied by wetland area and depth of accumulated decaying vegetation or peat.

Net Primary Production of wetlands, calculated as the amount of carbon stored in plant biomass, is estimated to be 1,300 g C/m² per year for North American wetlands.⁶³ As well, submergent, floating and emergent vegetation in freshwater marshes are estimated to sequester 1-1,000 g C/m², 10-2,067 g C/m² and 155-6,180 g C/m² per year for North American wetlands, respectively.⁶⁴ This vegetative matter shifts to the detrital and soil carbon pools as vegetation senesces and decomposes.

Table 6 outlines the Ontario Ministry of Natural Resources (2003) estimates of carbon storage in Ontario's wetlands.

Table 6 Estimates of carbon storage in Ontario's wetlands.⁶⁵

Wetland Class	Total Area (ha)	Stored Carbon (g C)	Carbon Storage per Unit Area (g C/ha) ¹
Bog	15,865 x 10 ³	17.6 x 10 ¹⁵	1.1 x 10 ⁹
Fen	9,961 x 10 ³	11.0 x 10 ¹⁵	1.8 x 10 ⁹
Swamp	307 x 10 ³	3.4 x 10 ¹⁵	57.3 x 10 ⁹
Marsh	209 x 10 ³	2.3 x 10 ¹⁵	84.2 x 10 ⁹
Open Water	178 x 10 ³	2.0 x 10 ¹⁵	98.9 x 10 ⁹

¹Calculation based on total carbon divided by total area per wetland class.

3.1.4 Flood Control

Credit Valley Conservation (2006) cites Governments of Canada and Ontario data which indicates that wetlands must occupy at least 10% of a watershed in order to provide flood protection.⁶⁶ Only 6% of the Credit Valley watershed is currently occupied by wetlands.⁶⁷

Zedler (2003) touts the benefits of small wetlands located high in a watershed to diminish flood volume and delay peak flows as well as the benefits of large wetlands located downstream for reducing total peak flow volume.⁶⁸ Flood mitigation also depends on each wetland's individual evapo-transpiration and infiltration rates and residence time.⁶⁹

3.1.5 Recreation Benefits

Recreational users of wetlands frequent these areas for a variety of reasons, of which fishing, hiking and birdwatching are common. Manuel (2003) reported that recreational benefits are commonly closely linked with the presence and characteristics of wetland wildlife.⁷⁰ Since fish and wildlife are involved in two of these uses, it stands to reason that biodiversity is a key factor influencing wetland recreational use. A wetland's recreational value is influenced by factors such as the condition of fish and wildlife habitat, water quality, abundance of fish populations, upland game hunting prospects, biodiversity, and perceived "wilderness"⁷¹. Recreational users must also be able to access the site, so infrastructure (e.g. roads) in the vicinity is a factor influencing recreational use.

3.1.6 Aesthetic Benefits

Aesthetic qualities (or viewsapes) can vary substantially from one individual to another. Wetland aesthetics are typically associated with residential landowners who may derive some benefit from viewing the wetland. Presence of open water, wetland shape and total wetland surface area are known to influence aesthetics. Manuel (2003) described a positive relationship between aesthetic value and factors such as openness, wildness, habitat diversity, and perceptions of oddness or mystery.⁷² Species diversity within wetlands is associated with aesthetic appeal; resale value of residential properties is correlated with plant and wildlife diversity.⁷³ The Wisconsin Department of Natural Resources (2008) recognizes wetlands

located within or near urban settings as being particularly valuable for the aesthetic and educational services. Open water, diverse vegetation, and lack of pollution also contribute to the value of specific wetlands for recreational and educational purposes and general quality of life.

3.1.7 Summary of Biophysical Functions of Wetlands

Table 7 provides a summary of the biophysical functions of wetlands.

Table 7. Summary of Biophysical Characteristics that Affect Wetland Ecological Services

Ecological service (ES)	Indicator of Service	Biophysical Factors that influence ES	Comments
Waste Treatment	NO ₃ ⁻ concentration in wetland outflow	<ul style="list-style-type: none"> • Organic matter content of wetland⁷⁴; • Continuity of wetland saturation⁷⁵ • Retention time⁷⁶ • Wetland area⁷⁷ • Shoreline complexity⁷⁸ • Inflow nitrogen concentration⁷⁹ • Hydraulic loading⁸⁰ • Wetland shape⁸¹ • Macrophyte cover and biodiversity⁸² • Plant surface area⁸³ 	<ul style="list-style-type: none"> • Continuous saturation is required for nitrogen attenuation • Large amounts of organic matter are needed for nitrate ions to bind • Longer retention time improves nitrate attenuation – water should be permitted to infiltrate soils • Wetland area has a positive relationship with nitrogen attenuation • Shoreline complexity has a negative relationship with nitrogen retention during summer • High macrophyte cover and biodiversity has been shown to improve nutrient attenuation⁸⁴ • Plant surface area is required for microbial growth and subsequent nutrient attenuation
	PO ₄ ⁻³ concentration in wetland outflow	<ul style="list-style-type: none"> • Rate of absorption to soil and organic matter⁸⁵ • Rate of uptake by macrophytes and microbes⁸⁶ • Species richness⁸⁷ • Dissolved oxygen⁸⁸ • Water temperature⁸⁹ • Wetland depth • Plant surface area⁹⁰ • Retention time⁹¹ 	<ul style="list-style-type: none"> • Increased amounts of organic matter provide more surface area for ions to sorb • Macrophytes and microbes remove phosphate ions from sorbed sites and metabolize them⁹² • Low dissolved oxygen and high temperatures have been linked to phosphate release from sediments⁹³ • Deeper wetlands have been shown to retain more phosphorus⁹⁴ • Plant surface area is required for microbial growth and subsequent nutrient attenuation • Longer retention time encourages greater precipitation of sediment- or particle-bound ions

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	Total <i>E.coli</i> (ppm)	<ul style="list-style-type: none"> • Infiltration⁹⁵ • Retention time⁹⁶ • Predation by microbes and macrophytes⁹⁷ • Wetland surface area⁹⁸ • Plant surface area 	<ul style="list-style-type: none"> • Longer retention time encourages greater precipitation of sediment- or particle-bound bacteria • Larger microbes or macrophytes consume bacteria • Increased surface area enables inactivation of bacteria by UV light • Greater plant surface area provides more opportunity for bacteria to sorb
Biodiversity	Native Species richness	<ul style="list-style-type: none"> • Shoreline complexity⁹⁹ • Wetland surface area¹⁰⁰ • Wetland maturity¹⁰¹ • Nutrient inflow¹⁰² • Proximity to roads¹⁰³ • Density of forest cover¹⁰⁴ • Diversity of plant cover¹⁰⁵ • Presence of open water¹⁰⁶ • Large, undeveloped tracts of land¹⁰⁷ 	<ul style="list-style-type: none"> • Shoreline complexity and surface area have a positive relationship with species richness • At least four years are required to reach maximum benthic species biodiversity; biodiversity of larger wildlife species takes longer to develop¹⁰⁸ • High nutrient concentrations in inflow have been shown to decrease biodiversity • Negative correlation between density of roads on adjacent lands and species richness • Strong positive correlation between forest density on adjacent lands and species richness
Climate Regulation	Total carbon stored (t C)	<ul style="list-style-type: none"> • Wetland area (ha) • Peat depth • Rate of growth of biomass 	<ul style="list-style-type: none"> • Amount of carbon stored is directly proportional to wetland area and peat depth¹⁰⁹ • Carbon storage is positively related to growth of plant biomass¹¹⁰
Flood control	Water storage capacity (m ³)	<ul style="list-style-type: none"> • Soil pore space • Soil organic material • Saturated water content • Natural water content 	<ul style="list-style-type: none"> • Water is stored in soil pores; more porous soil will store more water • Soil organic matter increases soil pore space • Flood mitigation potential is equal to the difference between saturated water content and

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		<ul style="list-style-type: none"> • Soil bulk density • Soil thickness • Wetland area • Water density • Return period 	<p>natural water content</p> <ul style="list-style-type: none"> • The equation relating these factors is available in Ming et. al. • Flood protection is more effective for floods with shorter return periods (i.e. 25 years)¹¹¹
Recreation benefits	Number of recreational visitors/year	<ul style="list-style-type: none"> • Continuity of wetland saturation¹¹² • Organic matter content of wetland¹¹³ • Retention time¹¹⁴ • Wetland area¹¹⁵ • Shoreline complexity¹¹⁶ • Inflow nitrogen concentration¹¹⁷ • Hydraulic loading¹¹⁸ • Wetland shape¹¹⁹ • Macrophyte cover and biodiversity¹²⁰ • Plant surface area¹²¹ 	<ul style="list-style-type: none"> • Recreational uses of wetlands include hiking, fishing, hunting and birdwatching • These recreational uses are strongly tied to biodiversity
Aesthetic benefits	Number of residential properties with wetland view	<ul style="list-style-type: none"> • Same as above (for recreation benefits). 	<ul style="list-style-type: none"> • Aesthetic value is generally captured through revealed preference approach (hedonic pricing and travel cost method) and stated preference (contingent valuation and choice modeling). • In either approach, most studies inherently assume that natural and man-made wetlands will factor positively in people's preferences

3.2 Linking Wetland Services and Human Activities

Severe anthropogenic disturbance of an aquatic ecosystem may lead to an abrupt and possibly very substantial disruption in the supply of one or more ecological services.¹²²

This break can be caused by a variety of human activities, including nutrient loading or land use conversion. A literature review of anthropogenic impacts on wetland function revealed that these impacts can be broadly categorized as follows:

- Pollution
- Land Use Change
- Climate Change
- Vegetation Composition

In this section the focus is on actions related to wetlands that currently exist. Further, what we are seeking to determine are the human actions that are currently influencing the provision of ecological services from intact wetlands.

3.2.1 Impacts of Pollution on Wetlands

Pollution is one of the leading factors that influence the ability of wetlands to perform ecosystem functions. Kennedy and Mayer (2002) cite that a critical threshold for phosphorus loading is 1 mg P/m² /year for North American wetlands.¹²³ Above this threshold, uptake and removal of nutrients by wetland plants is severely impeded. Excessive phosphorus loading is known to cause colonization of waterways by algae and other aquatic plants, leading to eutrophication, depleted dissolved oxygen and subsequent impairment of a variety of ecological services.

Moreno-Mateos *et. al.* stated that the spatial arrangement of pollution sources and sinks have a significant impact on the ability of wetlands to act as a pollution sink.¹²⁴ They report that the ability to mitigate the impacts of point and non-point source pollution including agricultural runoff, pesticides, fertilizers, oil, metals (e.g. copper, nickel, cadmium, zinc and lead) and polycyclic aromatic hydrocarbons is significantly reduced when the sources cover a land area exceeding 65% of the watershed.¹²⁵

3.2.2 Impacts of Land Use Change on Wetlands

Anthropogenic disturbance of the biophysical structures present in wetlands negatively impacts biophysical function. The magnitude of the impact is related to the extent and duration of the disturbance. For example, when a wetland is drained for agriculture, the damage is extensive and long-term. Wetland ecosystem functions are replaced by ecosystem functions of the new land use (e.g. agricultural).

Land clearing and resulting sedimentation can increase turbidity and biological oxygen demand and impede wetland function. Currently, the *Conservation Authorities Act* mandates a 120 m buffer around wetlands to prevent impact to ecological function; however, exemptions can be made for agricultural or other land uses.¹²⁶

The impacts of surrounding land-use conversion on wetland function are difficult to predict. Brauman *et. al.* (2007) reported that in general, impacts to hydrologic processes within watersheds are not measurable until at least 20% of land area has been altered; however, noticeable impacts have first appeared in watersheds with as little as 15% or as much as 50% conversion.¹²⁷ Brauman *et. al.* also suggest that in order for wetlands to have an impact on overall watershed hydrology, they must occupy at least 2%–7% of the total watershed area.¹²⁸

Kennedy & Mayer (2002) referenced a previous study which identified a negative correlation between the density of paved roads within 2 km of a wetland and species richness of all taxa except mammals.¹²⁹ Dams and other man-made developments can also impact wetland function by reducing inflows, reducing water volume and inhibiting periodic flooding.¹³⁰ Zedler (2003) postulates that when more than 80-90% of a watershed's natural wetlands have been drained, the risk of flooding and eutrophication of local water bodies increases significantly.¹³¹

3.2.3 Climate Change Impacts on Wetlands

Climate change will also impact wetland function by reducing the water table in dry areas, leading to increased carbon dioxide production, lower methane fluxes and lower dissolved oxygen fluxes.¹³² Methane is a much more potent and harmful greenhouse gas than carbon dioxide. Wetlands currently balance methane production with carbon dioxide storage to neutralize climate impacts.¹³³ This balance is likely to shift towards greater methane release and lower carbon dioxide storage as a result of climate change. Evidence of climate change has been consistently recorded at meteorological stations within the Credit Valley watershed over the past 30 years. Annual temperature increases have ranged from 0.03°C to 0.09°C.¹³⁴

Natural Resources Canada (2008) predicts the following impacts to ecosystems in Ontario's Great Lakes Region due to climate change:¹³⁵

- Introduction and proliferation of algae and invasive species due to warmer conditions;
- Impacts to commercial and recreational fisheries due to changes in water temperature (e.g., disappearance of cool- and cold-water fish species, such as lake trout); and
- Reduced water levels in Great Lakes coastal wetlands, leading to shoreline destabilization and reduction of biodiversity in historical migratory staging areas.

3.2.4 Vegetation Composition Impacts on Wetlands

Invasion of exotic species can alter ecosystem function when native wetland plants are replaced by invasive sedges, grasses or rushes.¹³⁶ One example is the introduction and subsequent proliferation of purple loosestrife (*Lythrum salicaria*) which displaces native wetland plants in Southern Ontario.

Unintentional introduction of exotic or invasive species by recreational users can also have significant negative impacts on wetland function. Seeds can be carried into a wetland area in mud stuck to shoes, bicycles or recreational vehicles. Once introduced, these species can take over native vegetation, creating monocultures or colonizing waterways.

Despite good intentions, wetland restoration efforts can also have negative impacts on wetland vegetation composition. Restored wetlands commonly fail in the areas of water balance, revegetation, wildlife rejection of habitat and introduction of invasive species, leading to further vegetation damage.¹³⁷

3.2.5 Summary of Human Impacts on Wetlands

Table 8 summarizes the human impacts on wetland ecological services.

Table 8. Impacts of human activities on ecological services in wetlands.^a

Ecological Service	Service Indicator	Action/Activity	Activity Indicator	Description
Waste Treatment/Water purification	Nitrate concentration (ppm)	Fertilizer runoff from adjacent land use	Rate of nitrate loading (ppm) from application of fertilizer in adjacent agriculture operations	Use of fertilizers for agriculture, domestic runoff and the runoff of feces from domestic sources and livestock operations can introduce excess levels of nitrates, phosphorous and choliforms (e.g. <i>E. coli</i>).
	Phosphorous concentration (ppm)	Fertilizer runoff from adjacent land use	Rate of phosphorus loading (ppm) from adjacent agriculture operations	
		Domestic runoff from use of soaps and fertilizers		
	Total choliforms (ppm)	Livestock waste runoff from adjacent land use	Rate of choliform loading from livestock waste (ppm) from adjacent agriculture operations.	
		Runoff of pet feces from domestic animals (e.g. dogs)		
	Heavy metals	Industrial spills or runoff from adjacent land use	Rate of metals loading from industrial sources	Runoff of heavy metals and PCBs from industrial sources can pollute waters and lead to bioaccumulation and wildlife mortality.
PCBs	Industrial spills or runoff from adjacent land use	Rate of PCB loading from industrial sources Rate of loading by fecal choliforms		
Flood control	Water storage (m ³ /ha)	Increase/decrease in wetland riparian buffer on adjacent land	Percentage wetland riparian buffer in riparian buffers	Converting forest cover to agriculture or developed land results in a decrease in water storage capacity and increase in velocity of surface runoff entering wetlands. This that can overwhelm the wetlands' ability to prevent flooding.
Biodiversity	Natural species richness (species/ha)	Climate change	Rate of extinction due to climate change (number of species)	As climate change occurs more rapidly than some species can adapt, those species will face extinction.

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			Pole-ward migration of species (km/decade). ¹³⁸	As soil temperatures become progressively warmer, plant range expansion (due to micro-site climatic variation) will result in traditional species being overtaken by southern neighbouring species.
		Increase/decrease in exotic/native species populations	Change in proportion of exotic plant species (for fibre or aesthetics).	Due to engineered or natural advantages, introduced out-compete some native species.
Climate Regulation	Carbon stored (tonnes/ha)	Increase/decrease in biomass of wetland vegetation	Percentage vegetation cover (by type) in wetland	Converting wetlands to other land uses will result in the release of soil and peat carbon due to decomposition of vegetation and reduced carbon sequestration in plant biomass.
Recreation benefits	Number of recreation visits per year	Facilities (treed trails, boardwalks, look-outs, swimming access, etc) that exist.	Km of trails created, # of look-outs built, budget for area maintenance and new facilities, etc.	Increasing the quality of the recreational resource (e.g. by adding new trails or improving existing ones) will lead to increased use of the resource
Aesthetic benefits	Number (and/or proximity) of residential properties with a view of the wetland.	Percentage of open water in the wetland	Increase wetland health and decrease colonization by weedy vegetation	The cost of residential properties will be greater near wetlands with a greater percentage of open water

^a Some human activities can affect more than one service. For instance, wetland riparian buffer changes will affect not only flooding services, but also biodiversity, waste treatment, etc. Also the size of the wetland (i.e., loss or creation) will affect this bundle of services as well. In this respect, some actions directed toward positively enhancing wetland services could be undertaken to enhance not just one, but many services, resulting in a bundling effect.

4. Wetland Valuation

4.1 Wetland valuation methods

There are a large number of methods that can be used to value ecological services. Seven of these have been typically used by researchers in the context of valuing wetlands, and include: (i) the production function method; (ii) expenditure-based methods; (iii) the travel cost method; (iv) the hedonic price method; (v) the contingent valuation method; (vi) the choice experiment method; and (vii) the benefits transfer method. Table 9 provides an overview of these methods.

Table 9. Selected valuation methods used to estimate the benefits of wetlands

Valuation Method	Description	Ecosystem Service Values Considered
Production function method (PFM)	Wetlands are treated as inputs into the production of services. Changes in wetland characteristics affect productivity, and impact the value of these services	Direct-use and indirect-use: fisheries, ground water recharge
Expenditure-based methods (EBM)	Wetlands are treated as a provider of ecosystem services that can be maintained, replaced, or substituted-for through increased expenditures.	Direct and indirect-use: waste treatment, nutrient retention, water retention, groundwater recharge, erosion control, climate regulation
Hedonic Price Method (HPM)	Wetlands are treated as a factor influencing the characteristics of residential properties to infer a WTP for the property.	Direct and indirect-use: aesthetics; flood control, ground water recharge
Travel cost method (TCM)	Wetlands are treated as a factor influencing the number of trips made by recreationists to particular sites and the costs of those trips to infer a WTP for the site.	Direct-use: Recreation services like hunting/fishing, bird watching, hiking
Contingent valuation method (CVM)	Wetlands are treated as a commodity in a hypothetical market and households are directly asked how much they are willing to pay for an improvement in the commodity.	Direct, indirect, and non-use: Aggregate value of bundled services (focus on non-use)
Choice experiment method (CE)	Wetlands are treated as having a number of environmental attributes and households are directly asked to make choices among alternative hypothetical projects having different improvements in attribute levels.	Direct, indirect, and non-use: Individual value for each service (focus on non-use)
Benefits transfer method (BT)	Wetlands are assumed to have similar values across sites, and benefit estimates from one or more previous study sites are transferred to the policy site of interest. Benefits can be based on individual value, average value, or function (meta-analysis) transfers.	Direct, indirect, and non-use: Individual value for each service

As shown in Table 9, a number of non-market valuation methods tend to focus on direct and indirect-use values (i.e., PFM, EBM, HPM, TCM). Of these methods, some focus further on particular user-groups (i.e., HPM focuses on residential landowner values, and TCM focuses on recreationist values). Other methods (i.e., CVM, CE, BT) tend to assess a wider array of values.

4.2 Data requirements, advantages and disadvantages of non-market valuation methods

Each non-market valuation method has a unique set of data collection and statistical analysis requirements. These are summarized in Table 10, along with some advantages and disadvantages associated with each method.

As shown in Table 10, all methods require the collection of both biophysical and economic data. The level or degree to which the biophysical data must be refined, however, ranges between and even within methods. For example, while the EBM typically requires researchers to define quantitative wetland indicators (e.g., nitrate absorption (ppm)) to establish the absorption required by a restored or substitute process, the CVM and CE methods allows researchers to define wetland indicators either quantitatively (e.g., nitrate absorption (ppm)) or qualitatively (e.g., low, medium, or high water quality) to help develop a hypothetical wetland improvement program. Obviously, the more precise the indicator measures are, the easier it is to: (i) establish the specific manner in which wetland improvements can be facilitated on the ground; and (ii) compare the benefits of the improvements with the costs of specific improvement projects.

With regard to economic data collection, Table 10 reveals that a number of non-market valuation methods use market prices to help elicit a value for wetlands (i.e., PFM, EBM, HPM), and as such tend to be less controversial than other methods that do not. However, as mentioned previously, these methods do not capture the full benefits of wetlands since they do not account for all the values and/or groups in society. This would tend to cause a downward bias in the valuation procedures. On the other hand, for the EBM in particular, the approach may not even incorporate social values if valuation is based on the cost of replacement or substitution, and may tend to cause an upward bias in that valuation procedure.

Those methods that do attempt to capture the full social benefits of wetlands (i.e., CVM, CE, BT) are often the ones that do not use market prices, specifically because they incorporate non-use values for which there are no market prices to refer to.

Table 10. Data requirements, advantages, and disadvantages of non-market valuation methods

Valuation Method	Data requirements and statistical analysis	Advantages/Disadvantages
Production function method (PFM)	<ul style="list-style-type: none"> • Collect data on biophysical characteristics (including wetland characteristics such as nutrient retention, groundwater recharge) affecting the production of an ecological good/service that has a price in the market. • Use regression analysis to estimate how a change in a wetland characteristic affects the productivity of the good/service. • Estimate the total value of the change in the good/service using market prices. 	<ul style="list-style-type: none"> • The use of market prices makes this method less controversial than others. • Focuses only on one direct or indirect value service at a time (not total benefit). • Difficult to establish a quantitative link between wetlands and productivity.
Expenditure-based methods (EBM)	<ul style="list-style-type: none"> • Collect data on the ecological services provided by a wetland (e.g., waste treatment, nutrient retention, flood control). • Estimate the market expenditures required to: (i) maintain services in existing wetland (i.e., avoided damage cost method); (ii) replace/restore degraded services in existing wetland (i.e., replacement cost method), or (iii) substitute-for the lost services using the next best alternative process (i.e., substitute cost method). • Use the increased expenditures as an approximate value of the wetland. 	<ul style="list-style-type: none"> • The use of market prices makes this method less controversial than others. • Focuses only on one direct or indirect value service at a time (not total benefit). • Does not estimate a true measure of social benefit since we cannot tell if the increased expenditure is more or less than the social value of the service.
Hedonic Price Method (HPM)	<ul style="list-style-type: none"> • Collect data on residential property sale prices along with structural, neighborhood, and wetland characteristics (e.g., proximity to site, water filtration, flood control) adjacent to each property. • Use regression analysis to estimate how a change in a characteristic affects sale price of a property. • Aggregate to all properties affected to estimate the change in total aesthetic benefits from a change in the wetland characteristic. 	<ul style="list-style-type: none"> • The use of market prices makes this method less controversial than others. • Focuses only on property owner benefits from the site (not total benefit). • Data for property price and structural/neighborhood characteristics may not be available.
Travel cost method (TCM)	<ul style="list-style-type: none"> • Survey visitors to two or more wetland sites, asking them about their region of origin, mode of transportation, duration of stay, etc. • Collect data on biophysical characteristics of each wetland (e.g. water filtration, nutrient retention, public access, boardwalks). • Use regression analysis to estimate how a change in travel costs affects the number of visits to each site (i.e., establish a demand curve for each site). • Then estimate how a change in a wetland characteristic affects that demand curve for a particular policy site and the total recreation benefits generated. 	<ul style="list-style-type: none"> • Data collection via surveying visitors may be subject to bias. • Focuses only on recreationist benefits from the site (not total benefit).

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<p>Contingent valuation method (CVM)</p>	<ul style="list-style-type: none"> • Select a number of important wetland characteristics to value (e.g., waste treatment, flood control, biodiversity, aesthetics), quantify or qualify existing levels, and design a hypothetical program that would improve these characteristics to specific levels. • Survey households and ask them to state their maximum WTP for the program. • Use regression analysis to examine the data for potential bias (protest responses, etc), and estimate an average household willingness-to-pay value for the bundled services from the sample. • Apply the average value to the population affected to estimate total benefits of wetland improvement. 	<ul style="list-style-type: none"> • Data collection may suffer from hypothetical bias, etc. • One of the few valuation techniques that can estimate non-use values (as part of a total value of a bundled set of services).
<p>Choice experiment method (CE)</p>	<ul style="list-style-type: none"> • Select a number of important wetland attributes to value (e.g., nutrient retention, flood control, biodiversity, aesthetics), quantify or qualify existing levels, and assign each two or more improvement levels. • Design a set of programs with unique levels of wetland attributes and costs to implement. Then use a survey to ask households to choose between programs in a repeated pair-wise fashion. • Use regression analysis to examine the data for construct validity (i.e., potential bias from protest responses, etc), and estimate an average household willingness-to-pay value for each attribute and level from the sample. • Apply the average value for each attribute to the population affected to estimate total benefit of the specific improvement in each attribute. 	<ul style="list-style-type: none"> • Data collection may suffer from hypothetical bias, etc. • One of the few valuation techniques that can estimate non-use values. • Has two advantages over CVM: (i) can estimate individual ecosystem service values; and (ii) respondents are given choices (i.e., choose a program with a cost) that better reflect decision-making in the real world.
<p>Benefits transfer method (BT)</p>	<ul style="list-style-type: none"> • Individual value transfers: the WTP value for a policy site is approximated using a value produced in previous study for another study site. • Average value transfers: the WTP value for a policy site is approximated using a group average value of previous studies for other study sites. • Benefit function (meta-analysis) transfers: the WTP value for a policy site is approximated by using a large number of previous study sites along with regression analysis to establish the factors that affect the WTP value (via a function), and then applying the characteristics of the policy site into the function. 	<ul style="list-style-type: none"> • Wetlands tend to have site-specific characteristics that differ significantly from one site to the next. The literature indicates that often a large transfer bias emerges when using this method.¹³⁹ • Primary valuation (site-specific) studies are preferred over this method.

4.3 Non-market valuation studies and range of wetland value estimates

There have been well over 200 published, primary wetland valuation studies conducted over the past 30 years. These studies have produced a wide array of values, depending largely on the location, estimation method, ecosystem services considered, and unit of value assessed. Table 11 provides a selection of these studies and their findings. A list of references for the studies included in this table can be found in Appendix A.

Table 11. Selected non-market valuation studies and range of wetland ecosystem service values

Valuation Method	Studies ^a	Ecosystem services considered	Range of Estimated Values
Production function method (PFM)	Bell (1997); Freeman (1991)	Fisheries	\$0.10 to \$135.44 (1969-93 \$US) per hectare per year
Expenditure-based methods (EBM)	Kazmierczak (2001); Chichilnisky and Heal (1998)	Water filtration (substitute cost method)	\$1.15 to \$1,087.67 (1996-01 \$US) per hectare per year
	Breaux et al. (1995)	Wastewater treatment (replacement cost method)	\$2,522 to \$3,899 (1992 \$US) per hectare per year
	King and Bohlen (1994)	Bundled services (replacement cost method)	\$4,000 to \$124,000 (1997 \$US) per acre
Hedonic Price Method (HPM)	Lupi et al (1991); Mahan et al. (2000)	Aesthetics, flood control, ground water recharge	\$19 (1989 \$US) to \$24 (1994 \$US) per hectare per year
Travel cost method (TCM)	van Vuuren and Roy (1993)	Hunting and fishing	\$271 to \$2,952 (1989 \$CDN) per hectare per year
	Cooper and Loomis (1991)	Waterfowl hunting	\$55.41 (1989 \$US) per hunter per season.
Contingent valuation method (CVM)	Hammit et al. (2001)	Wetland preservation	\$21 to \$65 (1993 \$US) per person per year
	Pate and Loomis (1997)	Salmon fishing and water quality	\$27.52 to \$87 (1989 \$US) per hectare per year
Choice experiment method (CE)	Birol et al. (2006)	Biodiversity	€ 7.7 to €15.62 (2006) per person per year
		Open water surface area	€ 8.45 to €11.02 (2006) per person per year
		Research & education	€ 3.9 to €10.79 (2006) per person per year
		Re-training of locals	€ 0.12 to € 0.15 (2006) per person per year
	Carlsson et. al. (2003)	Biodiversity	\$504.58-\$673.72 (2002 \$SEK) per person
		Habitat for fish	\$348.48 (2002 \$SEK) per person
Provide walking tracks and information signs		\$648.06 (2002 \$SEK) per person	

^a See the Appendix for the list of references in this table.

A number of researchers have surveyed the literature on non-market valuation estimates of wetland ecological services.^{140,141,142,143,144} Of these, Brander et al. (2006) provides the most in-depth and recent survey, covering over 190 non-market and market wetland valuation studies (with 215 value observations) around the world. Approximately one half of the studies covered were conducted in North America (111 observations), over one half were for fresh water marshes (124 observations), and just over one half used production function/market price methods (110 observations). Table 12 provides a summary of the average wetland ecosystem service value estimates reported.

Table 12. Average ecosystem service value estimates (converted to 1995 \$US per hectare per year), as reported by Brander et al. (2006)^a

Ecosystem service	# of value observations	Median value	Mean value
Wildlife habitat	67	\$85	\$3,000
Recreational hunting	50	\$70	\$2,500
Amenity	48	\$65	\$8,500
Recreational fishing	36	\$55	\$3,500
Raw Materials	32	\$50	\$450
Water quality	25	\$45	\$8,500
Flood protection	26	\$40	\$5,500
Water supply	18	\$30	\$2,000
Fuelwood	18	\$30	\$80
Biodiversity	13	\$20	\$11,500

^a Estimates are rounded (to the nearest \$5 for median values, and the nearest \$10/\$50/\$100 for mean values depending on the unit of measure) since actual estimates reported by Brander et al. (2006) were presented only in a graphical format (i.e., a bar chart).

Table 12 reveals a large variance between median and mean value estimates, indicating that the distribution of values is skewed with a long tail of higher-end values. Brander et al. (2006) emphasize the mean and median values of wetland ecosystem values vary considerably by continent, wetland type, and valuation method used. For instance, average wetland values are highest: (i) in Europe and North America; (ii) in unvegetated sediment and fresh water wetlands; and (iii) using the CVM, HPM, and EBM (specifically replacement cost) methods.¹⁴⁵ Also of importance were the socio-economic characteristics of the population surrounding the wetlands under consideration. Specifically, there was: (i) a positive relationship found between per capita income of the relevant population and the estimated wetland value per hectare per year; and (ii) a positive relationship found between population density and the estimated wetland value per hectare per year. Finally, the size of the wetland was found to be negatively related to the value per hectare per year, indicating a perceived scarcity premium with smaller wetlands.

Overall, Brander et al. (2006) urges caution in using the results of previous literature for benefits transfer, particularly in the case where policy site characteristics are not well represented in the underlying valuation studies.

4.4 Questions to consider when choosing among valuation methods

As discussed previously, wetlands provide a wide range of ecosystem service benefits to society. Economists have developed a wide range of methods that can be used to quantify these benefits in monetary terms. Each method has its distinct advantages and disadvantages. The applicability of each method depends on a number of factors:

1. What is the desired wetland service(s) to be valued?
 - a. An individual service?
 - b. A series of key individual services?
 - c. A bundle of services?
2. What is the desired type of value to be considered?
 - a. A direct-use value?
 - b. An indirect-use value?
 - c. A non-use value?
 - d. Some grouping of values?
3. What data is available (or can be collected given budget constraints)?
 - a. Biophysical data? What are the current levels of ecosystem service indicators (quantitative or qualitative measures)? How are indicators expected to change in the future (current trends)?
 - b. Economic data? What is known about the value of services produced? Any services (or products) traded in the market?
4. What are the policy scenarios (human actions/activities) under consideration?
 - a. Are there specific actions/activities defined? If so, what are the expected impacts of the actions/activities on the ecological services considered?

Once the above questions have been answered, it will narrow down the choice of valuation method that best applies to the case at hand.

5. Research Plan for Phase 2

After extensive discussions with CVC research team members, the research objectives, priorities, baseline data availability, and the policy scenario for Phase 2 were elicited. Based on this information, two applied research approaches are outlined. One of these approaches will be selected in consultation with the project management committee to proceed. The following summarizes the components of the research plan.

5.1 Research objectives:

The general objectives of the CVC Wetland Valuation Project are to:

1. Provide primary valuation data from the Credit River Watershed and demonstrate how valuation information can and should be used in decision-making (i.e. to education and build awareness on the use of environmental valuation).
2. Provide insight into benefits associated with CVC's wetland restoration strategy in such a way that the valuation can aid decision making in regards to carrying out the restoration strategy.

Concerning Objective 1, it is important to emphasize that economic valuation is ultimately concerned with the allocation of resources to improve human welfare. With this in mind, the contexts in which the valuation of wetland services can provide useful or necessary information are:

- Informing policy decisions in which trade-offs are being considered between competing alternatives (e.g., considering a policy that involves choosing the provision of one ecosystem service, such as biodiversity, over another, such as agricultural output)
- Providing damage estimates as a result of pollution or other negative environmental impacts

It was agreed upon that the first context above (i.e., informing policy decisions in which trade-offs are being considered) was most relevant to the current research project, since, as identified in Objective 2, the CVC is most interested in valuing services associated with their wetland restoration strategy.

5.2 Priority wetland services to be valued:

The top priority wetland services to be valued include: (i) water quality improvements (e.g., phosphorous, nitrogen, choliform, heavy metals, and PCBs); (ii) flood control improvement (e.g., water storage); (iii) biodiversity improvements (e.g., flora, fauna); (iv) recreational improvements (e.g., recreational fishing, bird watching, hiking) and (v) carbon sequestration. These services can be valued as a bundle. However, it is important to also consider the feasibility of identifying individual values for each.

5.3 Baseline data availability:

In terms of bio-physical data collected to-date, CVC has been monitoring wetland conditions in the watershed since 2005 as part of their integrated watershed monitoring program. The data collected for the wetland component of this program is designed to answer the question "Is the health of wetlands deteriorating in the Credit Watershed?" and "Have trends in wetland health indicators changed beyond normal variation (from baseline conditions) to signal a decline in ecosystem health?" In order to answer these questions, four wetland indicators are measured on a regular basis at 19 monitoring plots throughout the watershed, including:

- Woody vegetation: species present (tree, shrub, woody vine), and percent cover
- Ground vegetation: species present (forb, grass, sedge, rush, fern, herbaceous vine), and percent cover
- Floristic quality: Floristic Quality Index (FQI) based on data from woody and ground vegetation, and Mean Wetness Index
- Amphibians (frogs and toads): frog Species, and call level code

The data collected to date is still being processed but as an example, the top 5 most common regenerating species for **all** wetland sites for 2008 were:

Red-osier Dogwood	67
Speckled Alder	21
American Elm	15
Chokecherry	14
Common Buckthorn	14
Narrow-leaved Meadow-sweet	14
Wild Black Currant	14

In addition to these community and species scale indicators, the following landscape scale indicators are also measured:

5.3.1 Wetland land cover area

Wetlands comprise 6% of the total land cover in the Credit River Watershed, which is below Environment Canada guidelines recommending greater than 10% of a watershed be wetland habitat. The vast majority of wetlands are swamps, representing 81% of all wetlands, 18% are marshes and the remaining 1% are bogs. The upper and middle portions of the watershed contain similar wetland covers of 9% and 8% respectively; the lower watershed has the least wetland cover at 1% of regional area. The wetlands of the watershed, specifically in the upper and middle portions, exist primarily as wetland complexes².

² Wetland complexes are a group of wetlands that function as a unit in both biological and hydrological processes; impacts on individual wetlands affect the entire complex (Ontario Wetland Evaluation System 1993).

Table 13. Wetland type and area within the Credit River Watershed

Wetland Type		Existing Area (in ha)
Bogs		4
Swamps		
	Shrub Swamps	827
	Coniferous Swamps	1,774
	Deciduous Swamps	1,352
	Mixed Swamps	878
Marshes		1,061
Total		5,896

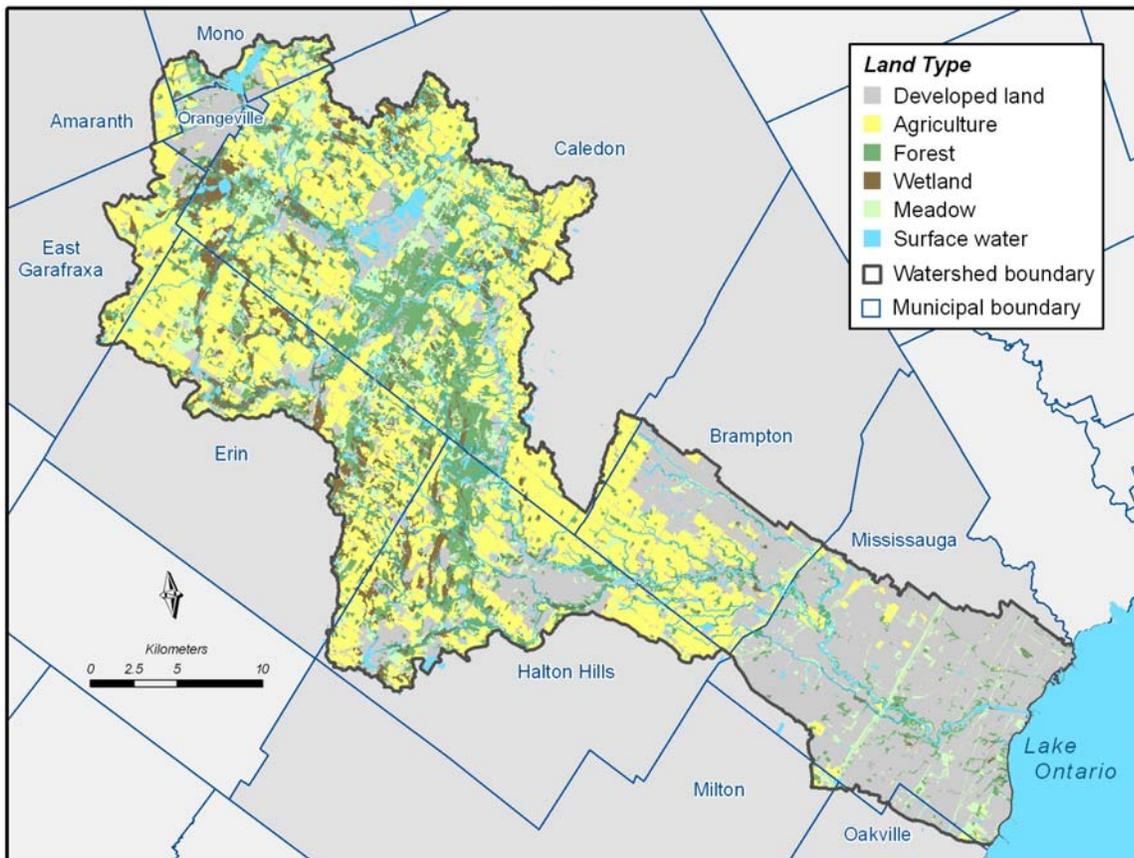


Figure 3. Land use types within the Credit River Watershed.

5.3.2 Size and distribution

Wetlands in the watershed tend to be small and overall there is a lack of relatively larger wetlands. Of the 1075 wetlands, the majority are less than 4 ha in size, with the mean and median size being 5 ha and 1.4 ha, respectively. Only one wetland in the watershed is greater than 200 ha.

5.3.3 Distance between habitats

Wetland to wetland

On average a wetland is 134 m away from the next nearest wetland, with half the wetlands less than 50m apart and a maximum distance of 4km between wetlands. Wetlands lands in the upper watershed were in closer proximity to each other wetlands in the middle and lower watershed.

The mean distance between wetlands in combination with observed spatial distribution reveals that wetlands are also spatially clustered in localized areas in the Credit watershed. This clustering is primarily due of physiography of the landscape (eg: moraines or melt water channels) forming large provincially significant wetland complexes that are protected from development.

Wetland to forest

Forests are on average 314m away from wetlands in the watershed, with half of the wetlands less than 22m away from a forest and a maximum distance of 4.2km between a forest and wetland. Forest wetland proximity is critical to wildlife species that require both habitats for different parts of their life cycle.

Wetland to successional

Wetlands are on average 43m from Successional communities, with half of the wetlands adjacent to Successional communities, and a maximum distance of 920m between a wetland and Successional community.

5.3.4 Land cover surrounding wetlands

As shown in Figure 4, within a 2km radius, wetlands are primarily adjacent to agriculture (39%), followed by Successional communities (20%).

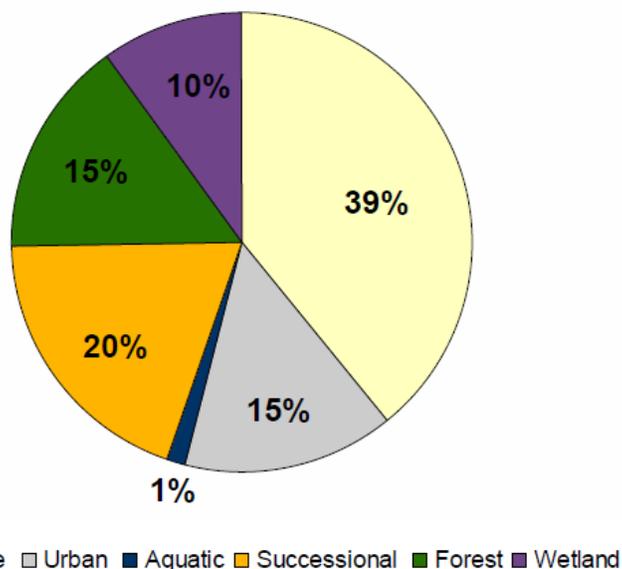


Figure 4. Land cover surrounding wetlands in the Credit watershed

These results suggest the majority of wetlands are not situated within natural landscapes and are adjacent to land-uses which generally impose negative edge effects or barriers. However, forests and agricultural land can offer ecological functions for wildlife movement. Wetlands were surrounded by less urban development than forests, primarily because in highly urbanized areas, such as the lower watershed, there are very few wetlands remaining. Agriculture and successional communities were the dominant land cover surrounding wetlands.

5.3.5 Existing Data Relating to Wetland Ecosystem Services

Generally speaking CVC collects extensive amounts of biophysical data for various purposes. Making use of this data for the purposes of valuing wetland restoration will be difficult and likely limited to helping describe the current state of biophysical conditions of watershed. Making concrete links between the existence of wetlands and provision of ecological services will not be possible without extensive monitoring designed to specifically measure such linkages. However, existing information was briefly surveyed within the context of a key ecological wetland services.

- Flood protection
 - o CVC has identified 22 flood damage centres throughout the watershed
 - o Existing hydrologic modelling has forecasted that peak flow rates at the damage centres would increase under anticipated future land use conditions
 - o Correlating changes in wetland area (resulting from wetland restoration) would require further hydrologic modelling.
 - o Monetary damages for each flood damage centre have been assessed by flood return period based on flood depth – damage cost curves
- Provision of biodiversity
 - o Measures of wetland biodiversity do exist, as mentioned above. The measures are designed to answer the following questions:
 - Is the species richness of native woody plants in wetlands changing?
 - Is the species richness of exotic woody plants in wetlands changing?
 - Is the species richness of native ground vegetation in wetlands changing?
 - Is the species richness of exotic ground vegetation in wetlands changing?
 - Is the proportion of sites occupied by each from species changing?

- These measures provide an indication of changes in wetland biodiversity at the specific wetland plots
- Improved water quality
 - Biophysical data collected (not specific to wetlands) include phosphorous, nitrogen, choliform, heavy metals, PCBs, and water storage.
 - Making statistical links between this data and the quantity of wetlands across subwatershed is being considered. However, such information will not be available until well into 2010.
- Recreation
 - There has been little socio-economic data collected by CVC to monitor public use of the watershed/wetlands for recreational fishing, bird watching, hiking, etc.
 - Rough estimates of recreational fishing exist for the watershed as a whole (an estimated 30,154 angler days per year). Data of wetlands specific usage does not exist.

5.4 The policy scenario to consider:

In 2005, together with Toronto and Region Conservation, CVC commissioned Gartner Lee Limited (GLL) to identify potential areas suitable for wetland restoration throughout their combined jurisdiction (CVC and TRCA): "Identification of Sites for Wetland Creation in the TRCA and CVCA" The areas were identified using conceptual and spatial modelling and analysis using geographic information system software. The models considered existing land use, topography, surficial geology, elevation of the water table, and proximity to existing drainage features. This exercise identified 244 potential restoration areas covering a total of 1733 ha of land (or about 1% of the watershed). If all areas were restored this would represent a 30% increase over existing wetlands. The largest area identified was nearly 230 ha in size and spans numerous land parcels each with a different land owner. Coordinating this scale of wetland restoration across multiple properties highlights just some of the difficulties in implementation.

The study by GLL was conducted at a landscape scale predicated by the scale of data available for use in the model. The purpose of the study was not to specifically identify wetland restoration sites but to examine landscape level opportunities from which CVC could drill down and identify specific achievable opportunities. Given, the scale of the data used in the modeling and is known of the types of wetland communities that likely existed in the watershed, some of the area within the polygons identified are not likely suitable for wetland recreation or restoration projects.

CVC is currently working with Dougan & Associates, Snell & Cecile Environmental Research and Phillips Engineering Ltd to move forward with the GLL study and develop a CVC Wetland Restoration Strategy. The strategy is beginning with a GIS analysis of areas where wetlands could feasibly be recreated/restored and potential opportunities to protect existing wetlands from the anticipated effects of climate change. This analysis will incorporate the GLL identified areas but will also include other areas.

Preliminary draft results of the GIS analysis of the CVC Wetland Restoration Strategy identifies 3,763 ha or 4% of the watershed as potential wetland restoration areas. As with the Gartner Lee Limited study further investigations are required to verify these opportunities at the site level. It is anticipated that site level investigations will be completed over the course of several field seasons; dictated by priorities for resource allocation and data availability.

Another issue pertains to policy implementation. While we can target priority areas for wetland restoration based on hydrologic and ecological suitability, if those areas exist on private property it can be very difficult to restore wetlands without a willing land owner. In the Credit River Watershed the vast majority of land is privately owned, making this a significant barrier to restoring wetlands. Assessing the compensation that landowners would demand for implementing this policy, as discussed later, could comprise a Phase 3 of this research project.

5.5 Applied research approaches to consider:

The above information provides a foundation for helping to target a select few applied research approaches that could be used to achieve the objectives set out in Section 5.1. The most important point to emphasize up-front is that the CVC would like to value a number of ecological services (possibly as a bundle), including direct-use (recreation), indirect-use (water quality, flood control), and non-use (biodiversity) components. The best approach to use to value all these services collectively is a stated preference (i.e., contingent valuation or choice experiment) method. Other methods are designed to capture the value of very specific services (see Table 10). Given the desire to value a range of services (including non-use values), the stated preference methods provide the best approach.

Appendix

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