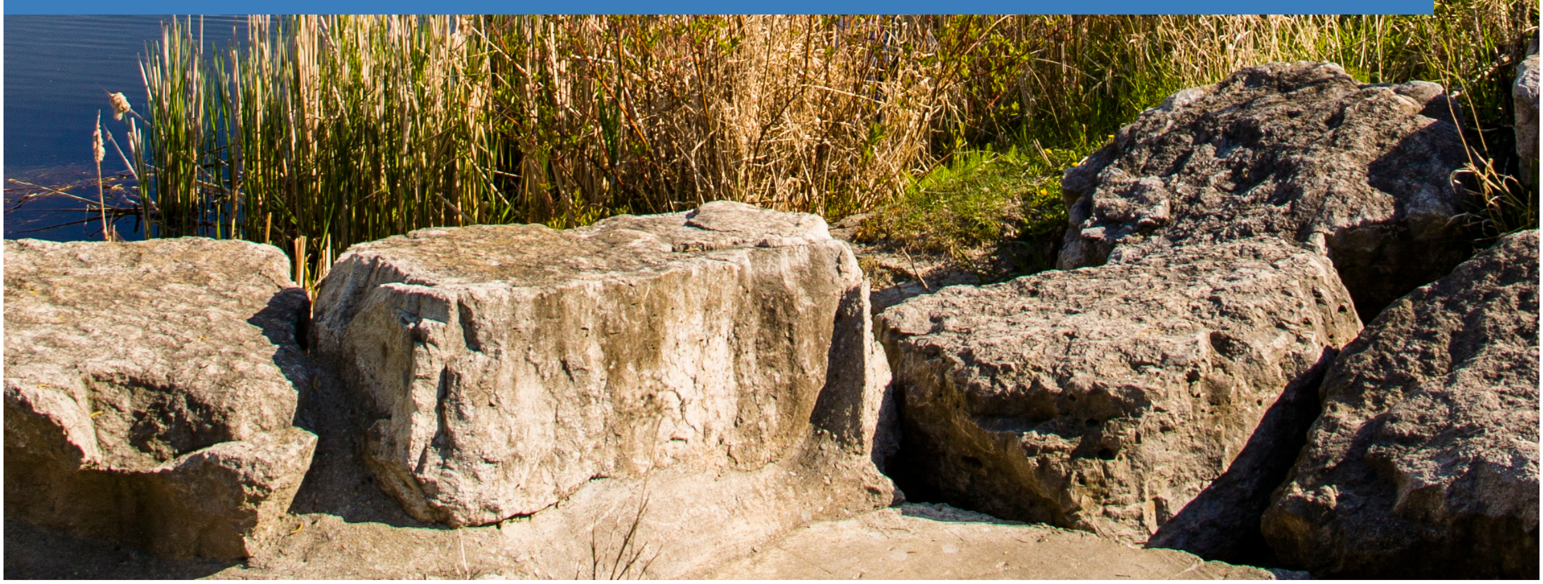
CREDIT VALLEY CONSERVATION

Municipal Natural Assets Initiative: Region of Peel Pilot



EPA-SWMM Modeling report

MNAI

Making Nature Count

Acknowledgements

The report was written for the pilot project under the Municipal Natural Assets Initiative. MNAI is aimed at changing the way municipalities deliver everyday services, increasing the quality and resilience of infrastructure at lower costs and reduced risk. The MNAI team provides scientific, economic and municipal expertise to support and guide local governments in identifying, valuing and accounting for natural assets in their financial planning and asset management programs and developing leading-edge, sustainable and climate resilient infrastructure.

Lead authors:

The report was written by the following CVC staff: Sakshi Saini, Amanjot Singh, Tatiana Koveshnikova and Kamal Paudel

Lead contributors and reviewers:

MNAI technical team: Michelle Molnar, Jake Sahl, Mike Thompson, and Joal Borggard

Region of Peel: Mark Head, Andrew Farr, Nadeem Dean, Learie Miller, Arvin Prasad, Dereck Lau

City of Mississauga: Greg Frew

Town of Caledon: Katelyn McFadyen and Rija Rasul

CVC staff: Gayle SooChan, Tim Mereu, Mike Puddister, Scott Sampson, Aviva Patel, Yvette Roy, Christine Zimmer, John Sinnige and Lorna Murison

Other reviewers:

MNAI: Roy Brooke, Sara Jane O'Neill

DSF: Theresa Beer

Convening organizations

Smart Prosperity Institute

David Suzuki Foundation

Town of Gibsons, BC
Roy Brooke and Associates

Acknowledgement of funders and supporters

Green Belt Foundation; The Salamander Foundation; Vancity; Tides Canada; Sitka Foundation; Real Estate Foundation of BC; Province of British Columbia through the Ministry of Community, Sport and Cultural Development

Regional and municipal partners: Region of Peel, City of Brampton, City of Mississauga, Town of Caledon and Toronto and Region Conservation Authority

ISBN DIGITAL 978-1-988424-16-3

Table of Contents

List of Tables

List of Figures

Appendices: Tables and Figures

Acronyms

BC	British Columbia
BMP	Best management practices
CAD	Canadian
CPR	Canadian Pacific Railway
CVC	Credit Valley Conservation
DEM	Digital elevation model
EMC	Event mean concentration
ELC	Ecological land classification
EPA-SWMM	Environmental Protection Agency Stormwater Management Model
ESRI	Environmental Systems Research Institute
GIS	Geographic Information Systems
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HRU	Hydrologic Response Unit
IDF	Intensity-duration-frequency
LID	Low impact development
MNAI	Municipal Natural Assets Initiative
MNRF	Ministry of Natural Resources and Forestry
MOECC	Ministry of the Environment and Climate Change
MSC	Meteorological Service of Canada
MTO	Ontario Ministry of Transportation
OWES	Ontario wetland evaluation system
SSD	Stage-storage-discharge
STEP	Sustainable Technologies Evaluation Program
TP	Total phosphorus
TSS	Total suspended solids

Executive Summary

Natural assets, such as forests, wetlands, and other green space, provide a range of services, often referred to as ecosystem services, upon which our society and economy depends. A well-managed natural asset will continue to produce a sustainable flow of goods and services, such as protection from floods and waste assimilation. Some of these services can be thought of as providing a "civic function": for example, a forest protecting source water, or a wetland helping to reduce downstream flooding and stress on municipal infrastructure.

Natural assets are under stress from population growth, development and climate change impacts. In order to protect these assets, it would be beneficial to account for them and manage them under existing municipal frameworks, strategies and policies, such as asset management and stormwater management plans and Official Plan policies. This requires valuation of natural assets for municipal services like stormwater management, drinking water provision, etc. In 2017, a pilot study was initiated by the Credit Valley Conservation for the Region of Peel to test a model to assess stormwater services provided by natural assets in Peel's jurisdiction. The study conducted a preliminary assessment of stormwater performance of the following types of natural assets: palustrine wetlands, isolated wetlands, riverine wetlands, forests, and open green spaces in two subwatersheds in the Regional Municipality of Peel's jurisdiction – Fletcher's Creek subwatershed and East Credit River subwatershed.

An EPA-SWMM model was set up to model one representative natural asset from each of the above categories. Groundwater data, where available, was used to calibrate models. Stormwater volume reduction and peak flow reduction were analyzed for the 100-year storm. Total suspended solids (TSS) and total phosphorus (TP) reduction were analyzed on an average annual basis. The cost of stormwater infrastructure required to match the stormwater services provided by existing natural assets was used to value the natural assets. The models were also run for a future climate scenario to test stormwater performance and again to determine the value of the services provided. Based on the results from modeling of each representative natural asset, a scaling factor was applied to all remaining natural assets in the two subwatersheds to estimate total level and financial value of stormwater services provided by the assets at the subwatershed scale under existing and future climate conditions.

The major assumption for the current study results is the scaling approach applied at the subwatershed scale. This approach assumes value of natural assets in any category being proportionate to surface area of the assets in that category. The subwatershed scale valuation results presented in the current study should therefore be used with caution. Other assumptions made during the modeling exercise are explained in more detail in Section 4: Stormwater modeling, and summarized in Section 8: Modeling limitations.

Study results indicate that all modeled natural assets provide attenuation of the 100-year peak flows. The modeled isolated wetland, forest and palustrine wetland provided the most benefit for peak flow attenuation at 100, 84 and 69 per cent, respectively. Modeled riverine wetland was limited in its ability to attenuate flows due to the channel flow volume. The modeled open green space was not able to attenuate flows to a great extent (9 per cent peak flow reduction achieved) because of less surface vegetation to provide interception of flows.

All modeled features, except the riverine wetland, exceeded the Ministry of Environment and Climate Change's (MOECC) enhanced water quality performance requirement of 80 per cent TSS removal on an average annual basis. This is because most of the flows on an annual basis are retained by most of these features. The 90th-percentile storm in an average year is 25 mm of rainfall and most of these natural assets have sufficient capacity to retain runoff generated by storms less than 25 mm. The modeled riverine wetland was able to provide good quality control for runoff from the direct drainage area, but not as much for flows coming through the channel (35 per cent total removal of sediment).

Stormwater storage volume required to replace stormwater services provided by existing natural assets in the two subwatersheds ranged from 40 to 230,465 cubic metres. Under climate change, stormwater storage volume required to replace stormwater services provided by existing natural assets ranged from 40 to 246,690 cubic metres.

Using the replacement cost valuation method[1], monetary value of the stormwater services provided by existing natural assets in the two subwatersheds was estimated at roughly CAD $704 million under current climate and CAD $764 million under climate change conditions. The difference in the value under existing and climate change scenarios demonstrates ever increasing importance of natural assets in providing critical services to municipalities in the future and their important role in increasing resilience and reducing pressures on municipal infrastructure from climate change impacts.

1 As described in Section 7 of the report

1. Introduction

The term "municipal natural assets" refers to the stock of natural resources or ecosystems that is relied upon, managed, or could be managed by a municipality, regional district, or other form of local government for the sustainable provision of one or more local government services. Municipalities like the Region of Peel are recognizing that it is as important to account for natural assets as for engineered ones.

The Municipal Natural Asset Initiative pilot study was initiated by the Credit Valley Conservation (CVC) to address the Region of Peel's interest in understanding if and how natural capital assets within the region's jurisdiction could be integrated into their asset management and financial planning processes. It is important to first establish the value in monetary terms of services that natural assets provide. Without this information, there is no rational basis to make management choices. The Region of Peel and its partner conservation authorities have been well aware of the value of the services that natural assets provide for some time. In fact, with Peel's support, over the past decade the CVC completed studies to develop an understanding of the value of various natural assets with respect to ecosystem services and health and well-being of its residents[2].

Recent work completed by the MNAI team for the Town of Gibsons, British Columbia demonstrated that natural assets provide significant stormwater services beyond ecological benefits (Sahl et. al. 2016). The B.C.-based team approached several municipalities in Canada to expand the work conducted in the Town of Gibsons. Using a similar approach, the region—in partnership with CVC and the MNAI team and in collaboration with local municipal staff—initiated this pilot study with the primary objective of valuing the stormwater services provided by natural assets. This report summarizes the results of the pilot study that assessed the level and the value of stormwater services provided by natural assets under both existing and future climate scenarios.

1.1 Objective

The main objective of this pilot study is to assign financial value to natural assets for their stormwater services. The valuation is based on the cost of engineered stormwater infrastructure required to replace stormwater services—water quality and quantity control—provided by natural assets. The scope of the pilot is limited to two subwatersheds within Peel's jurisdiction – East Credit subwatershed (rural) and Fletcher's Creek subwatershed (urban). The specific objectives include:

- Determining stormwater quality and quantity control provided by the natural assets under existing and future climatic conditions
- Determining change in stormwater quality and quantity without the natural assets under existing and future climatic conditions
- Determining size of engineered stormwater infrastructure required to match stormwater quality and quantity control provided by the natural assets under existing and future climatic conditions
- Determining the value of the stormwater services provided by the natural assets using the replacement cost method described above (as the cost of building engineered stormwater infrastructure required to provide the same level of services under existing and future climatic conditions).

2 Please visit www.cvc.ca/egs for the list of natural capital studies recently completed by CVC

1.2 Natural assets description

The MNAI defines natural assets as ecosystem features that are nature-based and provide services that would otherwise require the costly equivalent of engineered infrastructure. For local governments, natural assets can include forests which convey stormwater and recharge aquifers, wetlands which reduce flooding risk, and coastal areas which protect against storm surges and sea level rise, among others. By identifying natural assets at the community level and prioritizing those in municipal asset management portfolios, local governments can secure important budget savings while also delivering vital municipal services more efficiently and adapting to climate change (MNAI 2017).

For this study, three main groups of natural assets have been selected for stormwater analysis: wetlands, forests/woodlands, and open green spaces. Wetlands were further categorized into three types: palustrine, isolated and riverine. Further information on the classification of natural assets is provided in Appendix A.

1.3 Study area

The study area for this project includes two subwatersheds within the Credit River watershed and the Region of Peel. The Region of Peel is a regional municipality with a population of about 1.3 million that includes the area municipalities of City of Mississauga, City of Brampton, and Town of Caledon. The Credit River watershed starts near Orangeville, drains the countryside around Hillsburgh, Erin, Acton, the west half of Caledon and Brampton and most of Mississauga (Figure 1). The Credit River empties into Lake Ontario at Port Credit in Missisauga. There are thousands of natural areas throughout this study area (Region of Peel 2011).

The two subwatersheds that were selected from Peel's jurisdiction are subwatershed 13 or East Credit River subwatershed and subwatershed 5 or Fletcher's Creek subwatershed (see Figure 1). The selection of these subwatersheds was based on their land use, the former being rural and the latter an urbanized subwatershed in Peel region.

The East Credit subwatershed or subwatershed 13 is located in the upper northeast portion of the Credit River watershed, entirely within the Town of Caledon. It is 51 km^2 in area. There are two significant natural landforms within the East Credit River subwatershed: the Niagara Escarpment and the Oak Ridges Moraine. Generally, land use in the subwatershed is dominated by agriculture (48 per cent of the subwatershed), with only 8.5 per cent of the subwatershed consisting of urbanized areas and the remaining 43.5 per cent comprised of natural areas like forests, meadows, wetlands, and open spaces. The East Credit River joins the Credit River upstream of the Village of Inglewood (CVC 2007). Breakdown of natural assets in subwatershed 13 and their respective areas is presented in Table 1. Figure 2 shows distribution of natural assets in subwatershed 13.

The Fletcher's Creek subwatershed or subwatershed 5 lies within the lower third of the Credit River watershed; it drains an area of approximately 42.5 km^2 and is 18 km long. Approximately 9 per cent of the Fletcher's Creek subwatershed is located within the southern limits of the Town of Caledon. This area is predominately agricultural in use, however a portion of this area is planned to be developed through the Mayfield West development. Approximately 71 per cent of Fletcher's Creek lies within the City of Brampton. This area has diverse land use including existing urban area and lands undergoing construction making up 63 per cent of the subwatershed, some agricultural areas (17 per cent), and the remaining 20 per cent for forests, meadows, wetlands, open spaces. Fletcher's Creek drains into the Credit River just south of Highway 401 within the City of Mississauga (CVC 2012). The lands within the City of Mississauga have been mostly urbanized in recent years. Breakdown of natural assets in subwatershed 5 and their respective areas is presented in Table 1. Figure 3 shows distribution of natural assets in subwatershed 5.

Natural asset type	Subwatershed 13	Subwatershed 5
# of Palustrine wetlands Range of surface area	78 (0.17 – 17.8 ha)	17 (0.07 – 1.23 ha)
# of Isolated wetlands Range of surface area	20 (0.14 – 1.11 ha)	11 (0.03 – 0.96 ha)
# of Riverine wetlands Range of surface area	31 (0.29 – 27.6 ha)	3 (0.91 – 12.1 ha)
# of Woodlands/ Forests Range of surface area	215 (0.39 – 131.7 ha)	55 (0.15 – 32.2 ha)
# of Open green spaces Range of surface area	25 (0.8 – 103.2 ha)	146 (0.06 – 33.2 ha)

Table 1: Summary of natural asset types in subwatersheds 13 and 5

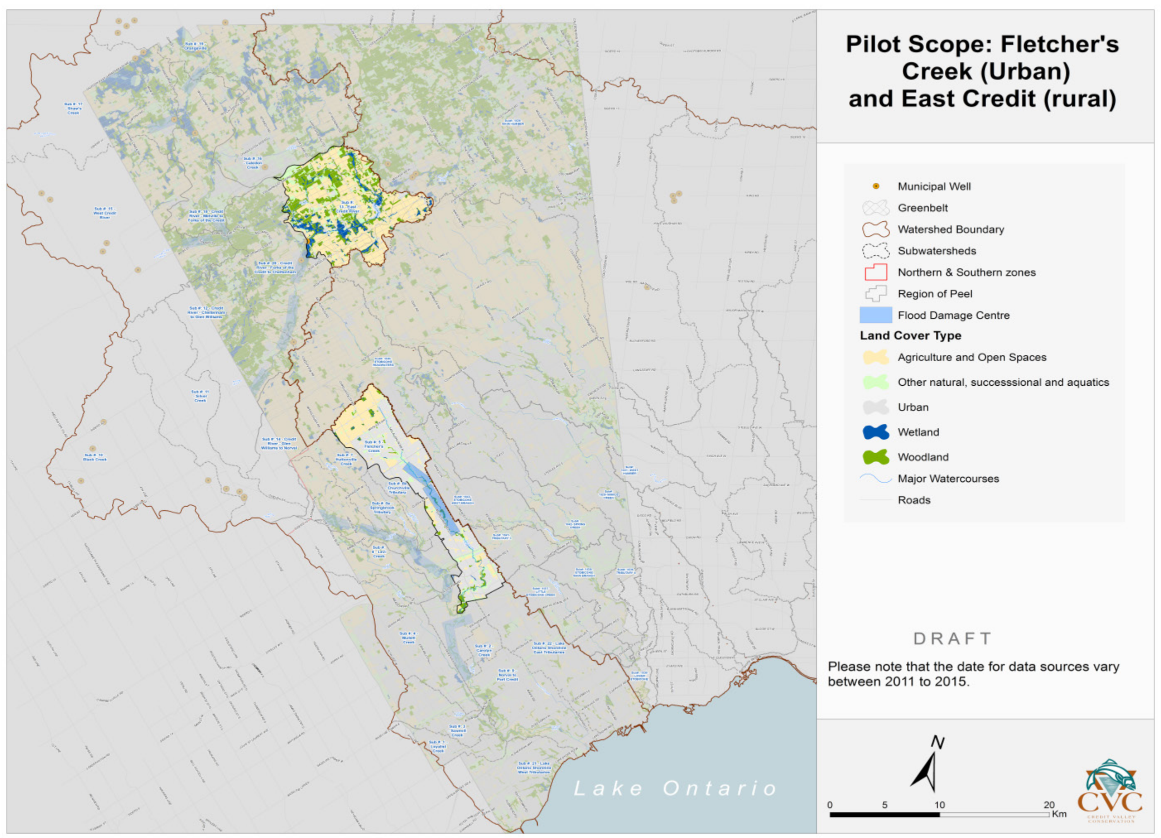


Figure 1: Location of pilot subwatersheds 13 and 5 within Region of Peel boundary

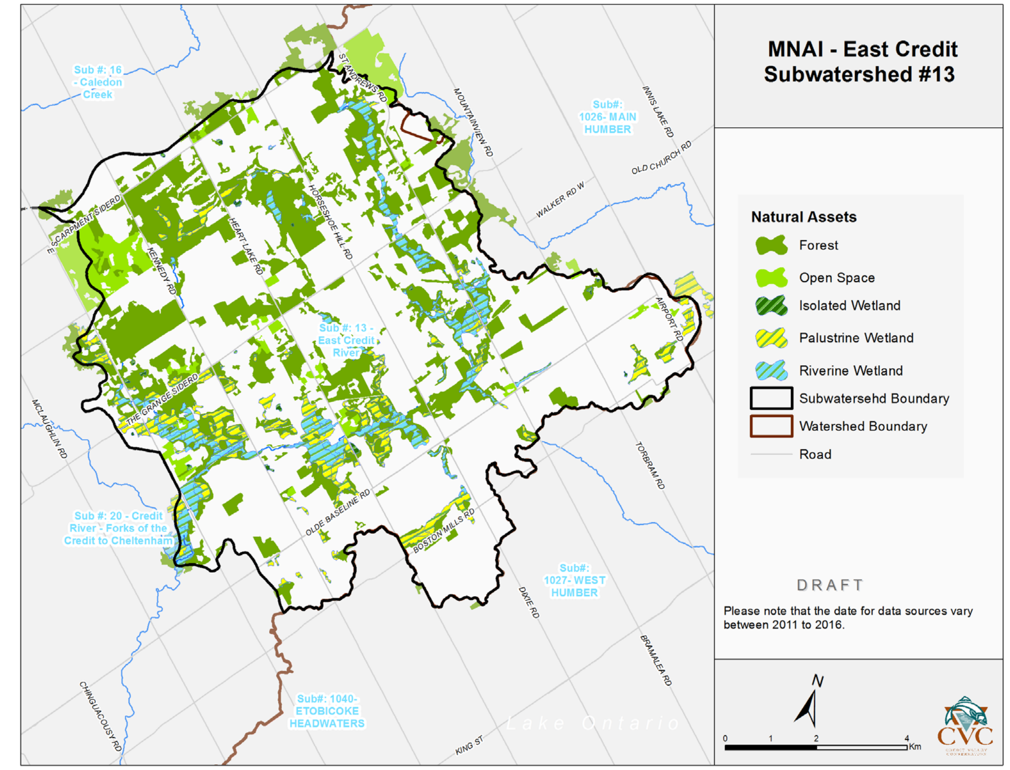


Figure 2: Distribution of natural assets in East Credit river subwatershed

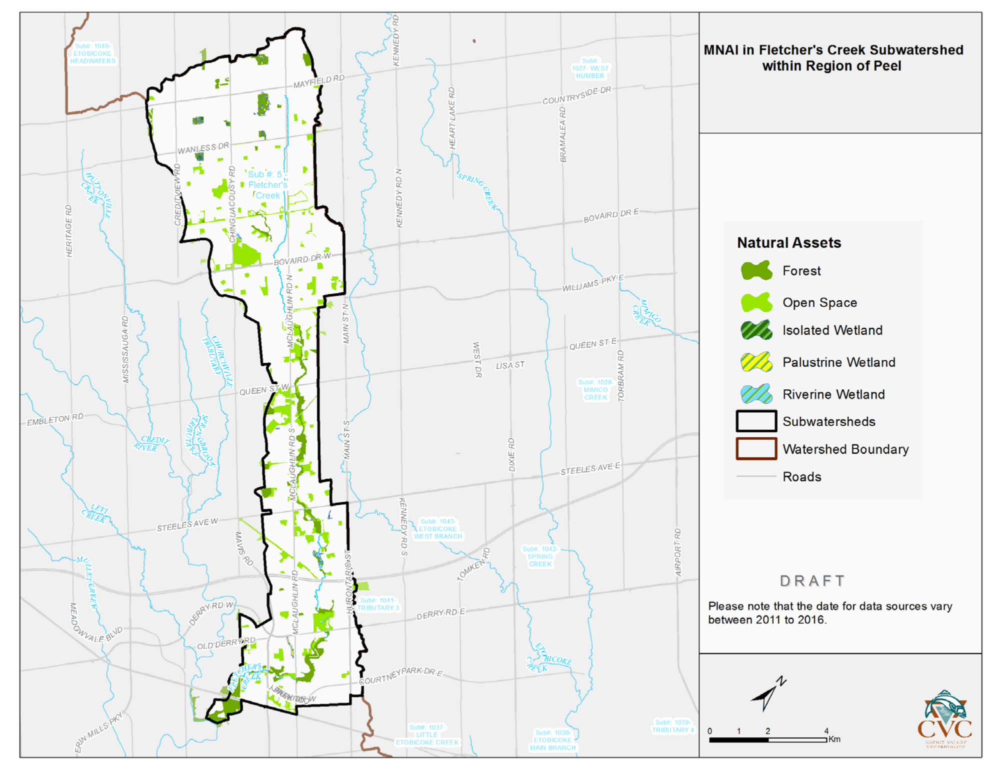


Figure 3: Distribution of natural assets in Fletcher's Creek subwatershed

2. Methodology

2.1 Natural assets valuation methodology

For this study, the following approach has been used to value all natural assets under existing and future climate conditions in the two subwatersheds:

1. Model an existing natural asset in each of the natural asset categories under existing land use conditions to determine peak flow and water quality. Detailed modeling methodology for each natural asset type is included in Section 4
2. Remove natural asset and determine size of stormwater management infrastructure required to match peak flow and water quality to the same level as was provided by the natural asset. Detailed methodology for sizing stormwater management infrastructure can be found in Section 6
3. Use area-proportionate scaling to expand stormwater storage volume required for one asset to all other assets of the same type in each subwatershed. More discussion on scaling can be found in Section 2.6
4. Value the natural assets by estimating cost of constructing stormwater management infrastructure required to replace services provided by natural assets. More details on the valuation of natural assets can be found in Section 7.

2.2 Model Selection

All modeling work presented in this report was completed using EPA-SWMM. This model was chosen as it is able to represent site conditions to a reasonable extent. In addition, this project selected this model to be consistent with the approach taken by other MNAI pilots (Sahl et. al. 2016) and University of Guelph's wetland study (Charbonneau 2016) which all use EPA-SWMM for modeling natural assets such as natural ponds, wetlands, etc.

The Stormwater Management Model (EPA-SWMM) is a dynamic hydraulic and hydrologic simulation model developed by the United States Environmental Protection Agency (US EPA). It is used for single-event analysis such as for running a 100-year return period storm as well as for continuous simulation, such as for an annual or multi-year analysis. The model generates stormwater quantity (volume and flows) and quality (pollutant loading) and routes it through the system. It handles losses due to evapotranspiration, infiltration, and snow melt as runoff moves through the system. It also incorporates a groundwater module to estimate groundwater recharge, evaporation from saturated and unsaturated soil layers, groundwater levels, and groundwater flow. It is possible, therefore, to model surface hydrology and partially model the subsurface hydrology with EPA-SWMM.

2.3 Climate data

Climate data required by the model are continuous precipitation data, continuous temperature data, and average evaporation rate for each month. The monthly average evaporation values from Toronto Pearson Airport used within the model are presented in Table B-2. Data from Toronto Pearson Airport was used to represent climate in both the subwatersheds for the 100- year storm and average annual analysis to estimate water quantity and quality performance, respectively. Pearson airport was selected due to its proximity to the study area and because both current and future climate information is available at this station. The Ontario Ministry of Transportation (MTO) has developed an intensity-duration-frequency (IDF) curve lookup tool (MTO 2016). The tool uses the latest Environment Canada data available from 147 Meteorological Service of Canada (MSC) stations across Ontario to determine rainfall intensities for any location in the province (JWMM 2015). It also uses historical trends to infer future climatic conditions thus generating IDF curves for future climate. The tool was used to retrieve information (average rainfall intensity and total depth) about the 100-year storm scenario at the Toronto Pearson Airport. This information was then used to fit a 24-hour SCS Type II storm distribution for water quantity analysis (i.e. peak flow control assessment). This type of storm distribution is typical of a summer convective storm. This storm was of interest for this study because conventional stormwater management structures are designed using 24-hour storm distribution. Details of the storm are provided in Table B-1.

Where calibration was conducted for specific natural assets, climate gauges close to the site were used to retrieve precipitation and temperature data. For the Ken Whillans wetland, CVC-operated rain gauge at Credit River at Boston Mills was used to get continuous precipitation data. CVC's Belfountain Conservation Area climate station provided continuous air temperature data. For Ridge Hill wetland, a Region of Peel gauge at McLaughlin Road was accessed to get precipitation information. Temperature was retrieved from a CVC station on Carolyn Creek at Creditview Road.

2.4 Climate change scenario

In addition to valuing natural assets under existing climate conditions, this study also assessed how the value of services provided by these assets will be affected by climate change. In order to assess this, future climate data retrieved from MTO's IDF curve lookup tool was used. The future year selected for the climate change analysis is 2065.

2.5 Scaling for valuation

One representative natural asset from each natural asset category has been modeled in the current study. Water quantity and quality performance of each modeled natural asset is used to size a stormwater management feature that would be required to provide the same level of service in absence of the natural asset. Because the valuation methodology uses the cost of stormwater management infrastructure to value each natural asset, extrapolating results of the stormwater storage requirement from the modeled natural asset to other assets in a category was deemed to provide a reasonable estimate of natural assets' value at a subwatershed scale.

The scaling factor applied to extrapolate stormwater storage volume results at a subwatershed scale is calculated as follows:

Scaling factor = V/A, Eqn. (1)

Where V= Stormwater storage volume required to replace services provided by a natural asset

A= Surface area of the natural asset

The scaling approach assumes that for all natural assets in one category the volume of stormwater infrastructure required to match services provided by the natural asset varies in proportion with the surface area of the asset, i.e. the larger the surface area of an asset the greater is the size of stormwater infrastructure needed and the higher is its value.

Secondly, due to the scale of this study it was not possible to delineate the drainage area of each natural asset individually within the two subwatersheds; hence the other assumption is that the drainage area of an asset is proportionate to the surface area of a natural asset. This is not to say that the area itself will be bigger or smaller based on the asset's surface area, but rather that the effective drainage area or the drainage area that generates runoff is assumed to vary in proportion to the area of the natural asset. For example, there may be a small natural asset with a large drainage area that does not generate as much runoff due to pervious soils. Vice-versa there may be a larger wetland with a smaller drainage area relative to its size which generates a lot of runoff due to less pervious soils. At other times there may be large wetland with a smaller drainage area relative to its size that only contributes some runoff to the natural asset, in which case the asset's value may be underestimated for it should be able to provide a greater level of control for smaller runoff volumes than the current study's estimates. Similarly, the performance of a small wetland with a large drainage area which generates a lot of runoff may be overestimated in the current study.

Apart from drainage area, the natural asset's bathymetry and subsurface conditions make a significant difference to performance as well. Such properties as soil type, vegetative cover, depth to water table, depth of surface storage, and bathymetry are factors that cause variation in the level of stormwater control provided by different assets in any natural asset category.

As demonstrated with the above examples, it can be said that at the subwatershed scale such differences generally cancel out to provide a decent estimate of the value of natural assets regardless of the assumptions made in this study.

However, it is recommended that for future analyses the drainage area of each natural asset be delineated separately. Considering land use and soil type of the drainage area, the inflow volume into each natural asset can be determined using the curve number method. It is recommended that the inflow volume be used to scale stormwater management infrastructure capacity required to match the asset's level of service.

3. Natural Assets Inventory

This section discusses how the natural assets were inventoried using Geographic Information Systems (GIS) systems and how the inputs for the EPA-SWMM models were created.

3.1 Hardware and software

Data accuracy and standardization is critical for the analyses and decision-making. It is important to be consistent with software, hardware and the professionals involved in development of the mapping wherever possible. A desktop computer with Intel(R) Core(TM) i7-2600 CPU, a 3.40GHz processor and 16 GB of RAM was used as the primary hardware. The primary software was from Environmental Systems Research Institute (ESRI), available from 2010 to 2017. ArcGIS 10.2 was the major platform for the GIS analysis. An ArcInfo level of ArcGIS, ArcHydro and Spatial Analyst extensions were also used for some data processing. Windows Picture and Fax Viewer, Microsoft Picture Manager, and Adobe Acrobat Pro were used to view, modify and update exported maps. Professional skills in raster-, spatial-, and vector-analysis and an understanding of scripting background were required to complete the project.

3.2 Data preparation and sources

A review of existing data at CVC was conducted to assess the best available data. Spatial data were compiled from a variety of sources (Table 2). Many of the data layers were derived from Ecological Land Classification (ELC; e.g. forest, ELC based wetlands). The most detailed base layer for ecological data was the ELC community series (OMNRSTU 1996, Lee *et al.* 1998) land cover and land use layer (herein referred to as the 'ELC layer'). The layer is scaled to 1:10,000 or better.

GIS Layers	Data Source	Year
ELC land cover and land use	CVC	2016
Forests (derivative from ELC)	CVC	2016
Wetlands (derivative from ELC)	CVC	2016
Open green spaces	CVC	2016
DEM	CVC	2016
Soil layer	Ontario Soil Survey	1953
Drainage network (for reference)	CVC	2016

Table 2: GIS data used in MNAI pilot study for the Region of Peel

The initial data used in this project were obtained from a variety of sources; however, the majority of the data layers were created in-house by digitizing and updating existing layers.

The minimum mapping unit (MMU) was 0.5 ha for natural and non-natural features (CVC 1998). The MMU was a guideline for orthophoto interpretation. In some cases, urban wetlands less than 0.5 ha have been mapped. Finally, features smaller than 0.5 ha delineated or inventoried through on-the-ground field work were also included.

3.3 Ecological Land Classification-based forests, wetlands, and open green spaces

The ELC layer was a primary data source in creating categories of the natural assets. This data layer (spatial) was developed by CVC based on the Ecological Land Classification for southern Ontario (Lee *et al.* 1996). This system was developed to provide a comprehensive and consistent province-wide framework upon which ecosystems can be described, inventoried and managed (Lee *et al.* 1998). Each ELC unit is uniquely identified based on its ELC ID and is linked to an associated ELC code which was later used to identify the aggregated assets such as forests, wetlands and open green spaces (Table 3). It is important to note that the mapping reflects actual land use, and may not correspond to the zoning or designations in municipal official plans.

ELC Code	ELC Type Names	Natural Asset Type
CUP1	Deciduous plantation	Forest/ Woodland
CUP2	Mixed plantation	Forest/ Woodland
CUP3	Coniferous plantation	Forest/ Woodland
CUW	Cultural woodland	Forest/ Woodland
FOC	Coniferous forest	Forest/ Woodland
FOD	Deciduous forest	Forest/ Woodland
FOM	Mixed forest	Forest/ Woodland
MOC	Commercial / industrial open space	Open Green Space
MOI	Institutional open space	Open Green Space
MOO	Other open space	Open Green Space
MOP	Private open space	Open Green Space
MOR	Recreational open space	Open Green Space
MOS	Manicured open space	Open Green Space
MA	Marsh	Wetland- MNAI
SWC	Coniferous swamp	Wetland- MNAI
SWD	Deciduous swamp	Wetland- MNAI
SWM	Mixed swamp	Wetland- MNAI
SWT	Thicket swamp	Wetland- MNAI

Table 3: Aggregation of natural assets based on ELC data[3]

3.4 Catchment delineation

Once the wetlands, forests or open green spaces features were created, a lowest elevation on those pilot features (see Section 4 for more details) was identified using Digital Elevation Model (DEM). The pilot features included one each from those three main categories. However, the wetland asset was divided into three subsets called palustrine, isolated and riverine wetlands. Overall, there were a total of five features (forest/woodland, open green space, palustrine wetland, isolated wetland and riverine wetlands. Please see Section 4 for more details). The catchments were created using ArcGIS, Spatial Analyst and ArcHydro extensions for those pilot features.

3.5 Hydrologic Response Unit (HRU)

Once the catchments were created for pilot features, hydrologic response units were created within these catchments. Hydrologic response units are areas within a catchment consisting of same soil type, ELC and land use type, and slope.

3 Please note that while the best attempt was made to address most significant natural asset categories within the pilot study areas, some categories such as cultural meadows and thickets as well as more rare natural types (bluff, talus, etc.) were not considered in the analysis. That can have an impact on the estimated level and value of services provided by natural assets.

The soil, ELC and land use layer and DEMs were used to calculate the information required for the HRUs. The information from the HRUs was used as input to the SWMM model (see Section 4 for more details). From within HRUs, the information from soil and slopes was directly included in the SWMM model, whereas the ELC and land use information was used to assign the percent imperviousness and pollutant washoff for the SWMM model.

4. Stormwater Modeling

This section describes the modeling methodology used for each of the natural assets modeled in this study, namely palustrine wetland, isolated wetland, riverine wetland, forest, open green space.

4.1 Palustrine wetlands

Palustrine wetlands receive their inflow from an upstream catchment through direct precipitation or groundwater inflow and generate surface outflow, either intermittently or permanently. To model the hydrology of a palustrine wetland, groundwater monitoring data was available for calibration for such a wetland in the Credit River watershed.

The Ken Whillans wetland is located in Caledon, just outside subwatershed 13 (Figure 4). It is a combination of a Maple mineral deciduous swamp and Willow mineral thicket swamp. It is a palustrine wetland and discharges to the Credit River. Surface water and groundwater levels have been monitored within the Ken Whillans wetland since 2012. There were some disturbances to the site including aggregate extraction, construction of a highway, trail and parking lot, prior to beginning of monitoring. There is also a municipal well located nearby which affects wetland groundwater levels.

Inventory and drainage area delineation work for this wetland was completed using ArcGIS software and has been outlined in Section 3. Catchment (also called upstream catchment or drainage area) characteristics for Ken Whillans wetland are presented in Table B-3.

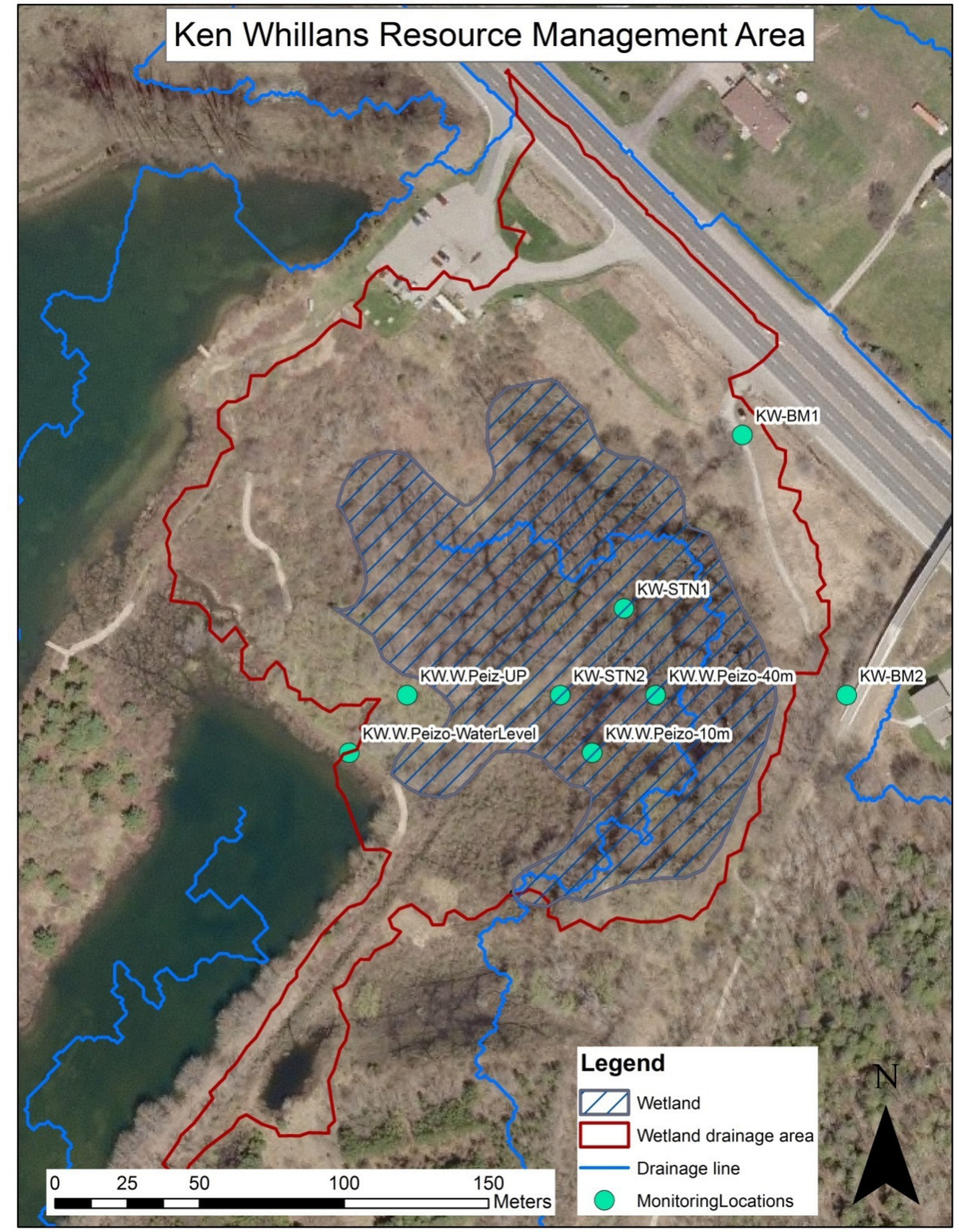


Figure 4: Location and drainage area details of Ken Whillans wetland

A model schematic for Ken Whillans is presented in Figure B-1. All surface and groundwater flows from upstream catchments are routed to the wetland catchment. The wetland catchment represents the subsurface storage within a wetland. Groundwater recharge, groundwater flow and evapotranspiration from the wetland occur in the wetland catchment. Excess surface runoff from the wetland catchment, which occurs once the surface depression storage depth of 6.5 mm is exceeded and/or when no more subsurface storage is available, is routed to the wetland storage node. The wetland storage node represents the surface storage of the wetland. Once flow enters the storage node it is assumed that no further seepage occurs. Water is lost from the wetland storage node either through surface evaporation or through discharge or outflow. The storage node has a stage-storage-discharge (SSD) curve associated with it, which controls rate of outflow from the wetland. The SSD was developed in HEC-RAS model by using the DEM.

A soil sample taken at the site by CVC staff informed that loam soils exist at the Ken Whillans wetland. Soil properties for this soil type are based on EPA-SWMM User's Manual[3] and are included in Table B-4. The Green and Ampt infiltration method is used to calculate infiltration in the model.

Finally, a key condition required for the 100-year storm analysis is the initial depth to water table during summer. Seasonal median groundwater levels within the Ken Whillans wetland were estimated in another CVC study based on multiple years of groundwater monitoring data at Ken Whillans (CVC 2016). During summer, the median depth to water table was determined to be 0.8 metres.

4.1.1 Continuous groundwater calibration

Groundwater and aquifer properties of a wetland control how much water is lost from the ground via evapotranspiration, groundwater outflow and groundwater recharge. These properties were calibrated based on monitored groundwater levels within the Ken Whillans wetland.

Continuous groundwater level data was available for Ken Whillans wetland at three locations— two within the wetland (at 10 m and 40 m from edge of wetland) and one upstream. These locations are presented in Figure 5 as 'KW.W.Peizo-10m', 'KW.W.Peizo-40m' and 'KW.W.Peiz-UP', respectively. All wetland locations have a surface logger and a shallow (1 m) and deep (2 m) piezometer. This study uses data from the deep piezometer at the downstream location (40 m from edge of wetland) to represent groundwater levels within the wetland during the calibration period.

Calibration was performed on wetland groundwater data on a continuous basis for the period of March 2014 to October 2016 with a focus on summer periods (July to October, CVC 2016). Because the 100-year storm analysis is focused on summer storms, it was important to have a strong calibration for the period of July to October. A site inspection helped improve the calibration when it was realized that there are two pools close to the wetland that are not part of the wetland's catchment but are potentially contributing flows intermittently. Based on this information and existing groundwater monitoring data, external flows were added in the model for the month of August. Figure 5 presents monitored and modeled groundwater levels within the wetland post calibration. Aquifer and groundwater properties for this wetland are presented in Table B-5 and Table B-6, respectively.

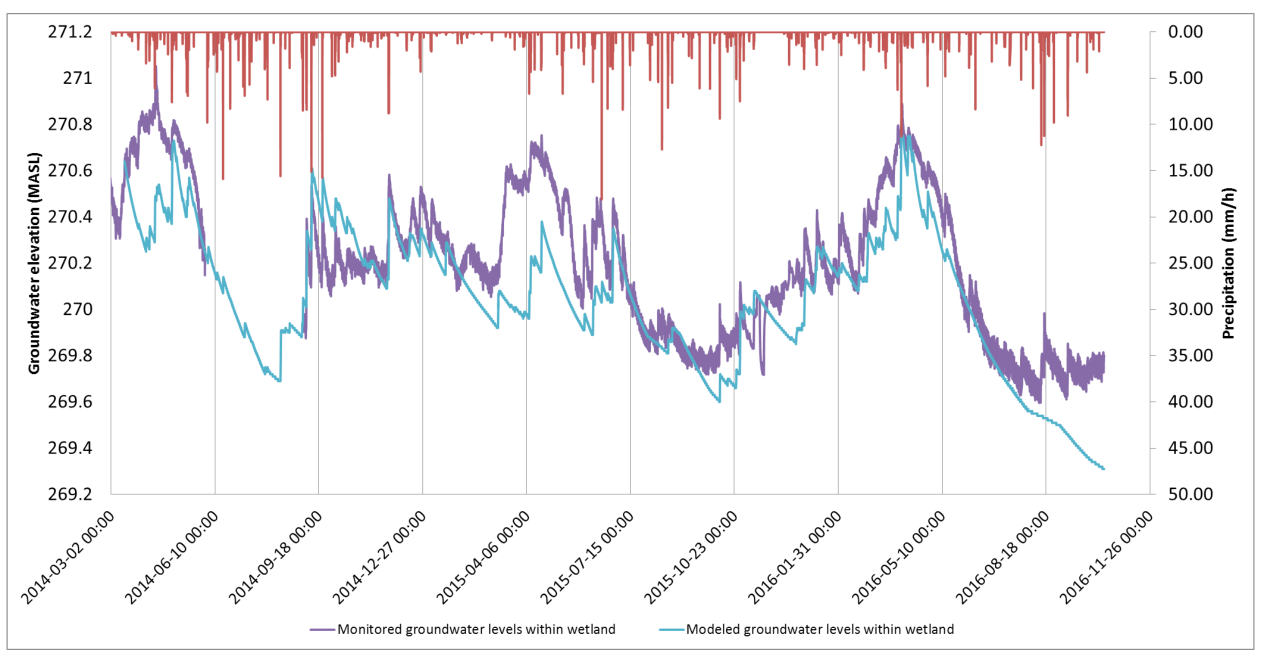


Figure 5: Groundwater levels within Ken Whillans wetland

4.1.2 Model verification through water balance analysis

A water balance aims to quantify all inflows (precipitation, surface inflow, and groundwater inflow), outflows (surface outflow, groundwater outflow, evapotranspiration, and groundwater recharge) and change in storage within any feature. The difference between sum of inflows and sum of outflows is the change in storage plus the residual. Errors arising from estimation of certain terms within the water balance, called the Residual, can be estimated by taking the difference between change in storage through summation of inflows and outflows and change in storage estimated by the model (Charbonneau 2016).

$$\mathbf{P + RO + GW_{in} - ET - GW_{out} - R - SW_{out} = \Delta S + Residual}, \qquad \text{Eqn. (2)}$$

Where P = Precipitation

RO = Surface inflow to wetland

GW_{in} = Lateral groundwater inflow to wetland

GW_{out} = Lateral groundwater outflow from wetland

ET = Evapotranspiration (evaporation and transpiration)

R = Groundwater recharge from wetland

SW_{out} = Surface outflow from wetland

ΔS = Change in storage within wetland

Residual = Error

Monthly water balances were undertaken for the Ken Whillans wetland to assess the model's prediction of wetland's hydrologic processes. Results of the water balance analysis are presented in Table 4. The model was run on a monthly basis with appropriate initial conditions to estimate the values presented herein. Evapotranspiration comprises a major portion of water loss from the wetland during the summer period.

Period	Precip (mm)	Surface inflow into wetland (mm)	GW inflow into wetland (mm)	Surface outflow from wetland (mm)	GW outflow from wetland (mm)	Recharge (mm)	Evapo-transpiration (mm)	Change in storage (mm)	Residual (mm)
June 2015	131.0	7.5	0.0	0.0	0.6	19.0	80.6	41.2	-2.9
July 2015	33.7	1.6	0.1	0.0	0.0	17.0	106.0	-77.7	-9.9
Aug 2015	74.5	3.8	0.0	0.0	0.0	17.3	93.0*	-24.5	-7.5
Sept 2015	31.5	1.4	0.0	0.0	0.0	17.7	62.9	-42.5	-5.2
Oct 2015	97.2	5.1	0.0	0.0	0.8	20.3	30.4	49.6	1.3
Nov 2015	23.6	1.2	0.0	0.0	0.0	18.4	11.2	-6.3	1.5
June2016	33.7	1.6	0.0	0.0	0.0	16.7	88.9	-61.6	-8.7
July2016	35.8	1.7	0.1	0.0	0.0	17.6	104.6	-74.2	-10.5
Aug 2016	85.2	6.9	0.0	1.4	0.0	17.5	90.3[1]	-12.5	-4.6
Sept 2016	50.4	2.5	0.0	0.0	0.0	17.4	62.5	-22.6	-4.4
Oct 2016	51.2	2.4	0.0	0.0	0.0	18.4	29.5	5.5	0.1
Nov 2016	42.6	2.1	0.0	0.0	0.0	17.9	9.9	14.5	2.4

Table 4: Monthly water balance analysis for summer at Ken Whillans wetland. SWMM model was run on a monthly basis to generate these results

Additionally, groundwater monitoring data was analyzed to estimate vertical and horizontal groundwater gradients within the wetland during the summer. This was done to confirm movement of groundwater within the wetland in the vertical and horizontal direction to support results of the model. Results of this analysis are presented in Table 5. Summer was characterized as the period from June 22 – September 21 for this analysis. There is, on average, a positive downward gradient during summer representing downward movement of water during this period. Negative horizontal gradients indicate flow is occurring from the 40 m location to the 10 m location within the wetland. The drainage line delineated by assessing the DEM (see Section 3) matches this observation.

Vertical hydraulic gradient (wet and dry) at 40 m from edge of wetland (m/m)			
	2012	2013	2014
summer (wet)	16.45	2.468	21.39
summer (dry)	8.225	4.113	15.63
Horizontal groundwater gradient (wet and dry) (m/m)			
summer (wet)	-0.003	-0.0023	0.001
summer (dry)	-0.003	-0.003	-0.00067

Table 5: Seasonal groundwater gradients at Ken Whillans wetland

4.2 Isolated wetlands

Isolated wetlands get their inflow from an upstream catchment or the precipitation falling directly on the wetland or occasionally some groundwater inflows. Outflow from the wetland is assumed to always be zero. By definition an isolated wetland generates no surface outflow.

An isolated wetland located within subwatershed 13 was selected for modeling. This wetland covers an area of 1.11 ha and is a coniferous swamp. The drainage area to this wetland is 13.91 ha of mixed land uses, predominantly agricultural. Characteristics of the wetland's catchment area are presented in Table B-7. The catchment area to wetland surface area ratio for this wetland is 12.6:1. The total imperviousness of the drainage area is 5 per cent. See Figure B-2 for the model schematic. Aquifer and groundwater properties are presented in Table B-5 and Table B-6, respectively. Monitored groundwater levels from another coniferous swamp were used to infer the initial depth to water table during summer for the isolated wetland modeled for this study. Based on the two years (representing average rainfall and soil conditions) of monitoring data at the monitored wetland the depth to water table during summer was estimated to be 1.43 m.

4.3 Riverine wetlands

Riverine wetlands are wetlands situated along a channel. These wetlands have more complex hydrology than other types of wetlands due to the channel routing. A riverine wetland in subwatershed 5 where groundwater levels are being monitored was chosen for modeling performance of riverine wetlands for this study.

Ridge Hill wetland is located in subwatershed 5 just south of the Canadian Pacific Railway (CPR) close to McLaughlin Road in the City of Brampton. It covers an area of approximately 12.08 ha which includes the stream corridor. Figure 6 shows the location, drainage area and monitoring well locations within this wetland. This wetland has groundwater monitoring data available from June 2015 that was used for groundwater calibration. Groundwater data recorded at the well located 40 m from edge of the wetland was used for calibration.

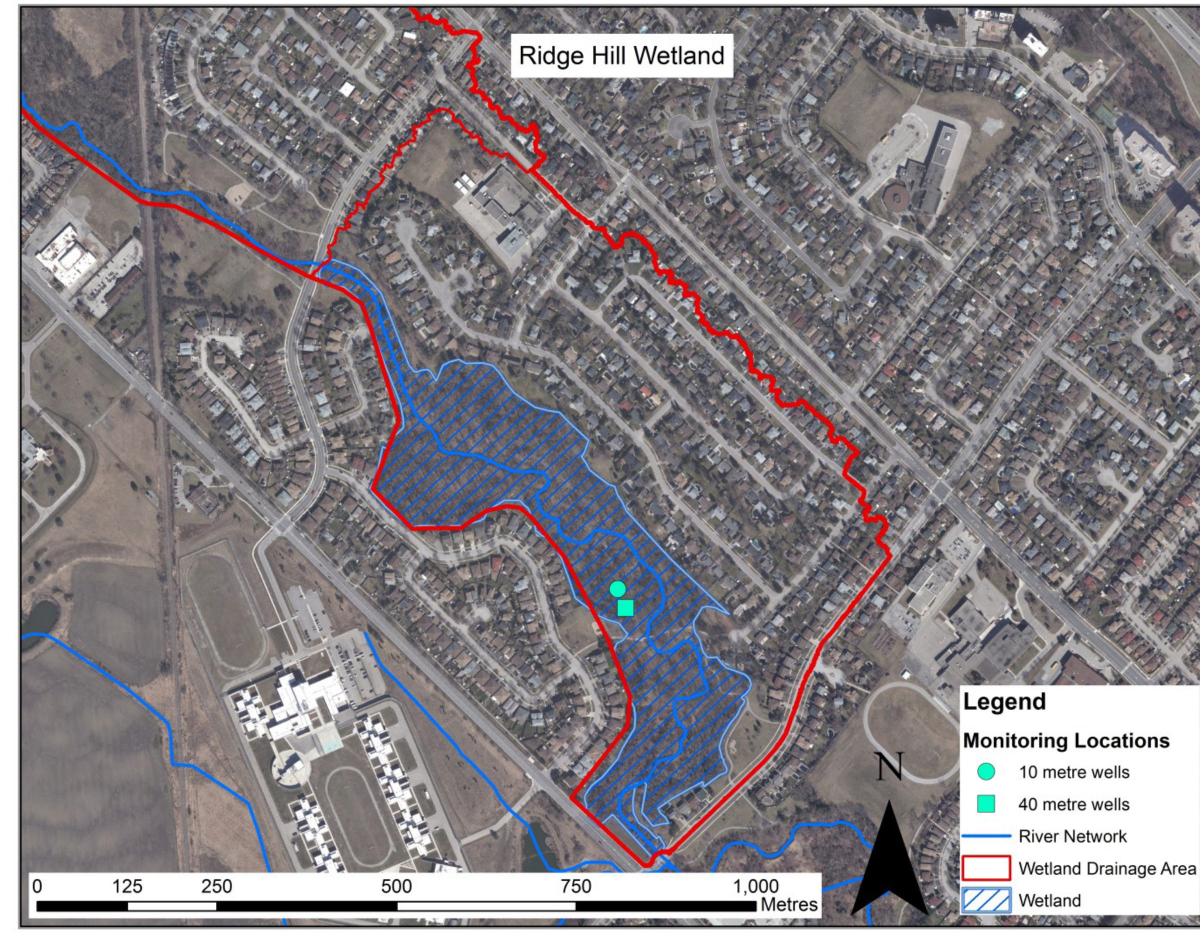


Figure 6: Location and drainage area details of Ridge Hill wetland

The drainage area of Ridge Hill was delineated differently than other types of wetlands. The wetland receives inflows directly from its catchment area, which enter the wetland through the surface or groundwater. A riverine wetland also receives inflow from the channel; therefore drainage area of the channel is an indirect drainage area to the wetland. The indirect drainage area to Ridge Hill was delineated at the upstream point of intersection of the wetland and the channel, Fletcher's Creek. The direct drainage area to the wetland was estimated by subtracting the indirect drainage area from the drainage area delineated at the downstream point of intersection of the wetland and Fletcher's Creek. See Table B-8 for drainage area characteristics of Ridge Hill wetland. The indirect drainage area of Ridge Hill comprises most of Fletcher's Creek subwatershed as this wetland is located on the main channel. The total indirect drainage area is 2,604 ha. The direct drainage area to the wetland is 38.3 ha. Model schematic for Ridge Hill is presented in Figure B-3.

The direct drainage area is routed through a wetland catchment where flow and volume attenuation and water quality control are provided for direct overland flows. Attenuation of flows along the channelized wetland is modeled by setting up a channel in EPA-SWMM. The roughness along the overbank of the channel was modified to 0.2 to represent wetland vegetation; the main channel has a roughness of 0.1. This channel roughness is based on calibration of an existing hydraulic model set up for the Fletcher's Creek subwatershed for floodplain mapping (See 4.3.2).

It is to be noted that since Ridge Hill wetland is located in an urbanized subwatershed, there are stormwater management controls within the indirect and direct drainage area. These stormwater management controls provide some attenuation of peak flows during all storms. For this study it has been assumed that no such controls exist in the indirect and direct drainage areas, therefore all flows are assumed to enter the wetland untreated.

4.3.1 Continuous groundwater calibration

Groundwater levels have been monitored at the Ridge Hill wetland since June 2015. Following the approach used for palustrine wetlands the groundwater and aquifer properties for Ridge Hill were calibrated based on measured groundwater levels within the wetland. Figure 10 presents results of the groundwater calibration for this site. Summer was the focus period and the calibration for this period was successful. Table B-9 shows aquifer properties for the direct catchment of the wetland and for the wetland itself. Groundwater properties are the same as for palustrine wetland (Table B-6).

4.3.2 Comparison with Fletcher's Creek hydrologic and hydraulic model

An OTTHYMO model was updated for the Fletcher's Creek subwatershed for the creek's floodline mapping study completed in 2005 (CVC 2005). This is a peer-reviewed hydrologic model of the Fletcher's Creek subwatershed. Since it is a peer reviewed model it made sense to compare the peak flow generated by the SWMM model created for this study and the OTTHYMO model. The OTTHYMO model used the 24-hour Chicago rainfall distribution for the 100-year storm, which results in total rainfall depth of 103.5 mm.

The peak flows for the 100-year storm were compared upstream of the wetland where Fletcher's Creek crosses the CPR line. At this location the peak flow predicted by the OTTHYMO model for the 100-year storm is 69 cm. Peak flow calculated by EPA-SWMM for the 100-year storm upstream is 65 cm.

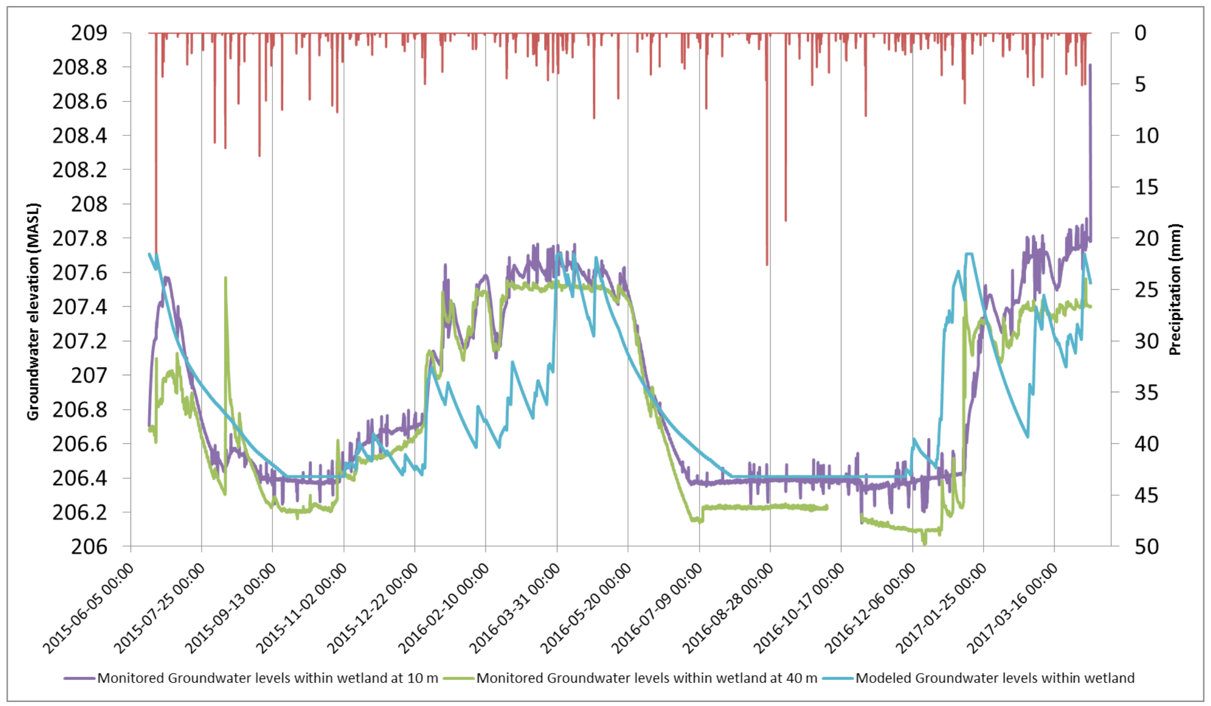


Figure 7: Groundwater levels within Ridge Hill wetland

For the floodplain mapping study a HEC-RAS model was set up to model the hydraulics of the channel. Parameters for the channel such as: channel length, entry and exit losses and channel geometry from the HEC-RAS model were used in the EPA-SWMM model. The HEC-RAS model was run for the 100-year storm and peak flow downstream of the wetland was compared to peak flow estimated by EPA-SWMM. The HEC-RAS model estimated peak flow at 57.2 cm and EPA-SWMM at 57.5 cm. The agreement between the model results indicates that the channel was set up appropriately in EPA-SWMM and provides more confidence in results from the model.

4.4 Forests

Forests or woodlands provide quantity and quality control by intercepting precipitation through leaves and runoff through roots as well as losing water through evapotranspiration. No groundwater or surface water level data exists for any forest within the study area. Therefore a representative forest area within subwatershed 13 close to the northern border of the subwatershed was selected for modeling. The forest covers an area of 28.7 ha and drains 46.8 ha of catchment area. Catchment characteristics are presented in Table B-10. Aquifer and groundwater properties used to model the forest are presented in Table B-5 and Table B-6, respectively.

The forest was modeled using the subcatchment feature in EPA-SWMM with increased depression storage of 7.62 mm and surface roughness of 0.8. Both these parameters contribute significantly to flow attenuation and their values were retrieved from the SWMM 5 User's Manual (US EPA 2015).

The depth to water table at the start of the simulation informs the model how saturated the soil is at the beginning of the rainfall event. If the water table is shallow or close to the surface at the start of the simulation, the soil is more saturated and will result in higher surface runoff because the water cannot infiltrate. To avoid overestimating stormwater performance of forests a conservative estimate of 1 m depth to water table was used for the 100-year storm analysis. For the average annual analysis, 0.45 m was used as the depth to water table at the beginning of the year (winter conditions).

The modeled forest consists of two soil types – loamy sand and silt loam. Since soil group B (silt loam) has lower hydraulic conductivity it was chosen to represent soils within the modeled forest.

4.5 Open green spaces

Open green spaces or open spaces provide pervious areas for stormwater to infiltrate and pollutants to be filtered. Due to the nature of sheet flow anticipated within open spaces it would be extremely difficult to monitor such features. Flow or groundwater monitoring data were therefore not available for open spaces within the study area. Aquifer and groundwater properties used for modeling of open green spaces are presented in Table B-5 and Table B-6, respectively.

The modeled open green space is in subwatershed 13. It has an area of 1.80 ha and is draining 30.2 ha of catchment area. The feature was modeled using subcatchment with appropriate depression storage of 5 mm and surface roughness of 0.25. Initial depth to water table was assumed to be 2 m to represent summer conditions. This is a very conservative estimate as an analysis of water table depths in this subwatershed presented deeper groundwater levels. Other groundwater and aquifer parameters for open spaces are based on calibration of groundwater parameters at the Ken Whillans wetland.

Open green spaces are generally not flat areas; therefore each slope category was modeled separately (<3 per cent, 3-5 per cent, >5 per cent) and the higher sloped areas were assumed to drain down to areas with less slope. Areas with higher slope are anticipated to provide less peak flow attenuation than areas with less slope because runoff travels more quickly on steeper slopes.

4.6 Water quality

In order to simulate water quality control provided by natural assets, the pollutant wash-off function in EPA-SWMM was used for all modeled natural assets. Under this approach, an event mean concentration (EMC) is specified for each land use type. Table B-12 presents EMC values for total suspended solids (TSS) and total phosphorus (TP) that were used for different land uses in this study. These values are based on a literature review of different land uses from two sources —the Toronto Wet Weather Study (City of Toronto 2006) and the International Stormwater Best Management Practices database (BMP database 2014). Based on these EMC values the catchment generates a load, which enters the natural asset.

A natural asset removes pollutants by two mechanisms—concentration reduction or filtration and volume reduction. Because this study is only concerned with pollutants leaving the system through surface runoff, it was assumed that water that has moved into the subsurface through infiltration is not going to produce any pollutant loading. This is the volume reduction mechanism of pollutant removal. Volume reduction is simulated within the model through hydrologic modeling and routing.

For removal through filtration, concentration-based pollutant removal efficiencies were specified for each type of natural asset. These removal efficiencies were based on a literature review of wetlands, forests, and open green spaces. All wetlands as well as forests are assumed to provide the same concentration reduction due to presence of vegetation in both systems. Seventy per cent TSS removal and 50 per cent TP removal (BMP database 2014) were used for palustrine and isolated wetlands and forests. For a riverine wetland, it was assumed that flows moving through the channelized portion of the wetland will undergo 10 per cent reduction in TSS and TP concentration. Open green spaces are assumed to provide removal similar to a dry pond. This equates to 60 per cent TSS removal and 20 per cent TP removal (BMP database 2014).

5. Hydrology and Water Quality Results

5.1 Design storm: Stormwater quantity control

The model was run for the 100-year storm to estimate volume and peak flow control achieved by natural assets. Stormwater performance of the natural assets under the 100-year storm for current and future climatic conditions (2065) is presented in Table 6.

Natural asset type	Scenario	Asset and drainage area information			Stormwater quantity results			
					Design storm (100 year return period)			
		Feature Area (Ha)	Drainage area of feature (Ha)	Imperviousness	Volume in and out (m^3)	Volume reduction	Peak flow in and out (cms)	Peak flow reduction
Palustrine wetland= Ken Whillans	Existing climate	1.58	1.98	5%	3,192/ 2,010	37%	0.32/ 0.10	69%
	Climate change				3,420/ 2,210	35%	0.35/0.11	69%
Isolated wetland	Existing climate	1.11	13.9	5%	2,650/ 0	100%	0.46/ 0	100%
	Climate change				3,012/0	100%	0.54/ 0	100%
Riverine wetland= Ridge hill	Existing climate	12.08	2,643	34%	2,005,050/ 1,980,330	1%	72.2/ 57.5	20%
	Climate change				2,185,070/ 2,146,980	2%	78.9/ 62.0	21%
Forest	Existing climate	28.74	46.8	5%	57,776/ 34,602	40%	2.87/ 0.47	84%
	Climate change				62,207/ 38,090	39%	3.25/ 0.54	83%
Open green space	Existing climate	1.80	30.2	3%	15,361/ 13,950	9%	2.11/ 1.56	26%
	Climate change				16,891/ 15,372	9%	2.40/ 1.82	24%

Table 6: Stormwater quantity performance of modeled natural assets

Performance of the modeled natural assets is assumed to be representative of all natural assets in that category within subwatershed 13 and 5.

Isolated wetlands provide 100 per cent control of all precipitation and runoff received by them. Palustrine wetlands provide 69 per cent peak flow control and 36 per cent runoff volume retention. Riverine wetlands provide 20 per cent peak flow control and almost negligible runoff volume retention. Riverine wetlands receive inflow through the channel as well as direct inflow from the direct drainage area. The peak flow control provided for channelized flow is only through surface roughness of the overbank and the increased floodplain width. Under the 100-year storm, minimal runoff volume is retained because the time of concentration or the time it takes water to move through the wetland is very small. Runoff volume control is provided for in overland flow from the direct drainage area, but in comparison to the channel volume this is negligible. Forests provide 84 per cent peak flow control and 40 per cent runoff volume control for the 100-year storm. Open green spaces provide 26 per cent peak flow control and 9 per cent runoff volume control.

All natural assets show resiliency to climate change as performance of the features remains largely unchanged although more runoff is entering the features under climate change.

5.2 Average annual: Stormwater quality control

An annual simulation was run to estimate water quality control achieved by natural assets. Water quality was estimated using average annual rainfall time series because stormwater management infrastructure is designed for pollutant removal on an average annual basis. Results from the water quality analysis are presented in Table 7.

Isolated wetlands are estimated to provide 100 per cent pollutant removal because they infiltrate all runoff. The modeled palustrine wetland and forest provided similar pollutant load removal due to the same concentration-based removal efficiencies. Wetlands and forests provide similar volume control (see Table 6). Riverine wetlands are estimated to provide 35 per cent removal of all pollutants entering the wetland through the channel as well as overland flow. Most of this removal is attributable to filtration as water moves through the channelized wetland. Open spaces are estimated to provide most of the pollutant removal through filtration due to minimal volume retention capacity.

Water quality control remains unchanged under the climate change scenario with the exception of open green spaces. Open green spaces exhibit a difference in water quality performance under climate change which may be due to decreased volume retention under future average annual rainfall; results for volume reduction on an average annual basis are not presented in this report because they are not of interest for hydrologic performance.

Natural asset type	Scenario	Stormwater quality results			
		Average annual rainfall			
		TSS load in and out (kg)	TSS load reduction	TP load in and out (kg)	TP load reduction
Palustrine wetland= Ken Whillans	Existing climate	77.5/ 1.8	98%	0.31/ 0.01	96%
	Climate change	89.2/ 3.4	96%	0.36/ 0.02	94%
Isolated wetland	Existing climate	1,111/ 0	100%	1.68/ 0	100%
	Climate change	1,273/ 0	100%	1.91/ 0	100%
Riverine wetland= Ridge hill	Existing climate	634,060/ 413,470	35%	1,673/ 1,088	35%
	Climate change	792,080/ 516,567	35%	2,125/ 1,384	35%
Forest	Existing climate	2,659/ 28.6	99%	5.97/ 0.11	98%
	Climate change	3,908/ 173	96%	8.61/ 0.62	93%
Open green space	Existing climate	775/ 116.3	85%	2.08/ 0.59	72%
	Climate change	1,444/ 359.4	75%	3.51/ 1.67	53%

Table 7: Stormwater quality performance of modeled natural assets under existing climate only

6. Sizing Stormwater Infrastructure for Valuation of Natural Assets

In order to value the natural assets, stormwater retention ponds or Infiltration chambers were chosen as proxies for the stormwater services provided by natural assets. The MOECC Planning and Design Manual for Design of Stormwater Management Infrastructure (MOECC 2003) was followed to size retention ponds for stormwater control for all natural assets except isolated wetlands. Section 4.6.2 of the MOECC manual outlines the design of retention ponds also known as wet ponds.

For all natural assets except isolated wetlands, the final stormwater storage capacity required is based on water quality and quantity control volume plus 0.3 m freeboard. The design sheets for each of the stormwater pond's design are included in Appendix B.

Isolated wetlands, which provide 100 per cent volume control, would need to be replaced with an Infiltration chamber which would be sized to control all the volume that an isolated wetland is able to retain. The stormwater storage capacity requirement for the isolated wetland was derived by using Sustainable Technologies Evaluation Program's (STEP) LID costing tool which allows sizing of infiltration chamber based on contributing drainage area and stormwater storage volume to be provided (STEP 2013). It is assumed that 100 per cent of the pollutants will also be controlled by the Infiltration chamber.

A summary of stormwater storage capacity that would be required to replace services provided by each modeled natural asset under existing and future climate is presented in Table 8 below.

Natural asset type	Scenario	Asset and drainage area information			SWM capacity required (m^3)	SWM capacity required per unit area (area here refers to feature area plus drainage area) (m^3/ha)
		Feature Area (Ha)	Drainage area of feature (Ha)	Impervious-ness		
Palustrine wetland= Ken Whillans	Existing climate	1.58	1.98	5%	874	246
	Climate change				934	262
Isolated wetland	Existing climate	1.11	13.9	5%	5,528[2]	368
	Climate change				6,284	419
Riverine wetland= Ridge hill	Existing climate	12.08	2,643	34%	59,190	22
	Climate change				63,675	24
Forest	Existing climate	28.74	46.8	5%	26,550	351
	Climate change				29,400	389
Open green space	Existing climate	1.80	30.2	3%	4,020	126
	Climate change				4,303	134

Table 8: Stormwater storage volume requirement for modeled natural assets

A summary of the range of stormwater storage volume that would be required to replace services of all the natural assets in subwatersheds 13 and 5 under the two climate scenarios is presented in Table 9 and Table 10, respectively.

Natural asset type	Scenario	Number of natural assets	Total area of natural assets (ha)	Range of stormwater storage volume required (m^3)	Total stormwater storage volume required (m^3)
Palustrine wetlands	Existing climate	78	223.2 (0.17 – 17.8 ha)	96 - 9,802	123,170
	Climate change			103 – 10,474	131,628
Isolated wetlands	Existing climate	20	8.08 (0.14 – 1.11 ha)	694 – 5,528	40,180
	Climate change			789 – 6,284	45,675
Riverine wetlands	Existing climate	31	220.3 (0.29 – 27.6 ha)	1,406 - 135,123	1,078,920
	Climate change			1,513 – 145,369	1,160,735
Forests	Existing climate	215	1276 (0.39 – 131.7 ha)	362 - 121,650	1,178,870
	Climate change			401 -134,708	1,305,419
Open green spaces	Existing climate	25	228.7 (0.8 – 103.2 ha)	1,786 - 230,465	510,660
	Climate change			1,912 – 246,689	546,613

Table 9: Stormwater storage volume required for all natural assets in subwatershed 13

Natural asset type	Scenario	Number of natural assets	Total area of natural assets (ha)	Range of stormwater storage volume required (m^3)	Total stormwater storage volume required (m^3)
Palustrine wetlands	Existing climate	17	8.33 (0.07 – 1.23 ha)	39 - 679	4,600
	Climate change			41 – 725	4,913
Isolated wetlands	Existing climate	11	3.83 (0.03 – 0.96 ha)	149 – 4,775	19,049
	Climate change			170 – 5,428	21,654
Riverine wetlands	Existing climate	3	16.1 (0.91 – 12.1 ha)	4,457 - 59,187	78,925
	Climate change			4,795 – 63,675	84,910
Forests	Existing climate	55	213.5 (0.15 – 32.2 ha)	141 - 29,784	197,240
	Climate change			156 – 32,981	218,415
Open green spaces	Existing climate	146	347.3 (0.06 – 33.2 ha)	139 - 74,223	775,735
	Climate change			148 – 79,448	830,345

Table 10: Stormwater storage volume required for all natural assets in subwatershed 5

Results from this study indicate that forests and riverine wetlands would require the largest stormwater infrastructure at 1.4 million cubic metres and 1.2 million cubic metres, respectively, for the two subwatersheds. This is attributable not just to the amount of stormwater control these natural assets provide but also the total area they cover at the subwatershed scale: 1,490 hectares for forests and 236 hectares for riverine wetlands. Following close behind are open green spaces which cover a total area of 576 hectares and are estimated to require 1.3 million cubic metres of stormwater infrastructure. Despite being almost double the total area of riverine wetlands, open green spaces need less stormwater infrastructure because stormwater inflow to individual open green spaces is significantly smaller than inflow to individual riverine wetlands. Palustrine wetlands would require 0.1 million cubic metres of stormwater infrastructure. The total area covered by palustrine wetlands is 232 hectares. Isolated wetlands cover approximately 12 hectares of area and require total stormwater infrastructure capacity of 0.06 million cubic metres. Although isolated wetlands provide the highest level of stormwater services, as reflected in the stormwater management capacity per unit area shown in Table 8, the cumulative results do not reflect this due to the significantly smaller area covered by these features at the subwatershed scale.

Under the climate change scenario it has been estimated that performance of all natural assets remains largely unchanged (see Table 6 and Table 7). However, since the magnitude and intensity of rainfall is greater under climate change, the inflow to the natural assets will be larger, and a bigger stormwater management pond or infiltration chamber will be required to provide the same control as is being provided by existing natural assets under the climate change scenario.

7. Valuation of Natural Assets

The replacement cost method was used to estimate the value of natural assets. It is based on the assumption that the value of the natural assets is at least equal to the cost of replacing them with the engineered infrastructure capable of providing the same level of stormwater services[4].

The cost of constructing wet stormwater management pond was assumed to be $175 per cubic meter of storage (Jake Sahl et al., 2016)[5] The cost of constructing an infiltration chamber was used to determine the values of stormwater services provided by isolated wetlands. As explained in Section 6, isolated wetlands, which provide 100 per cent volume control, would need to be replaced with an infiltration chamber that would be sized to control all the volume that an isolated wetland is able to retain. The cost for infiltration chamber was assessed at $460/m^3 and was derived by using the LID costing tool[6].

Applying these costs to the stormwater pond storage volume estimates listed in Section 6, it was found that it would cost $514,898,155 under existing climate and $560,338,745 under climate change scenario to replace the flood protection and water quality control services provided by the natural assets in the East Credit subwatershed. For the Fletcher's Creek subwatershed, these services were estimated at $189,088,810 under existing climate and at $204,025,380 under the climate change scenario.

Values of NAs ($)	Sub 13	Sub 5
Total value under existing conditions	$514,898,155	$189,088,810
Total value under climate change	$560,338,745	$204,025,380
Difference in value	$14,936,570	$45,440,590

Table 11 Total value of stormwater services provided by all natural assets in subwatersheds 5 and 13

Table 12 shows the total value and per unit area value of stormwater services provided by different types of natural assets[7].

4 Only capital costs of constructed stormwater infrastructure were used for the valuation.

5 This estimate was obtained from the economic valuation study for the Town of Gibsons, BC (2016) and is within the reasonable range of cost estimates for similar facilities in Ontario, For example, Urban Stormwater Economics: A Comparative Cost-Benefit Study of Site Technologies & Strategies for the City of Toronto (2008): https://www2.daniels.utoronto.ca/sites/daniels.utoronto.ca/files/old/Kesik_TGDS_CB-Study_Oct2008_Appendix_D.pdf

6 Source: Sustainable Technologies Evaluation Program (2013). Low Impact Development Costing Tool Version 1.1. Downloaded from http://www.sustainabletechnologies.ca/wp/home/urban-runoff-green-infrastructure/low-impact-development/low-impact-development-life-cycle-costs/

7 Per ha values provided in this table are estimates for only two stormwater services provided by natural assets. These estimates are not intended to be used in trade-off decisions (e.g., land conversion) to assess comparative value of each asset

Natural asset type	Scenario	Total value of natural assets both Subs 5 & 13	SWM capacity per unit area[3]	Value of SWM services per unit area[4]
		$	m^3/ha	$/ha
Palustrine wetlands	Existing climate	22,359,925	246	43,050
	Climate change	23,894,500	262	45,850
Isolated wetlands	Existing climate	13,061,240	368[5] *(176.55)*	81,213
	Climate change	14,844,200	419 *(200.66)*	92,306
Riverine wetlands	Existing climate	202,623,225	22	3,850
	Climate change	217,988,400	24	4,200
Forests	Existing climate	240,821,875	351	61,425
	Climate change	266,669,200	389	68,075
Open green spaces	Existing climate	225,120,700	126	22,050
	Climate change	240,967,825	134	23,450

Table 12: Value of stormwater services per unit area

8. Modeling Limitations

Limitations need to be recognized with the modeling work presented in this report that can have an impact on the certainty of the results. It should be noted, however, that this was a pilot study to test the approach. More detailed data at the site and subwatershed scale can be used to better inform the modeling analysis and subsequently the decision-making process. Some of these limitations may already have been outlined in the preceding sections.

- The study did not entail a detailed discretized model. With limited resources and timelines, it was out of the scope of the current study to set up a fully discretized model. A catchment with natural assets was divided into hydrologic response units which were spatially lumped to simplify model set up. Due to spatial lumping, time of concentration—or the time it takes flows to reach the outlet—may not be a true representation of actual conditions. This affects peak flows as the time to peak for each catchment may be different. The peak inflow to the natural asset as a result may be underestimated or overestimated.
- It was assumed that no stormwater management control measures exist in the catchment of a natural asset. This may not be the case for an urban catchment where one or more stormwater management practices may be controlling flows and water quality prior to entering natural assets.
- The cumulative benefit of having natural assets upstream of other assets was not assessed in the current study. It was assumed that the drainage area of a natural asset does not contain any other natural assets which will provide significant quantity or quality control. For example, a wetland's catchment may include open green space or forests or other types of wetlands, but the storage and water quality control provided by these upland features is not considered in the results of that wetland.
- Wetlands have been modeled as a two component system with subsurface storage upstream of surface storage. As a result, seepage only occurs when the ground is not saturated. Once the ground is saturated or its infiltration capacity is exceeded, runoff enters the surface node and no seepage is assumed to occur from water that has moved to the surface node. In reality, seepage will occur from the ponded water as subsurface capacity becomes available due to deeper groundwater recharge. This modeling approach has likely resulted in an underestimation of the level of control the wetland is able to provide.
- It was assumed that volume infiltrated by a natural asset contributes zero pollutant loading. This may not be an accurate representation of pollutant removal by a natural asset because water moves through the subsurface and pollutants can be carried by groundwater to receiving channels. Water quality results presented in this study do not take into account pollutants leaving the natural asset through groundwater.
- Stormwater management infrastructure like wet ponds cannot be designed for the same water quality performance as most of the natural assets. Ponds are designed to only provide 80 per cent TSS removal. Therefore, value of some of the assets may be underestimated from a stormwater quality perspective.
- Although all natural assets provide some level of volume control, stormwater management ponds have only been sized for peak flow control and not volume retention. This is because ponds do not retain any water. The only water lost from a pond would be from evaporation and minimal seepage if pond is not lined; but this is very small in proportion to the total volume. Therefore, value of the assets may be underestimated in this study if infiltration and groundwater recharge are of concern.
- Only capital costs of constructed stormwater infrastructure were used for the assessment of stormwater services provided by natural assets, which could result in underestimated cost of grey infrastructure substitutes due to their maintenance costs and hence, underestimated value of natural assets.
- The model did not consider long-term impacts on ecological integrity from climate change or contaminated inputs

9. Next Steps

Pilot results demonstrated the importance of natural assets in regulating stormwater quantity and quality in the region. They also stressed the need for better understanding and stronger evidence of the benefits, costs and risks associated with managing natural assets within existing frameworks, plans and strategies. Based on the feedback received from the region and lower-tier municipalities, the key next steps were identified as follows[8]:

1. Completing an inventory of natural assets and producing a mapping tool to assist the region and the lower-tier municipalities in: a) scaling up results from the pilot to assess the value of stormwater management services provided by natural assets on a region-wide basis; b) estimating impacts of climate change on natural assets and the key services they deliver; and c) prioritizing restoration/management projects for these assets
2. Building site-specific business case(s) that will:
    - identify a set of best management practices and restoration options for key natural assets to maximize their civic functions
    - assess benefits associated with enhancement/restoration of natural assets for municipalities and local communities
    - provide life cycle cost comparison of natural assets versus built infrastructure to help municipalities to achieve optimal solutions with respect to municipal asset planning and service delivery and reduced vulnerability to climate change
    - provide recommendations on how to integrate natural asset considerations in municipal infrastructure planning and asset management frameworks

In addition to the key steps identified above, potential model refinements to address the limitations identified in sections 2.5, 3.5 and 8 can be performed, depending on staff time and other resource availability.

9.1 Beneficiary considerations

At the request of CVC, the MNAI technical team prepared an initial draft beneficiary considerations document to identify significant co-benefits of wetlands, forests and open green spaces in the Credit River watershed and the Region of Peel. Understanding the range of additional benefits provided by intact ecosystems, the range of beneficiaries, their estimated values and threats to the continued provision of services can assist with the development of a business case for the integration of natural assets into local asset management practices.

The following eight co-benefits were identified through the assessment:

- Climate regulation
- Water supply
- Habitat
- Air quality regulation
- Pollination

8 Contingent upon receiving funding requested under FCM's Municipalities for Climate Innovation Program or other external funding

- Recreation
- Amenity and cultural values
- Health and well-being

For further information, the full draft of the assessment is provided in Appendix C.

10. Summary and Conclusion

The pilot study demonstrated that natural assets provide stormwater quantity and quality control commensurate with engineered infrastructure and that they are resilient and continue to perform the same level of service under climate change conditions despite the higher volume and velocity of flows.

The above conclusion has been arrived at after modeling three different kinds of natural assets and assessing the volume and peak flow reduction for the 100-year storm, and TSS and TP load reduction on an average annual basis.

Study results indicate that all natural assets provide attenuation of the 100-year peak flows. Isolated wetlands, forests and palustrine wetlands provide the most benefit for peak flow attenuation at 100 per cent, 84 per cent and 69 per cent, respectively. Riverine wetlands are limited in their ability to attenuate flows due to the channel flow volume. Open green spaces are not able to attenuate flows to a great extent (9 per cent peak flow reduction achieved) because of less surface vegetation to provide interception of flows.

All features, except riverine wetlands, exceed the enhanced water quality performance requirement of 80 per cent TSS removal on an average annual basis. This is because most of the flows on an annual basis are retained by most of these features. The 90th-percentile storm in an average year is 25 mm and most of these natural assets have sufficient capacity to retain runoff generated by storms less than 25 mm. Riverine wetlands are able to provide good quality control for runoff from the direct drainage area but not as much for flows coming through the channel (35 per cent total removal of sediment).

Performance of existing natural assets under climate change was not affected, demonstrating the resilience of these assets under changing climate conditions. Grey stormwater infrastructure is not as resilient. The capacity required depends on inflow volume. Larger capacity of stormwater management infrastructure is required under climate change due to higher inflows from higher intensity and magnitude 2 – 100-year storms with climate change.

Stormwater storage volume required to replace stormwater services provided by existing natural assets ranged from 40 to 230,465 cubic metres. Under climate change conditions, stormwater storage volume required to replace stormwater services provided by existing natural assets ranged from 40 to 246,690 cubic metres.

Using the replacement cost valuation method, monetary value of the stormwater services provided by existing natural assets in the two subwatersheds was estimated at roughly CAD $704 million under current climate and CAD $764 million under climate change conditions. The difference in the value under existing and under climate change scenarios emphasized the increasing importance of natural assets in providing critical services to municipalities in the future and their important role in increasing resilience and reducing pressures on municipal infrastructure from climate change impacts.

References

1. Centre for Watershed Protection and US Forest Service (2008).Watershed Forestry Resource Guide. http://forestsforwatersheds.org/reduce-stormwater/

2. City of Toronto (2006).Wet Weather Flow Management Guidelines.*https://www1.toronto.ca/city_of_toronto/toronto_water/files/pdf/wwfm_guidelines_2006-11.pdf*

3. Charbonneau, C. (2016). Hydrologic Analysis for the Protection of Wetlands in Urban Development (master's thesis).University of Guelph, Guelph, Ontario, Canada.*https://atrium.lib.uoguelph.ca/xmlui/bitstream/handle/10214/9888/Charbonneau_Caroline_201608_MASc.pdf?sequence=1*

4. Credit Valley Conservation (1998). Credit Watershed Natural Heritage Project detailed methodology: Identifying, mapping, and collecting field data at watershed and subwatershed scales. Version 3, April 1998. 137p.

5. Ontario Ministry of Natural Resources, Science and Technology Unit (OMNRSTU) (1996). Southern Region Ecological Land Classification: Community Catalogue.

6. Credit Valley Conservation (2005). Final Report *Fletcher's Creek Flood Line Mapping Study.*

7. Credit Valley Conservation (2007). Characterization Report *East Credit Subwatershed Study. http://www.creditvalleyca.ca/wp-content/uploads/2011/10/FINALPhase1-Sub13.pdf*

8. Credit Valley Conservation (2010).Ecological Goods and Services*. http://www.creditvalleyca.ca/watershed-science/our-watershed/ecological-goods-services/*

9. Credit Valley Conservation (2012).Draft Fletcher's Creek Restoration Study Characterization Report*. http://www.creditvalleyca.ca/wp-content/uploads/2015/05/DRAFT-Fletchers-Creek-Characterization-Report.pdf*

10. Credit Valley Conservation (2016). Draft Report *Ecohydrological analysis of groundwater data from the CVC wetland at Ken Whillans RMA. http://www.creditvalleyca.ca/wp-content/uploads/2015/05/DRAFT-Fletchers-Creek-Characterization-Report.pdf*

11. International Stormwater BMP Database (2014). International Stormwater BMP Database Pollutant Category Statistical Summary Report Solids, Bacteria, Nutrients, and Metals. *http://www.bmpdatabase.org/Docs/2014%20Water%20Quality%20Analysis%20Addendum/BMP%20Database%20Categorical_StatisticalSummaryReport_December2014.pdf*

12. Journal of Water Management Modeling (2015). Renewal and Update of MTO IDF Curves: Defining the Uncertainty. *https://www.chijournal.org/C386*

13. Lee, H.T., Bakowsky, W.D., Riley, J., Bowles, J., Puddister, M., Uhlig, P., and McMurray, F.S. (1998). Ecological land classification of southern Ontario: First approximation and its application. Ontario Ministry of Natural Resources, Southcentral Science Section, Science Development and Transfer Branch.SCSS Field Guide FG-02.

14. Ministry of Environment and Climate Change (2003). Stormwater Management Planning and Design Manual. *https://www.ontario.ca/document/stormwater-management-planning-and-design-manual/stormwater-management-plan-and-swmp-design#section-0*

15. Ministry of Natural Resources and Forestry (2014).Ontario Wetland Evaluation System.*http://files.ontario.ca/environment-and-energy/parks-and-protected-areas/ontario-wetland-evaluation-system-southen-manual-2014.pdf*

16. Ontario Ministry of Transportation (2016). IDF Curves finder. *http://www.mto.gov.on.ca/IDF_Curves/map_acquisition.shtml*

17. Region of Peel (2011). Credit River Watershed and Region of Peel Natural Assets Inventory Volume I. https://www.peelregion.ca/planning/pdc/data/monitoring/pdfs/Volume-1.pdf

18. Municipal Natural Asset Initiative (2017). Defining and Scoping Municipal Natural Assets. *http://institute.smartprosperity.ca/sites/default/files/finaldesignedsept18mnai.pdf*

19. Sahl, J., Hamel, P., Molnar, M., Thompson, M., Zawadzki, A. and Plummer, B. (2016). Economic Valuation of the stormwater management services provided by the Whitetower Park ponds, Gibsons, BC

20. Sustainable Technologies Evaluation Program (STEP) (2013). Low Impact Development Costing Tool Version 1.1. Downloaded from http://www.sustainabletechnologies.ca/wp/home/urban-runoff-green-infrastructure/low-impact-development/low-impact-development-life-cycle-costs/

21. University of Guelph (2016). Hydrologic Analysis for the Protection of Wetlands in Urban Development.

22. US EPA (2015). Storm Water Management Model User's Manual Version 5.1.

Appendix A: Natural Asset Description

Wetlands are land types that are commonly referred to as swamps, fens, marshes and bogs. They occur intermittently across the landscape, along lakes, rivers and streams, and in other areas where the water table is close to the surface. According to the Ontario Wetland Evaluation System (OWES) (MNRF 2014), the physiographic position of a wetland in the landscape defines its type. Four types of wetlands have been defined in the OWES—isolated, palustrine, riverine and lacustrine. Lacustrine wetlands are associated with lakes and are not included in this study because no such wetlands exist in the study area.

Palustrine wetlands are defined either by absent or intermittent inflow and either intermittent or permanent outflow (see Figure A-1). In wetlands where a small intermittent stream joins a large permanent stream or river, all of the wetland area which drains into the small stream is palustrine, but the part adjacent to the larger permanent stream or river is riverine.

Isolated wetlands are defined as wetlands that generate no surface outflow because all of the inflow is stored and/or lost through infiltration and evaporation (See Figure A-2). The sources of inflow to isolated wetlands can include precipitation, diffuse overland flow and occasional groundwater inflows. OWES recognizes that isolated wetlands, because they have no surface outflow, are 100 per cent efficient at attenuating flood crests. If isolated wetlands are removed and their storage capacity lost, there is an increased risk of flooding to areas downstream of such wetlands.

Riverine wetlands include the channel of continuously moving water to the 2 m depth, as well as adjacent wetlands and normal flood plains of rivers and permanent streams (if flow is not permanent then the wetland is palustrine) (see Figure A-3).

Forests or woodlands or woodlots are any spaces dominated by trees. Trees and forests reduce stormwater runoff by capturing and storing rainfall in the canopy and releasing water into the atmosphere through evapotranspiration. In addition, tree roots and leaf litter create soil conditions that promote the infiltration of rainwater into the soil. This helps to replenish our groundwater supply and maintain stream flow during dry periods. The presence of trees also helps to slow down and temporarily store runoff, which further promotes infiltration, and decreases flooding and erosion downstream. Trees and forests reduce pollutants by taking up nutrients and other pollutants from soils and water through their roots, and by transforming pollutants into less harmful substances (Center for Watershed Protection and US Forest Service 2008).

Open green spaces are spaces partly or completely covered with grass, trees, shrubs, or other vegetation. They can include parks, community gardens, and cemeteries. Such spaces provide pervious surfaces in otherwise urbanized catchments and stormwater draining to these spaces has a chance to be filtered and infiltrated before reaching receiving streams.

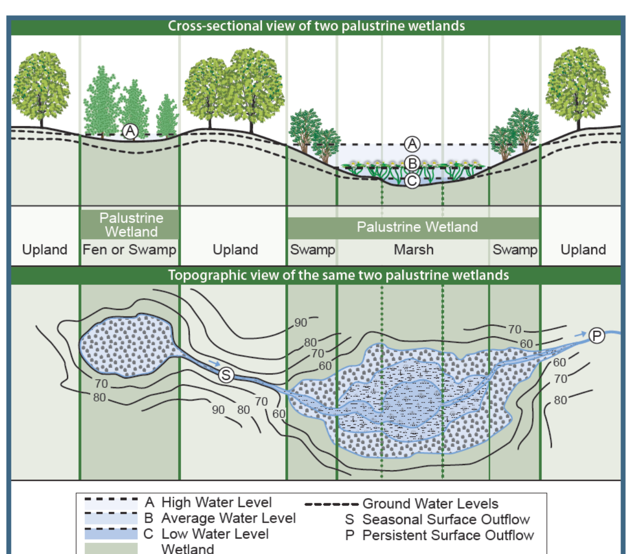


Figure A-1: Classification of palustrine wetlands (MNRF 2014)

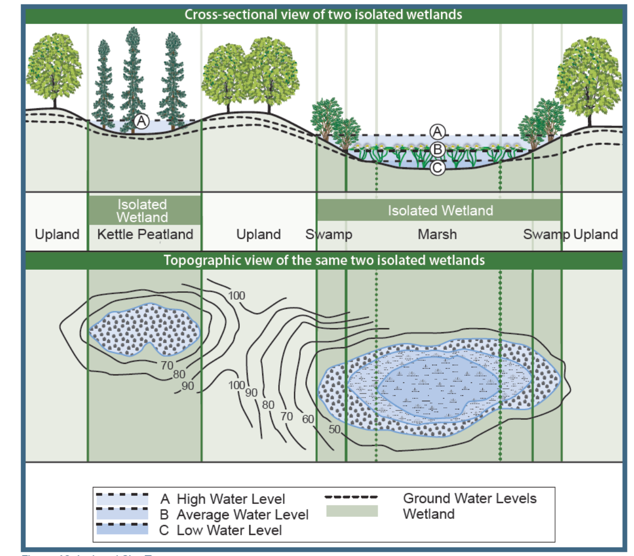


Figure A-2: Classification of isolated wetlands (MNRF 2014)

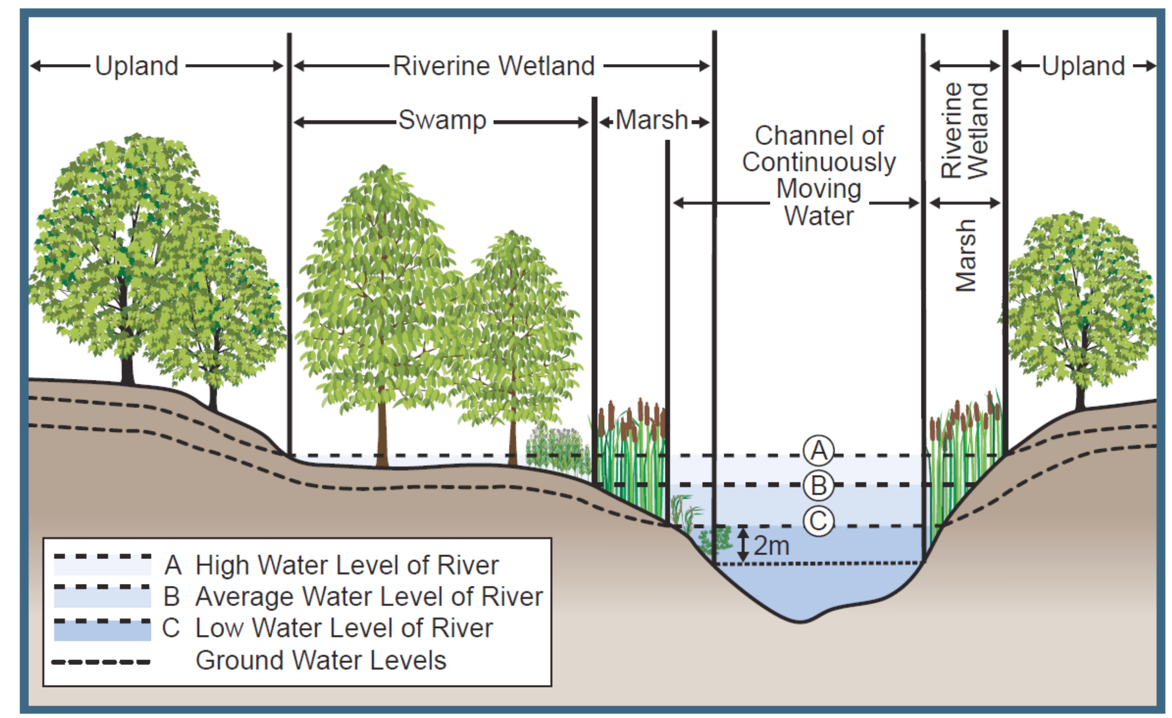


Figure A-3: Classification of riverine wetlands (MNRF 2014)

Appendix B: Natural Assets

Model input parameters

Table B-1: Rainfall information for the 100-year storm

Climate scenario*	Average rainfall intensity (mm/h)	Rainfall depth (mm)
2010	5.2	124.5
2065	5.5	132.0

*IDF curves based on Toronto Pearson International Airport data, retrieved from MTO's IDF curve look up tool. Existing climate based on year 2010. 2065 used for future climate scenario. The 100 year 24 hour SCS storm distribution is used.

Table B-2: Average daily evaporation based on month

Month	Monthly evaporation average (mm/day)
January	0.03
February	0.04
March	0.29
April	1.13
May	2.45
June	3.77
July	4.35
August	3.84
September	2.67
October	1.35
November	0.47
December	0.10

Table B-3: Catchment area of Ken Whillans wetland

Catchment land use	Area (ha)	Average Slope	Soil
Cultural Meadow	0.753	3.5%	Loam
Cultural Woodland	0.0782	3.5%	Loam
Deciduous Swamp	0.798	3.5%	Loam
Rural Development	0.305	2%	Loam
Thicket Swamp	0.0473	3.5%	Loam

Table B-4: Green-Ampt properties for different soil types

Soil Type	Soil capillary suction head (mm)	Soil saturated hydraulic conductivity (mm/h)	Initial moisture deficit (fraction)
Sand	49	120	0.375
Loamy sand	61	30	0.332
Silt loam	170	6.6	0.217
Loam	88.9	3.3	0.310

Table B-5: Aquifer properties for catchment area and for natural assets

Aquifer properties*	Catchment	Natural Asset
Porosity (fraction)	0.35	0.35
Wilting point (fraction)	0.116	0.116
Field capacity (fraction)	0.232	0.232
Conductivity (mm/h)	3.302	3.302
Conductivity slope (fraction)	5	5
Tension slope (fraction)	1	1
Upper evaporation fraction	0.6	0.6
Lower evaporation depth (m)	0.7	2.2
Lower groundwater loss rate (mm/h)	0.05	0.05
Bottom elevation of aquifer (m)	269	269
Initial water table elevation (m)	270.33	269.95
Initial unsaturated zone moisture content (fraction)	0.2	0.2

* All modeled natural assets except Ridge Hill wetland use these parameters to represent the aquifer

Table B-6: Groundwater properties for catchment area and for natural asset

Groundwater properties	Catchment	Natural Asset
A1 coefficient	0.00001	0.001
B1 exponent	2	2
A2 coefficient	0	0
B2 exponent	0	0
A3 coefficient	0	0

Table B-7: Catchment area of isolated wetland

Catchment land use	Area (ha)	Average Slope	Soil
Deciduous forest	0.028	3.5%	Sand
Deciduous forest	0.642	3.5%	Loamy sand
Rural development	0.138	2%	Silt loam
Rural development	0.312	2%	Sand
Non-intensive agriculture	1.104	3.5%	Sand
Non-intensive agriculture	10.703	3.5%	Loamy sand
Regional road	0.023	2%	Silt loam
Regional road	0.053	2%	Sand
Regional road	0.911	2%	Loamy sand

Table B-8: Catchment area of Ridge hill wetland

Catchment land use	Area (ha)	Average Slope	Soil
Indirect drainage area			
Agriculture	441.52	3.5%	clay loam
Agriculture	10.25	3.5%	silt loam
Agriculture	6.18	3.5%	silty clay loam
City park	110.91	3.5%	clay loam
City park	16.66	3.5%	silt loam
City park	0.82	3.5%	silty clay loam
Construction	188.20	3.5%	clay loam
Construction	4.37	3.5%	silt loam
Construction	3.03	3.5%	silty clay loam
Forest	177.89	3.5%	clay loam
Forest	35.40	3.5%	silt loam
Forest	10.57	3.5%	silty clay loam
High-density residential	64.42	2%	clay loam
High-density residential	4.17	2%	silt loam
High-rise residential	10.32	2%	clay loam
Highway	63.89	2%	clay loam
Highway	3.38	2%	silt loam
Highway	1.94	2%	silty clay loam
Industrial	239.94	2%	clay loam
Industrial	6.47	2%	silt loam
Institutional	56.49	2%	clay loam
Institutional	3.99	2%	silt loam
Institutional	0.66	2%	silty clay loam
Medium-density residential	143.67	2%	clay loam
Medium-density residential	11.63	2%	silt loam
Medium-density residential	4.78	2%	silty clay loam
Mixed residential	13.65	2%	clay loam
Mixed residential	0.39	2%	silt loam
Open space	43.04	3.5%	clay loam
Open space	3.59	3.5%	silt loam
Open space	0.43	3.5%	silty clay loam
Residential estate	801.01	2%	clay loam
Residential estate	53.54	2%	silt loam
Residential estate	29.27	2%	silty clay loam
Road	21.15	2%	clay loam
Road	1.13	2%	silt loam
Road	0.34	2%	silty clay loam
Wetland	10.68	1%	clay loam
Wetland	1.77	1%	silt loam
Wetland	2.85	1%	silty clay loam
Direct drainage to wetland			
City park	1.61	3.5%	clay loam
City park	0.11	3.5%	silt loam
City park	0.55	3.5%	silty clay loam
Forest	1.34	3.5%	clay loam
Forest	0.11	3.5%	silt loam
Forest	9.64	3.5%	silty clay loam
Institutional	1.56	2%	Clay loam
Medium-density residential	0.18	2%	Clay loam
Residential estate	11.19	2%	clay loam
Residential estate	7.61	2%	silt loam
Residential estate	3.56	2%	silty clay loam
Wetland	0.82	1%	Silt clay loam

Table B-9: Aquifer properties for Ridge hill wetland

Aquifer properties	Catchment	Ridge hill wetland
Porosity (fraction)	0.4	0.38
Wilting point (fraction)	0.116	0.187
Field capacity (fraction)	0.232	0.310
Conductivity (mm/h)	3.302	1.016
Conductivity slope (fraction)	5	5
Tension slope (fraction)	1	1
Upper evaporation fraction	0.8	0.8
Lower evaporation depth (m)	0.7	2.2
Lower groundwater loss rate (mm/h)	0.05	0.07
Bottom elevation of aquifer (m)	210	209.7
Initial water table elevation (m)	210.5	209.75
Initial unsaturated zone moisture content (fraction)	0.2	0.2

Table B-10: Catchment area of forest

Catchment land use	Area (ha)	Average Slope	Soil
Cultural woodland	1.985	5%	Loamy sand
Cultural woodland	0.212	5%	Silt loam
Rural development	0.269	5%	Loamy sand
Rural development	0.605	5%	Silt loam
Deciduous forest	15.14	5%	Loamy sand
Deciduous forest	2.74	5%	Silt loam
Mixed forest	0.903	5%	Loamy sand
Mixed forest	0.849	5%	Silt loam
Coniferous plantation	6.02	5%	Loamy sand
Coniferous plantation	0.007	5%	Silt loam

Table B-11: Catchment area of open green space

Catchment land use	Area (ha)	Average Slope	Soil
Coniferous plantation	0.00	3%	silt loam
Coniferous plantation	0.04	3%	loamy sand
Coniferous plantation	0.00	4%	silt loam
Coniferous plantation	0.04	4%	loamy sand
Coniferous plantation	0.01	5%	silt loam
Coniferous plantation	0.79	5%	loamy sand
Cultural meadow	0.17	3%	loamy sand
Cultural meadow	0.18	4%	loamy sand
Cultural meadow	2.31	5%	loamy sand
Cultural savannah	0.01	3%	silt loam
Cultural savannah	0.00	3%	loamy sand
Cultural savannah	0.03	4%	silt loam
Cultural savannah	0.00	4%	loamy sand
Cultural savannah	0.41	5%	silt loam
Cultural savannah	0.63	5%	loamy sand
Cultural woodland	0.11	3%	loamy sand
Cultural woodland	0.31	4%	loamy sand
Cultural woodland	2.19	5%	loamy sand
Intensive agriculture	1.79	3%	loamy sand
Intensive agriculture	0.00	4%	silt loam
Intensive agriculture	2.58	4%	loamy sand
Intensive agriculture	0.00	5%	silt loam
Intensive agriculture	12.68	5%	loamy sand
Manicured open space	0.02	3%	silt loam
Manicured open space	0.08	3%	loamy sand
Manicured open space	0.02	4%	silt loam
Manicured open space	0.12	4%	loamy sand
Manicured open space	0.21	5%	silt loam
Manicured open space	1.35	5%	loamy sand
Non-intensive agriculture	0.09	3%	loamy sand
Non-intensive agriculture	0.13	4%	loamy sand
Non-intensive agriculture	1.40	5%	loamy sand
Regional road	0.02	3%	loamy sand
Regional road	0.05	4%	loamy sand
Regional road	0.18	5%	loamy sand
Rural development	0.01	3%	silt loam
Rural development	0.08	3%	loamy sand
Rural development	0.00	4%	silt loam
Rural development	0.15	4%	loamy sand
Rural development	0.07	5%	silt loam
Rural development	1.94	5%	loamy sand

Table B-12: Key properties of different land uses

Land use type	Imperviousness	Manning's roughness for pervious / impervious areas	Depression storage for pervious/ impervious areas (mm)	Total suspended solids EMC (mg/L)	Total Phosphorus EMC (mg/L)
Agriculture, intensive	0%	0.17	5.08	100.00	0.2
Agriculture, non-intensive	0%	0.13	5.08	100.00	0.2
Wet meadow	0%	0.41	5.08	100.00	0.2
Commercial/industrial	95%	0.15/ 0.011	2.54/ 1.27	67.00	0.3
Educational/institutional	50%	0.15/ 0.011	2.54/ 1.27	63.00	0.36
Construction	35%	0.15/ 0.011	2.54/ 1.27	331.00	0.39
Cultural meadow	0%	0.41	5.08	55.00	0.2
Cultural savannah	0%	0.41	5.08	55.00	0.2
Cultural thicket	0%	0.8	7.62	55.00	0.2
Cultural woodland	0%	0.8	7.62	55.00	0.2
Forest, deciduous	0%	0.8	7.62	55.00	0.2
Forest, mixed	0%	0.8	7.62	55.00	0.2
Open space, commercial/ industrial	0%	0.15	5.08	70.00	0.12
Open space, institutional	0%	0.15	5.08	70.00	0.12
Open space, other	0%	0.15	5.08	70.00	0.12
Open space, private	0%	0.15	5.08	70.00	0.12
Open space, recreational	0%	0.15	5.08	70.00	0.12
Marsh	0%	0.65	6.5	9.43	0.1
Plantation, coniferous	0%	0.8	7.62	55.00	0.2
Plantation, deciduous	0%	0.8	7.62	55.00	0.2
Plantation, mixed	0%	0.8	7.62	55.00	0.2
Development, rural	30%	0.15/ 0.011	2.54/ 1.27	91.00	0.36
Swamp, deciduous	0%	0.65	6.5	9.43	0.1
Swamp, thicket	0%	0.65	6.5	9.43	0.1
Collector	90%	0.15/ 0.011	2.54/ 1.27	84.00	0.16
Highway	90%	0.15/ 0.011	2.54/ 1.27	331.00	0.39
Railroad	80%	0.15/ 0.011	2.54/ 1.27	70.00	0.12
Regional road	50%	0.15/ 0.011	2.54/ 1.27	331.00	0.39
Residential, high density	65%	0.15/ 0.011	2.54/ 1.27	91.00	0.36
Residential, high rise	50%	0.15/ 0.011	2.54/ 1.27	91.00	0.36
Residential, low density	30%	0.15/ 0.011	2.54/ 1.27	91.00	0.36
Residential, medium density	50%	0.15/ 0.011	2.54/ 1.27	91.00	0.36
Residential, mixed	45%	0.15/ 0.011	2.54/ 1.27	91.00	0.36

Model Schematic

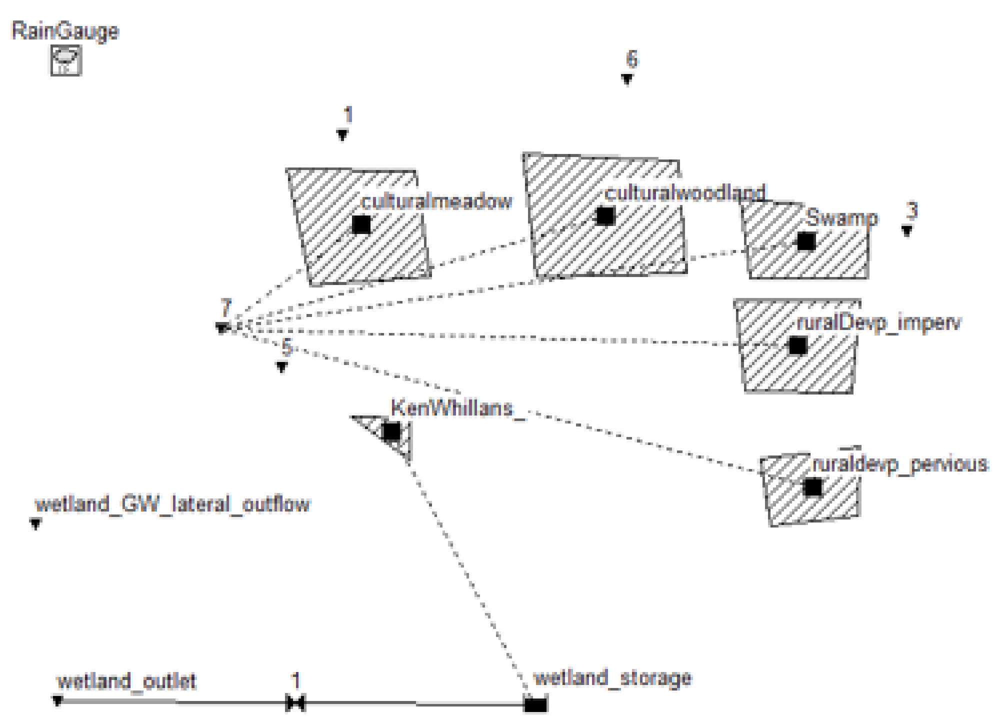


Figure B-1: Model schematic for Ken Whillans (palustrine) wetland

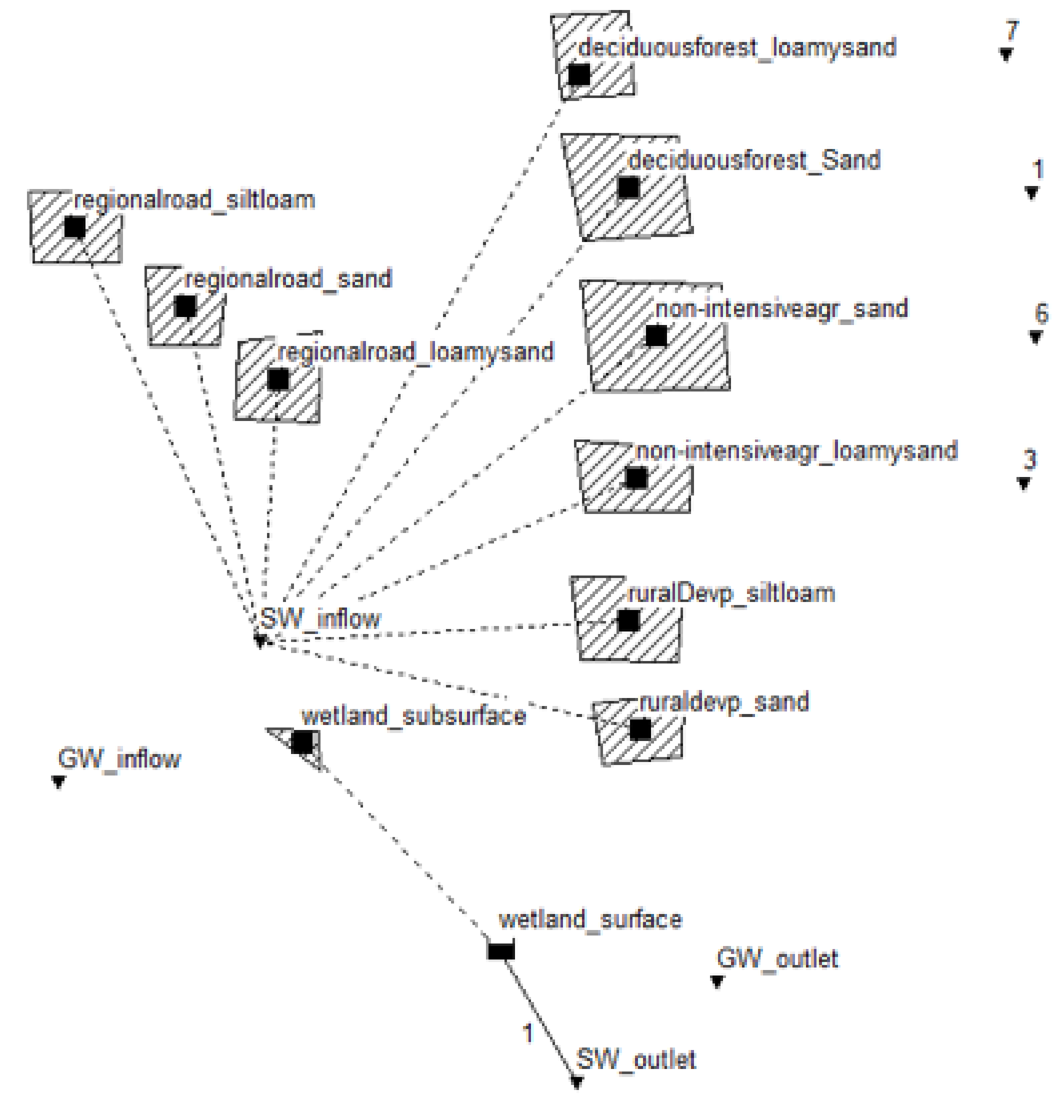


Figure B-2: Model schematic for an isolated wetland

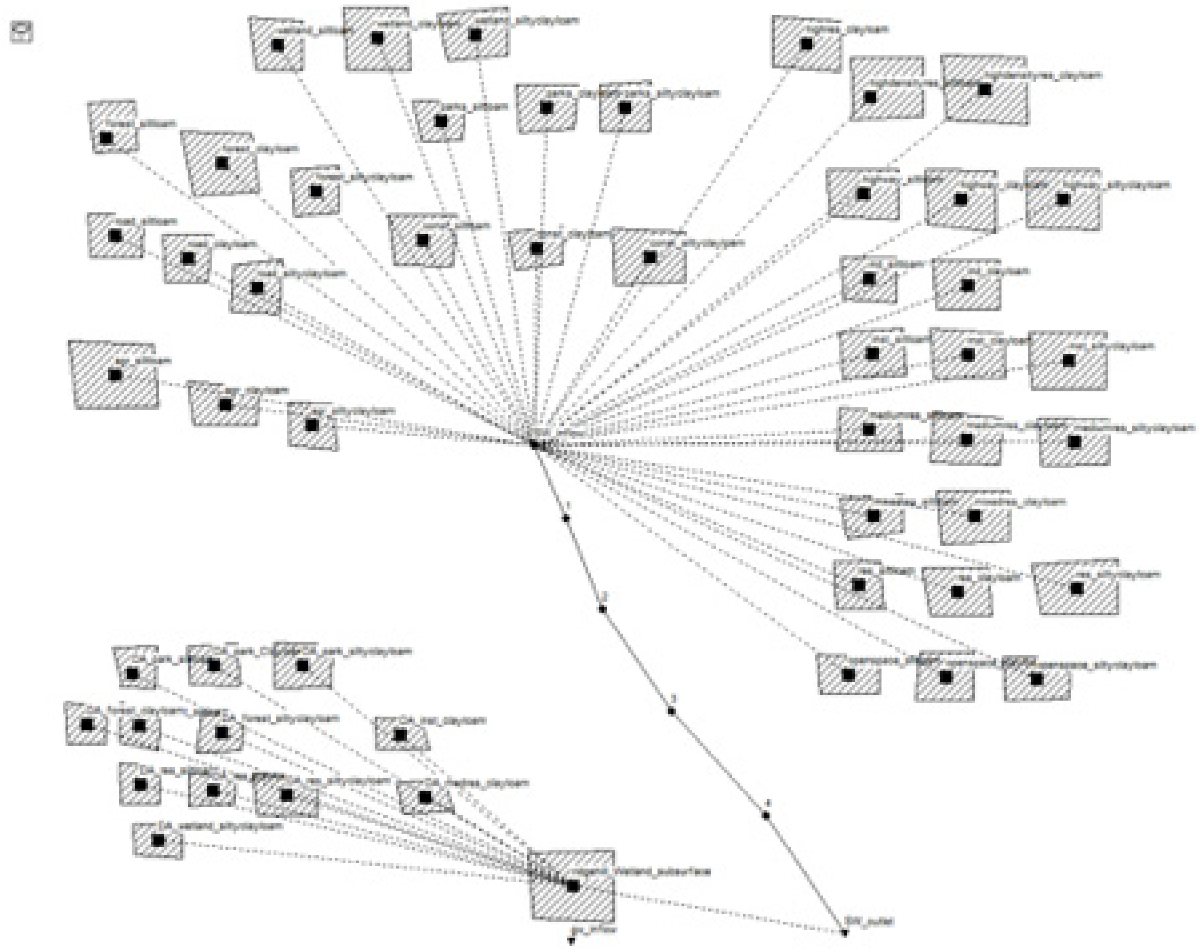


Figure B-3: Model schematic for Ridge Hill (riverine) wetland

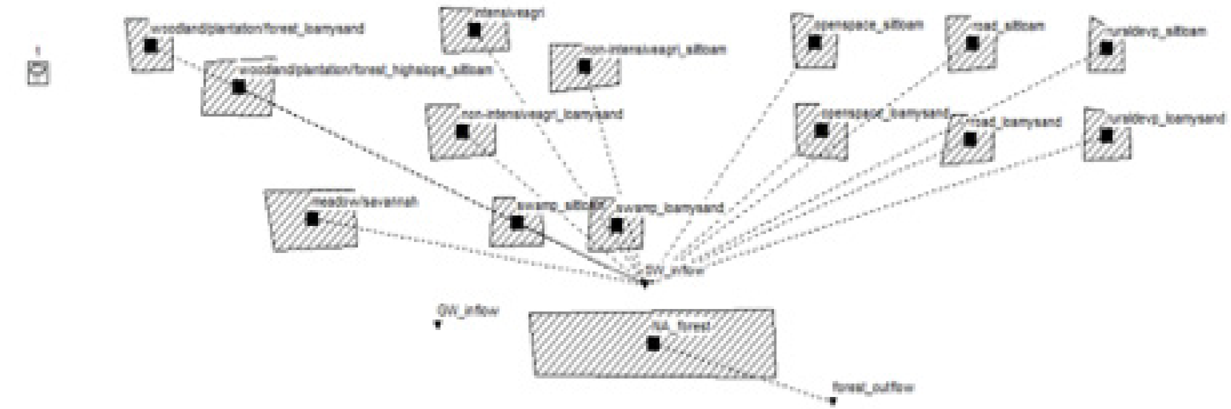


Figure B-4: Model schematic for a forest

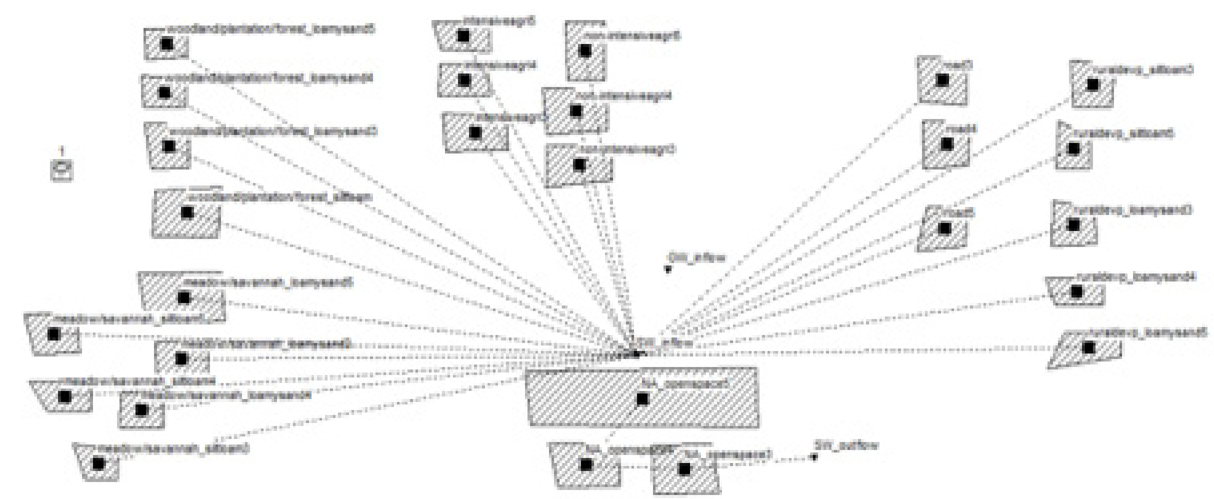


Figure B-5: Model schematic for an open green space

Appendix C: Beneficiary Considerations: Co-benefits of wetlands, forests and open green spaces

Draft prepared by Michelle Molnar, Municipal Natural Assets Initiative

Context: In 2017, Credit Valley Conservation (CVC) completed a study of the stormwater management-related values of natural assets in two pilot subwatersheds of the Credit River watershed (CRW) within the Region of Peel boundaries. Following the pilot results, the Region of Peel and CVC are considering extending the study to assess the stormwater services across the entire region. This draft beneficiary considerations document identifies significant co-benefits of wetlands, forests and open green spaces in the Credit River watershed and the Region of Peel. Understanding the range of additional benefits provided by intact ecosystems, the range of beneficiaries, their estimated values and threats to the continued provision of services can assist with the development of a business case for the integration of natural assets into local asset management practices.

In developing the following suite of co-benefits for discussion, consideration has been given to CVC existing research on ecosystem services (https://www.cvc.ca/egs), reports prepared for the Friends of the Greenbelt Foundation, as well as the latest literature on connecting ecosystem services to beneficiaries. Every effort was made to utilize existing data, but it should be noted that some data may be out of date due to changes to land use, degradation, or changes to environmental management.[9]

Key threats to the provision of ecosystem services in the Region of Peel:

Population growth

Peel Region is the second largest municipality in Ontario after Toronto and one of the fastest growing municipalities in Ontario. Between 2011 and 2016, the Region of Peel grew from 1,350,000 to 1,438,000 people (1).

In the Credit River watershed alone, the population is expected to reach slightly fewer than one million people by 2018, which corresponds to an 18 per cent increase from 2008; whereas in Ontario, the expected population increase for that time period is 13 per cent (2). This increase in population will exacerbate the threats of land use change and urban development, climate change and pollution.

Land use change and urban development

The conversion of rural landscapes to urban landscapes is a significant threat to watershed health in the Credit River watershed. Impacts include increased wastewater disposal, increased stormwater run-off, higher peak river flows, increased sediment erosion, degradation of aquatic habitats, increased water temperatures, and reduced groundwater discharge and recharge.

The loss of pervious surfaces generally implies a complete loss of the ecological services of the converted landscape and a reduction in the wider ecosystem functioning. As of 2011, an estimated 28 per cent of the watershed land use was classified as impervious (3). Taking future developments into account, the percentage of impervious areas is anticipated to increase.

Climate change: An assessment of the most significant climate change issues forecasted for southern Ontario include water shortages, lower Great Lakes water levels, flooding, forest fires, reduced agricultural production, damages to infrastructure and property, power outages and outbreaks of water-borne diseases (4). The degree to which the region will be affected by such issues is strongly influenced by its approach to adaptation.

The regulating services provided by ecosystems are critical for climate change mitigation, adaptation and disaster risk reduction. Examples of these services include climate and water regulation, protection from natural hazards (e.g. floods), carbon sequestration and storage, water and air purification, and disease and pest regulation. Ecosystem management is an important component of climate change strategy as it increases the resilience of natural systems and human communities to climate change impacts (5).

9 All values have been adjusted to 2017 Canadian dollars.

Waste and pollution: Urban and rural waste and pollution occurs regularly throughout the watershed. In rural areas these pollutants include farm pesticides, herbicides and fertilizers as well as wastes from faulty septic systems and improperly handled manure. In urban areas, the pollutants include oil, pet waste, fertilizers, pesticides, salt and treated human waste from sewage treatment plants (3).

Table C-1 Co-benefits of wetlands, forests and open green space

1. Climate Regulation	
Ecosystem service description	Ecosystems play an important role in moderating local weather and influence climate locally, regionally, and globally. Ecosystems influence global climate by emitting greenhouse gases to or by absorbing greenhouse gases from the atmosphere. The reflective properties of the Earth's surface, affected by ecosystem properties, such as the amount, type and structure of the vegetation and the amount of surface water, influence the amount of incoming solar energy that is absorbed or reflected back to space. Certain types of ecosystems (e.g., prairie grasslands, forests, wetlands, bogs) serve as important stores that lock up greenhouse gases from the atmosphere. Plants and marine algae remove and sequester carbon dioxide in their tissues thus influencing global temperatures. How the climate is regulated by ecosystems impacts humans in a variety of ways, for example, by altering food production conditions, controlling humidity levels, and influencing storm intensity. (6)
Context	Existing CVC research has considered the capacity and estimated value of forests, wetlands and other natural and semi-natural spaces for carbon regulation in the CRW. Results indicated that the annual removal of carbon dioxide is approximately 0.75 tonnes per hectare of forest and 0.375 tonnes of carbon per hectare of meadows (7). Further analysis of the carbon storage in forests in the CRW estimated that 13,326 tonnes of carbon are stored annually, for a total of 6.52 million tonnes of carbon storage (8).
Affected regions, industries, &/or populations	All regions and population groups within the Region of Peel and the CRW are impacted by climate change. The lower portions of the watershed have lost more natural areas compared to the middle and upper portions of the watershed due to urbanization. The remaining forests, wetlands, and green spaces have heightened importance for climate adaptation. The middle and upper portions of the watershed support agricultural economy, which may experience reduced agricultural production.
Values from existing literature (2017 dollars)	Wetlands: The annual value of wetlands for climate regulation is estimated at $9.7 million. (7) Forests: Estimated annual value of forest for climate regulation (sequestration & storage) is $19 million. (7) Meadows: The annual value of meadows for climate regulation was estimated at $5.7 million. (7)
Key threats to climate regulation services	Loss of ecosystems due to land use change and urban development. In particular, it is estimated that up to 25 to 50 hectare of forest can be lost to development in the CRW each year. (8)

2. Water Supply	
Ecosystem service description	Fresh water is fundamental to life and is consumed by humans for drinking, irrigation, sanitation, waste management, and industrial use. Fresh water is a necessary input to the production of foods and fibres, and used for many essential and non-essential activities. (6)
Context	There are two main sources of drinking water for the residents of the Credit River watershed: Lake Ontario for people who live in Mississauga and Brampton, and groundwater for the remaining communities in the middle and upper portions of the watershed. Those in the middle and upper portions of the watershed depend on the health of forests and wetlands that continue to filter and replenish groundwater supplies. If these services were no longer available, the next most likely supply of water would be Lake Ontario. The estimated cost to replace this service in Caledon alone is $118 million (2017 CAD). (7) Seasonal water shortages have been documented in the Peel Region. Future climate change projections warn of decreased groundwater recharge, which is of particular concern for shallow aquifers. Projections also point to lower lake levels due to increased evaporation and timing of precipitation. Source water protection is a crucial adaptation measure. (4)
Affected regions, industries, &/or populations	Residents of the middle and upper portions of the Credit River watershed. Shallow wells in this region are sensitive to low water or drought conditions. Residents of the lower watershed who access water from Lake Ontario via shallow water intakes or pipelines designed for high historical water levels may experience problems resulting from more frequent low water levels. (4)
Values from existing literature	Wetlands: The annual value of wetlands in the CRW for water supply was estimated at $30.7 million. (7) Forest: The annual value of forests in the CRW for water supply was estimated at $81.5 million. (7)
Key threats	Waste and pollution Climate change

•

3. Habitat	
Ecosystem service description	Habitats provide everything that an individual plant or animal needs to survive: food, water, and shelter. Each ecosystem provides different habitats that can be essential for a species' lifecycle. Migratory species, including birds, fish, mammals, and insects, all depend upon multiple ecosystems during their migrations. (6)
Context	CVC has tracked species within the Credit River watershed. Although inventories are on-going, the following has been identified within its boundaries. (9) 264 species of birds 79 fish species 55 species of mammals 5 species of turtles 7 kinds of snakes 17 amphibians (frogs, toads, salamanders & newts) 1420 species of plants The Credit River watershed is home to at least 44 Species At Risk (SAR), including 24 bird species, 5 plant species, 4 fish species, and 3 turtle species.
Affected regions, industries, &/or populations	The lower portion of the watershed has experienced habitat loss due to high levels of urban development, whereas the middle and upper portions of the watershed have lost habitat due to agricultural land conversion. CVC research has estimated that 48 per cent (13,331 acres) of wetlands in the CRW have been lost or degraded since 1954. The leading causes of this decline include expansion of urban areas, agriculture and industrial developments. (10)
Values from existing literature	Wetlands: The annual value of wetlands for habitat was estimated at $1.05 million. (7) Forests: The annual value of woodlots for habitat was estimated at $1.9 million. (7) Meadows: The annual value of meadows for habitat was estimated at $1.8 million. (7)
Key threats	Climate change Land use change and urban development Waste and pollution

4. Air Quality Regulation	
Ecosystem service description	The maintenance of good air quality relies on ecosystems to exchange chemicals with the atmosphere through bio-geochemical cycles. Human health is directly impacted by air that is polluted, for example, through burning fossil fuels or industrial emissions. Air quality regulation by ecosystems ensures numerous benefits, including clean, breathable air and the prevention of respiratory and cardio-vascular diseases. (6)
Context	Higher temperatures associated with climate change are expected to significantly impact air quality. The Ontario Medical Association (2005) has estimated that the annual illness costs of air pollution in Ontario include 5,800 premature deaths, more than 1,600 hospital admissions, almost 60,000 emergency room visits and 29 million minor illness days. The number of premature deaths may exceed 10,000 by 2026. (11) Urban heat island effect can produce temperatures of up to 3°C warmer than surrounding rural areas. The number of days with Humidex Advisories is projected to double by 2050, leading to an increase in the number of heat-related illnesses and deaths.
Affected regions, industries, &/or populations	• Vulnerable populations impacted by poor air quality • Agricultural crop production can be reduced by air pollution
Values from existing literature	Forests: The annual value of forests for gas regulation was estimated at $6.9 million. (7)
Key threats	• Waste and pollution • Climate change

5. Pollination	
Ecosystem service description	Most plants require pollination to reproduce. Natural pollination occurs primarily by insects, and also by wind, birds, and bats. Changes to ecosystems and impacts to pollinator species from human activity alter the abundance and distribution of pollinators and hence their effectiveness. (6)
Context	The annual value of agricultural crops in the CRW is estimated at $9.8 million. Most of these crops would not exist without the pollination services of insects that are estimated to be almost $4.6 million per year. (7)
Affected regions, industries, &/or populations	Middle and upper portions of watershed.
Values from existing literature	Forest: The annual value of forests for pollination was estimated at $1.3 million (7). Meadows: The annual value of meadows for pollination was estimated at $0.8 million. (7)
Key threats	Land use change and urban development Climate change

6. Recreation	
Ecosystem service description	Nature-based recreation and leisure are highly valued aspects of life for people around the world, whether in urban, rural or remote wilderness settings. These activities are all dependent on the direct experience of nature and engagement with it in some form. They provide significant quality-of-life benefits, including physical, psychological, and emotional well-being. These activities generate direct economic benefits to society, but can be a contributing factor to ecosystem degradation if not wisely managed. (6)
Context	The Credit River watershed is home to a wide variety of recreational activities including recreational fishing, hiking (particularly along the Bruce Trail), and time in parks, forests and conservation areas. (7) Anticipated climate change impacts include decreased boating opportunities due to navigation difficulties owing to low water levels and reduced recreational fishing as cold-water species (e.g. lake trout) will decline in number. Other warm weather recreational opportunities, such as golf and beach visits, will generally benefit from longer seasons. (4)
Affected regions, industries, &/or populations	Recreational fishery (particularly for cold-water species) affected negatively Other forms of warm-weather tourism positively impacted
Values from existing literature	Water/aquatic: The value of the Credit River recreational fishery is estimated at $1.4 million per year (2017 CAN). (15) The benefits of other (non-angling) river-based recreation in the watershed are estimated at $8.1 million per year. (7) Forest: The annual value of forests for recreation was estimated at $5.6 million. (7) Meadows: The annual value of meadows for recreation was estimated at $0.8 million. (7)
Key threats	Climate change Land use change and urban development Waste and pollution

7. Amenity & cultural	
Ecosystem service description	Ecosystems influence the types of social relations that are established in particular cultures. Many societies place high value on the maintenance of either historically important landscapes (“cultural landscapes”) or culturally significant species. Identity and heritage are grounded in experience everywhere, in every type of ecosystem, and are informed by relationships with nature that are distinctive to each place. Ecosystems thus support social cohesion through shared experience and shared understanding of the world. (6)
Context	The Greenbelt Legislation now largely protects the upper and middle portions of the Credit River watershed from urban development. In addition, the Credit River watershed contains portions of the Oak Ridges Moraine and the Niagara Escarpment – areas providing significant and cultural amenity values. These values are partially captured by the amount people are willing to pay for restoration and/or property close to natural features.
Affected regions, industries, &/or populations	All natural spaces possess amenity and cultural values.
Values from existing literature	<u>Forests</u>: The annual value of forests for amenity and cultural services in the CRW was estimated at $7.4 million. (7) Residents in the watershed are willing to pay significant amount for wetland restoration programs ($268 to $302 annually per household over the 5 years – 2017 CAN). (10) On average, natural features in south Mississauga increase individual property values by about 2.4 per cent of the average property value in the area. • Natural features in north Mississauga increase individual property values by 3.6 per cent of the average property value. (12)
Key threats	• Land use change and urban development • Climate change • Waste and pollution

8. Health & Well-being	
Ecosystem service description	Direct contact with nature is essential to support human cognitive development and psychological health. Two key benefits are decreased incidence of crime and improved socialization. It is also proven to support physical health and healing (in addition to benefits that come through physical exercise). (6)
Context	People living close to trees and green spaces are less likely to be obese, inactive, or dependent on anti-depressants. Children living close to green spaces have higher birth weights, are less likely to develop allergies or Attention-Deficit Disorders. The elderly are more likely to live longer if they reside near walkable green spaces. (13) In a survey of 1,000 CVC residents, approximately 70% of people rated natural areas as an important part of their health and well-being. (14) 21.2 per cent visit natural areas at least once per week to improve physical fitness 19.1 per cent visit to relieve stress 11.3 per cent visit to restore concentration and productivity
Affected regions, industries, &/or populations	All natural areas support health and well-being. The protection and conservation of green spaces close to human populations—particularly vulnerable populations—should be prioritized.
Values from existing literature	N/A
Key threats	Land use change and urban development Climate change Waste and pollution

References:

23. Region of Peel. 2015-20115 Strategic Plan: https://www.peelregion.ca/strategicplan/

24. Kataure, V. 2014 Socio-demographic profile: the Credit River watershed 2008-2018 https://cvc.ca/wp-content/uploads/2015/04/FINAL-Demographic-Profile-web.pdf

25. Credit River Watershed Health Report. 2012.

26. https://cvc.ca/watershed-science/watershed-monitoring/credit-river-watershed-health-report/

27. Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., editors (2008): From Impacts to Adaptation: Canada in a Changing Climate; Government of Canada, Ottawa, ON, 448 p.

28. Munang, R., Thiaw, I., Alverson, K., Liu, J., and Han, Z. (2013). The role of ecosystem services in climate change adaptation and disaster risk reduction. *Environmental Sustainability, 5 (1):* 47-52.

29. Value of Nature to Canadians Study Taskforce. 2017. Completing and Using Ecosystem Service Assessment for Decision-Making: An Interdisciplinary Toolkit for Managers and Analysts. Ottawa, ON: Federal, Provincial, and Territorial Governments of Canada.

30. CVC and the Pembina Institute. 2009. Natural Credit: Estimating the Value of Natural Capital in the Credit River Watershed https://cvc.ca/wp-content/uploads/2011/06/Natural-Credit-Estimating-the-Value-of-Natural-Capital-in-the-Credit-River-Watershed.pdf

31. Woodrising Consulting Inc. and ArborVitae Environmental Services Ltd. 2010. An Analysis of Present and Future Carbon Storage in the Forests of the Credit Valley Watershed. iv, 54 pp. https://cvc.ca/wp-content/uploads/2011/01/CVC-CarbonStudyFinal.pdf

32. CVC Plants and Animals of the Credit: https://www.creditvalleyca.ca/watershed-science/plants-animals-communities/plants-and-animals-of-the-credit/

33. Lantz, V., Boxall, P., Kennedy, M. and Wilson, J. 2010. Valuing Wetlands in Southern Ontario's Credit River Watershed. https://cvc.ca/wp-content/uploads/2011/01/ValuingWetlandsPhase2-final.pdf

34. Ontario Medical Association. 2005. The illness costs of air pollution: 2005 – 2026 health and economic damage estimates; Toronto, ON, 11 p.

35. DSS Management Consultants Inc. 2009. The Credit River Watershed - Property Value Appreciation: Impacts of Natural Features. https://cvc.ca/wp-content/uploads/2011/07/CVC-NatFeatRpt-Mar31_09.pdf

36. American Society of Landscape Architects. Health Benefits of Nature. https://www.asla.org/healthbenefitsofnature.aspx

37. Green Analytics. 2011. The Importance of Ecosystem Services to Human Well-Being in the Credit River Watershed. https://cvc.ca/wp-content/uploads/2012/02/cvc-human-well-being-report.pdf

38. DSS Management Consultants Inc. 2008.The Credit River Watershed: Valuation of Angling" http://www.creditvalleyca.ca/bulletin/downloads/cvc-anglingRpt-Jan29.pdf

39. CVC. 2011. Ecological Economics 101: Value of Ecological Services in the Credit River Watershed. https://cvc.ca/wp-content/uploads/2011/08/EGS_FACTSHEET_MAIN_FINAL.pdf

(Footnotes)

1 External groundwater flows within SWMM can only be added onto the surface of the catchment. Due to infiltration of the external flows during August, evaporation does not take place within the model. In reality these flows are coming in through the subsurface and hence evaporation continues to take place from the upper soil layers. This is a model limitation. In order to work around this limitation, evapotranspiration results presented here for August do not consider the external flows added to the model.

2 Infiltration chamber is sized to control the stormwater volumetric storage provided by isolated wetlands. Capacity presented here is the actual size of the infiltration chamber and not the stormwater capacity it provides. For example, an infiltration chamber of 5,528 m3 is estimated to provide 2,650 m3 of stormwater storage capacity (i.e., the actual storage capacity of the chamber is approximately 48 per cent of the total infrastructure volume requirements). In section 7, the stormwater capacity rather than the total size of the infiltration chamber, was used to assess the value of the stormwater services it provides.

3 Area here refers to feature area plus drainage area

4 Area here refers to feature area plus drainage area

5 The actual storage capacity of the infiltration chamber is approximately 48 per cent of the total infrastructure volume requirements. Here the stormwater capacity (numbers in brackets), rather than the total size of the infiltration chamber, was used to assess the value of the stormwater services it provides.