Spring | 18

The Municipal Natural Assets Initiative overview guidance document for stormwater management

The Municipal Natural Assets Initiative

About MNAI

The Municipal Natural Assets Initiative (MNAI) was launched in 2015 to refine and scale up a pioneering approach by which the value of natural asset-based solutions to municipal service delivery can be understood, measured and managed within the asset management frameworks increasingly used by local governments. This approach is termed municipal natural asset management and MNAI's goal is to make it mainstream across Canada.

The Convening Partners of the Municipal Natural Assets Initiative are:

- Brooke and Associates
- David Suzuki Foundation
- Smart Prosperity Institute
- Town of Gibsons

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Contents

List of Abbreviations

AMBC	Asset Management British Columbia
CMS	Cubic meters per second
DCC	Development cost charge
DEM	Digital elevation model
EBM	Ecosystem-based management
EPA	Environmental Protection Agency
FCM	Federation of Canadian Municipalities
GAAP	Generally accepted accounting practices
GI	Green infrastructure
GIS	Geographic information system
LID	Low-impact development
MNAI	Municipal Natural Assets Initiative
NAD	North American Datum
NAMS	New Zealand Asset Management Support
SWMM	Stormwater management model
TEEB	The Economics of Ecosystems and Biodiversity
TEK	Traditional ecological knowledge
UNEP	United Nations Environment Programme
WTP	Willingness to pay

About this guidance document

Overview:

The *Municipal Natural Assets Initiative's guidance document for stormwater management* is being developed at a time when local governments are displaying a growing interest in green infrastructure (See Box 1). This interest is driven by factors including the need for resilient and cost-efficient infrastructure to meet constrained budgets and the anticipated impacts of climate change. As local governments in Canada recover from two decades of declining public infrastructure investments, they remain painfully aware of the ever-increasing costs of delaying repairs, rehabilitation and replacements. This is exacerbated by increasingly regular extreme weather events and shifting seasonal patterns brought by climate change that demand adaptable and resilient solutions.

Many municipalities are developing an asset management strategy to better manage their infrastructure assets. Asset management is an integrated, systematic process to "*meet required service levels, in the most cost effective manner, through the management of assets for present and future customers*" (NAMS, 2016). It embraces a lifecycle approach and strives for continuous improvement in asset management practices. Changes to public sector accounting guidelines, eligibility criteria for federal gas tax grants, provincial legislative requirements and program support and funding are also driving uptake of asset management strategies.

Box 1: Terms

The services of urban ecosystems are frequently portrayed as green infrastructure. This refers to natural vegetation and vegetative technologies that collectively provide society with a broad array of products and services for healthy living (Green Infrastructure Ontario Coalition, 2016). GI incorporates the natural environment as well as engineered systems that take a `design with nature` approach to providing services.

This guide focuses on a subset of green infrastructure that we define as **municipal natural assets**. This term refers to the stocks of natural resources or ecosystems, such as forests, streams or meadows, that contribute to the provision of one or more services required for the health, well-being, and long-term sustainability of a community and its residents (O'Neill et al, 2017).

The term municipal natural assets reinforces the understanding that nature provides a direct and tangible flow of benefits into the future, and should therefore be treated as any other asset.

A logical extension of the asset management approach is the inclusion of 'natural capital', which complements the integrated and forward-thinking solutions of asset management. Natural capital refers to any physical asset within the natural environment that provides societal value by contributing to an ecosystem service, and an ecosystem service can be defined as any natural process that benefits humanity (Voora & Venema, 2008). Throughout this document, the term 'natural assets' refers to the subset of natural capital that is of relevance for the sustainable provision of one or more municipal services.

Local governments derive a range of benefits from ecosystem services. While urban ecosystems only provide a fraction of these benefits, the services they do provide have over-sized value due to their proximity to large populations of beneficiaries (Gómez-Baggethun & Barton, 2013). In fact, natural assets and their associated services can be viewed as the original form of infrastructure, with forested watersheds filtering water, wetlands treating waste, streams and creeks storing stormwater runoff and vegetative systems providing flood protection, for example. As human populations grew, however, the threat of overloading nature and its processes require alternatives be developed. In today's urban environments, the prevalence of constructed grey infrastructure makes it easy to forget the indispensable role that nature plays in the process.

As anthropogenic impacts on ecosystems increase, there is a growing need to standardize techniques for economic valuations of natural capital to facilitate its inclusion in decision-making. MNAI complements studies in Canada that recognize the value of natural systems. These studies represent the value of nature across a broad range of scales, focusing on aspects of natural systems relevant to the targeted audience. For instance, the Credit Valley Conservation's *Grey to Green Guides* make the business case for low impact developments at a site level, whereas Environment Canada's *The Value of Nature to Canadians Study* identifies the social, cultural and economic values of nature to Canadians to support federal and provincial government policy and decision-making.

Such studies are providing increasing evidence that municipal natural assets can be more cost-effective over the long-term and more resilient than conventional infrastructure. It also doesn't depreciate if properly maintained and provides a wide range of secondary benefits beyond a particular municipal service. Integrating natural assets into municipal service plans, for example through integrated stormwater management, can offer cost-savings and broader social and ecological benefits. This emerging evidence led to the development of the Municipal Natural Assets Initiative and, in turn, this guide.

Purpose of guide

This guide addresses a key barrier to widespread adoption of solutions for the effective management of natural assets: a lack of awareness and understanding of how to incorporate natural assets into municipal asset-management systems. While there are multiple guides for municipalities that address the process for managing conventional (or grey) infrastructure to maximize benefits, reduce risk and reflect community values, there is almost no guidance on how to incorporate natural assets into the asset management process.

Failing to include the value of ecosystem services into management decisions in the face of increased urbanization is further impeding ecological functioning and the subsequent societal benefits that result from them. A lack of scientific and economic information on the connection between land use and ecosystem services makes it difficult to put mechanisms in place to protect those ecological services. This guide uses EPA's stormwater management model (SWMM) to understand the biophysical and economic contributions of stormwater regulation services provided by watersheds and urban ecosystems for their inclusion in asset management. Although SWMM is used throughout this guide, other hydrologic, hydraulic, and water quality models can be employed to reach similar results (see Appendix A for a review of models).

Scope of guide

This guide focuses on municipal watershed ecosystem services related to urban stormwater management, specifically stormwater retention and regulation of water quantity and quality. These services are of special importance because they can rarely be replaced ex situ (Gomez-Baggethun et al., 2013). As the Municipal Natural Assets Initiative evolves, additional guides will be developed for other municipal services such as carbon sequestration and draught mitigation.

In urban environments unmanaged stormwater can lead to flooding and other flow disruptions in addition to water pollution. Natural watersheds provide the hydrological services of flow regulation (including flood mitigation and enhanced base flow during dry periods), groundwater recharge, erosion control, sedimentation prevention and water purification. **The goals of this guidance document are to define the range of stormwater regulation services provided by watersheds and urban ecosystems, present a model that simplifies and standardizes biophysical and economic measures for these services and identifies best management practices to maintain natural assets.**

While the MNAI approach focuses on the services of intact ecosystems (and the natural assets within them), several stormwater models can incorporate various forms of engineered green infrastructure. We have included guidance on incorporating GI into asset management, but recommend beginning the natural asset management process with intact natural systems.

This guidance document is being shared to allow local governments and interested individuals help test and refine this approach. The document has been used successfully for one cohort of local government pilots and has been refined based upon feedback. Further refinements are anticipated as additional municipalities and local governments utilize the document.

This document complements asset management guides developed for local governments such as *The Canadian Infrastructure Report Card: Asset Management Primer* (FCM et al., 2015), Ontario's *Building Together: Guide for Municipal Asset Management Plans* (Ontario Ministry of Infrastructure, 2012), *Optimized Asset Decision Making @ The Region of Peel* (Public Sector Digest, 2010) and the *Asset Management BC framework* (AMBC, 2014). It does not attempt to address all components of asset management, but highlights novel considerations required for local natural assets and associated services.

Target audience:

The target audience for this guidance document is municipal and regional planners, infrastructure engineers, water managers, financial managers, asset management task forces, decision and policy makers and stakeholders with a strong interest in water and asset management projects.

Using this guide

This document provides general guidance to local governments who wish to incorporate natural assets into their asset management process. It guides users through required steps and considerations. It is not a user manual, however, and does not provide uniform or prescriptive approaches. Instead, the intent is to allow local governments the ability to tailor and scale approaches to their community's needs and resources.

Detailed technical appendices are provided for new or novel topics and activities.

This document should be used sequentially, without skipping sections, although sections may need to be revisited due to the iterative nature of asset management.

Overview of document

Part 1: Municipal natural asset management

Part 1 introduces the concept of municipal natural asset management and outlines why municipalities should consider natural assets in addition to conventional, grey infrastructure in asset management.

Part 2: Getting started

Part 2 conveys activities to complete an assessment of the role of nature in stormwater management. This includes information on staffing requirements, planning for field monitoring, and a summary of the model and time and data requirements.

Part 3: Assess

Part 3 outlines activities to assess the condition and value of natural assets. It includes instruction on scenario development and running and interpreting the model.

Part 4: Plan

Part 4 covers the unique considerations that natural assets require in asset management planning. Topics include developing monitoring and maintenance plans, integrating modelling results into asset management plans, strategies and policies, as well as long-term financial planning and beneficiary considerations.

Part 5: Implement

Part 5 discusses the final stage of asset management. This section addresses how to plan and staff for on-going monitoring and maintenance plans.

Part 6: Next steps

Following municipal natural asset strategy implementation, local governments might want to complete the process for another sub-catchment within their jurisdiction and/or expand upon the analysis. This section addresses some of the next steps to consider.

The diagram below depicts the steps a local government will work through to complete an assessment of their natural assets. It is adapted from Asset Management BC's *Asset Management for Sustainable Service Delivery: A BC Framework.*

Figure 1: The Municipal Natural Asset Framework

Part 1: Municipal natural asset management

The importance of natural stormwater management in urban areas

Our daily lives rely on municipal infrastructure. Roads, transportation networks, water treatment plants, pipes, sewers, recycling plants, parks, seawalls and other infrastructure support our quality of life, protect our health and keep us safe. Infrastructure provides a foundation that allows us to live in a healthy and organized manner. Local governments are managers of infrastructure-based assets.

The focus for stormwater management in cities is often on moving water off roads and properties quickly by creating extensive areas of concrete and asphalt to channel streams and rivers. This has led to declines in the quality and purity of water, erosion and flooding. When rain falls onto impervious surfaces, it cannot soak into the ground. Instead it drains through collections systems such as gutters and storm sewers, picking up trash, bacteria, chemicals and other pollutants before discharging into local water bodies. These higher water flows cause erosion and flooding in urban streams and creeks and can damage property and infrastructure.

In natural areas, rainwater is absorbed and filtered by soil and vegetation, lessening pollution, erosion and flooding. Natural assets utilize natural functions to reduce and treat stormwater at its source, while providing a range of environmental, social and economic benefits. Furthermore, several studies have shown natural infrastructure is more a cost-effective and resilient approach than single-purpose conventional stormwater infrastructure that depreciates over time (FCM 2004, EPA 2010, Cirillo and Podolsky 2012).

A word about co-benefits

This guidance document focuses on the stormwater benefits of local natural assets and assists with managing such assets. In the process of incorporating these services into an asset management plan, care must be taken to also recognize the co-benefits of natural assets in decision-making. For instance, in addition to stormwater management services, wetlands also process waste, provide educational and recreational benefits, store carbon and provide habitat for wildlife.

Economic and policy decisions that focus narrowly on the trade-offs between conventional infrastructure and natural assets may overlook the broader range of benefits to the detriment of the community. While many of the co-benefits of natural assets may not be fully understood or quantifiable in monetary terms (e.g. cultural, aesthetic and health and well-being benefits), there are several recommended approaches to incorporate co-benefits into decision-making:

- Biophysical measures. Ecological measures include measures of extent and condition, process integrity and ecosystem processes and functions.
- Qualitative descriptions. Socio-economic measures may include statements of significance, priority ranking or the judgement of experts.
- Traditional ecological knowledge. TEK refers to indigenous forms of traditional knowledge that are handed down through generations regarding the sustainability of local resources.
- Surveys. Surveys may indicate the relative importance of particular forms of natural assets and/or their associated services to the community.
- Non-market economic valuation: Non-market economic valuation methods for natural assets can be broadly categorized into three groups: direct market valuation, revealed preference and stated preference methods. A fourth category, the benefit transfer (or value transfer) method, applies results from prior studies for an ecosystem service to a new area of interest. Each of these methods has its strengths and weaknesses (see Appendix E for a description of each) and most can only be applied to a subset of ecosystem services, depending on the type of value that the service contributes to humanity.

Part 2: Getting started

Staffing:

Asset management strategies require a multi-disciplinary, team-based approach. Municipal asset management plans were historically the domain of individual departments (e.g. Parks or Public Works) and resulted in data that was not comparable across departments. Today there is recognition that a more holistic approach to municipal assets is needed.

Table 1 provides a general list of specialists and expertise that might be required for projects to integrate natural assets into asset management. Not all of these skills are required for a project, and some projects may need additional expertise. Municipal in-house expertise can be augmented with external specialist/consultants as required. Underpinning this is a requirement for staff involvement from key departments such as engineering, public works, parks engineering, planning and finance to ensure a holistic and effective approach. *It is highly recommended that time be allocated upfront to developing a work plan that identifies required skills, roles and responsibilities and associated time allocations for each member of the team.*

Table 1: Specialized skills matrix

Specialist	Integrated stormwater management planning	Hydrology	Hydraulics	Stormwater modelling	Water quality	Design	Spatial mapping/ Data acquisition	Natural asset valuation	Accounting/ GAAP	Biology/ Aquatics	Construction/ Estimating
Environmental economist											
Civil/ hydrotechnical engineer											
Hydrologist											
Aquatics scientist/ ecologist											
GIS specialist											
Accountant											
Water quality engineer											

Determining where to start:

This section provides a short overview of key stormwater management issues that can be addressed by municipal natural assets. It also provides advice on how to determine which forms of natural assets to start with when considering incorporating them into asset management.

Table 2 offers an overview of natural asset solutions addressed in this guidance document and identifies their associated stormwater management benefits. It confirms whether an asset is considered municipal natural asset(s) or engineered green infrastructure — or both. While the MNAI approach is focused on the services of intact ecosystems, the stormwater model can incorporate engineered green infrastructure, which can be used to simulate natural ecosystem services.

Table 2: Natural Assets for Stormwater Management

Nature-based asset	Municipal natural asset or engineered green infrastructure?	Water supply regulation (flow regulation, including flood mitigation & flow enhancement)	Water supply regulation – groundwater recharge	Water quality regulation – erosion control	Water quality regulation – sediment prevention	Water quality regulation – water purification
Wetlands & ponds (natural and constructed)	Both					
Streams & creeks	Natural asset					
Forests	Natural asset					
Meadows	Natural asset					
Permeable pavement	Engineered GI					
Rain gardens	Engineered GI					
Green roofs	Engineered GI					
Infiltration trench	Engineered GI					
Vegetative swales	Engineered GI					

Wetlands (natural & constructed):
Natural and constructed wetlands provide temporary storage for flood waters and improve water quality by assimilating municipal and industrial wastewater through sedimentation, filtration, adsorption and decomposition processes.

Streams & creeks:
Streams and creeks mitigate damage from floods, provide drinking water sources and filter pollutants. They also improve water quality through sedimentation, filtration, adsorption and decomposition processes.

Forests:
The leaves and bark of trees reduce the volume of water entering gutters and pipes following a storm. They also contribute to cleaner water and the recharge of groundwater.

Meadows:
Meadows (or open green spaces) are spaces partly or completely covered with grass, trees, shrubs, or other vegetation. Such spaces provide pervious surfaces in otherwise urbanized catchments and filter and drain stormwater before reaching receiving streams. They also filter dust from the air, provide shade and lower temperatures in urban areas, and reduce erosion of soil into our waterways.

Permeable pavement:
Permeable pavements include pervious concrete, porous asphalt or permeable interlocking pavers. These surfaces infiltrate, filter and store rainwater.

Rain gardens and bio-retention cells:
Rain gardens (sometimes called bio-retention cells) are shallow, vegetated basins that collect and absorb runoff. They mimic natural hydrology by infiltrating, evaporating and transpiring stormwater runoff.

Green roofs:
Green roofs are covered with vegetation planted over a waterproofing membrane. They absorb rainwater, filter water and treat air in urban environments.

Infiltration trench:
An infiltration trench is a shallow excavated trench filled with gravel or stone to manage stormwater runoff, prevent flooding and downstream erosion and improve water quality.

Vegetative swales:
Vegetative swales are shallow, broad channels that are vegetated along the bottom and sides of the channel. They reduce stormwater runoff through infiltration and filtering by vegetation. Their ability to reduce runoff velocity prevents downstream erosion.

The model:

A. Overview of the approach

The proposed approach to assess stormwater services provided by natural asset(s) involves the following steps:

1. Characterize the natural asset(s) of interest
2. Develop a list of alternative scenarios used to compare the natural asset(s)' services
3. Run a hydrologic model (SWMM) for all scenarios
4. Conduct economic valuation
5. Incorporate information on beneficiaries

Part 3 gives details on each step. The following section gives an overview of the hydrologic model recommended for these analyses.

B. Hydrologic model

Determining the economic value provided by natural assets requires understanding their function in a landscape's hydrologic processes. These processes are commonly simulated using computer models where sets of equations determine, for example, how water infiltrates in a given land use, or how the shape of a stream channel impacts the flow rate. There are dozens of stormwater models that have been developed to answer these questions, each taking a slightly different approach to address a specific issue (see Appendix A). While many of these models would perform satisfactorily for this analysis, this guidance document will focus on the U.S. Environmental Protection Agency's (EPA) Storm Water Management Model (SWMM) version 5.1.010.

We have chosen to use the SWMM model because:

1) it is freely available
2) it is widely used (e.g. a number of municipalities have developed a stormwater management plan based on this model)
3) it can be run with a wide range of commonly available input data
4) it is capable of providing an appropriate set of outputs
5) there are several proprietary software packages built on top of the SWMM engine, allowing users to expand on this analysis, if resources allow.

There are many resources and reference materials available on the EPA website on the SWMM model. Here, users will find the model software, a guided tutorial and the SWMM reference manual, which details required inputs, describes the computational routines and lists model outputs. The following paragraphs provide a brief summary of the information found in the reference manual.

SWMM models rainfall-runoff processes and can be used for single event or continuous simulations of stormwater quantity and quality. During setup, users define sub-catchments that have homogeneous landscape characteristics, as well as the network of pipes and channels to which each sub-catchment drains (US EPA, 2015). SWMM is both a hydrologic and hydraulic model, capable of simulating water surface elevations along the conveyance network.

Inputs

Users may input precipitation data for an extended time period or for a single storm event. Temperature data over the same time period (daily minimums and maximums) allow the model to separate precipitation into rain or snow, and to calculate evapotranspiration rates using the Hargreaves method (US EPA, 2016). The user may also input wind speed data to help calculate snow transport and removal.

After entering climatic data, the user defines sub-catchment characteristics to determine runoff generation. This includes area, slope, percentage of imperviousness, soil properties and outlet point. There are several options for computing infiltration and input data will vary based on the user's choice. The simplest approach uses curve numbers to approximate the runoff response of an area based on soil and land use type. The more complex methods (i.e. Horton or Green-Ampt) require users to specify hydraulic conductivity of the soil along with other soil characteristics that impact infiltration. Sub-catchments may be divided into different land use types, for which the user can input pollutant-loading data to calculate sediment or nutrient loading.

It is possible, but not mandatory, to define an aquifer to which some or all sub-catchments drain. If there is an aquifer, SWMM will also model groundwater-surface water interactions in a single run. The geometry of pipes, channels and storage structures within the conveyance network can be set by the user, as well as the flow routing method (several options of varying complexity). Low-impact development (LID) controls can also be added to the sub-catchments. Appendix B lists data sources.

Processes and outputs

Once relevant parameters are defined, SWMM computes the runoff response for each sub-catchment and routes flows through the conveyance network. Model output includes peak runoff, total runoff, peak flows at each point of the conveyance network, storage for each LID control, groundwater infiltration rates, groundwater storage, surface water storage and pollutant build-up and wash-off (US EPA, 2016).

The key outputs from the SWMM modeling process depend on which natural assets are being valued, but will often be peak flow rate and total flow volume at a specific point of interest within the modeled stream network. By altering the SWMM model to simulate removal or replacement of natural assets, users can assess the impact of these assets on the model outputs of interest. Depending on which economic valuation method is chosen, users will either convert the change in peak or total flow into a monetary value by applying a dollar per cubic meter per second (cms) or dollar per cubic meter value, or by determining the cost of achieving the same peak or total flow with engineered infrastructure.

Scope and limitations

Users interested in modeling flooding should be aware that the EPA SWMM model does predict flood volumes along the stream network but does not simulate flooding adjacent to the stream channel. If valuing natural assets based on their ability to reduce flood damage risk at specific locations is a priority, a proprietary model that expands the functionality of the freely available version of SWMM (e.g. PCSWMM or XPSWMM) is a good choice. These models can perform a detailed flooding analysis with digital elevation models that predict the flow of water after it overflows the stream channel.

SWMM can represent nearly any form of natural asset through a mix of hydraulic components, LID controls and hydrologic parameters. Ponds, wetlands and forests are readily simulated and freely available articles and papers describe how to include these in a SWMM model (see https://www.openswmm.org/Forum). For an in-depth look at how to include ponds in a SWMM model for natural asset valuation, see the Case Study: Gibsons, B.C. Natural Asset Valuation document.

Time and data requirements:

This section summarizes data needs and provides municipal time estimates for conducting a natural asset assessment. It should be noted that these estimates could vary widely depending on:

- data availability,
- size and complexity of the modeled area, and
- user familiarity with model.

Appendix B provides more detailed information on data sources and data formatting.

Table 3: Time and data requirements

Step	*Data needs* / <u>Data acquired</u>	*Estimated time*
Determine which natural assets will be considered	*Natural asset inventory (optional); Geospatial boundaries for study area*	4-8 hours
Online data collection	<u>Hourly precipitation; hourly temperature; observed streamflow; digital elevation model (DEM); soil properties; previous studies; land use/ land cover; watershed boundary</u>	20-115 hours
Field data collection	<u>Stream channel geometry; storage pond geometry; wetland extents; soil properties</u>	40-160 hours
SWMM model creation	*Hourly precipitation data; hourly temperature data; soil properties; sub-catchment slopes, impervious (%), soil properties; stream network characteristics*	24-100 hours
SWMM model calibration	*Observed streamflow data*	15-60 hours
Scenario development	*Grey infrastructure alternatives*	15-200 hours
Biophysical results comparison	*Peak flow rates; total flow volumes*	10-45 hours
Economic valuation	*$/cms; or $/m^3; or cost to construct grey infrastructure alternative*	2-10 hours

Planning: Collection of field monitoring data

The asset management team should consider whether there is a need to collect field data over the coarse of a natural asset assessment. Monitoring data may be required to fill or broaden knowledge gaps or for model calibration. When this is the case, the team should plan for the time of year to initiate data collection to align with the weather events being modelled (e.g. spring data collection to capture heavy storm events in Toronto versus winter data collection to capture heave storm events in Vancouver).

Part 3: Assess

Natural Asset Inventory

In the same way a municipality has an inventory of conventional built assets, it also needs to take stock of natural assets. This can get very complicated very easily, so to start it is recommended:

1. Consider and list the significant environmental components of your community, even if the municipality does not own them. For instance, large parks, such as Stanley Park in Vancouver and Burns Bog in Delta, or natural shorelines.
2. Using Table 2 above, ask which natural assets provide services that are comparable to or enhance municipal infrastructure.
3. Prioritize, according to your unique situation and community needs.

Alternatively, a local government can prepare a natural asset inventory or an asset registry to make them visible and increase the likelihood that they will be maintained. The level of specificity provided in asset management inventories varies from government to government, but at a minimum should include: location, condition, value and estimated life of an asset. An example of a natural asset inventory is provided in Appendix C from the Regional Municipality of York, which captures forest assets. Appendix C also provides examples of natural asset registries from the Victoria Capital Region District (BC) and the Greater London Authority (UK).

Characterizing natural assets:

The municipal natural assets within a watershed that can assist in stormwater management, whether natural or engineered, need to be identified and mapped. Typical assets include storm drain systems, ditches, culverts and pipes, natural watercourses, wetlands, lakes and ponds, forested areas, groundwater recharge areas and stormwater retention facilities. The features of an asset relative to stormwater management need to be assessed and the stormwater parameters quantified. For ponds and wetlands, the condition, surface area, depth, storage volume and discharge characteristics should be characterized, as well as the potential for sediment and nutrient retention. While reports, surveys, stormwater models and 'as-built' drawings or mapping may contain some information; a site inspection from a qualified professional is generally required.

This process is an opportunity to identify options to improve the function of natural assets. The assessment should include the ability to enhance the capability of an asset to manage stormwater, public perception, recreation and safety.

Appendix D provides additional guidance on conducting a condition assessment.

A word about Risk Assessment:

Once local governments have a sense of the services provided by natural assets and their condition, a simple risk identification exercise can help prioritize efforts and identify areas of high potential risk, where **Risk = Likelihood of Event * Impact of event** (Town of Gibsons, 2017)**.**

Table 4 below provides an example of a risk identification exercise. Generally, it is advised to start with an indicative assessment to get a sense of potential risks. If the indicative assessment points to high likelihood *and* high impact, then it is advisable to complete a detailed assessment. It is outside the scope of this document to discuss how to complete a full risk analysis.

Table 4: Risk Identification Example

Natural asset	*Services*	*Hazards*	*Impact*	*Likelihood*	*Risk*
Aquifer	Water provision	Leak from gas storage tank	High	Medium	High
		Spill from transport truck	High	Low	Medium - high
Foreshore	Protection of business and residential districts from storms	Storms, development	High	Low	Medium - high
Healthy creek distant from developments	Stormwater absorption, conveyance, and flood protection	Development and overuse	Low	Low	Low
Degraded creek near area with land intensification	Stormwater absorption, and flood protection	Development and overuse	Medium	High	High

Source: Town of Gibsons, 2017

Developing alternative scenarios:

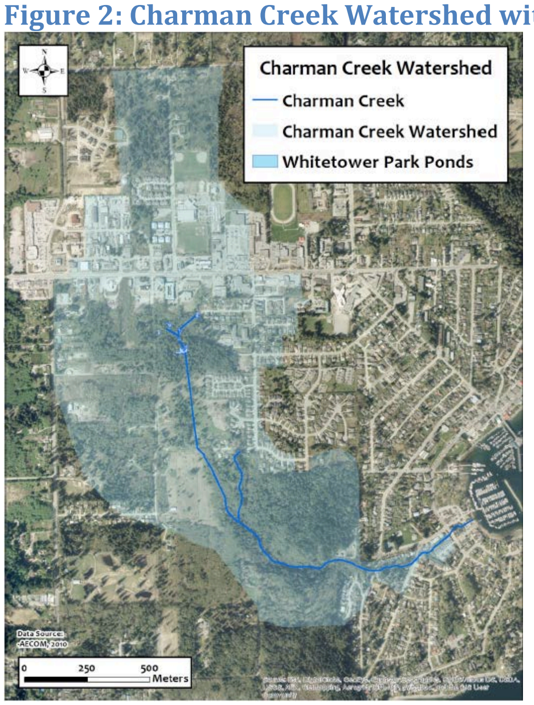
Scenario development is a key component in the natural asset valuation process. It is possible to identify the value of individual natural assets by comparing the hydrology of watersheds with alternative natural assets, which correspond to past or possible future states of the study watershed. In terms of modeling, these hypothetical watersheds translate into several variations of the hydrologic model, which can be used to tease out the impacts of individual model components.

We recommend a replacement cost approach combined with SWMM (or another stormwater model) to determine the value of a natural asset of interest. When using the replacement cost method, the value of the natural asset is assumed to be at least equal to the cost of replacing the services provided by the natural asset with grey infrastructure.

Example

Detention ponds can be constructed throughout a city to provide water storage in place of a wetland, thereby maintaining acceptable peak flow rates even in the absence of the wetland (the natural asset of interest in this example). Detention ponds are easily modeled in SWMM by adding a 'storage pond' component and sizing it appropriately, making them one of the simplest replacement cost options. Users, however, can choose to model any number of grey infrastructure alternatives, including bypass pipelines, channelization of stream reaches, expansion of the existing stream channel, etc.

Figure 2: Charman Creek Watershed within Gibsons, BC



In some cases, it may be desirable to simulate management alternatives alongside a number of climate and land use change scenarios to determine how different options will perform under future conditions. Climate changes can be simulated by adjusting input precipitation and temperature time series, and land use changes can be simulated by adjusting sub-catchment parameters (e.g. percentage impervious, internal routing, infiltration properties, etc.).

The scenarios modeled in SWMM will vary depending on the questions answered in any given analysis. As a starting point, we recommend the following suite of scenarios:

(1) Existing current conditions

The 'current conditions' scenario is a representation of the modeled system in its present state. This scenario uses data gathered online or in the field, and its flow predictions should be validated against observed flow data or the predictions of a previously validated model. All other scenarios will be built using the 'current conditions' scenario as a starting point.

(2) Business as usual development

This scenario represents the area of interest without the natural asset of interest. By comparing predicted peak flows, for example, at a specific point in the stream network from both the 'existing current conditions' and 'business as usual development' scenarios, it is possible to quantify the impact of that natural asset. In this example, if there is a well understood relationship between flow rate and management cost, then the change in flow rate between the two scenarios would simply be multiplied by the $ per cms cost. Otherwise, a third scenario would be developed.

(3) Development with natural assets

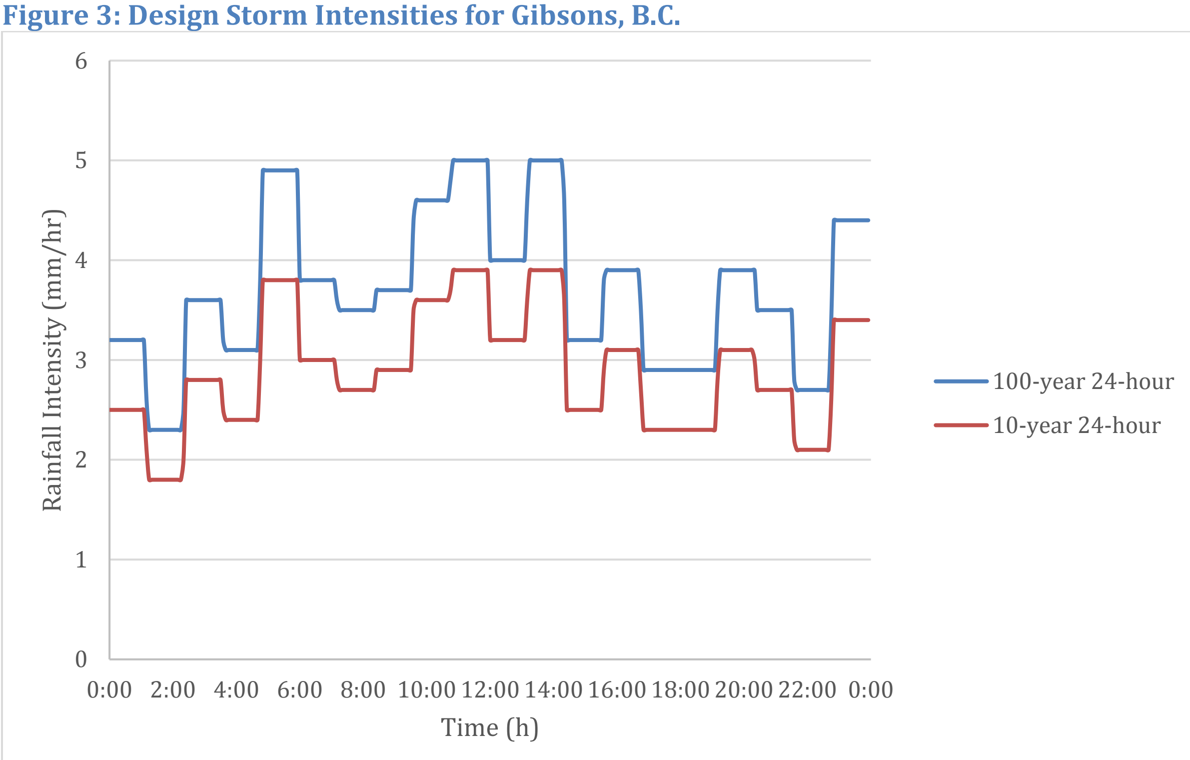
This scenario is used to determine the cost of using grey infrastructure to provide the same services originally provided by the natural asset. Once users have quantified the lost service by comparing scenarios 1 and 2, they can determine an option for using grey infrastructure to replace the lost service. This new management approach would then be added to the SWMM model to verify that it is indeed capable of bringing peak flows (in this example) back to the level of current conditions. Following this, costs can be estimated to construct the grey infrastructure alternative (e.g. using a $/m^3 estimate for detention ponds), and this would become the 'replacement cost' for the natural asset.

Running the hydrologic model:

Once all necessary scenarios have been modeled in SWMM, the user must decide what time frame to simulate using the model. There are two approaches to choose between: single-event vs. continuous time series.

The single-event approach refers to simulating a single storm event, usually a 24-hour design storm. A design storm approximates an actual storm in terms of intensity and duration for a given return interval. For example, the 100-year 24-hour design storm for Gibsons, B.C. entails 88.9 mm of rainfall of varying intensity over the course of the event, whereas the 10-year 24-hour design storm for the same location entails 66.1mm of rainfall over the same period. See link to case study on pg. 18 for more details.

Figure 3: Design Storm Intensities for Gibsons, B.C.



The 100-year design storm represents a storm that has a return interval of 100 years (i.e. on average, it only occurs once every 100 years) and the 10-year design storm represents a storm that has a return interval of 10 years.

Design storms are useful when simulating the impacts of development or management schemes on peak flow rates, because peak flows generally occur during large storms. When simulating a design storm, it is important to consider initial conditions, such as soil moisture storage, which can have a large impact on the hydrologic response of a watershed to a storm.

The 'continuous time series' approach refers to simulating an extended period, up to several decades, which includes both dry and wet periods. This requires the user to have access to (at least) hourly precipitation data for the duration of the modeled period and may not be possible in every situation. Continuous time series are useful when simulating the impacts of development or management schemes on total flow volumes. Natural assets are particularly effective at managing stormwater during small precipitation events (i.e. those that occur often throughout a year). This can have a large impact on total flow volumes over an extended period while having no impact on peak flow rates over the same period. This is particularly relevant in British Columbia where the majority of precipitation over the course of a year occurs during small rainfall events.

Ultimately, determining whether to use design storms, continuous time series, or both will depend on data availability and the types of natural assets being assessed.

Once the SWMM model has been run for the first time, it is important to compare the predicted outflows with observed data. If predicted outflows are different from observed flows, the model user must make adjustments to parameters to try to improve the accuracy of predictions. This process of comparing predicted vs. observed values and adjusting the model accordingly is called calibration and is a necessary step, whenever possible (i.e. when observed flow data is available). If adjustments are needed, hydrologic parameters (e.g. sub-catchment slope and width) are the usual starting point. Once sub-catchment runoff/infiltration ratios are satisfactory, adjustments to hydraulic parameters may be in order if model predictions remain different from observed values.

In situations when there is no observed data to use in calibrating the model, model results must only be used to draw relative comparisons between scenarios, rather than using the absolute values for management decisions.

SWMM output tables present a wide range of information, and most can be ignored for natural asset valuations. The key output tables for this analysis are:

- the ‘sub-catchment runoff summary’,
- the ‘node inflow summary’,
- the ‘storage volume summary’,
- ‘link pollutant loads’ and
- the ‘link flow summary’.

In most cases, these tables will provide all necessary information to calibrate the SWMM model and assess the impacts of the natural asset(s) of interest.

Conducting the economic valuation:

Once the model calibration and scenario development processes are complete, scenarios can be compared using the information in the SWMM output tables. Key biophysical metrics are contained within the ‘node inflow summary’ and ‘storage volume summary’ tables. These tables lists peak flow rates and total flow volumes for each node within the stream network. Comparing these metrics between the ‘current conditions’, ‘current conditions with natural asset 1 removed’, and ‘current conditions with natural asset 1 removed, with replacement’ should provide all of the biophysical measures necessary to complete the analysis.

Several options for the economic valuation are possible (See Appendix E for a review of economic valuation methods):

1. When using the replacement cost method, the alternative scenario with the asset being replace by grey or green infrastructure is needed.

Example: Having simulated the replacement of the natural asset with detention ponds, users should refer to the ‘storage volume summary’ output table from the ‘current conditions with natural Asset 1 removed, with replacement’ scenario. The sum of values in the ‘maximum volume (m^3)’ column is equal to the total volume of detention ponds required to replace the lost natural asset. By multiplying this volume by the $/$m^3$ construction cost associated with building detention ponds, the user will reach an estimate for the economic value of the natural asset (i.e. natural asset 1).

2. If using a different method (e.g. benefit transfer), the baseline scenario, i.e. without the natural asset, may be sufficient. In that case, one would use the

difference in stormwater retained between the two scenarios, and multiply it by the unit cost of stormwater retention (See Appendix E).

3. If the grey infrastructure alternative scenario does not achieve the desired peak or total flow reduction (i.e. is not capable of fully replacing the services provided by the natural asset), then it will be necessary to develop a different grey infrastructure approach, along with an additional SWMM model scenario. Multiple grey infrastructure scenarios would provide a basis to compare results.

Note:
Estimates of economic value derived from uncalibrated models should be considered 'ball-park' estimates, at best. Uncalibrated models can still be useful for deciding whether a more detailed analysis would be worthwhile in the future, and are therefore useful tools for allocating energy and resources.

Integrating beneficiary information:

The idea that nature benefits human beings is central to the concept of natural capital. Therefore, it is critical to identify *who* is benefiting from the services of stormwater management. As noted earlier, direct benefits of well-managed stormwater include:

- Flood mitigation for local and downstream residents
- Erosion control and improvement of water quality (for downstream facilities, e.g. reservoir)
- Restoration of "stream health"(i.e. biological integrity of receiving waters, through water quality and quantity regulation)
- Sometimes, increase in groundwater recharge and potentially baseflow (water storage for agriculture or other uses).

Table 5 summarizes the beneficiaries, how demand for this service varies and a possible valuation approach. The next section details how this information can be used in practice in a natural asset management strategy.

Table 5. Services related to stormwater management by natural assets, with associated beneficiaries, drivers of demand for this service and a possible valuation approach

Service	*E.g. beneficiaries*	*Driver of demand*	*Possible assessment method (and data needs)*
Flood mitigation	Urban dwellers in flood prone areas and downstream population centers	Presence and vulnerability of urban dwellers in flood prone areas or downstream population centers	Use flood maps (historic or modeled data) to identify urban dwellers at risk and overlay this information with supply of service
Water quality improvement	Water treatment facilities or reservoir managers (avoided sedimentation)	Sensitivity of water treatment facilities to increases in sediment loads or water quality impairment	Use the relationship between water quality and facilities' treatment costs to assess the importance of the water purification service
Improvement of stream health	Taxpayers, recreationists, stakeholders valuing clean water	Stormwater regulations, current biological state of stream waters	Use stormwater regulations as the valuation framework (see Appendix E)
Increase in groundwater recharge	Within city or downstream groundwater users	Whether the area is prone to water scarcity	Use a regional hydrogeological assessment to assess how increase in infiltration may impact groundwater recharge and baseflow

Using beneficiaries information in natural asset management

Any or all of the beneficiaries in Table 5 can be considered in a natural asset management strategy. The type of information sought by a municipality will guide the assessment method, which generally falls into two categories: using beneficiary information for economic valuation or spatially explicit mapping of ecosystem services.

- Use of beneficiary data in economic valuation: when using stormwater regulations as a valuation framework, taxpayers will be the direct beneficiaries of the stormwater management service. Taxpayers may be further divided into groups based on the stormwater tax structure (e.g. if it is based on property area or tied to income tax)
- Use of beneficiary data for spatial mapping of ecosystem services: when a service is inherently spatial (e.g. flood mitigation) it is useful to spatially represent the importance of such service. For example, one can flag areas (sub-watersheds) that are prone to flooding as providing higher levels of

service and prioritize decisions to protect or improve the service inside these areas. Figure 2 illustrates such analysis for the White Tower ponds in Gibsons, B.C.

Note: the sub-watersheds used in the stormwater models are derived from physical infrastructure (elevation map and drainage network) and may not align with socio-economic data. Further post-processing may be needed to combine both sources of information.

Part 4: Plan

The natural asset management policy outlines the principles and guides development and implementation of natural asset management across an organization. The policy should link community objectives and the management of conventional and natural assets into plans, strategies, processes and financial records. This section documents the unique considerations that natural assets require.

Developing monitoring and maintenance plans for natural assets:

The effectiveness of a natural asset within a stormwater management plan needs to be measured periodically to ensure that the natural asset performance is functioning as expected and unimpeded over time. The data required for this purpose are rainfall and streamflow.

The managed watershed should have at least one continuous rainfall gauge which measures and records rainfall at a maximum interval of five minutes.

Ideally, streamflow should be measured upstream and downstream of a natural asset such as a wetland or detention pond. Continuous monitoring of streamflow is best but the installation and maintenance of streamflow gauges can be costly. At a minimum, crest gauges, which measure the highest water level a stream reaches at the monitoring locations, should be installed. The water level is converted to flow using a manually measured water level – streamflow relationship. Crest gauges are inexpensive and easy-to-install, but the water level reached during a high rainfall must be manually recorded and the gauge reset. Ideally, a stream gauge should be linked by a cell or satellite network to facilitate automated data downloading accessible via a website. This allows real-time monitoring of the system and will minimize data gaps from technical malfunctions.

Rainfall and streamflow data can be used to calibrate stormwater models and derive rainfall – runoff relationships. The measured streamflows can be checked against modelled/design criteria to ensure that stormwater retention assets, either natural or engineered, are operating as anticipated.

Maintenance of a stormwater natural asset will require periodic removal of sediment, which accumulates in detention ponds. The pond's inlet and outlet structures should be inspected at least twice a year, and after every major storm event, to ensure they meet stormwater management plan expectations.

Additional information to develop and cost operations and maintenance activities, typical frequencies and required skills is provided in Appendix F.

Integrating results into asset management plans, strategies and policies:

In an attempt to reduce human impacts on ecosystems, many have called for ecosystem-based approaches to manage human settlements. An ecosystem-based management (EBM) approach strives to understand the interaction between biophysical and socio-economic dimensions of a landscape to manage the ecosystem as a whole. It is a shift away from conventional management approaches that are jurisdictional, short-term and regard humans as independent of nature.

Urban and regional planners are critical decision-makers in urban EBM implementation. The consideration of EBM principles when siting new developments, restoring existing ones and identifying appropriate monitoring and maintenance practices are essential to protect natural assets in the long-term. While there is no definitive set of EBM principles, there is general agreement on the following:

- <u>Link knowledge of human impacts on ecosystems to urban and regional planning policies</u>. Develop an understanding of the interface between human activities and ecosystem health when working to reduce unintended consequences of urban development on ecosystems. It implies an explicit attempt to integrate the needs of the environment, society, the economy and institutions.
- <u>Consider the spatial and temporal scales of ecosystems</u>. Use ecosystems to develop scientifically defined management boundaries. This entails the recognition that ecosystems operate on different temporal scales (e.g. natural asset restoration may take longer to establish services than conventional infrastructure but will last longer if properly maintained.)
- <u>Monitor to improve ecological integrity</u>. Emphasize the health of the whole ecosystem ahead of the concerns of special interests. Ecological integrity can be measured by the presence of native diversity and the resiliency of the ecosystem, including species abundance and diversity.
- <u>Recognize that humans are components of the ecosystem</u>. Explicit consideration of human values and preferences in developing natural asset management plans.
- <u>Establish clear and measurable indicators</u>. The use of indicators can provide feedback on natural asset management approaches. Ecological indicators for monitoring an ecosystem's health can include population measures of locally

significant species and/or toxins in a water body. Social indicators include human population and employment levels.

- Ecosystems are complex and adaptable. Natural assets and the services they provide depend upon a variety of outside factors for their continued existence. Because it is difficult to predict the conditions necessary for their health and renewal, setting thresholds for each indicator and identifying targets for ecosystem health is important. This may include species composition within an ecosystem or the state of habitat.
- The role of adaptive management in monitoring and managing natural assets. Considers the role of uncertainty and uses an iterative process to meet policy goals. It includes activities such as identifying plans and procedures to assess the health of natural assets. Common monitoring measures include the total number of ecologically important species and pollution levels.
- The need for inter-agency cooperation and organization change. Involvement of multiple departments and/or agencies to develop management plans for natural assets. This may lead to organizational change to adapt to new information.

A natural asset approach to asset management sees ecological and natural assets as infrastructure, as something that provides multiple social, environmental and economic functions. Natural asset systems should be considered *natural* infrastructure in a fashion similar to built infrastructure, so that they can be designed to function as a whole rather than as separate parts. Nature in cities should be administered in an integrated way similar to conventional or grey infrastructure.

Long-term financial planning:

Integrating natural asset management plans with financial planning is necessary for processes including developing, reviewing, updating and implementing strategies for sustainability. The integration of natural assets may require considerations additional to those required for conventional infrastructure. Important considerations include:

- Valuing a natural asset: Identifying the value of each asset is an important preliminary step in financial planning. Unfortunately, despite the fundamental importance of natural capital and associated ecosystem services — without which neither the economy nor life itself would be possible— traditional neoclassical economics rarely takes natural capital into account (Daly & Farley, 2004). This oversight makes it difficult to understand the value of the benefits and ecosystem services we receive from intact natural capital.

Economists have developed techniques to put dollar values on the non-market goods and services provided by ecosystems. Different approaches are used depending on the ease of measuring the flow of ecosystem services. There is no universal best approach. An approach that is suitable to assess the health of one service — for instance, the market cost of artificially providing flood mitigation — may not be appropriate for others. The techniques can be grouped into three approaches: 1) direct market valuation; 2) revealed preference; and 3) stated preference (See Appendix E).

Direct market valuation methods derive estimates of ecosystem goods and services from related market data. Revealed preference methods estimate economic values for ecosystem goods and services that directly affect the market prices of a related good, and stated preference methods obtain economic values by asking people to make trade-offs among sets of ecosystem or environmental services or characteristics. Several guides exist that advise on the preferred methodology for each service and decision-making application. Those of particular relevance to local governments include:

  - TEEB (2012), The Economics of Ecosystems and Biodiversity in Local and Regional Policy and Management. Edited by Heidi Wittmer and Haripriya Gundimeda. Earthscan, London and Washington.
  - Farber et al. (2006), Linking Ecology and Economics for Ecosystem Management. *Bioscience,* 56(2), 121 – 133.

- <u>Maintenance costs for natural assets</u>: Financial management of natural assets should include monitoring, maintenance and, potentially, restoration costs. These may include additional staff or contractors, monitoring instruments, time for staff to collect, assess and adjust monitoring and management for changed conditions, as well as the material and time for restoration activities.

- <u>Depreciation</u>: One of the most difficult and contentious financial decisions concerns how to depreciate natural assets. While it is clear that built assets depreciate differently than natural assets, there is no standard practice for depreciating natural capital. We must, however, account for natural asset depreciation in appraising municipal or regional wealth.

  Depreciation for natural assets is represented by the net losses to natural resources (e.g. minerals, forests and wetlands). Converting and/or degrading local ecosystems depreciates ecological endowment (Barbier, 2014). Failing to account for this dramatically impacts economic indicators and their role in decision-making.

Municipalities can choose from a number of methods to account for the depreciation of natural assets:

- Set depreciation at the longest term accounting standards allow
- Match depreciation to the ecosystem health and environmental management trends from the assess stage (i.e. if ecosystem health or environmental management is declining, set a depreciation rate to reflect this)
- Set depreciation to zero if the asset management goal is to maintain ecosystem health
- Recognize appreciation if asset management goal is to improve ecosystem health

- <u>Funding sources for natural assets</u>: Funding natural assets is a challenge for local governments even though they can be less costly than engineered infrastructure over the long run. Much work remains to identify funding sources and adjust funding requirements for natural assets. *Smart Prosperity Institute* (previously *Sustainable Prosperity)*, a convening partner to MNAI, completed a study titled *Incenting the Nature of Cities* (Cairns et al, 2016) on financial approaches to support GI in Ontario*.* The report identifies the following market-based approaches:
    - Stormwater user fees and fee discounts
    - Stormwater credit trading
    - Grants, rebates and installation financing
    - Development charge discounts
    - Development incentives
    - Habitat compensation banks

  In British Columbia, Development Cost Charges (DCCs) can support the rehabilitation of natural assets in situations where the project meets the requirements of an eligible capital cost that supports a DCC-eligible service, and the restoration and enhancement project will service, directly or indirectly, the development in which the charge is imposed (e.g. storm services).

  Lastly, local governments can access provincial &/or federal funding sources. The Clean Water and Wastewater Fund is supporting the Town of Gibsons to update their Integrated Stormwater Management Plan (ISMP), which will have a focus on the role of natural assets that underpin the Town's stormwater management system. In addition, the *Investing in Canada Plan* announced by the Federal government in 2017 provides for Integrated Bilateral Agreements with Provinces. These Agreements include a national $9.2 billion *Green Infrastructure Stream* enabling the use of natural infrastructure such as natural shorelines and wetlands for adaptation, resilience and disaster mitigation. If appropriate definitions, direction, guidance and targets are put in place by provinces, then this will result in a substantial boost for the health of natural assets.

Part 5: Implement

The final stage of asset management addresses how to implement your asset management plan, strategy and related policies. This will include developing on-going monitoring and maintenance plans and processes for adaptive management of natural assets.

Required skills for maintaining and monitoring natural assets:

Maintaining and monitoring natural stormwater assets requires a combination of hydrology and engineering expertise. Typically, a hydrologist or hydrotechnical engineer will have the credentials to design and execute a hydrometeorological monitoring system, including streamflow and rainfall monitoring. A technician can manage the monitoring system's data collection.

Interpretation and validation of the data, flow modelling and ongoing guidance should be done under the supervision of an engineer and/or hydrologist (or a hydrogeologist, if the study area is in a recharge zone). This is especially important if complex stormwater systems/hydraulics are involved or if there is a risk of flooding causing property damage or safety hazards. Larger municipal centres or their partners (e.g. conservation authorities in Ontario) often have these skills internally and, if not, consultancies across Canada provide these services.

On-site maintenance work, such as clearing out sediment traps/ponds, can generally be managed by municipal staff. Note that a permit or approval from the regulator(s) is often required to conduct in-stream works, and such work should be timed to minimize hazards to fish and wildlife. For further information, see Appendix F.

Part 6: Next steps

Following the implementation of a natural asset strategy, local governments may choose to complete the process for another sub-catchment within their jurisdiction and/or expand upon the analysis. This section addresses some of the next steps that a community could consider.

How to tie sub-catchment assessments together:

In some cases (e.g. large watersheds, inadequate resources for comprehensive assessment) it would be impractical to build a complete SWMM model for an entire watershed. In this situation, users should identify a priority sub-watershed area and construct a SWMM model for that portion of the larger watershed. Inflows from upstream can be added manually to the sub-watershed model by specifying a constant or time-varied inflow value at a junction. These estimates can be refined as resources become available for in-depth analysis. Similarly, the outflow time series from a sub-watershed can serve as input to a further downstream sub-watershed. This allows for a step-by-step natural asset valuation for a large watershed.

Expanding on the analysis:

Workflow considerations are based on the use of the freely-available software EPA SWMM 5.1.010 as the biophysical model. However, there are several proprietary software suites, such as PCSWMM and XPSWMM that can be added to the engine to enhance functionality and strengthen the analysis.

PCSWMM and XPSWMM integrate geographic information systems (GIS) capabilities with SWMM and make it easier to calculate sub-catchment and stream network properties. These software suites also allow for '2D flood analysis' to determine the lateral extent of flooding along a stream channel.

Using 2D flood analysis tools enables an 'avoided cost' economic valuation approach, which could provide a more reliable natural asset valuation estimate in some situations. By determining the lateral flooding extent in a model scenario with a natural asset removed, the user can find out the extent of damage to structures in the floodplain. Because this damage is effectively prevented when the natural asset is in place, the cost of the damage can be viewed as the value of the natural asset.

The costs of PCSWMM and XPSWMM are high, and they may not be good investments for most municipalities. The methods described in the previous sections can be used for expanded analysis as part of a PCSWMM- or XPSWMM-based approach.

APPENDIX A: Publically-Available Stormwater models

Table A-1 below provides a list of publically available stormwater models. The following definitions apply to the model functions described in the table.[1]

- Rainfall-Runoff Calculation Tool: peak flow, runoff volume, and hydrograph functions, only. More complex modeling should utilize hydrologic modeling which incorporate rainfall-runoff functions.
- Hydrologic: includes rainfall-runoff simulation plus reservoir/channel routing.
- Hydraulic: water surface profiles, flow rates, and flow velocities through waterways, structures and pipes. Models that include Green Infrastructure typically also assess how the BMPs manage the water through inflow, infiltration, evapotranspiration, storage and discharge.
- Combined Hydrologic & Hydraulic: rainfall-runoff results become input into hydraulic calculations.
- Water Quality: pollutant loading to surface waters or pollutant removal in a BMP.
- BMP Calculators: spreadsheets that predict BMP performance, only.

Table A-1: Publically available stormwater models

Model or Tool	*Model Types*						*Input Complexity*	*Simulation Type (Event, Continuous, or Both)*	*Link to Further Information*
	Rainfall- Runoff Calculation Tool	*Hydrologic Model*	*Hydraulic Model*	*Combined Hydrologic and Hydraulic Model*	*Water Quality Model*	*BMP Calculator*			
Rational Method (equation)	X						Low	Event	https://www.lmnoeng.com/Hydrology/rational.php
HEC-HMS		X					Medium	Both	http://www.hec.usace.army.mil/software/hec-hms/

[1] Based upon definitions provided in 'Minnesota Stormwater Manuel'.

Model or Tool	Model Types						Input Complexity	Simulation Type (Event, Continuous, or Both)	Link to Further Information
	Rainfall- Runoff Calculation Tool	Hydrologic Model	Hydraulic Model	Combined Hydrologic and Hydraulic Model	Water Quality Model	BMP Calculator			
WinTR-20		X					Medium	Event	https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/null/?cid=stelprdb1042793
WinTR-55		X					Low	Event	https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1042901
HEC-RAS			X		X		Medium	Both	http://www.hec.usace.army.mil/software/hec-ras/
EPA SWMM				X	X		Medium/ High	Both	https://www.epa.gov/sites/production/files/signpost/index.html.
P8					X		Medium	Both	http:wwwalker.net/p8/
Basins					X				https://www.epa.gov/ceam/better-assessment-science-integrating-point-and-non-point-sources-basins
QUAL2E/ QUAL2K					X		Medium		https://www.epa.gov/aboutepa/about-national-exposure-research-laboratory-nerl
WinHSPF				X	X		High	Both	http://www.aquaterra.com/resources/hspfsupport/index.php
SWAT				X	X		Medium/ High	Both	https://swat.tamu.edu
PLOAD					X		Low	Event	https://www.epa.gov/ceam/better-assessment-science-integrating-point-and-non-point-sources-basins#models
PondNet					X		Low	Event	http://wwwalker.net/
WASP					X		High	Both	https://www.epa.gov/aboutepa/about-national-exposure-research-laboratory-nerl
SUSTAIN		X			X		Medium	Both	http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/

Model or Tool	*Model Types*						*Input Complexity*	*Simulation Type (Event, Continuous, or Both)*	*Link to Further Information*
	Rainfall- Runoff Calculation Tool	*Hydrologic Model*	*Hydraulic Model*	*Combined Hydrologic and Hydraulic Model*	*Water Quality Model*	*BMP Calculator*			
EPA National Stormwater Calculator		X					Low	Both	http://www.epa.gov/nrmrl/wswrd/wq/models/swc/

Appendix B: Data sources

This section deals with core datasets for creating the basemap for the SWMM program to use.

1. DEM
2. Catchment/Sub-catchment boundaries
3. Land use/Land cover
4. Climate data
5. Storm sewer/Drainage ditch network
6. Soils

Derived datasets

1. % slope
2. % imperviousness
3. % land use

DEM data

Digital Elevation Model (DEM) data can be freely obtained from Geogratis: https://www.nrcan.gc.ca/earth-sciences/geography/topographic-information/free-data-geogratis/11042

DEM data is available at two scales: 1:50,000 and 1:250,000. Depending on the latitude of the map tile, grid resolution varies from 8 to 23 metres for the 1:50,000 NTS tiles and from 32 to 93 metres for the 1:250,000 NTS tiles respectively (based on geographic coordinates). The data consists of elevation data relative to mean sea level, with coordinates based on the North American Datum (NAD) 1983 horizontal reference datum.

Municipalities may have their own DEM data, which can be used in place of the federal government's DEM datasets.

Catchment / Sub-catchment boundaries data

The boundaries may be created either manually guided by the contour data or by using GIS tools to automatically create the boundaries. The spatial resolution of the input DEM is a factor in the level of detail for the catchments. Existing stormwater runoff networks such as ditches need to be considered when delineating catchment/sub-catchment boundaries. Many municipalities have a GIS dataset for their stormwater network.

Land cover data
This dataset is used to determine the percentage of land cover that is classified as either pervious or impervious. Impervious features typically include hard surfaced areas such as roads, parking lots, sidewalks, building roofs, playground surfaces and sports fields. Pervious features are those which are not hard surfaced, for example treed areas, lawns and parks.

The degree of detail can vary from coarse to very fine. It may be necessary to create this dataset from scratch if it does not already exist.

AVHRR (Advanced Very High Resolution Radiometre) data is available from Geogratis:
https://www.nrcan.gc.ca/earth-sciences/geography/topographic-information/free-data-geogratis/11042
Spatial resolution will be coarse (1 km by 1 km) and may not be suitable.

The USGS has freely available satellite imagery: http://earthexplorer.usgs.gov/
Spatial resolution of the satellite imagery depends on the type of imagery and the platform used to acquire it.

Land use data
Land uses are categories of development activities or land surface characteristics assigned to sub-catchments. Examples of land uses are residential, commercial, industrial and undeveloped. Land surface characteristics might include rooftops, lawns, paved roads, undisturbed soils, etc. Land uses are used solely to account for spatial variation in pollutant buildup and washoff rates within sub-catchments. Municipalities may have this data. You might need to create this dataset if it does not exist. The "gold" standard, which may not be practical, would be a detailed map of land use activities associated with each sub-catchment.

Climate data
SWMM requires data on precipitation, air temperature and evaporation. Data on wind speed is optional and is used only for snowmelt calculations.

Some climate data is freely available from Environment Canada:
www.climate.weather.gc.ca

Provincial government departments and municipalities may also have climate data. The location of climate stations may not be truly representative of the area being studied, however; this can occur when there are extreme changes in the topographic relief in the area. Should this happen, you may have to add additional climate stations to better represent the rainfall events.

Storm sewer and other similar networks
This data should be obtained from the stormwater engineering department of the municipality.

Soils data
Soils data may be available from provincial government agencies and possibly municipal departments. Spatial resolution will vary from very broad brush to fine detail, but may not cover the area of interest. It could be necessary to create this dataset for the area being studied.

Derived data
Per cent slope calculations
Use the GIS to calculate the average slope for each catchment/sub-catchment. Be aware that average slope value may not be truly representative of the catchment. For example: a catchment may be generally uniform in slope, but could be cut by a very steep ravine or gully. Consider separating out the ravine/gully and do a comparison in the average slope calculation to see if there is a significant difference between the two values.

Per cent impervious calculations
This value is influenced by the level of detail in the land cover dataset. The "gold" standard would be to have every hard surface feature mapped within the catchment boundary. This may not be practical.

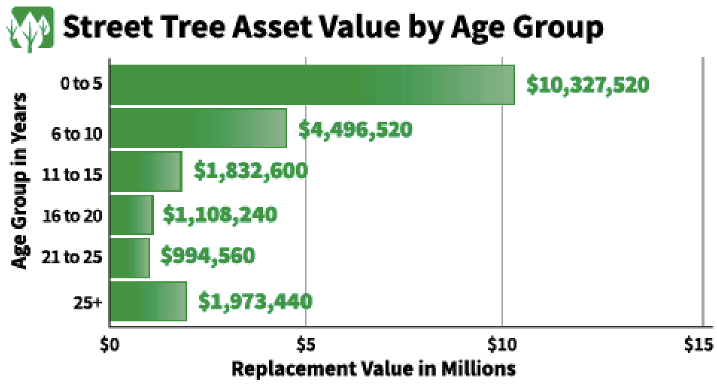
Per cent land use calculations
These values are influenced by the level of detail in the land use dataset.

Data format
The standalone version does not let you to input the GIS shapefiles data directly. Instead, use the GIS to calculate various values (surface area, width, per cent slope, per cent impervious, per cent pervious, etc) which SWMM uses for its modeling.

The GIS can be used to create a basemap, ungeoreferenced or georeferenced, which can be imported into SWMM as a backdrop image. The user then digitizes, using the background image as a guide, the outlines of the sub-catchments.

APPENDIX C: Natural Asset Inventories & Registries

Regional Municipality of York



Condition | B	Condition is impacted by maintenance performed as well as age of the various species of trees The condition score for the York Regional Forest is based upon results of the Forest Stewardship Council audit for 2013
Reliability | B	The Region maintains a comprehensive database of all Regional street trees within urban areas. This database information as well as routine assessment of trees, contributes to the positive trend in Urban Forest reliability Of the **2,365 hectares** of Regional Forest, **992 hectares** were deemed to have adequate regeneration In addition to thinning of the forests, the Region continues to plant seedlings underneath the canopy of existing trees
Capacity | B	**78%** of available planting spaces along Regional roads in urban areas have been planted Based upon the population of York Region, there are **2 hectares** of the York Regional Forest per **1,000 people**

Further details can be found in the Environmental Services State of Infrastructure Report Card 2013 - Clause No. 2 in Report No. 10 of Committee of the Whole **adopted by Council May 15, 2014.**

The Regional Municipality of York **State of Infrastructure** REPORT 2013

source: Regional Municipality of York, 2015.

Victoria Capital Region District Asset Registry

The table below provides an example of an advanced asset register template for natural assets being researched by the Victoria Capital Region District. The template uses UniFormat, a standard for classifying building specifications and cost analysis in the U.S. and Canada.

UNI-FORMAT CODE FOR NATURAL ASSETS			
Level 1	**Level 2**	**Level 3**	**Level 4**
Ecosystem Group	**Group Elements**	**Individual Elements**	**Sub-Elements**
H – COASTAL/MARINE			
H- COASTAL/MARINE	H10 Intertidal Zone		
	H20 Altered Shorelines		
	H30 Rocky Shorelines		
	H40 Sand/Gravel Shorelines		
	H50 Boulder/Cobble Shorelines		
	H60 Pocket Beaches		
	H70 Estuaries		
	H80 Intertidal Mud Flats		
	H90 Salt Marshes		
	H100 Coastal Sand Dunes		
	H200 Tidal Lagoons		
	H300 Coastal Bluffs		
I - FRESHWATER			
I - FRESHWATER	I10 Riparian Zones		
	I20 Streams & Rivers		
	I30 Wetlands		

J - TERRESTRIAL			
J - TERRESTRIAL	J10 Riparian Zones		
	J20 Coastal Douglas Fir		
	J30 Coastal Western Hemlock		
	J40 Garry Oak Meadows		
	J50 Inland Cliffs/Bluffs		
Terrestrial (example)	*Coastal Douglas Fir*	*J2010 Roots*	
		J2020 Crown	*J2021 Leaves*
			J2022 Branches
		J2030 Trunk	*J2031 Heartwood*
			J2032 Xylem
			J2033 Cambium
			J2034 Pholoem/Inner Bark
			J2034 Bark
Province wide	Alpine Tundra		
	Spruce – Willow - Birch		
	Boreal White and Black Spruce		
	Sub-Boreal Pine - Spruce		
	Sub-Boreal Spruce		
	Mountain Hemlock		
	Engelmann Spruce – Subalpine Fir		
	Montane Spruce		
	Bunchgrass		
	Ponderosa Pine		
	Interior Douglas-fir		
	Coastal Douglas-fir		

Greater London Authority Asset Registry

The asset registry below is for Beam Parklands, a multi-functional greenspace in the London Borough of Barking and Dangenham. The Land Trust, who has developed the asset registry following the framework for corporate natural accounting set out by the Natural Capital Committee, manages the site. The purpose of the framework is to assist decision-making regarding the natural asset they own and manage.

Account Unit	*Extent / Indicator*	*Units*	*Baseline year (2009)*	*Redevelop-ment (2011)*	*Reporting year (2014)*	*Source*	*Notes*
Grassland	Extent: Area of dry acid grassland (Priority BAP habitat)	Hectares	?	?	23.2	HLS Options map (2013) – split 11.4 ha HK6 and 11.8 ha HK16	To be confirmed Grasslands are cut annually on rotation, but arisings are not collected (FEP, 2013). HLS options could results in removal of arising and cutting after flowering plants have seeded (FEP, 2013)
	Species: reptile survey [flowering plants diversity?]	No. of species	?	One common lizard sighting (Nov 2011)	?	LBBD (2012)	Site reptile survey planned for 2012/13 (results?). Target reptiles include: slow worm, grass snake and common lizard. [Flowering plants, invertebrates and birds survey (Skylarks & lapwings)?]
	Prevention of alien species	No. of species	?	?	?	LBBD (2012)	Prevent spread of common ragwort and other invasive species.
	Livestock	No.	n/a	n/a	None, except for illegal grazing for horses		Potential for future controlled grazing to maintain semi-natural grasslands {need to maintain optimum number}
Rivers and Streams	Extent: Length of Wantz Stream & Beam River	Metres	?	2,200 enhanced	? (Circa 2, 500m?)	EA (2009b)	To be confirmed River Terrace Gravels deposited by Thames over the underlying London Clay, so dry and somewhat acidic

Account Unit	*Extent / Indicator*	*Units*	*Baseline year (2009)*	*Redevelop-ment (2011)*	*Reporting year (2014)*	*Source*	*Notes*
	Length of river restoration	Metres	?	600	?	EA (2009b)	To be confirmed
	Species – Otter	Sightings	Nil	Nil	?	LBBD (2012)	No reported sightings of otters, but the river system is suitable. [Fish species?]
Standing Water	Extent: Number of pools [include canal? – c 1.2km>]	Number	?	?	9	HLS Options Field data Sheet (2013)	Seven ponds <100m^2 and two >100m^2, all of high wildlife value.
	Species – Great Crested Newt	Sightings	Nil	Nil	?	LBBD (2012)	Great Crested Newt is a target species of high value. Not yet recorded but the site suitability is high – especially the Romford Canal. Survey planed for 2012/13 [results?] Scrapes, pools and well established ponds and ditches with emergent vegetation, such as *Carex, Glyceria,* and *Phragmites,* are likely to support scarce species of beetles, spiders and flies. – (LBBD, 2012)
	Prevention of alien species	No. of species	?	?	?	LBBD (2012)	Australian swamp stonecrop has been recorded in two of the ponds adjacent to the Wantz stream. If this is not treated it will spread to the other water bodies of the site. (LBBD, 2012)
Reedbeds	Area of reedbeds	Hectares	?	+2.0	3.1	EA (2009b) HLS Options Field data Sheet (2013)	To be confirmed
	Habitat: species diversity	?	?	?	?		Plants: reed sweet-grass; reed; reedmace; howthorn Bird: lesser whitethroats

Account Unit	*Extent / Indicator*	*Units*	*Baseline year (2009)*	*Redevelop-ment (2011)*	*Reporting year (2014)*	*Source*	*Notes*
Fenland	Extent: Total area of fen/ wetlands	Hectares	?	?	9.2	HLS Options Field data Sheet (2013)	To be confirmed
	Area of Wet Fen	Hectares	?	+2.9	?	EA (2009b)	To be confirmed
	Area of Floodplain Grazing Marsh	Hectares	?	+3.7	?	EA (2009b)	To be confirmed
	Species – Water Vole	Sightings	Nil	Nil	?	LBBD (2012)	No conclusive evidence of water vole found, however the site is highly suitable for the species. Water Vole survey planned for 2015/16 (LBBD, 2012)
	Invasive species	No. species	?	?	?	LBBD (2012)	Japanese knotweed and Himalayan balsam recorded on upper banks of River Beam (LBBD, 2012) [removed?}
Woodland	Extent: Total area of woodland	Hectares	?	?	6.2	HLS Options Field data Sheet (2013)	This includes woodland, orchard and successional areas.
	Area of traditional orchards	Hectares	?	+0.2	0.5	EA (2009b) HLS Options Field data Sheet (2013)	To be confirmed
	[Scattered trees to be included?]	No. of trees	?	?	?	-	Annual tree survey to be carried out on the boundary trees – London planes. (LBBD, 2012)
Parkland (not covered elsewhere)	Extent: Total area	Hectares	?	?	c.11	-	To be confirmed – estimated as total area of 53ha less the areas identified above.
	Hedgerows	Metres	?	1000	?	EA (2009b)	To be confirmed. 450m applied for under HLS options.

Account Unit	Extent / Indicator	Units	Baseline year (2009)	Redevelop-ment (2011)	Reporting year (2014)	Source	Notes
Total site	Extent: Total site	Hectares	53	53	53	LBBD (2012)	
	Flood storage	Metres cubed	433,000	+30,000	?	Jacobs (2008) ; NE (2013a)	To be confirmed
	Biodiversity	?	?	?	?	LBBD (2012)	Site invertebrate survey planned for 2013/14. Site breeding bird survey planned for 2014/15. Important bird species include: house sparrow, linnet, starling, reed bunting, kingfisher and skylark
	Recreational Indicators:						
	Paths	Metres	?	+8000	?	NE (2013a)	To be confirmed
	Boardwalks	Metres	?	+65	?	EA (2009b)	To be confirmed
	Benches	No.	?	8	+4	A2N (2014)	-
	Outdoor classrooms	No.	-	2	-	A2N (2014)	-
	Litter bins	No.	-	+8		A2N (2014)	-
	Notice boards	No.	-	+4	-	A2N (2014)	-
	Interpretation panels	No.	-	+5	-	A2N (2014)	-
	Natural play grounds	No.	-	+2	-	A2N (2014)	By London Play

APPENDIX D: Condition Assessment

The role of the condition assessment:

The assessment of assets is an early and fundamental stage of asset management. It provides the foundation for scenario analysis, asset management plans, operations and maintenance plans and long-term financial planning. The data collected will help determine how best to manage the assets. For instance, it will identify gaps between the present state of natural assets and the desired state of assets and associated service levels, as well as the activities needed to close these gaps.

Assessing the current state of assets includes gaining a clear understanding of the:

- Asset condition
- Customer and technical levels of service
- Asset risks
- Asset operations and maintenance costs

Why it's important:

The condition assessment provides the basis to understand natural assets and their contributions to service delivery – today and into the future. In addition, they provide an opportunity to identify options that will improve the assets functioning. The ability to enhance the capability of an asset to manage stormwater, recreation and safety should therefore be considered during the assessment. A comprehensive assessment can also[2]:

- Indicate the effectiveness of asset management practices
- Be easily communicated with staff and council to build awareness of the current state, risks and priorities
- Inform asset management objectives.
- Form the basis for policy, strategy and plan development or improvements.

Activities:

The municipal natural assets within a watershed that can assist in stormwater management, whether natural or engineered, need to be identified and mapped. Typical assets include storm drain systems, ditches, culverts and pipes, natural watercourses, wetlands, lakes and ponds, forested areas, groundwater recharge areas and stormwater retention facilities.

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[2] Asset Management BC. (2014).

While some reports contain asset information, in other cases it will have to be created. Start by gathering information from past assessments, studies, plans or through staff knowledge. In those instances where new information is needed, resources need to be allocated, with the understanding that your organization's knowledge of the asset should increase over time. A site inspection from a qualified professional is essential for conducting a condition assessment.

The information required to do a condition assessment can be obtained from sources such as:

- Municipal reports (e.g. OCP's and development plans)
- Surveys
- Stormwater models (through built-in drawings or mapping)
- Municipal GIS
- Development and restoration plans
- IMAP BC (for topographic information)
- Google Earth (for topographic information)

Typical data requirements by asset type:
The following information is required for each asset type below:

<u>WETLANDS (Including ponds, marshes, streams, creeks):</u>

- Asset conditions— physical, demand/capacity and functional conditions
- Surface area and depth
- Potential water storage volume
- Discharge characteristics
- Groundwater recharge or discharge
- Vegetative growth
- Potential for sediment and nutrient retention

<u>CHANNELS AND STREAMS TO/FROM WETLANDS:</u>

- Asset conditions— physical, demand/capacity and functional conditions
- Bank— full flow capacity (available flow area: width and depth, slope, roughness coefficient)
- Beaver activity
- Macrophyte density
- Manmade structures/controls

<u>FORESTS:</u>

- Asset conditions— physical, demand/capacity and functional conditions
- Type of trees— coniferous, deciduous or mixed
- Thickness and completeness of forest duff layer
- Soil type
- Coverage of ground by trees (30%, 50%, 75% or 100%)

<u>GREEN SPACE:</u>

- Asset conditions— physical, demand/capacity and functional conditions
- Soil type and permeability
- Slope of space (flat, gentle or steep)
- Vegetative cover (grass, shrubs)

In all cases and across all asset types, information should be collected on asset risk (including emerging risks such as climate change), current and desired levels of service, maintenance and monitoring alternatives and options to improve the functioning of assets.

APPENDIX E: Methods for economic valuation of ecosystem services

Common valuation approaches, with a focus on cost-based methods, are described below.

Direct market valuation

When possible, the value of an ecosystem service is determined based on market information related directly to that service. These methods are known as direct market valuation approaches and include market pricing, production and cost-based approaches (TEEB 2010).

Market Pricing Approach

This is the simplest economic valuation method. It assesses the value of ecosystem services that are bought and sold in existing markets based on their market price, which is driven by economic principles such as supply, demand, cost of production, etc. (King & Mazzotta, 2000). This is a common approach for valuing provisioning services (i.e. water supply) but cannot be applied to ecosystem services which are not bought and sold in a marketplace.

Production Approach

The production approach (a.k.a. the factor income method) measures the value of ecosystem services that contribute to the production of goods and services that are available in markets (King & Mazzotta, 2000). The assumption is that improvements in the input quality of the ecosystem service of interest will decrease the costs of production for another ecosystem service whose market value can be more easily quantified (TEEB 2010). This would be a useful method, for example, to determine the value of reducing pollutant input to a water source used to produce bottled water. Unfortunately, economic data on the relationship between the ecosystem service of interest and the market valued good or service are often unavailable or inadequate (Daily et al., 2000). This method commonly requires in-depth economic analysis, disqualifying it for this study.

Cost-Based Approaches

The two major cost-based approaches are the avoided cost and replacement cost methods. These are the most commonly used approaches to value regulating services (Barbier, 2007; TEEB, 2010; Whiteoak & Binney, 2012). They rely most heavily on output from a hydrologic model and are the most relevant methods for our purposes. The avoided cost method of valuation assumes that the value in ecosystem services can be measured by calculating the damage to infrastructure that would occur if the ecosystem service was lost (Whiteoak & Binney, 2012). For stormwater management, this might mean determining the potential damage to homes as a result of increased flood risk or the damage to a stream network caused by increased erosion associated with higher flow volumes. The approach begins by quantifying the increased/decreased probability of damage occurring under a given land use change scenario. Once the relationships between area of land use change and both incidence rate of damaging events and damage caused per event are understood, it is fairly simple to assign an economic value to the ecosystem service in question (Whiteoak & Binney, 2012). This method's limitation is that it requires a sophisticated understanding of the relationship between an ecosystem service and the potential damages associated with the process that service is regulating (Whiteoak & Binney, 2012). Any hydrologic model used in our analysis to inform the avoided cost analysis must be powerful enough to accurately model this relationship.

The replacement cost method of ecosystem service valuation sets the value of the service equal to the cost of replacing the service using man-made infrastructure. For stormwater management, this might mean the cost of constructing new retention basins to reduce flood risk, dredging excess sediment from a stream system to offset loss of erosion control or the cost to process degraded quality water in treatment facilities. The approach begins by determining the extent to which a service will be affected given a land use change, then calculating the cost to build infrastructure to replace the loss of service. The first limitation of this method is that the assumption that cost is equivalent to value is not necessarily true. In some situations, individual willingness to pay (WTP) might exceed the cost of a service, thus the value of the service would be higher than the cost. This tends towards underestimations of the value of an ecosystem service by the replacement cost method (Whiteoak & Binney, 2012). Another limitation is that there is often more than one option for replacing a lost ecosystem service, and the costs of the options will be highly variable from situation to situation and dependent on external factors. This might increase the difficulty of creating a standard tool using this approach.

Revealed Preference

If market information for an ecosystem service is unavailable, there is another set of approaches that rely on parallel market transactions which relate indirectly to the ecosystem service being valued. These are known as revealed preference methods, the most important of which are hedonic pricing and the travel cost method (TEEB 2010).

Hedonic Pricing

This method measures the value of ecosystem services that directly affect market prices. It is most commonly used to value ecosystem services that impact the price of housing real estate (King & Mazzotta, 2000). The hedonic pricing method could be applied to stormwater regulating ecosystem services such as flood peak attenuation using the assumption that decreased flood risk would increase property values. However, determining to what extent the property values are affected by a given ecosystem service requires an in-depth study into a specific region to make sure that all other factors are also accounted for. Significant time and money must be spent on economic data gathering and analysis, ruling this approach out for our analysis.

Travel Cost Method

The travel cost method assumes that the value of an ecosystem service can be measured by the amount people are willing to spend to access it. Thus, the value of changes in the quality of a recreation site can be measured by the change in costs for people to travel to the site. This method is useful for measuring the recreational value of a forest or lake, but is not generally applicable to regulating services like water purification or erosion control, so it is not applicable to our study (King & Mazzotta, 2000).

Stated Preference

If neither direct nor indirect market information is available for an ecosystem service, a hypothetical market must be used. Stated preference methods take this approach and they are based on survey responses which try to estimate individuals' WTP for a good or service (Voora & Venema, 2008). Stated preference methods include the contingent valuation and choice and group valuation methods (TEEB 2010). These rely on survey data to determine an individual's WTP for an ecosystem service, either by asking directly (contingent valuation) or by asking people to choose between different trade-offs (contingent choice) (King & Mazzotta, 2000). Group valuation takes some elements from contingent valuation and applies them in a group setting, adding the element of deliberation (TEEB 2010). These methods are widely used for economic valuation and can be used for any type of ecosystem service, with some major limitations. Peoples' willingness to accept (WTA) often exceeds their actual willingness to pay (WTP), thus potentially invalidating the results from any of these methods (TEEB, 2010). Getting reliable results depends on professionally designed surveys. For both of these reasons, stated preference methods are not applicable for this analysis.

Benefit Transfer

The benefit transfer method (a.k.a. value transfer method) involves applying values derived in previous analyses to the same ecosystem service in a different area. This method is fairly common (see Costanza et al. 1997, Costanza et al. 2006, Schmidt and Batker 2012) and can be quite effective. It allows researchers to skip the biophysical modeling phase of analysis. For example, carbon sequestration by trees is fairly uniform in different regions. On the other hand, flood prevention benefits per acre of forest can be highly variable from region to region. According to Farber et al. (2006), economic valuation studies for the types of ecosystem services of interest to us in this analysis have only a 'medium' transferability across sites. Given this, and the fact that the ultimate goal of this study is to integrate economic valuation with output from a hydrologic model, the benefit transfer method is not applicable for our purposes.

Appendix F: Operations and Maintenance Plans

The effectiveness of a natural asset within a stormwater management plan needs to be measured periodically to ensure that the performance of the natural asset is functioning as expected and unimpeded over time. This document provides information on maintenance challenges, activities, typical frequencies and required skills. In addition, it addresses monitoring needs.

This note focuses on wetland monitoring and maintenance to illustrate the types of considerations and planning required. The material draws heavily from EPA's *Stormwater Wet Pond and Wetland Management Guidebook* (https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf).

Challenges:

Water quality impacts:

- Without proper maintenance, nutrients such as nitrogen and phosphorus found in runoff can accumulate in ponds and wetlands leading to degraded conditions such as low dissolved oxygen, algae blooms and odors.
- Large rain events can flush excess nutrients into the receiving water body.

Habitat impacts:

- Placement of ponds or wetlands in low-lying areas may harm natural wetlands or existing riparian areas, interrupting surface or groundwater flow.
- Large rain events may cause breaches that cause downstream erosion and degradation.

Health and safety issues:

- Ponds and wetlands may generate large mosquito populations. The proliferation of mosquitos is usually an early indication that there is a maintenance problem.
- Safety issues are often a concern for children playing in and around wet ponds.

Aesthetics:

- While ponds and wetlands can increase property values, poorly maintained wetlands can become an issue for neighbours.

Common maintenance issues include:

- Permanent pools too low
- Permanent pools too high
- Clogging
- Pipe repairs
- Vegetation management
- Dredging and much removal

Table 1: Inspection skill level descriptions	
Skill level	***Description***
0	No special skills or prior experience required, but some basic training is necessary (via manual, video, in-person training)
1	Inspector, maintenance crew member or citizen with prior experience with ponds and wetlands
2	Inspector or contractor with extensive experience with pond and wetland maintenance issues
3	Professional engineering consultant

Table 2: Typical Inspection/Maintenance Frequencies for ponds & wetlands		
Frequency	*Inspection Items (skill level)*	*Maintenance items*
One time – after 1st year	• Ensure that at least 50% of wetland plants survive (0) • Check for invasive wetland plants (0)	• Replant wetland vegetation
Monthly to quarterly – or after major storms	• Inspect low flow orifices and other pipes for clogging (0) • Check the permanent pool or dry pond area for floating debris, undesirable vegetation (0) • Investigate the shoreline for erosion (0) • Monitor wetland plant composition and health (0 – 1) • Look for broken signs, locks, and other dangerous items (0)	• Mowing – at minimum spring and fall • Remove debris • Repair undercut, eroded and bare soil areas
Several times per hot/warm season	• Inspect stormwater ponds and stormwater wetlands for possible mosquito production (0-1)	• Inspect for mosquitos
Semi-annual to annual	• Monitor wetland plant composition and health (0-1) • Identify invasive plants (0-1)	• Set-up a trash and debris clean-up day • Remove invasive plants

Table 2: Typical Inspection/Maintenance Frequencies for ponds & wetlands		
Frequency	*Inspection Items (skill level)*	*Maintenance items*
	• Ensure mechanical components are functional (0-1)	• Harvest wetland plants • Replant wetland vegetation • Repair broken mechanical components if needed
Every 1 to 3 years	• Complete all routine inspection items above (0) • Inspect riser, barrel, and embankment for damage (1-2) • Inspect all pipes (2) • Monitor sediment deposition in facility and reservoir (2)	• Pipe and riser repair • Complete reservoir maintenance and sediment removal when needed
Every 2 to 7 years	• Monitor sediment deposition in facility and reservoir (2)	• Complete reservoir maintenance and sediment removal when needed
Every 5 to 25 years	• Remote television inspection of reverse slope pipes, underdrains and other hard to access piping (2-3)	• Sediment removal from main pond/wetland • Pipe replacement if needed

Table 3: Maintenance Activities and Schedules			
Category	*Management Practice*	*Maintenance Activity*	*Schedule*
Ponds	Extended detention ponds, wet ponds, multiple ponds systems, pocket ponds	• Cleaning and removing debris after major storm events • Harvesting of vegetation when a 50% reduction in the original open water surface area occurs • Repairing embankment and side slopes • Repairing control structures	Annual as needed
		• Removing accumulated sediment from reservoirs or sediment storage areas	5-year cycle

Table 3: Maintenance Activities and Schedules

Category	*Management Practice*	*Maintenance Activity*	*Schedule*
		when 60% of the original volume has been lost	
		• Removing accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle
Infiltration practices	Infiltration trench	• Removing accumulated sediment from reservoirs or sediment storage areas when 60% of the original volume has been lost	5-year cycle
		• Removing accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle
	Infiltration basin	• Cleaning and removing debris after major storm events • Mowing and maintenance of upland vegetation areas • Cleaning out sediment	Annual or as needed
		• Removing accumulated sediment from reservoirs or sediment storage areas when 50% of the original volume has been lost	3 to 5 year cycle
Open channel practices	Dry swales, grassed channels, biofilters	• Mowing and litter/debris removal • Stabilizing eroded side slopes and bottom • Managing the use of nutrients and pesticides • Dethatching the bottom of the swale and removing thatching • Disking or aeration of swale bottom	Annual or as needed
		• Scraping of swale bottom, and removal of sediment to	5-year cycle

Table 3: Maintenance Activities and Schedules			
Category	*Management Practice*	*Maintenance Activity*	*Schedule*
		restore original cross-section and infiltration rate • Seeding or installing sod to restore ground cover	

References:

Asset Management BC. (2014). Asset Management for Sustainable Delivery: A BC Framework (Long Version). http://www.civicinfo.bc.ca/Library/Asset_Management/Tools_and_Resources/Asset_Management_for_Sustainable_Service_Delivery_-_A_BC_Framework--Asset_Management_BC--September_16_2015.pdf.

Barbier, E.B. (2007). Valuing Ecosystem Services as Productive Inputs. *Economic Policy* 22 (49): 177–229.

Barbier, Edward. (2014). Economics: Account for depreciation of natural capital. *Nature,* 515, 32-33.

Cairns, S., Arros, P., and O'Neill, SJ. (2016). *Incenting the Nature of Cities: Using Financial Approaches to Support Green Infrastructure in Ontario.* Sustainable Prosperity. http://www.sustainableprosperity.ca/sites/default/files/publications/files/Metcalf_Green_Prosperity_Incenting-Cities_web.pdf.

Cirillo, Colleen and Liat Podolsky. (2012). *Health, Prosperity & Sustainability: The Case For Green Infrastructure In Ontario*. Toronto: Green Infrastructure Ontario Coalition. http://www.greeninfrastructureontario.org/sites/greeninfrastructureontario.org/files/The_Case_for_Green_Infrastructure_in_Ontario.pdf.

Costanza, R., d'Arge, R., de Groot, R.S., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260.

Credit Valley Conservation. Low Impact Development Guidance Documents: http://www.creditvalleyca.ca/low-impact-development/low-impact-development-support/stormwater-management-lid-guidance-documents/.

Credit Valley Conservation, Aquafor Beech Limited, and Water Canada. (2015). *Grey to Green Business & Multi-Residential Retrofits.* https://cvc.ca/wp-content/uploads/2015/01/Grey-to-Green-Business-and-Multiresidential-Guide1.pdf.

Daily, G.C., Soderqvist, T., Aniyar, S., Arrow, K., Dasgupta, P., Ehrlich, P.R., Folke, C., Jansson, A., Jansson, B., Kautsky, N., Levin, S., Lubchenco, J., Maler, K., Simpson, D., Starrett, D., Tilman, D., Walker, B. (2000). The value of nature and the nature of value. *Science* 289: 395–396.

Daly, H., & Farley, J. (2004). *Ecological economics: Principles and applications.* Washington DC: Island Press. http://indomarine.webs.com/documents/ecological_economics_principles_and_applications.pdf.

Environmental Protection Agency. (2009). *Stormwater wet pond and wetland management guidebook*. https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf.

Farber, S., R. Costanza, D.L. Childers, J. Erickson, K. Gross, J.M. Grove, C. Hopkinson, J. Kahn, S. Pincetl, A. Troy, P. Warren, M. Wilson. (2006). Linking Ecology and Economics for Ecosystem Management. *Bioscience* 56(2): 117---129.

Federation of Canadian Municipalities (FCM). (2004). *Demonstrating the Economic Benefits of Integrated, Green Infrastructure*. https://www.fcm.ca/Documents/tools/GMF/Demonstrating_the_Economic_Benefits_of_Integrated_Green_Infrastructure_Final_Report_EN.pdf.

Federation of Canadian Municipalities (FCM). (2016). *The Canadian Infrastructure Report Card: Asset Management Primer.* *http://www.canadainfrastructure.ca/downloads/circ_asset_management_primer_EN.pdf*.

Federal, Provincial, and Territorial Governments of Canada. (2014). *2012 Canadian Nature Survey: Awareness, participation, and expenditures in nature-based recreation, conservation, and subsistence activities*. Ottawa, ON: Canadian Councils of Resource Ministers. http://www.biodivcanada.ca/2A0569A9-77BE-4E16-B2A4-C0A64C2B9843/2012_Canadian_Nature_Survey_Report(accessible_pdf).pdf.

Greater London Authority. (2015). EFTEC: Beam Parklands Natural Capital Account. https://www.london.gov.uk/sites/default/files/beam_parklands_natural_capital_account_final_report_eftec_november_2015.pdf.

Green Infrastructure Ontario Coalition. (2016). *Benefits.* http://www.greeninfrastructureontario.org/benefits .

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, 86, 235–245.

Government of Canada. (2012). *The Value of Nature to Canadians Study: An FTP ADM initiative*. http://biodivcanada.ca/default.asp?lang=En&n=24D8B61F-1.

King, D. M., & Mazzotta, M. (2000). *Ecosystem Valuation*. http://www.ecosystemvaluation.org/default.htm

Minnesota Stormwater Manual. (2017). https://stormwater.pca.state.mn.us/index.php/Available_stormwater_models_and_selecting_a_model.

NAMS. (2016). *Infrastructure Asset Management Defined*. http://www.nams.org.nz/pages/173/infrastructure-asset-management-defined.htm.

O'Neill, S.J., Cairns, S., and Brooke, R. (2017). *Defining and Scoping Municipal Natural Assets.* http://mnai.ca/media/2018/02/finaldesignedsept18mnai.pdf.

Ontario Ministry of Infrastructure. (2012). *Building Together: Guide for Municipal Asset Management Plans.* http://www.moi.gov.on.ca/pdf/en/Municipal%20Strategy_English_Web.pdf.

Public Sector Digest. (2010). *Optimized Asset Decision Making @ The Region of Peel. http://www.peelregion.ca/finance/PDFs/psd-critical-knowledge-sept2010.pdf.*

Regional Municipality of York. 2015. *Corporate State of Infrastructure Report. https://www.york.ca/wps/wcm/connect/yorkpublic/e95bee6e-20db-47b1-88c8-5c1361adf1e2/mar+12+corporate+ex.pdf?MOD=AJPERES.*

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.

TEEB. 2010. *Ecological and Economic Foundations*. Edited by Pushpam Kumar. Earthscan, London and Washington.

TEEB. (2012), *The Economics of Ecosystems and Biodiversity in Local and Regional Policy and Management*. Edited by Heidi Wittmer and Haripriya Gundimeda. Earthscan, London and Washington.

The Federation of Canadian Municipalities, Canadian Construction Association, Canadian Public Works Assocation and the Canadian Society for Civil Engineering. (2014), *Canadian Infrastructure Report Card: Asset Management Primer.* http://www.canadainfrastructure.ca/downloads/circ_asset_management_primer_EN.pdf.

Town of Gibsons. (2017). *Advancing Natural Capital Management: The Town of Gibsons experience in financial planning & reporting.* http://mnai.ca/media/2018/01/GibsonsFinancialPlanningReport-WEB.pdf.

UNEP. (2014). *Green Infrastructure Guide for Water Management.* http://web.unep.org/ecosystems/resources/publications/green-infrastructure-guide-water-management.

US Environmental Protection Agency. (2010). *Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure.* http://nepis.epa.gov/Exe/ZyNET.exe/P100FTEM.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2006+Thru+2010&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C06thru10%5CTxt%5C00000033%5CP100FTEM.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL.

US EPA (United States Environmental Protection Agency). (2015). *Stormwater Management Model User's Manual Version 5.1. Office of Research and Development Water Supply and Water Resources Division*. EPA/600/R-14/413b.

US EPA (United States Environmental Protection Agency). (2016). *Stormwater Management Model Reference Manual: Volume 1- Hydrology (Revised)*. Office of Research and Development Water Supply and Water Resources Division. EPA/600/R-15/162A.

Voora, V. & Venema, H. (2008). *The Natural Capital Approach: A Concept Paper*. Prepared for Environment Canada – Policy Development Division. International Institute for Sustainable Development. Winnipeg, Manitoba.

Whiteoak, K., & Binney, J. (2012). *Literature Review of the Economic Value of Ecosystem Services that Wetlands Provide*. Prepared for Department of Sustainability, Environment, Water, Population and Communities, Australia.