# Combatting Canada's Rising Flood Costs:

## Natural infrastructure is an underutilized option

September, 2018

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**CITATION** Moudrak, N., Feltmate, B., Venema, H., Osman, H. 2018. Combating Canada's Rising Flood Costs: Natural infrastructure is an underutilized option. Prepared for Insurance Bureau of Canada. Intact Centre on Climate Adaptation, University of Waterloo.

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# Executive Summary

The financial impacts of climate change and extreme weather events are being felt by a growing number of homeowners and communities across Canada. The increase in P&C insurance losses is indicative of the growing costs associated with these events. These losses averaged $405 million per year between 1983 and 2008, and $1.8 billion between 2009 and 2017. Water damage is the key driver behind these growing costs. Fortunately, as documented in this report, flood risk can be limited through conservation and restoration of natural infrastructure features, such as ponds, wetlands and vegetated areas. This report demonstrates how to quantify the benefits and costs of these natural features as a strong complement or a viable alternative to grey infrastructure option for flood mitigation. As a general "rule of thumb", in order of preference, the most cost-effective means to mitigate flood losses utilizing natural systems is to:

(i) retain what you have;
(ii) restore what you've lost; and
(iii) build what you must.

This report presents ample evidence to suggest that efforts by governments to limit flood risk may be consistent with – and reinforce – their fiduciary responsibility to administer good governance. Flood risk is mounting across Canada from fluvial sources, such as rivers and lakes; pluvial sources, such as intense rainfall inundating urban environments; and coastal sources, such as storm surges compounded by rising sea levels. As this responsibility is likely to grow in response to increasing climate change and the associated extreme weather events, natural infrastructure merits consideration alongside grey infrastructure solutions as a means of limiting flood risk across all levels of government and all jurisdictions.

Beyond the specific methods needed to assess and compare grey infrastructure against natural infrastructure options relative to their utility to mitigate risk, a framework is required that would provide guidance to those considering or opting for a natural infrastructure solution. The natural infrastructure implementation framework that is being introduced provides such a structure, and it is consistent with the natural infrastructure preservation commitments Canada has made under the Paris Agreement, the United Nations' Sendai Framework for Disaster Risk Reduction and the Pan-Canadian Framework on Clean Growth and Climate Change.

Natural infrastructure can be a cost-effective way to mitigate material financial losses that would otherwise result from flooding, as can be exemplified by:

- Naturally occurring ponds in the coastal town of Gibsons, British Columbia (BC), that provide $3.5 million to $4 million of stormwater storage services annually;
- A 250-metre naturalized channel in the town of Oakville, Ontario, that provides $1.24 million to $1.44 million of stormwater conveyance and storage annually;
- Naturally occurring wetlands in southern Ontario that reduce flood damage costs to buildings by $3.5 million (or 29%) at a rural pilot site and by $51.1 million (or 38%) at an urban pilot site; and
- A restored and engineered wetland in Manitoba that is valued at $3.7 million for the flood reduction, water quality improvement, carbon sequestration and other benefits it provides.

Moreover, natural infrastructure can offer other valuable environmental and social benefits that are often not attainable through the implementation of traditional, grey-engineered solutions. A thorough cost-benefit analysis should measure all infrastructure options through a common cost-benefit lens. For example, although naturally occurring ponds provide stormwater storage capacity, which helps attenuate flooding, they also create habitat for aquatic species, improve biodiversity and provide aesthetic benefits to the community. These additional benefits are not available through a grey infrastructure solution, such as a stormwater storage tank, and this needs to be reflected in a cost-benefit analysis. A comprehensive assessment of the financial, environmental and social costs and benefits (i.e., a total economic value [TEV] assessment) is required to illuminate these otherwise uncaptured benefits.

Canada will continue to experience loss and degradation of its natural infrastructure assets if it does not start to apply a robust TEV assessment for natural versus grey infrastructure solutions.

To assist governments, practitioners and investors with land-use planning and infrastructure investment decisions, this report includes a framework for natural infrastructure project implementation (Figure 1).

**Figure 1: Framework for Natural Infrastructure Project Implementation**

The framework provides an improved due diligence process for the assessment and implementation of natural infrastructure projects. It also adds economic rigour to the way in which costs and benefits are assessed, including assessments of materiality and feasibility, approaches to calculating TEV and net present value (NPV), and accounting for uncertainty. This expands the utility of the framework beyond local communities and makes the framework relevant to parties seeking to direct green infrastructure spending in Canada (e.g., Infrastructure Canada, corporate sponsors and foundations).

The framework is part of a broader suite of measures that could be taken to further the uptake of natural infrastructure projects. To increase the ability and willingness of communities to explore and adopt natural infrastructure solutions, Canada should also consider the following measures:

- Assess the TEV of natural infrastructure as part of land-use planning and infrastructure investment decisions;
- Establish sustainable funding models and mechanisms for natural infrastructure conservation and restoration (e.g., landowner compensation schemes, economic linkages between de-risking and longer-term savings);
- Establish funding mechanisms and criteria that explicitly recognize the unique programmatic needs of implementing effective natural infrastructure solutions within broader infrastructure funding frameworks;
- Work with municipalities, the new Canada Infrastructure Bank and the financial sector to develop and implement new financial instruments to accelerate natural infrastructure investment and implementation; and
- Develop forums for convening traditional actors responsible for natural infrastructure preservation (e.g., conservation authorities, environmental non-governmental organizations [NGOs]), municipalities, institutional investors, and insurers to deliver market-based solutions.

As illustrated throughout this report, a new skill set – one that combines financial acumen with broader environmental and social impact assessment – is required to curtail the possible debilitating loss of natural infrastructure assets in the country. If Canada remains committed to the Sendai Framework and the Paris Agreement, it needs to act now, in innovative and unprecedented ways, before it cannot act at all.

# Chapter 1: The Need for Climate Adaptation in Canada

Climate change–associated extreme weather events and flooding are becoming more frequent in Canada, bringing ever-increasing costs to governments, insurers, investors and ultimately all Canadians. Since 2009, flooding from coastal and inland sources has emerged as the most pervasive and costly natural disaster in the country, causing financial and psychosocial distress to homeowners in virtually all regions.

To limit the impacts of extreme weather and flooding, all levels of government are making new infrastructure investments and implementing climate adaptation strategies. While the primary focus has been on implementing traditional grey infrastructure solutions (e.g., dams, diversion channels, water and wastewater plant upgrades, and the construction of new dikes) to limit risk, there is a growing recognition that natural infrastructure solutions can play an important role in climate adaptation and disaster risk reduction.

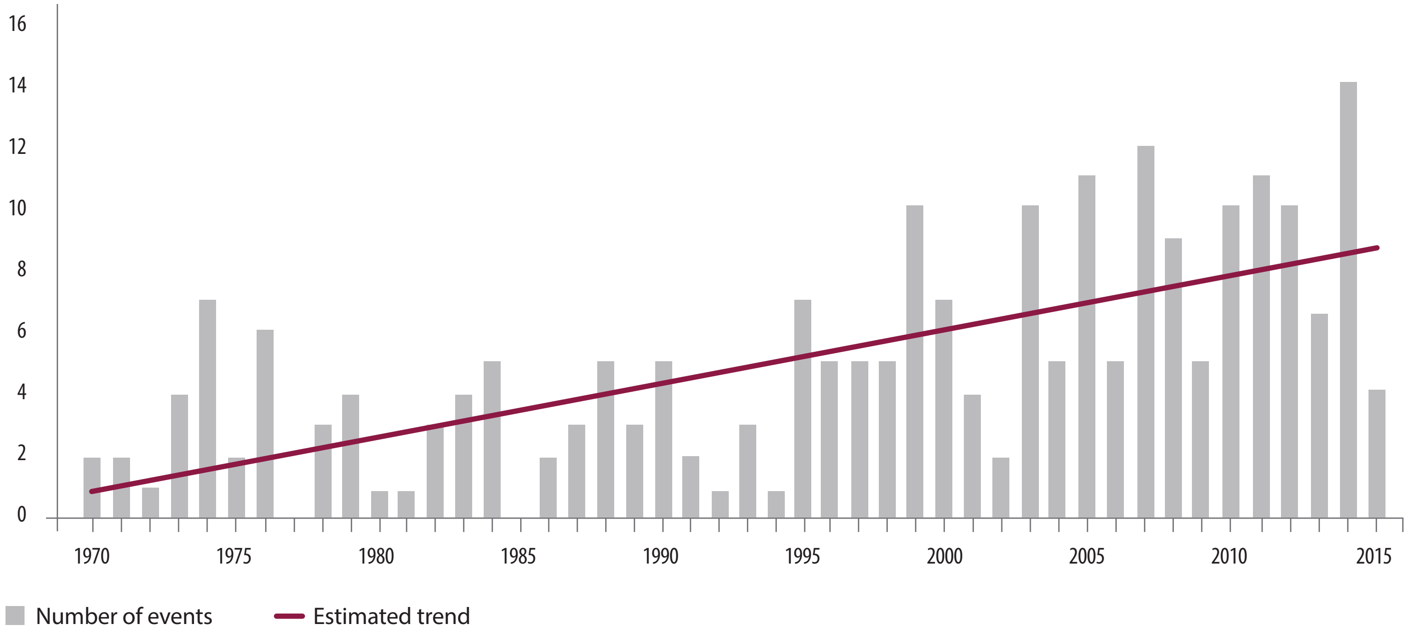
**Chapter 1** examines the need for climate adaptation – particularly flood risk reduction – in Canada. **Chapter 2** features Canadian case studies in which natural infrastructure projects were used for flood risk reduction and provided a range of other environmental and societal benefits. These case studies demonstrate that there is a significant economic benefit associated with natural infrastructure conservation and restoration. **Chapter 3** presents a framework for implementing natural infrastructure projects. A key element of the framework is quantifying the broad economic benefits that natural infrastructure offers (e.g., flood attenuation, water quality improvement). **Chapter 4** explores additional ways that the uptake of natural infrastructure can be improved. **Chapter 5** concludes that it is possible – and indeed imperative – for communities in Canada to consider both grey and natural infrastructure solutions for climate adaptation. It also emphasizes that the framework featured in the report can help identify circumstances where natural infrastructure solutions are the best fit.

## 1.1: Escalating costs of natural disasters and flooding in Canada

In the coming years, climate-related natural catastrophes and their associated economic losses are expected to increase. The Intergovernmental Panel on Climate Change projects continued global warming and increased global frequency of heavy precipitation events in the 21st century,[2] with Canada warming faster than the global average and experiencing more frequent and severe weather.[3] Similarly, Environment and Climate Change Canada predicts growth in the frequency and severity of extreme weather events in Canada.[4] These projected trends are already manifesting, presenting a significant economic concern.

According to Public Safety Canada, the number of natural disasters for which provinces and territories required and obtained federal assistance under the Disaster Financial Assistance Arrangements (DFAA) increased dramatically between 1970 and 2015 (Figure 2).[5] Similarly, the Office of the Auditor General of Canada noted that from 2009 to 2015, DFAA's compensation to the provinces and territories was greater than any of the previous 39 fiscal years combined.[6] The DFAA's spending on flooding accounted for 75% of all weather-related expenditures.[7]

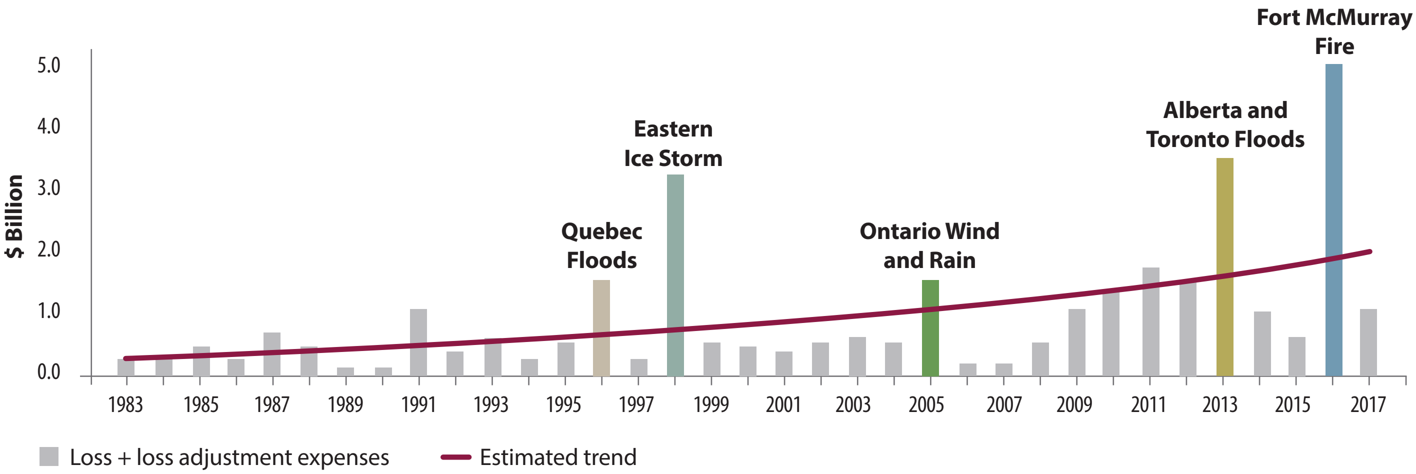
### Figure 2: Number of Natural Disasters in Canada Requiring DFAA Compensation for Provinces and Territories (1970–2015)



Source: Public Safety Canada. 2016–2017 Evaluation of the Disaster Financial Assistance Arrangements.

IBC has determined that “property and casualty insurance payouts from extreme weather have more than doubled every five to 10 years since the 1980s.”[8] While insurable payouts averaged $400 million per year from 1983 to 2008 in Canada, for eight of the last nine years leading up to 2017, insurance payouts for catastrophic losses exceeded $1 billion per year (Figure 3). The insurance gap in Canada is also significant; for every dollar of insured losses borne by insurers in Canada, three to four dollars are borne by governments and home and business owners.

## Figure 3: Catastrophic Insured Losses in Canada (1980–2017)



Source: IBC Facts Book, PCS, CatIQ, Swiss Re, Munich Re and Deloitte.
*Values in 2017 dollars; total natural catastrophe losses normalized by inflation and per-capita wealth accumulation.

## 1.2: Repeated flooding stresses Canada’s mortgage holders

There are 1.7 million Canadian households (19% of Canada’s population) at risk of river (fluvial) and surface water (pluvial) flooding.[i] For areas where flood insurance coverage is limited or unavailable, and where Canadians are at the highest risk of flooding, this represents a significant economic concern.

Flood damages can cost homeowners tens of thousands of dollars to repair. For example, according to the National Flood Insurance Program in the U.S., a 15-centimetre flood in a 2,000-square-foot home is likely to cause about US$40,000 in flood damage.[9] With limited or no flood insurance, it may be challenging for homeowners to cover this cost on their own.

As of 2017, the Canadian Payroll Association reported that almost half of working Canadians are living paycheque to paycheque, with 47% of working Canadians indicating that it would be difficult to meet their financial obligations if their paycheque was delayed by even a week.[10] Consequently, there is an emerging risk facing Canada’s mortgage market. In the future, flood-related mortgage default rates may increase as saving rates remain low and more households are subject to debilitating flooding.

[i] IBC commissioned an analysis of fluvial and pluvial residential flood risk for Canada based on 2015 residential housing stock excluding apartment buildings and condos.

## 1.3: Climate risk and flooding affect credit ratings

Global credit rating agencies, including DBRS, Moody's and Standard & Poor's, are beginning to examine climate change risks and potential impacts on ratings of tradable assets, including municipal bonds.[11] The Carbon Disclosure Project predicts that tax base, debt levels and management quality are the three main areas that credit rating analysis for municipal bonds will start to incorporate to determine how well municipalities are addressing climate and extreme weather risks.[12] Indeed, in November 2017, Moody's Investors Service, the bond credit rating dimension of Moody's Corporation, outlined four key credit risks associated with climate change that their credit rating analysts look at when examining U.S. local and state government risks:

1. **Economic disruption** (e.g., property loss and/or damage, lower revenues, business interruption, increased debt and higher insurance costs)
2. **Physical damage** (e.g., property loss and/or damage, loss of utilities, transportation and communication networks)
3. **Health and public safety** (e.g., loss of life, jeopardized critical emergency service provisions)
4. **Population displacement** (e.g., short-term displacements and longer-term population migration).[13]

Notably, coastal and non-coastal flood risks comprise two of the six total metrics of climate risks assessed by Moody's:

1. Gross domestic product (GDP) coastal counties/total state GDP, 2016
2. Tropical cyclone damage (1980–2017)/state GDP, 2016
3. Coastal dwelling units in 100/500 year flood plains/total coastal dwelling units
4. Damage from non-tropical cyclone weather events (1980–2017)/state GDP, 2016
5. Non-coastal dwelling units in 100/500 year flood plains/total non-coastal dwelling units
6. Agricultural, forestry, fishing and hunting/total state GDP, 2016.[14]

In Canada, where flooding is the most common extreme weather risk facing municipalities, the focus of credit rating analysis for municipal bonds will undoubtedly reflect the initiatives that local governments deploy to improve their flood resiliency. Measures to mitigate physical exposure to climate risks will weigh increasingly on credit ratings.

## 1.4: Flooding gives rise to lawsuits

Flood-related lawsuits involving homeowners, developers, local governments, conservation authorities, Indigenous peoples, provinces and private businesses are on the rise in Canada. Table 1 provides examples of these lawsuits. These cases demonstrate the need for flood resilience at all levels of government, as well as for businesses and society.

### Table 1: Examples of Stormwater Management and Flood-Related Lawsuits in Canada

| CASE NAME AND YEAR | DESCRIPTION<br>(damages, cost and settlement amounts included where identified) | DEFENDANTS |
|---|---|---|
| *Anderson et al. v. Manitoba et al.,* 2017 (ongoing) | A $950-million class action lawsuit was brought forward by 4,000 residents of four First Nations following severe flooding in spring 2011. The flood resulted in damage to property and the evacuation of many families from their homes. The plaintiffs brought claims of negligence, nuisance and breach of treaty rights, alleging that the Government of Manitoba caused the flooding through its water and flood control measures that affected the water levels around the four First Nations. The class action lawsuit was certified in January 2017 and is moving forward. | Province, Association of Native Fire Fighters Inc. |
| Muskoka Class Action, 2016 (ongoing) | Muskoka residents as well as cottage and business owners launched a $900-million class action lawsuit against the Province of Ontario after flooding and high water levels caused damage. The plaintiffs allege that the Ministry of Natural Resources and Forestry was negligent for failing to control water levels. | Province |
| *Cerra et al. v. The Corporation of the City of Thunder Bay,* 2012 (ongoing) | In May 2012, floods resulted in severe damage in Thunder Bay, Ont. The plaintiffs allege negligence in repairing, inspecting and maintaining the water pollution control plant, as well not diligently operating and supervising at the time of the flood (including an allegation that alarms were ignored). The $300-million claim is ongoing. The court certified action on consent in 2013. | Municipality |
| Maple Ridge Class Action, 2010[15] (ongoing) | After a 2010 flood, 15 households filed a class action lawsuit against a developer and contractor, two engineering firms and the City of Maple Ridge, BC. The plaintiffs allege that the defendants were negligent, arguing construction failure, faulty workmanship and design, and failure to inspect basements for leaks and repair leaks as requested. The plaintiffs also argue that the houses were not waterproofed to code, despite the municipality's inspection, review and issuance of permits. The trial was scheduled to begin in 2016. | Municipality, developer, contractor, engineering firms |
| *Panza et al. v. The Corporation of the City of Mississauga et al.,* 2012 | Upper- and lower-tier municipalities, the Province of Ontario and the conservation authority were all named as defendants in a negligence claim related to systemic flooding in the Lisgar area of Mississauga over several years. The $200-million class action lawsuit was withdrawn before trial. However, this case shows the potential for systemic flooding giving rise to class action lawsuits. | Province, municipality, conservation authority |

## Table 1: Examples of Stormwater Management and Flood-Related Lawsuits in Canada

| CASE NAME AND YEAR | DESCRIPTION<br>(damages, cost and settlement amounts included where identified) | DEFENDANTS |
|---|---|---|
| *Dicaire v. Chambly (Town)*, 2008 | The Quebec Court of Appeal dismissed a class action lawsuit by owners of 1,723 homes that flooded in 1997 when sewers backed up following heavy rains. The court ruled that the sewers were designed to withstand a five-year storm as required by provincial guidelines, and the town was not obliged to do more. However, the court noted that current design standards might not protect municipalities in future lawsuits, in light of "recent climate phenomena" and other scientific advances. | Municipality |
| *McLaren v. Stratford (City)*, 2005 | A major flood in the city of Stratford, Ont., after a severe rainfall in 2002 left many with sewage in their basements. The plaintiffs (city residents) claimed negligence in the design, construction, operation and maintenance of the storm and sanitary sewer system. The class action lawsuit was certified by the court in 2005, and the case was settled in 2010, eight years after the flood. Stratford settled for $7.7 million after already spending $1.3 million in emergency relief, and then upgraded its system to a 250-year storm standard. | Municipality |

Source: Zizzo Strategy. 2017. Legal Risks and Requirements to Address Flood Resilience. Prepared for the Intact Centre.

## 1.5: Flooding affects the mental health of Canadians

Mental health impacts associated with flooding can include general mental distress, anxiety, post-traumatic stress disorder and depression. Mental distress is defined as being of "sufficient intensity to disrupt a person's normal life patterns."[16]

In Canada, several studies indicate that Canadians experienced mental distress because of flooding both in the immediate term and over the long term:

- A 2017 study of 200 households in Montreal that experienced flooding found that "almost 70% of respondents reported having suffered from anxiety, sleep disturbances or concentration problems since the floods."[17]
- A 2004 study of 176 households in Manitoba found that over a third experienced psychological distress following a major flood event.[18]
- A 2016 study of men and women affected by the 2013 Alberta floods found a 164% increase in the use of anti-anxiety medication and a 232% increase in the use of sleeping aids among women in High River, one of the worst-hit areas.[19]
- A 2000 study of Saguenay-Lac-St-Jean, Que., residents following the 1996 floods found that 12% had to take sick leave or were absent from work, and 6% took an early retirement.[20]

Findings from a 2018 Intact Centre study of 100 households in flood-affected neighbourhoods in southern Ontario confirm that flooding can cause mental distress. Three years after experiencing a flood, nearly 50% of households are "significantly worried" about flooding when it rains. Furthermore, homeowners who experienced basement flooding had to take, on average, seven days off work following the flood event.[21]

## 1.6: Canada's commitment to disaster risk reduction through natural infrastructure

To improve resilience against natural disasters, all levels of government in Canada have begun to prepare for extreme weather and develop climate adaptation strategies and plans. These efforts are consistent with the Paris Agreement, which Canada signed in 2016;[22] with the United Nations' Sendai Framework for Disaster Risk Reduction;[23] and with the Pan-Canadian Framework on Clean Growth and Climate Change.

Both the global Sendai Framework and the Pan-Canadian Framework recognize that natural infrastructure is a key priority for disaster risk reduction. Under the Sendai Framework, national and local governments are advised to strengthen the sustainable use and management of ecosystems and implement integrated environmental and natural resource management approaches for disaster risk reduction."[24] Under the Pan-Canadian Framework, both traditional and natural adaptation solutions are noted to "build resilience, reduce disaster risks, and save costs over the long term."[25] In the words of Ralph Goodale, Canada's Minister of Public Safety, "with astute science, engineering, planning, and investment, we could develop a network of upstream water control structures – large and small, natural and constructed – together with properly designed channels, reservoirs, wetlands, and wooded areas to manage water flows in a smarter, more effective way, countering the debilitating cycles of uncontrolled floods and drought."[26]

In its 2017 budget, Canada announced $2 billion for a Disaster Mitigation and Adaptation Fund, and stated that natural infrastructure was eligible. Unfortunately, the $20 million minimum project cost and funding-matching criteria will likely exclude applications for programs that feature natural infrastructure, as they are usually not that expensive to implement. Furthermore, the analytical and institutional capacity to identify, design and finance natural infrastructure options is not well developed. This report first profiles the utility of natural infrastructure for climate adaptation and then outlines an analytical framework that practitioners can use to develop the business case for natural infrastructure conservation and restoration.

# Chapter 2: The Utility of Natural Infrastructure for Climate Adaptation

This chapter first outlines the considerable loss of natural infrastructure, particularly wetlands, in Canada. It then provides Canadian case studies in which the benefits and costs of natural infrastructure were evaluated. The case studies demonstrate that natural infrastructure merits consideration as a complement to grey infrastructure solutions for climate adaptation.

## 2.1: Defining natural infrastructure – A multifaceted climate adaptation solution

For the purpose of this report, natural infrastructure is defined as "a strategically planned and managed network of natural lands, such as forests, wetlands and other open spaces, which conserves or enhances ecosystem values and functions and provides associated benefits to human populations."[27, 28] Natural infrastructure can be further defined as "fully natural" or "engineered" using the following criteria:

- Fully natural infrastructure (e.g., a wetland, forest or flood plain), once established, requires no human intervention or management.
- Engineered infrastructure, such as a water retention facility, can leverage natural processes but be optimized through human design and management. For example, an engineered retention storage project (a small reservoir) can intercept floodwaters and release them through an engineered outlet. The reservoir produces many of the same ecological benefits as, for example, a wetland, with the important distinction that water levels can be manipulated by human intervention.

A key benefit of using natural infrastructure for climate adaptation is that typically, it can serve a number of functions (e.g., both flood and drought attenuation) and have a variety of additional ecological and societal benefits.[29, 30] Meanwhile, traditional grey infrastructure is generally designed to meet a limited set of purposes.[31, 32, 33, 34]

Natural infrastructure can be a strong complement to traditional infrastructure solutions.[35, 36] For example, reforesting watersheds above dams helps prevent erosion, which slows the reservoir sedimentation processes and, in turn, increases power generation efficiency and the longevity of hydropower facilities.[37] Similarly, small-scale hydraulic retention structures (i.e., structures that can store water during intense rainfall periods to reduce flooding and release water for irrigation during droughts) can also help improve water quality by capturing nutrients and sequestering carbon through growth in vegetation.[38, 39, 40, 41]

Table 2 summarizes and compares the costs and benefits of grey and green infrastructure.

## Table 2: Conceptual Comparison of Costs and Benefits of Natural Infrastructure versus Grey Infrastructure Solutions for Stormwater Storage (e.g., naturally occurring ponds versus storage tanks)

| COSTS (EXAMPLES) | NATURAL INFRASTRUCTURE | GREY INFRASTRUCTURE |
|---|---|---|
| **Pre-Construction** | x | x |
| • Baseline data collection | x | x |
| • Stakeholder consultation | x | x |
| • Site identification | x | x |
| • Assessment of design alternatives | x | x |
| • Detailed engineering design of selected alternative | x | x |
| • Land acquisition | x | x |
| • Environmental assessment | x | x |
| • Permitting and legal fees | x | x |
| • Development of construction specifications | x | x |
| • Development of monitoring program and key performance indicators (KPIs) | | |
| **Construction** | | |
| • Site preparation | x | x |
| • Site construction | x | x |
| **Post-construction** | | |
| • Infrastructure maintenance activities | x | x |
| • Infrastructure condition assessment | x | x |
| • Monitoring against KPIs | x | x |
| • Evaluation and reporting | x | x |
| • Carbon cost over project life cycle | | x |
| **Administration** | | |
| • Project management and oversight | x | x |

| BENEFITS (EXAMPLES) | NATURAL INFRASTRUCTURE | GREY INFRASTRUCTURE |
|---|---|---|
| • Stormwater storage | x | x |
| • Water quality | x | |
| • Habitat creation / improvement | x | |
| • Microclimate stabilization (e.g., urban heat island reduction) | x | |
| • Air filtration | x | |
| • Recreational amenity and aesthetic services | x | |
| • Energy savings | x | |
| • Carbon savings | x | |

## 2.2: Canada's natural infrastructure being lost to development – Conservation and restoration required

Despite the intrinsic value of natural infrastructure preservation, Canada continues to experience the loss of wetlands, forests and vegetated areas. The loss of natural infrastructure is most pronounced in southern Canada, where population growth is concentrated, and agriculture and urban development have expanded.[42] For example:

- In southern Ontario, 72% of the original wetlands have been lost to development (e.g., agriculture, urban sprawl and other land conversion).[43]
- In Alberta, approximately 64% of the original wetlands in settled areas no longer exist.[44]
- In BC, over 70% of the original wetlands disappeared in the lower Fraser Valley and parts of Vancouver Island, and an 85% wetland loss has been documented in the South Okanagan.[45]

The considerable loss of these natural environments increased the respective communities' vulnerability to floods, droughts and water contamination.

To mitigate further natural infrastructure loss and ecosystem degradation, governments across Canada introduced policies and regulations for natural infrastructure conservation. For example, the federal policy on wetland conservation includes two key commitments: (1) no net loss of wetland functions on federal lands and waters through restriction of development related to these wetlands; and (2) enhancement and rehabilitation of wetlands in areas where the continuing loss or degradation of wetlands has reached critical levels.[46] Other examples of the government's commitment to protect and conserve natural infrastructure include Ontario's Wetland Conservation Strategy[47]; the Alberta Wetland Policy[48]; the establishment of the Saskatchewan Wetland Conservation Corporation, which delivers wetland, native prairie and riparian habitat protection programs in the province; and Manitoba's water conservation policies, which guide conservation and management of the province's lakes, rivers, groundwater and wetlands. In addition, various organizations across Canada continue to undertake natural infrastructure restoration projects.

## 2.3: Investing in natural infrastructure is good business for Canada – Case studies

The following case studies illustrate the utility of efforts to conserve and restore natural infrastructure assets in Canada. They're part of a growing body of research that demonstrates that natural infrastructure is an economically viable solution for climate adaptation in Canada and should be considered alongside traditional engineering projects for disaster risk reduction.

## Case Study #1: Assessing the value of natural assets for the coastal town of Gibsons, BC

The Municipal Natural Assets Initiative (MNAI) assesses the financial value of natural infrastructure in terms of the municipal services it provides. MNAI engages with municipalities across Canada to identify, value and account for the contribution of natural assets to municipal government service delivery (i.e., services that engineered assets would otherwise need to deliver). The municipalities are able to use MNAI assessments to integrate natural infrastructure into traditional asset management decisions.[49]

Gibsons was the first municipality in North America to utilize an MNAI assessment framework and declare natural infrastructure assets as municipal assets. The town then committed to operate and maintain its natural assets in the same manner as storm sewers, roads and other traditional engineered assets.[50]

Specifically, Gibsons assessed the value of its naturally occurring aquifer[ii] to provide water storage services and its ponds to provide stormwater management services. Gibsons found that at a cost of $30,000 per year for maintenance and monitoring, the aquifer provided water for approximately 70% of the town's projected population.[51] The assessment of its naturally occurring ponds in the town's White Tower Park found that providing the same stormwater management services through engineered assets would have cost about $3.5 million to $4 million.[iii] These assessments led Gibsons to protect its aquifer and White Tower Park ponds from proposed new housing developments.[52] Furthermore, Gibsons now recognizes the financial value of natural infrastructure assets in its financial statements:

> The Town is fortunate to have many natural assets that reduce the need for engineered infrastructure that would otherwise be required. This includes the Gibsons aquifer (water storage and filtration), creeks, ditches and wetlands (rain water management) and the foreshore area (natural seawall). Canadian public sector accounting standards do not allow for the valuation and recording of such assets into the financial statements of the Town. As such, these natural assets are not reported in these financial statements. Nevertheless, the Town acknowledges the importance of these assets and the need to manage them in conjunction with engineered infrastructure. For example, on July 19, 2016, the Town adopted a revision to the Development Cost Charges Bylaw 1218, which included a $3.2 million valuation for an increase in the White Tower storm retention pond volumes. This pond system is a natural storage and retention system that would replace, in part, a traditional pipe system. The valuation recognizes the service this natural asset will provide.[53]

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[ii] A layer of rock that contains water or allows water to pass through it

[iii] The assessment of ponds cost $45,000; the cost of dredging was estimated at $15,000 every three years.

Ten other Canadian jurisdictions now participate in MNAI. In BC, the City of Grand Forks, City of Nanaimo, City of Courtenay, District of Sparwood and District of West Vancouver participate in MNAI. In Ontario, the Town of Oakville (see Case Study #4), the Regional Municipality of Peel and the City of Oshawa participate. In New Brunswick, the Western Valley Regional Service Commission and Southeast Regional Service Commission participate in MNAI. As MNAI gains popularity, it could be leveraged across Canada as a standard practice to account for the economic value that natural infrastructure delivers as a municipal asset.

## Case Study #2: Estimating the benefits of wetland conservation in rural and urban municipalities in southern Ontario

Recognizing that flood attenuation is the number one climate adaptation priority for communities in Canada, the Intact Centre developed an approach to quantify the value of wetlands for flood-damage cost-reduction. It first tested the approach at two pilot sites in southern Ontario, one urban and one rural. The Intact Centre found that if wetlands are maintained in their natural state, under conditions of a severe rainfall event (a one-in-500-year event) they can reduce flood damage costs to buildings – including homes and apartments as well as industrial, commercial and institutional structures – by close to 40%.[54]

The Intact Centre deployed the following four-step approach to assess the flood attenuation benefits of wetlands:

1. **Complete hydrologic and hydraulic modelling for the study area, with and without the natural infrastructure features of interest.** The hydrologic and hydraulic modelling provided flood extents and depths with wetlands and without natural infrastructure features (i.e., by replacing natural infrastructure features with a different land use in the models). The hydrologic and hydraulic modelling considered a range of rainfall events (e.g., two-year, five-year, 10-year, 25-year, 50-year and 100-year). A key output of this step was raster data[55] and shapefiles,[56] which showed flood extents and flood depths for each of the modelled rainfall events, under conditions of natural infrastructure features (wetlands) being preserved or lost to development.
2. **Complete land use and building footprint analysis.** Local government websites provided land use and building footprint data. This data was overlaid with flood-extent and flood-depth data from Step 1 to confirm which structures were inundated for the specified range of rainfall events. The expectation was that when natural infrastructure features were preserved, fewer buildings would be inundated, or the levels of building inundation would be lower, compared to being lost to development. This analysis was completed using Geographic Information System (GIS) software (i.e., ArcMap GIS).

3. **Detailed analysis of inundated buildings.** Once the inundated building structures were identified in Step 2, they were classified according to use (e.g., residential, office, institutional, industrial, retail) and structural type (e.g., single-family home, apartment building). Other details about the inundated buildings, such as main-floor elevation relative to grade and presence of underground parking and basements, were collected to analyze the flood damage cost for each inundated building. This data was collected through virtual examination of buildings using specialized software developed by IBI Group, a global architecture, planning, engineering and technology firm. The tool, implemented in Google Earth Pro, relies on Google Earth imagery to help users visually inspect buildings and download relevant recorded data to Excel for further flood damage cost analysis.
4. **Calculation of flood damages with and without the natural infrastructure features of interest.** After all of the inundated buildings were classified in Step 3, IBI Group's Rapid Flood Damage Assessment Model (a free, publicly available software developed for the Government of Alberta's Provincial Flood Damage Assessment Study[57]) was used to calculate the estimated annual flood damages to buildings, with and without wetlands.[58]

The study found that at the rural pilot site, where wetlands remained intact, flood damage costs were $8.9 million, which was $3.5 million or 29% lower than the $12.4 million cost that would have been realized had agricultural development replaced the wetlands. At the urban pilot site, when wetlands were maintained in their natural state the cost of flood damages were $84.5 million, which was $51.1 million or 38% lower than the $135.6 million that would have occurred consequent to agricultural replacement. The study illustrated that simply leaving wetlands in their natural state was meaningful for flood attenuation.[59]

## Case Study #3: Assessing the value of the Pelly's Lake wetland restoration project in Manitoba

The Pelly's Lake water retention wetland system, near Holland, Man., is located in a heavily drained agricultural area upstream of a high-flood-risk area of the Boyne River system. The Boyne River is a tributary of the Red River, which has a history of severe flooding. The Red River contributes approximately 60% of the nutrient load to Lake Winnipeg, the most eutrophic large lake in the world. Pelly's Lake is a 121-hectare wetland area, frequently flooded under natural conditions and overgrown with an aggressive macrophyte species, Typha (e.g., cattail), which flourishes in wet, nutrient-enriched environments and consumes large amounts of nitrogen and phosphorus.

In 2015, a retention structure was built to manage water releases at Pelly's Lake, effectively transforming a natural slough and marginal agricultural land into an engineered wetland and reservoir. The key benefits of the engineered wetland include the ability to control water releases for flood attenuation, late-season recharge of waterways further downstream, and the ability to release sufficient water from the reservoir so that conventional agricultural equipment can access the site and harvest the cattails. Harvesting cattails as a biomass crop produces multiple benefits including improved water and habitat quality, as demonstrated by the increased diversity of plant and bird species (e.g., waterfowl and songbirds).[60]

In 2017, University of Saskatchewan researchers assessed the economics of Pelly's Lake and disseminated their analyses in three peer-reviewed publications.[61, 62, 63] The return on investment analysis that follows is based on these publications, with Table 3 summarizing the key inputs in the calculation. The estimated internal rate of return (IRR)[iv] for this project, assuming a 20-year life cycle, was estimated at 32% with the net Benefit-Cost Ratios (nBCRs)[v] ranging from 2.8 to 3.64, depending on the discount rate.

- At a 3% discount rate, the NPV was calculated at $3,700,148, with an nBCR of 3.64.
- At a 4% discount rate, the NPV was calculated at $3,262,905, with an nBCR of 3.21.
- At a 5% discount rate, NPV was calculated at $2,883,146, with nBCR of 2.83.

## Table 3: The Pelly's Lake, Man., Water Retention Wetland System, Cost and Benefits (in 2017 dollars)

| CAPITAL EXPENSE (CapEx) | | IN 2017 DOLLARS |
|---|---|---|
| Land | | $467,183 |
| Civil works | | $550,000 |
| | **Total CapEx** | **$1,017,183** |
| **OPERATING EXPENSE (OpEx)** | | **IN 2017 DOLLARS** |
| Operations and maintenance | | $45,000 |
| Harvest | | $80,000 |
| | **Total OpEx** | **$125,000** |
| **TOTAL BENEFITS** | | **IN 2017 DOLLARS** |
| Flood attenuation ($740/ha; 121 ha) | | $89,540 |
| Biomass production ($16.20/t; 1,550 t) | | $25,100 |
| Carbon dioxide offsets ($25/t; 3,100 t) | | $77,500 |
| Phosphorus ($60/kg; 1,500 kg) | | $90,000 |
| Nitrogen ($36/kg; 4,650 kg) | | $167,400 |
| | **Total benefits** | **$449,540** |
| | **Net benefits = Total benefits - Total OpEx** | **$324,540** |

For context, the United Kingdom Treasury published value for money (VfM) guidance documents. These documents are widely used for public procurement and public-private-partnership infrastructure projects.[64, 65] Projects with an nBCR between 2 and 4 are regarded as having a "high" VfM, and those above 4 are regarded as having a "very high" VfM.

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[iv] The IRR is the rate at which the project breaks even.

[v] Defined as Net Present Value (the difference between the present value of benefits and the present value of costs associated with the project, over a period of time) divided by Total Capital Expenditure.

The full VfM proposition for Pelly's Lake, outlined above, may be underestimated for several reasons:

- The land acquisition cost is based on fair market value for high-value agricultural land in Manitoba, not the actual value of the land that Pelly's Lake occupies (low value, frequently flooded).
- The unit flood risk reduction benefit ($740 per hectare) applied to Pelly's Lake is adapted from two published meta-analyses of the benefits provided by wetlands in agricultural landscapes.[66, 67] Flood risk reduction benefits should be based on a detailed local modelling study using hydrodynamic modelling, LiDAR and the local value of flood-exposed agricultural land, municipal infrastructure, agricultural infrastructure and livestock.
- The biomass value represents the low-end of the bio-product value spectrum for Typha's use as a local space heating fuel. The benchmark spot price for an equivalent biomass source (industrial wood pellets) averaged US$162.87/tonne between 2009 and 2017.[68]
- The carbon credit price is constant over the 20-year life of the project at $25 per tonne, whereas current Canadian federal policy anticipates the introduction of a carbon tax in 2018 at $10 per tonne and an escalation to $50 per tonne by 2022.
- The phosphorus value ($60 per kilogram) was conservative. Tertiary phosphorus removal technologies now in use in Canada have unit costs above $1,000 per kilogram[69] and the phosphorus offset program now operational in the Lake Simcoe watershed uses a $35,000 per kilogram for phosphorus offset charge.[70]
- There are unaccounted benefits of improved habitat for waterfowl and songbirds associated with active wetland management, as well as groundwater recharge, drought resiliency and irrigation benefits.

The Pelly's Lake case study reveals that the investment case for natural infrastructure projects can be high to very high. It's built on several public and private co-benefits, and the use of ecosystem markets (particularly for carbon and phosphorus) can be important to harness the multi-functional character of natural infrastructure. This case study also reveals the importance of geographic targeting to identify potential natural infrastructure development sites with high hydrologic and low agricultural value to minimize land acquisition costs.

## Case Study #4: Assessing the value of natural infrastructure in the town of Oakville, Ont.

Through MNAI, Oakville conducted a pilot study that assessed the projected value of the municipal services provided by a naturalized channel (an open unregulated watercourse) both under existing and intensified land uses.

Oakville has a population of 193,832[71] and is located in southern Ontario. It borders Lake Ontario, is about halfway between Toronto and Hamilton, and is in the Halton Region. Oakville is part of the Greater Toronto Area, one of Canada's most densely populated areas, and is experiencing rapid growth and land development.

For the MNAI analysis, Oakville selected a non-regulated channel (i.e., a flood plain not regulated by the area's conservation authority) in an older part of the community, which receives stormwater from upstream lands, including municipal right-of-ways and residential and employment lands. The channel was evaluated in terms of the stormwater conveyance, flood attenuation, infiltration and water quality improvement benefits it provides.

For the study, Amec Foster Wheeler, an engineering and project management company [72] working on behalf of the town, contributed technical services, including executing engineering modelling and analysis. It was determined that the economic value of municipal services provided by the channel increases over time, as Oakville changes its land use through redevelopment and intensification. Specifically, the engineering analysis confirmed that the channel, that's about 250 metres long, serves a well-defined stormwater conveyance function and reduces peak flows downstream during rainfall events. The infiltration and water quality benefits were less clear, but were acknowledged to exist to some degree. The cost of operating and maintaining the channel was assumed nil because the channel is contained on private land, where Oakville does not provide operations and maintenance services.

The economic benefits of the channel's stormwater conveyance and flood attenuation are significant. Under intensified land use conditions, to provide the same conveyance function using equivalent grey infrastructure (i.e., 1,350- to 1,500-millimetre diameter pipes, at a unit cost of $847 per metre of pipe) would cost $725,000. Similarly, to attenuate flooding for a 100-year storm event, using equivalent grey infrastructure (i.e., through an end-of-pipe storage facility, with the pipe enclosure in place) would cost an additional $715,000 under intensified land use conditions.

In summary, the naturalized channel provides stormwater conveyance and flood attenuation benefits, which would otherwise cost Oakville $1.24 million to $1.44 million under current and intensified land use conditions, respectively.

# Chapter 3: Framework for Natural Infrastructure Implementation

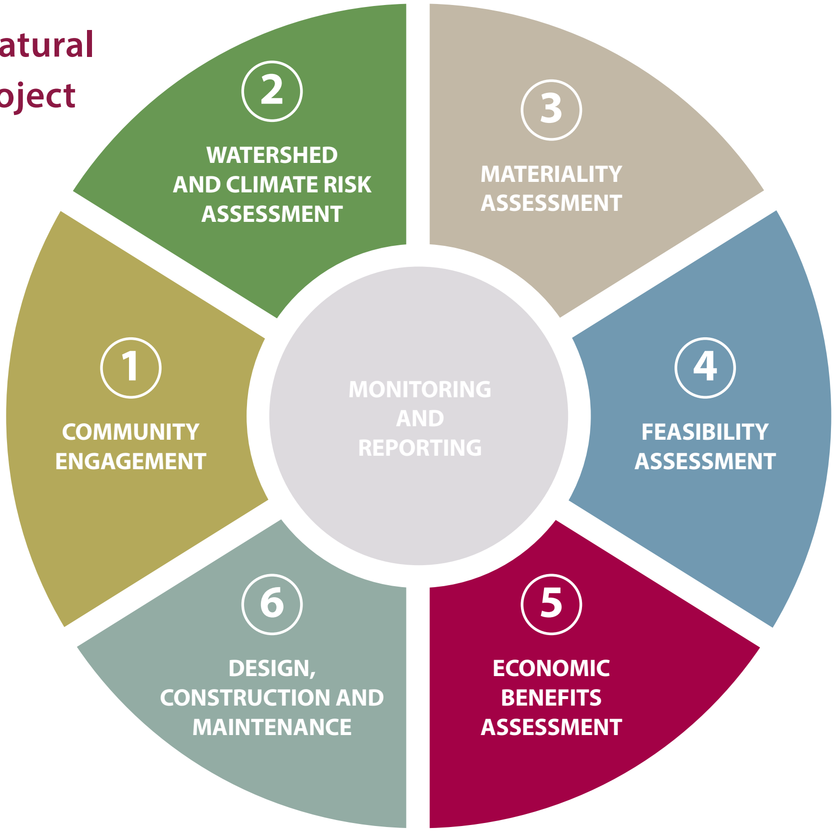
As outlined in chapters 1 and 2, natural infrastructure conservation and restoration are integral to the climate adaptation and disaster risk reduction commitments that Canada made under the Pan-Canadian Framework on Clean Growth and Climate Change and the Sendai Framework for Disaster Risk Reduction. However, several barriers must be overcome before policymakers, engineers and investors can embrace natural infrastructure as an optimal climate adaptation option. In their review of natural infrastructure projects, researchers note that the absence of a well-established framework to identify, quantify and communicate the multiple benefits of natural infrastructure projects is a key gap that can also preclude larger-scale natural infrastructure project deployment:[73]

> Gray infrastructure solutions have dominated water management systems and engineering curricula for decades, which have led to informal biases and skepticism of natural infrastructure approaches. These informal biases are perpetuated in that capital budgeting and asset valuation methods fail to account for natural infrastructure as an asset. As a result, because infrastructure decision makers and constituents do not have a clear understanding of the benefits of natural infrastructure, they often do not attempt to incorporate natural infrastructure into traditional infrastructure designs… . Infrastructure decision makers often lack the technical capacity to design natural infrastructure projects that optimize costs and benefits. Site-specific assessment of environmental factors that must be considered in evaluating natural infrastructure projects is beyond the typical uniform water system development process, and few engineers are trained in such assessments. One complicating factor is the inherent uncertainty associated with natural systems, and how, for example, natural infrastructure might respond to a changing climate. Without reliable quantitative analysis, those charged with evaluating infrastructure options are limited to (weaker) qualitative arguments for natural infrastructure investments.

The framework presented below outlines the necessary steps that organizations can follow to (1) evaluate the business case of such investments and (2) confirm that the projects deliver the intended benefits. The cost-benefit assessment, which allows natural and grey infrastructure to be compared, and this framework can be applied to a range of natural infrastructure projects, including wetland and riparian buffer restoration, reforestation, riverbank naturalization and flood plain restoration.

Each component of the framework shown in Figure 4 is described in the sections that follow. While all framework components require the preparation of a strong business case for natural infrastructure implementation, they can be completed at different times or simultaneously.

## Figure 4: Framework for Natural Infrastructure Project Implementation



Before reviewing the framework in detail, it is critical to underscore two points. First, every effort should be made to conserve natural infrastructure in its natural state, especially in ecologically sensitive areas in Canada. To this end, planners and policymakers should be cautioned that restoration projects in one geographical area cannot be used to justify ecosystem loss in another. For example, a study of 621 restored and created wetlands around the globe found that even after 50 to 100 years after restoration, restored wetlands recovered only 74% of their biogeochemical functions relative to the control group of 556 naturally occurring wetlands. In other words, the abundance of species and the biodiversity of native animals and plants could not be fully recovered through restoration efforts within that time.[74] Similarly, an analysis of forest restoration projects in Alberta on reclaimed lands across the oil sands region showed that most plants have not stabilized, even after 20 years since reclamation.[75]

Furthermore, even when natural infrastructure assets are protected, it is not always possible to guarantee the protection status. For example, the City of Kelowna, BC, established a 10-year partnership with the Central Okanagan Naturalists' Club and the Wildlife Branch of BC's Ministry of Environment, Lands and Parks to develop a rating system for wetlands located in the city. The partnership culminated in the addition of a Wetlands Management Strategy, Bylaw 8327, to the Official Community Plan (OCP) in 1999. This OCP amendment protected certain wetlands from development by assigning them a "protected wetlands" status. However, following one of the first rezoning applications for a residential development that came forward to council a few weeks later, the OCP was rewritten. The current OCP, Bylaw 8600, no longer contains the term "protected wetlands" but rather "high and moderate wetlands," making the legal mechanism less stringent for protecting wetlands from further development.

The second major point to underscore is that infrastructure decision-making ought to consider natural infrastructure options on an equal footing with grey infrastructure. To identify the most appropriate option, the TEV of natural infrastructure must be compared and contrasted with grey infrastructure solutions that aim to achieve the same objectives (e.g., reduce stormwater runoff, improve water quality) .

Specifically, the analysis should account for the NPV of the costs and benefits associated with implementing natural "green" infrastructure and conventional "grey" infrastructure solutions, including a side-by-side comparison of their economic, environmental and social impacts. This holistic "triple bottom line" valuation enhances the due diligence behind land use planning and investment decisions, and should be conducted to fairly compare the two alternatives.

## 3.1: Community engagement

A key priority in undertaking any natural or grey infrastructure project is to secure key stakeholder support for the project. As noted below, every community has different challenges and priorities, which influence how projects are valued, selected and designed. With continuous community engagement and support, project proponents dramatically increase the likelihood of the project being implemented.

Community engagement can take various forms and will differ depending on the stage of the project. In the initial stage, community engagement is focused on creating awareness and buy-in for the project. Public consultation is a key element in establishing such buy-in, as well as in identifying challenges and opportunities associated with implementing the project in the community. As a project progresses through to construction phases, communication and outreach activities continue.

Since most natural infrastructure projects are highly visible, they can be utilized for public education on climate change, water scarcity, biodiversity and other topics. Transparency about project objectives and intended outcomes is necessary to establish accountability with project funders and community members. The key elements of community engagement include regular project performance reports and updates through local newspapers, radio and social media.

## 3.2: Watershed and climate risk assessment

Prior to undertaking any natural or grey infrastructure project, it is critical to assess the watershed[vi] where the proposed project would be implemented. This includes confirming current watershed challenges (e.g., flooding, drought, water quality issues and habitat loss), as well as investigating potential future challenges associated with projected land use changes, climate variability and extreme weather events. The relative materiality of these challenges will drive the natural or grey infrastructure project and site selection process. This process will help determine whether a solution that targets multiple problems might be a better, more cost-effective solution.

Typically, publicly available documents, such as municipal land use and development plans, environmental assessments, flood risk assessments and flood reports, will be relevant. Global circulation models (GCMs) and climate-adjusted intensity duration frequency (IDF) curves[76] can aid in quantifying climate change trends and analyzing the potential impacts of extreme rain events for a given watershed.

In terms of outcome, the watershed assessment should confirm (1) the most pressing hydrologic and climate change issues faced by communities located in the watershed and (2) the geographic areas of concern (e.g., areas subject to chronic flooding, drought-sensitive areas).

## 3.3: Materiality assessment

Once a range of watershed challenges has been identified, it is important to confirm their relative materiality in order to prioritize them. To conduct a materiality assessment, engage key stakeholders (e.g., municipal representatives, community groups, conservation authorities, local developers, homebuilders, residents) in an exercise to rank each challenge in terms of its impact and urgency. This process will help determine whether a solution that targets multiple problems might be a better and more cost-effective solution.

For example, if there are multiple areas that experience flooding in a community, and one of those areas has a baseball field while another has a hospital, then addressing flooding at the hospital is the obvious priority. In other instances, the decision may be less clear: protecting certain water sources from pollution may be a priority for one stakeholder group while preventing habitat loss at a different location may be more important to another group.

Conflicts between competing objectives – such as conflicts between flood management and biodiversity – may need to be resolved. For example, flood risk reduction generally requires floodwater storage during peak flows, which is then followed by releasing the floodwater to provide storage for subsequent high-flow events. Some habitat functions may be negatively affected by these water release requirements.[77]

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[vi] A watershed is an area, delineated by topography, where all precipitation drains to one point or outlet

Therefore, it is critical to prioritize issues for a community because these priorities will determine the design of a particular natural or grey infrastructure system. As discussed above, a system with the primary objective of flood attenuation will have a fundamentally different design from a system that aims to create habitat. Since the design of a natural infrastructure project requires interdisciplinary planning to achieve ecological, social and economic goals, decision-making must rely on an integrated, systemic method of valuation that accurately accounts for environmental, social and economic costs and benefits. A variety of resources are available to guide materiality assessments to ensure that interdisciplinary input is reflected from the onset of the project. For climate adaptation, natural infrastructure projects will be typically designed to attenuate floods and droughts, with improved water quality and habitat creation as co-benefits.[78]

## 3.4: Feasibility assessment

Following the watershed assessment, a feasibility analysis can confirm which natural or grey – or a combination of natural and grey – infrastructure projects best address the priority issues. Sometimes, natural infrastructure projects may offer a solution to more than one watershed challenge identified during the materiality analysis, increasing their value proposition regarding traditional grey infrastructure solutions. Feasibility analysis consists of assessing the technical, legal and regulatory, organizational, social and economic factors for implementing any given natural or grey infrastructure project. Grey infrastructure projects would typically serve as a baseline for the feasibility assessment.[79]

The first step of the feasibility assessment is to collect baseline data to provide the basis for comparing different options and analyzing the impacts of doing nothing (the status quo option). For example, if a community determines that flood attenuation is its primary concern and would like to explore the possibility of a wetland restoration project, then the baseline scenario would entail collecting and analyzing relevant baseline data, including:

- Hydrologic and hydraulic modelling that demonstrates the depth and extent of flooding for a range of rainfall events;
- Flood damage assessments that indicate the costs that can be expected for a given location under current and future conditions (e.g., accounting for changes in land use and climate);
- Assessments of wetland capacity to attenuate flooding (i.e., wetland storage capacity); and
- Relevant field observations and monitoring data to confirm modelling projections and assumptions.

It is important to note that every watershed is unique in terms of its physical attributes, including its geomorphology, hydrology, topography and climate. Engineering expertise is required to model the baseline scenario and analyze the design alternatives. Such expertise may be available through the municipality, conservation authorities and/or engineering consulting firms.

**BOX 1:** Researchers note that light detection and ranging (LiDAR) technology offers the best-in-class data product for analyzing natural infrastructure features (e.g., wetlands, depression areas) as an input to hydrologic and hydraulic modelling. For example, Federal Floodplain Mapping Framework for Canada,[80] recommended LiDAR because it can produce high-resolution digital elevation models, which are then used to derive water storage volumes for natural infrastructure features. Coarse (low-resolution) models are incapable of resolving the subtle topographic features that characterize the potential sites for natural infrastructure projects.[81] Moreover, LiDAR provides a cost-effective solution for generating a systematic overview of the watershed and can help optimize the natural infrastructure site selection process.

Source: Wang, Lei, and Jaehyung Yu. "Modelling detention basins measured from high-resolution light detection and ranging data." Hydrological Processes 26;19 (2012): 2973–2984.

Once the baseline scenario is completed, the feasibility analysis addresses the remainder of the considerations for project implementation (Table 4). Project proponents should document the modelling tools used to analyze the baseline scenario and evaluate the effectiveness of a natural infrastructure project to achieve the desired objectives. Documentation should include key modelling assumptions and parameterization.

## Table 4: Feasibility Analysis – Sample Considerations for a Wetland Restoration Project Aimed at Flood Attenuation

| FACTORS | CONSIDERATIONS |
|---|---|
| Technical | • Is climate data available to project future climate risks?<br>• What is the impact of a status quo, or do-nothing, approach on flood damages for the location?<br>• What are the potential alternatives to the proposed activity (e.g., natural versus engineered solutions to achieve desired benefits)?<br>• What are the possible wetland restoration options to achieve the required water storage capacity?<br>• Is sufficient land available for an engineered natural infrastructure option?<br>• Are there design alternatives that provide additional benefits (beyond flood attenuation)? At what additional cost? |
| Legal and regulatory | • Is the proposed activity a regulated or exempt activity?<br>• Would environmental assessment be required for the project?<br>• What permits, if any, would be required to carry out the project?<br>• What is the cost and time to complete the required studies and obtain permits?<br>• What are the post-construction monitoring and reporting requirements? |
| Organizational | • What resources are required to support project planning and implementation?<br>• Is there internal capacity to execute the project?<br>• What are the costs of securing external expertise for the project? |
| Social | • Who are the key stakeholders that need to be engaged for various stages of the project?<br>• Is there community support for the project?<br>• Do the affected landowners support the project?<br>• Is there opposition to the project? |
| Economic | • What are the expected costs of implementing this project?<br>• What is the impact of climate projections on costs and benefits?<br>• What are the expected benefits, recognizing that once the adaptation feature is in place, savings accrue every time that disaster cost is avoided?<br>• What are the expected operational and maintenance expenditures?<br>• What are the expected monitoring costs?<br>• What is the total budget required to execute the project and maintain it over the expected life cycle? |

## 3.5: Economic costs and benefits assessment

When selecting natural or grey infrastructure projects, it is important to ensure that both options are analyzed, allowing for costs and benefits to be directly compared and contrasted. To this end, grey infrastructure projects would typically serve as the baseline for the cost-benefit assessment, and the economic, environmental and social impacts of natural versus grey infrastructure project implementation would be evaluated side by side.

As the PricewaterhouseCoopers (PwC) Canada case study (case study #5) demonstrates, the TEV framework can be used to assess the economic, environmental and social impacts associated with project implementation. Specific to natural infrastructure projects, TEV divides the economic value for a given natural infrastructure project into use values and non-use values. Use values can further be divided into:

- Direct-use values, which refer to actual uses, such as hunting, fishing, birdwatching and hiking;
- Indirect-use values, which refer to the benefits derived from ecosystem functions, such as natural water filtration, flood protection and carbon sequestration; and
- Option values, which are approximations of an individual's willingness to pay to safeguard an asset for the option of using it at a future date.

Non-use values are the values that people assign to the ecosystem services even if they never have and never will use those services (e.g., preserving wetlands for enjoyment by future generations). Accordingly, the TEV of natural infrastructure is the sum of all relevant use and non-use values.[82]

To calculate the TEV of natural infrastructure, non-market benefits associated with ecological functions that natural infrastructure provides have to be monetized. Some of the more common techniques used by economists to monetize ecological functions include:

- **Market-pricing approaches**, which rely on the availability of market prices to derive values for ecosystem goods and services. For example, to estimate the flood attenuation value of wetlands, researchers could estimate the cost of flood damages to buildings attributable to wetland loss and inquire about how much people living in these buildings would be willing to pay to avoid these costs. Alternatively, these same people could be asked about their willingness to pay for construction and maintenance of engineered structures to deliver flood-risk reduction benefits. Another example of a market-pricing approach is a replacement-cost method. Under this method, the value of a given ecosystem service is viewed as the cost of replacing that service by an alternative means. For example, some studies have valued clean drinking water provided by watershed protection by using the cost savings from not having to build a water filtration plant.[83]

- **Revealed-preference approaches**, which estimate the value of ecosystem services by observing the choices made by individuals, which can be attributed to how they value various ecosystem services; for example, the amount that individuals are willing to pay for houses with a direct view of the lake versus the amount they are willing to pay for similar houses located farther from the lake may help estimate the aesthetic value attributable to the lake.
- **Stated-preference approaches**, which measure society's willingness to pay to preserve ecosystems for future uses. For example, this can involve asking people directly how much they would be willing to pay for a specific ecological function or the amount of compensation they would be willing to accept to give up an ecological function.

Appendix B describes these approaches in more detail and provides a case study in which a stated-preference approach was used to assess the value of wetland restoration in Manitoba.

## Case Study #5: Assessing green infrastructure benefits for a public parking lot in southern Ontario – TEV

In 2017, Metrolinx, a Government of Ontario agency created to improve the coordination and integration of all modes of transportation in the greater Toronto and Hamilton areas, engaged PricewaterhouseCoopers (PwC) Canada, supported by Autocase, to develop a TEV methodology for environmental and social capital accounting as applied to a cost-benefit analysis of investments in green infrastructure.[84]

The methodology was piloted on the Mount Pleasant GO station parking lot, located in Brampton, on the Kitchener GO train line. The objective of the pilot was to generate considerations for how TEV could be integrated within Metrolinx's capital project planning and budgeting (CapEx) and operation/maintenance planning and budgeting (OpEx) processes.

PwC compared the incremental value of the parking lot designed with green infrastructure features relative to a baseline scenario without green features (Table 5).

## Table 5: Description of Baseline and Green Infrastructure Design Options for Public Parking Lot, Southern Ontario

| | ASPHALT ROADS/PAVEMENT, CONCRETE SIDEWALKS AND STORMWATER PIPING | LANDSCAPING AND VEGETATED BIOSWALE (PERVIOUS SURFACES) | UNDERGROUND STORAGE TANKS |
|---|---|---|---|
| **Baseline scenario** | 23,700m2, 600 parking spots | None | None |
| **Green infrastructure design** | 23,700m2, number of parking spots unknown | 3,800m$^2$ | 220m$^3$ storage* |

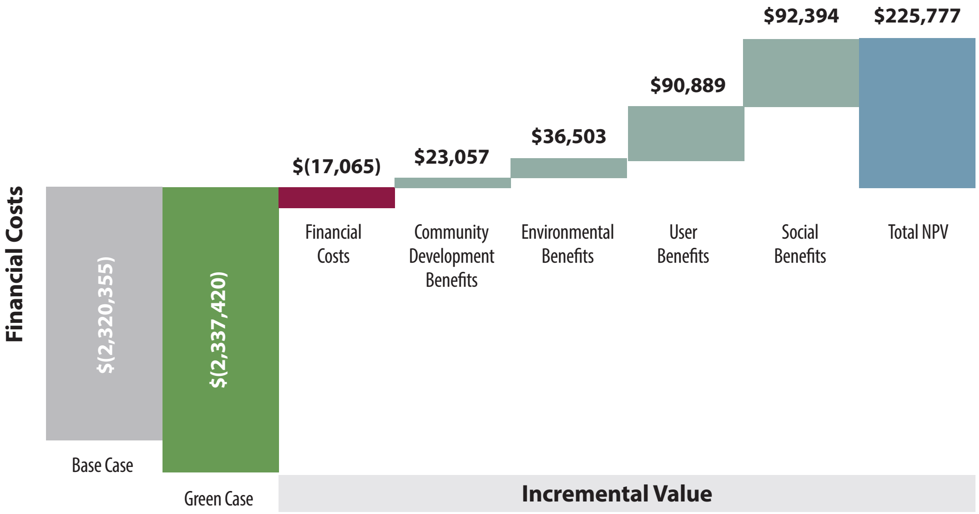
*This area is not included in the total site area, as it is located underground.

The annual costs and benefits associated with each project option were assessed for a 60-year period and then converted to NPV using a 3.5% discount rate. The cost-benefit analysis included site-level financial considerations and broader environmental and social impacts. Appendix A outlines the financial, environmental and social costs and benefits applicable to a TEV approach for green infrastructure considered by PwC.

By applying the TEV analysis to the sample parking lot, PwC found that investing in green infrastructure at the Mount Pleasant GO station parking lot would generate an NPV of $225,777 over 60 years, compared to a base-case option without any green features. The benefit-to-cost ratio was 12.35, with an NPV-to-initial-cost ratio of 8.95. Accordingly, the total economic case for green infrastructure design was compelling: the financial, environmental and social benefits for the green design of the parking lot were over 10 times higher than the additional financial investment required to support the marginally higher operating costs of green infrastructure features.[85]

Moreover, the pilot illustrated that applying the TEV lens to infrastructure projects can change the picture of costs and benefits dramatically. Under a traditional, grey-engineered infrastructure analysis (i.e., base case) considering only the financial cost would yield an NPV of -$2,320,355. Under the green infrastructure analysis considering only the financial cost would yield an NPV of -$2,337,420. By applying the TEV framework to compare the baseline and green infrastructure design cases, a more robust and holistic understanding of investment costs and benefits was achieved, resulting in an overall marginal NPV of $225,777 (Figure 5).[86]

## Figure 5: Comparing Baseline and Green Infrastructure Design: Financial Costs, and Social and Environmental Benefits for Mount Pleasant GO Station Parking Lot, Metrolinx (NPV by Impact Category; in 2017 dollars; 3.5% Discount Rate)



The Mount Pleasant GO station parking-lot case study completed by PwC and Autocase for Metrolinx demonstrates the utility of a green parking lot design in southern Ontario. The TEV method could be further expanded to incorporate climate change resilience in asset planning and design, likely leading to an even higher NPV for green parking lot design. Parking lots are a significant part of Metrolinx's asset portfolio (Metrolinx is one of North America's largest public parking lot operators) and a significant part of the urban landscape in Canada.[87] Accordingly, the case study demonstrates that for parking lot (re)construction projects, green infrastructure design options can be economically viable and should be assessed and considered.

**BOX 2:** As it relates to the assessment of the economic benefits and costs associated with natural infrastructure projects, the distinction between the ecological functions that these projects deliver and the ecosystem values that society may place on them is important to note. For example, for wetland restoration projects, wetland ecological functions are natural processes (physical, chemical, biological) that are associated with wetlands, and are independent of the benefits of those processes to humans. Wetland values reflect the ecosystem services that wetlands provide to humans and the societal values placed upon these services. For any given wetland ecological function, the associated wetland value may differ depending on individual or community preferences; ecological functions do not have a market price. However, in order to establish the business case for natural infrastructure project implementation, the monetization of non-market benefits (e.g., habitat protection, climate moderation, flood attenuation and aesthetic value) is required.

Source: Hanson A. L., Swanson D., Ewing G., et al. 2008. Canadian Wildlife Service Technical Report Series. Wetland Ecological Functions Assessment: An Overview of Approaches.

### 3.5.1: Measurement of benefits – Considerations for natural infrastructure projects

The benefit-transfer technique is often used to estimate the monetary benefits of ecological functions (e.g., habitat creation, water storage). This technique relies on borrowing unit values (or benefit functions) developed to assess the value of a natural resource at one location and applying this unit value to another location of interest. However, caution should be exercised when using a benefit-transfer technique, because no two ecosystem sites are identical and the relationships between the total areas and benefits produced are not perfect analogues. For example, larger wetlands generally have a greater capacity to reduce runoff and other inflow pollutants. Also, the size of a wetland does not have a linear relationship with its capacity to remove pollutants. (After a certain point, pollutant removal capacity begins to decrease per unit area of a wetland.)[88] The wetland's shape may also influence the effectiveness of its ability to remove pollutants.[89]

Since natural infrastructure projects are always site specific and not every community values ecosystem services in the same manner, the benefit-transfer technique increases the likelihood and magnitude of valuation errors. Therefore, this technique should only be used to estimate the natural infrastructure benefits, and such estimates should subsequently be confirmed through further analysis. For example, field studies to examine local site conditions and community surveys confirmed how local residents value the ecological functions being assessed.[90]

### 3.5.2: Measurement of costs – Considerations for natural infrastructure projects

A variety of factors influence the costs of natural and grey infrastructure projects, including project objectives, project size, site selection, engineering and construction complexities, maintenance and monitoring requirements. Unlike grey infrastructure projects, for which project costs have been documented over time, companies involved in natural infrastructure restoration work rarely disclose detailed breakdowns of the actual costs incurred. Accordingly, proponents of natural infrastructure projects should consider retaining expert advice (e.g., engineering consulting firms, municipal engineers and conservation authorities) to assess these costs in advance of project commencement.

At minimum, the cost analysis should consider the pre-construction, construction and post-construction costs (Table 6). Experts recommend reserving 15% of the total project cost for any potential adjustments, which may include removal of invasive species, re-planting of wetlands and/or riparian areas, or pest control.[91]

## Table 6: Cost Considerations Associated with Natural Infrastructure Project Implementation (by Key Project Phase)

| PHASE | COST CONSIDERATION |
|---|---|
| Pre-construction | • Baseline data collection<br>• Stakeholder consultation<br>• Site identification<br>• Assessment of design alternatives<br>• Detailed engineering design of selected alternative<br>• Land acquisition<br>• Environmental assessment<br>• Permitting and legal fees<br>• Development of construction specifications<br>• Development of monitoring program and KPIs |
| Construction | • Site preparation (e.g., moving earth and debris removal)<br>• Site construction |
| Post-construction | • Site maintenance<br>• Monitoring against KPIs<br>• Evaluation and reporting |
| Administration | • Project management and oversights |

A number of factors can greatly influence the cost of natural infrastructure project implementation, including:

- The cost and time for obtaining permits, approvals and authorizations from federal, provincial and local governments and Indigenous peoples, if required for the project.
- The ownership of land that is optimal for natural infrastructure project implementation (the land may be under private ownership).
- The availability and quality of baseline data, which can greatly influence the cost of project design. For example, if all required data is available for a wetland restoration project, the pre-construction phase can represent 20% to 30% of the total project cost. If data availability is limited, the cost of pre-construction can range from 50% to 55% of the total project cost.[92]
- The development and screening of alternative designs to achieve project objectives – for example, primarily flood control, drought mitigation or water quality improvement, or multiple objectives – typically require engineering expertise.
- The cost of monitoring, which would be the most intensive during the first five years from project implementation, with lower costs for mid-term monitoring (five to 10 years) and long-term monitoring (10 years or longer). The cost will vary based on (1) regulatory requirements and (2) expected length of time for a natural infrastructure system to become established. For example, a restored wetland may take 60 to 100 years to be fully established (i.e., to reach the productivity levels of undisturbed wetlands), with the possibility of invasive species further delaying this process.[93, 94]

In addition to the above direct costs, all projects should consider the associated "opportunity costs." For example, if a natural infrastructure project replaces residential development, the opportunity cost is the foregone economic benefit from land development charges and property tax revenues. If a natural infrastructure project takes place on agricultural land, then the opportunity cost is foregone income from lost crop areas. In southern Ontario, the opportunity cost of agricultural land development was estimated at $385.82 per hectare annually.[95] Simply put, an accurate estimate of land acquisition costs must be factored into the overall natural infrastructure investment analysis.

A cost estimation example is provided by Ducks Unlimited Canada that considered a 3,647-hectare wetland restoration project in the Black River sub watershed in southern Ontario (100 kilometres north of the City of Toronto) and found that the total per-hectare cost of restoring the wetland was $27,664, or $100,890,608 for the entire 3,647 hectares. Including the opportunity cost of foregone land use ($4,335,459), the total restoration cost increased to $105,226,067. Table 7 outlines the composition of this cost estimate.

## Table 7: Component Costs of Wetland Restoration on a Per-Hectare Basis in Southern Ontario

| WETLAND RESTORATION COMPONENT | WETLAND RESTORATION COST PER HECTARE |
|---|---:|
| Pre-construction costs | $8,645 |
| Construction costs | $13,832 |
| Future management costs | $3,458 |
| Administration costs | $1,729 |
| **Total** | **$27,664** |

Source: Ducks Unlimited Canada. 2011. A Business Case for Wetland Conservation: The Black River Subwatershed.

Site-specific characteristics can cause seemingly similar natural infrastructure projects to differ significantly in cost, sometimes by a factor of five or 10. Therefore, it is critical to investigate, using baseline data, the unique site characteristics and confirm the transferability of cost estimates between sites.[96]

### 3.5.3: Calculating NPV

Once the benefits and costs have been quantified in monetary terms, the NPV of the project can be calculated to select the optimal investment option. If the NPV is zero or less, then the investment may not be justified. Projects with the highest NPV, irrespective of whether they are natural or grey infrastructure solutions, should be considered first and foremost for implementation.

When calculating NPV, it is important to remember that engineered projects have a limited operational lifetime; the average lifetime of a dam constructed for flood mitigation is 50 years before upgrades and major maintenance are required.[97] Natural infrastructure projects, though, may last longer. Moreover, natural infrastructure projects tend to have an uneven distribution of benefits and costs over time. For example, a wetland restoration project may have high up-front costs associated with pre-construction and construction phases, during which time no benefits are realized (for example, it takes five to 10 years to realize hydrologic benefits for a constructed wetland and longer for biochemical benefits to be realized).[98]

Therefore, a critical element in determining the NPV of a project is the discount rate used in the calculations. In Canada, the social time preference rate was estimated at 3%, which can be applied to natural infrastructure projects.[99] To date, the use of this rate for natural assets remains controversial because discounting reduces the importance of events in the distant future as well as the welfare of future generations (which is not fully consistent with the sustainable development principles of intergenerational equity).[100]

The standard formula for calculating NPV is shown below, where Bt and Ct are the benefits and costs, t is an arbitrary time in the future, T is the expected lifetime of the project, and r is the discount rate. Note that the costs and benefits are discounted using the same rate.

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1 + \mathrm{r})^{\mathrm{t}}}$$

### 3.5.4: Accounting for uncertainty in calculations

Various factors can have an impact on the accuracy of net benefit calculations for natural and grey infrastructure projects. These factors include assumptions about climate change, land use and ecosystem performance.

For a wetland restoration project, the following risks can represent additional costs to the project and affect NPV calculations.

- **Pollution:** This is a leading factor that influences the ability of wetlands to perform ecosystem functions. For example, the processes associated with wetland flood attenuation interact with nutrient and sediment retention and generally improve downstream water quality. On the other hand, fecal deposits from wildlife and birds in newly restored habitat may enter floodwaters or infiltrate groundwater, causing water quality degradation, groundwater pollution and human health concerns.[101]

- **Climate change:** In dry climate conditions, wetland functions may be affected through reductions in the water table, leading to increased carbon dioxide production.[102]
- **Changes in vegetation:** Invasion by exotic species can alter ecosystem function, when invasive sedges, grasses or rushes replace native wetland plants.

To address uncertainty, an emerging best practice is to simulate system performance with as much synthetic (i.e., obtained through climate models, not through direct measurement) climate data as possible to estimate the probability distribution of NPV (i.e., to estimate the probability of achieving varying levels of NPV). Probabilistic simulation techniques (Monte Carlo simulations) can be used to treat the inherent uncertainty in NPV calculations. Monte Carlo simulations allow users to perform risk analysis by substituting a range of values – a probability distribution – for any variable that has inherent uncertainty, so that multiple project possibilities can be modelled. A Monte Carlo simulation can be run in Excel and many other programs. These programs randomly generate possible values for each variable, based on the estimated confidence intervals and types of probability distribution. The computer then calculates a probability distribution for the outcome (i.e., the NPV). Appendix C outlines some readily available programs that address calculation uncertainties for natural infrastructure projects.

## 3.6: Design, construction and maintenance

Once the natural or grey infrastructure project receives the go-ahead, a detailed engineering design of the selected alternatives takes place. Depending on the complexity of the design, the construction phase can span from a couple of weeks to several years.[103] It is important to note that just like grey infrastructure projects, natural infrastructure projects too are season- and weather-sensitive. Accordingly, construction schedules and plans need to reflect these realities to ensure that project delivery is on time and on budget. Once the project is constructed, its longer-term success often depends on regular operation and maintenance (O&M). The O&M activities and associated costs need to be accounted for over the life cycle of the project, irrespective of whether it is a natural or grey infrastructure solution.

As wetland restoration projects relate to natural infrastructure. Here are the key construction steps:

- Mobilization (contractors bring in materials and equipment);
- Demolition of structures and moving utilities (e.g., transmission and cable lines);
- Clearing and grubbing of trees and brush;
- Earthwork excavation and grading (removal of up to six inches of soil);
- Soil preparation; and
- Planting and irrigation.[104]

Regular maintenance activities for a wetland restoration project would typically include:

- Annually adjusting weirs, vegetation and water-control structures, and mosquito and predator control;

- Mowing vegetation and repairing water control structures (e.g., dikes, levees, berms) on an as-needed basis; and
- Maintaining the water-control structures that are used to achieve the desired water level and downstream flow conditions.[105]

Community volunteers sometimes provide natural infrastructure project maintenance. While this approach is cost-effective, there is a risk that community volunteers may not be able to conduct the required maintenance over the long term. Moreover, some maintenance activities require professional expertise and should be contractually secured. For example, specialized contractors should carry out the regular removal and disposal of contaminated sediment from wetland restoration projects requiring remediation.

## 3.7: Monitoring and reporting

### 3.7.1: Performance monitoring

A robust monitoring program spans all key phases of the project, from pre-construction to construction and post-construction. To track project performance against design objectives, KPIs are selected at the onset of the project. The literature on KPI selection methods emphasizes the importance of selecting indicators that are relevant, analytically sound and measurable (Table 8).[106]

**Table 8: The Organisation for Economic Co-operation and Development (OECD) – Criteria for Selecting Environmental Indicators**

| | |
|---|---|
| Policy relevance and utility for users | An environmental indicator should:<br>• Provide a picture of environmental conditions and pressures on the environment or society's responses;<br>• Be simple, easy to interpret and able to show trends over time;<br>• Be responsive to changes in the environment and related human activities;<br>• Provide a basis for international comparisons;<br>• Be either national in scope or applicable to regional environmental issues of national significance; and<br>• Have a threshold or reference value that it can be compared to, so that users can access the significance of the values associated with it. |
| Analytical soundness | An environmental indicator should:<br>• Be theoretically well founded in technical and scientific terms;<br>• Be based on international standards and international consensus about its validity; and<br>• Lend itself to being linked to economic models, forecasting and information systems. |
| Measurability | The data required to support the indicator should be:<br>• Readily available or made available at a reasonable cost-benefit ratio;<br>• Adequately documented and of known quality; and<br>• Updated at regular intervals in accordance with reliable procedures. |

**Note:** As indicators are used for various purposes, it is necessary to define the general criteria for selecting indicators and validating their choice. Three basic criteria are used in OECD work: policy relevance and utility for users, analytical soundness and measurability. These criteria describe the ideal indicator; not all criteria will be met in practice. Adapted from: *OECD. 2003. Environmental Indicators. Development, Measurement and Use.*

Since some natural infrastructure projects have a long time span before becoming self-sustainable (e.g., 50 to 70 years for wetlands, 75 to 150 years for forests), it is important to consider the cost effectiveness of data collection and monitoring programs over the short, medium and long terms, and select the appropriate indicators.

When developing the monitoring program, natural infrastructure project proponents should describe which indicators to measure (e.g., where, when and for how long). For example, to track the effectiveness of restored wetlands to cycle nutrients and improve water quality, the monitoring programs should indicate the location of water sampling locations and the sampling schedule. Indicators tracked may include:

- Ultimate biochemical oxygen demand (mg/L);
- Five-day biochemical oxygen demand (mg/L);
- Dissolved oxygen concentration (mg/L);
- Wetland open-water temperature (°C);
- Total suspended solids (mg/L); and
- Total dissolved solids (mg/L).

Engagement with project funders, partners and key stakeholders is often helpful in selecting relevant indicators. Moreover, when project proponents require regulatory permits or environmental assessment, it may be necessary to secure external expertise for monitoring performance indicators against the prescribed permit and environmental assessment parameters.[107]

### 3.7.2: Risk monitoring

From inception through to the end, each project, whether it involves natural or grey infrastructure, is subject to risk. Some risks can be anticipated and assessed from the standpoint of their impact and likelihood to occur. For example:

- Projects requiring environmental assessment and permits may run the risk of delays in the approval process;
- Extreme weather events may affect the construction schedule; and
- A changing economic environment may affect the availability and/or continuity of project funding.

Project proponents should monitor and manage relevant risks. A risk register (or risk log) can help keep track of new and emerging risks, as well as to document risk mitigation actions and responsible parties. A sample risk register is shown in Table 9.

## Table 9: Sample Risk Register

| DESCRIPTION OF RISK | LIKELIHOOD (LOW, MEDIUM, HIGH) | IMPACT (LOW, MEDIUM, HIGH) | OVERALL RATING | STATUS (DATE) | MITIGATION ACTIONS | ASSIGNED TO | ASSIGNED BY |
|---|---|---|---|---|---|---|---|
| enter data here | enter data here | enter data here | enter data here | enter data here | enter data here | enter data here | enter data here |

### 3.7.3: Outcome assessment and reporting

The conscious and deliberate use of natural infrastructure for climate adaptation is still a novel approach. Accordingly, the documentation of the benefits versus the costs incurred from natural infrastructure conservation and restoration projects is critical. This information constitutes the basis of a value-for-money assessment of natural versus grey infrastructure solutions and is critical to the business case articulation of either solution.

# Chapter 4: Additional Mechanisms to Promote Natural Infrastructure

To advance the perception and uptake of natural infrastructure as a cost-effective, practical means to limit flood damage in Canada, consider the following steps.

- **Assess the TEV of natural infrastructure in land use planning and infrastructure investment decisions.** Applying the TEV lens can dramatically change the picture of costs and benefits. Considering only the financial costs of these projects will likely understate the value of conserving and/or restoring natural infrastructure assets. Applying the TEV framework provides a more robust, holistic understanding of investment costs and benefits that includes an assessment of broader environmental and social impacts. The TEV assessment can be found in the Canadian Cost-Benefit Analysis Guide developed by the Treasury Board of Canada Secretariat and in the natural infrastructure assessment framework contained in this report.[108]
- **Establish sustainable funding models for natural infrastructure conservation and restoration.** Tax exemptions for land conservation may be one way to incentivize private landowners to conserve land and maintain it in a healthy, natural state. For example, Ontario implemented the Conservation Land Tax Incentive Program (CLTIP) to support the long-term private stewardship of Ontario's provincially important natural areas.[109, 110] Under the CLTIP, portions of a landowner's property that have eligible natural heritage features may qualify for a 100% property tax exemption. Lessons learned from CLTIP implementation should be explored further to understand the utility of the program for wider rollout in Canada. Other programs such as Alternative Land Use Services (ALUS) have not only recognized natural infrastructure as a municipal asset and incorporated it into municipal asset management decisions, they have effectively encouraged landowners to restore, enhance and construct natural areas on agricultural lands. ALUS Canada provides programmatic and financial support to farmers and ranchers who restore and maintain wetlands, grasslands and riparian areas. Its projects are designed according to the best available science and are third-party verified.[111] It is important to quantify economic links between the implementation of such measures and the associated savings that benefit nearby municipalities. Without such quantification, these programs may be difficult to sustain politically.
- **Establish funding mechanisms and criteria that explicitly recognize the unique programmatic needs of implementing effective natural infrastructure solutions within broader infrastructure funding frameworks.** The smaller scale and distributed nature of natural infrastructure makes it difficult to fit it into the structure of traditional infrastructure funding programs. Criteria – including eligibility, time frames, investment thresholds and matching requirements – must be created specifically to support natural infrastructure proposals from municipalities, provinces and NGOs. However, entirely separate programs

would be an effective response to the reality that municipalities will continue to favour the development of capital-intense and larger grey infrastructure projects over smaller-budget natural infrastructure plans if they are competing within the same funding streams. Alberta's Watershed Restoration and Resiliency Program, created after the devastating 2013 Calgary flood, is an exemplary model of a natural infrastructure fund that supports watershed planning, project design and implementation on public and private lands that are high priority for flood and drought mitigation.

- **Work with municipalities, Canada's new Infrastructure Bank and the financial sector to develop and implement new financial instruments to accelerate natural infrastructure investment and implementation.** Canada's new Infrastructure Bank was explicitly created to help municipalities fund infrastructure development using a longer-term funding horizon and to provide investors with opportunities to fund such infrastructure in innovative ways. Given the longer-term cost-benefit structure of natural infrastructure and the long-term higher return on investment that it affords, the Infrastructure Bank should consider innovative programming in this area. Furthermore, the G7 has begun examining insurance mechanisms that provide explicit premium incentives to recognize the de-risking afforded by natural infrastructure in coastal regions. Coral reefs, barrier islands and mangrove forests provide effective protection from tropical storms and hurricanes, and global reinsurers have been examining ways to incent the protection of this natural coastal infrastructure in order to reduce onshore losses. Catastrophe bonds are risk-linked securities that transfer risk to investors in exchange for an investment return. These bonds can be priced to provide incentives for protecting natural infrastructure, thereby lowering risk.
- **Develop forums for convening groups that are traditionally responsible for natural infrastructure preservation (e.g., conservation authorities and environmental NGOs), municipalities, institutional investors and insurers to deliver market-based solutions.** Currently, expertise in the value of natural infrastructure is isolated from the investment community and finance professionals who are capable of devising new market-based instruments. Under the auspices of the United Nations' Environment Program, the Convention on Biological Diversity and domestic work on Sustainable Finance, these walls are beginning to come down. However, specific forums more clearly rooted in the financial realm are needed to attract the financial innovators needed to overcome the challenges that have hindered treating natural infrastructure as anything but an externality. Institutional investors can play a significant role in financing the uptake of natural infrastructure solutions in Canada. For example, Canada's major banks already offer financial products (e.g., green and climate resilience bonds) that help finance conservation and restoration projects in Canada. Research into how those groups that have been traditionally responsible for natural infrastructure preservation can interact with institutional investors to deliver market-based solutions is a worthwhile next step.

# Chapter 5: Conclusion

Government efforts to limit flood risk are consistent with, and reinforcing of, fiduciary responsibility to administer good governance. As this responsibility is likely to increase as climate change and extreme weather events worsen, governments should consider the utility of natural infrastructure, alongside grey infrastructure solutions, to limit flood risk across all jurisdictions.

In Canada, several factors limit the wider adoption of natural infrastructure solutions for disaster risk reduction and climate adaptation. These factors include lack of detailed guidance to assess the business case of natural infrastructure projects, the lack of comparable data on the actual costs and benefits associated with natural infrastructure project implementation and maintenance, and the lack of sustainable funding mechanisms and programs to scale natural infrastructure adoption. By demonstrating that communities can assess grey and natural infrastructure options against a common standard, we hope to encourage widespread use of natural infrastructure in circumstances in which it is the best solution.

This report has introduced a natural infrastructure implementation framework that enhances the Value for Money analysis of natural infrastructure projects in Canada. The framework benefits natural infrastructure project proponents who aim to communicate the business case for their conservation and/or restoration projects, as well as potential investors who need to demonstrate diligence and the impact of their natural infrastructure investments. Infrastructure Canada could also use the proposed framework to direct green infrastructure spending, as could corporate endowment funds and foundations seeking to finance natural infrastructure projects.

Despite the range of benefits that natural infrastructure offers for disaster risk reduction and climate adaptation, Canada continues to experience the loss of wetlands, forests and vegetation. This loss is particularly prevalent in southern areas, where population growth, agricultural expansion and urban development are most pronounced.

Similarly, investments in natural infrastructure restoration projects are not being made at the scale and rate that could remedy and offset the loss of natural infrastructure. This is a significant omission at a time when Canada has committed to combatting climate change impacts under the Paris Agreement, the United Nations' Sendai Framework for Disaster Risk Reduction, and the Pan-Canadian Framework on Clean Growth and Climate Change, each of which outlines the imperative of preserving natural infrastructure.

This report profiles one means by which Canada can meet its international and national climate commitments, through the preservation and restoration of natural infrastructure that is pervasive by design, cost-effective by good fortune, and underutilized to date.

# Appendix A: Green Infrastructure – A TEV Approach by PwC Canada

In 2017, Metrolinx, a Government of Ontario agency created to improve the coordination and integration of all modes of transportation in the greater Toronto and Hamilton areas, engaged PwC to develop a TEV methodology for environmental and social capital accounting as applied to the cost-benefit analysis of investments in green infrastructure. The table below outlines the financial, environmental, and social costs and benefits associated with the TEV approach for green infrastructure that was applied to this analysis.

| IMPACT CATEGORY | IMPACT | DESCRIPTION |
|---|---|---|
| Financial (internal) | Capital cost | Difference in capital costs between the green-case and the base case options. |
| Financial (internal) | Operations and maintenance cost | Difference in operating costs between the green-case and the base-case options over the full assessment period. |
| Financial (internal) | Replacement cost | Difference in cost of replacing assets as they reach the end of their useful lives within the assessment period between the green-case and the base-case options. |
| Financial (internal) | Residual asset value | Difference in remaining useful life of assets at the end of the assessment period between the green-case and the base-case options. |
| Financial (internal) | Utility cost | Difference in electricity and natural gas costs between the green-case and the base-case options due to shading and the reduced heating and cooling loads for nearby buildings. |
| User (internal) | Ambience value | Contingent value of ambience improvements due to green features monetized as a function of user time spent on-site. |
| Environmental (external) | Carbon sequestration | Carbon sequestration benefits of on-site vegetation, and lower greenhouse gas emissions resulting from reduced on-site energy use and lower embodied energy of construction materials in the green-case option, monetized using a social cost of carbon. |
| Environmental (external) | Air pollution | Reduction in criteria air contaminant emissions in the green-case option due to the use of vegetation and lower energy use, monetized using a social cost of different air pollutants. |
| Environmental (external) | Water quality | Improvements in water quality due to the reduction in sewer outflow as a result of increased site/building retention and infiltration capacity, monetized through avoided stormwater treatment costs or willingness-to-pay estimates for water quality improvements. |
| Social (external) | Flood risk | Reduction in surface flood risk by replacing impervious surfaces (e.g., asphalt, concrete and roofing) with permeable surfaces such as vegetation, turf, trees, porous materials or green roofs, monetized by estimating the percentage of city-wide flood volumes and damage mitigated. |
| Social (external) | Urban heat island effect | Cooling in ambient temperatures resulting from increased vegetation and replacement of asphalt and other reflective surface materials with white/non-reflective materials; this leads to positive impacts on heat-related morbidity and reductions in health costs. |
| Community development (external) | Property value | Property value uplift in the surrounding area due to improvements in the aesthetic value associated with green infrastructure. |
| Community development (external) | Community use benefits | Contingent value of community-use services associated with green features (e.g., recreational spaces). |
| Community development (external) | Shadow wage benefit | Reduction in local poverty resulting from an increase in jobs due to construction, and operation and maintenance associated with the addition of green features. |

*Source: PricewaterhouseCoopers Canada LLP. 2017. Assessing Green Infrastructure Benefits for Mount Pleasant GO Station Parking Lot Infrastructure Project. Prepared for Metrolinx.*

# Appendix B: Direct-Market Valuation, Indirect-Market Valuation and Survey-Based Valuation Approaches[112]

## Market-Price Approaches

| VALUATION METHOD | DESCRIPTION | ADVANTAGES | DISADVANTAGES |
|---|---|---|---|
| Market price | The market-price method estimates the economic value of ecosystem products or services that are bought and sold in commercial markets. | Price, quantity and cost data is relatively easy to obtain for established markets. | The true economic value of goods or services may not be fully reflected in market transactions, due to market imperfections and/or policy failures. |
| Cost-based | This method evaluates the economic benefit of a given ecosystem good or service by using the market value of a substitute traded on the market, or the cost of measures necessary to avoid the environmental damage in the first place. | Market data is available and robust. | This is not a true measure of economic welfare. |
| Production function | The production function approach is a common economic technique that relates output to different levels of inputs of the so-called factors of production (land, labour, capital, raw materials). | This approach has a strong intuitive and practical appeal, so it's popular with policy decision-makers. | Specifying a biophysical relationship can be complex and/or data-intensive. |

## Revealed-Preference Approaches

| VALUATION METHOD | DESCRIPTION | ADVANTAGES | DISADVANTAGES |
|---|---|---|---|
| Travel cost | The travel-cost method is predominantly used to estimate direct-use values associated with recreation sites. Visitor time and expenditures to visit a particular site are used to represent the value of that site. | Useful for observing actual or potential behaviour. Can be used to understand restoration impact to recreational users. Can differentiate between different types of users. | Potential bias in choice of dependent variable, in multi-purpose trips, with incorrect recording of preferences and statistical technique. |
| Hedonic pricing | The hedonic method is used to value environmental amenities that affect the price of residential properties. It is particularly appropriate for evaluating projects in urban settings. | Useful for observing actual consumer behaviour. Can be used to assess potential impacts to property values, preferences by property owners for extent and level of restoration. | Very data-intensive and limited mainly to data related to property. |
| Averting behaviour | This method is similar to the travel-cost method, but differs to the extent that it infers values from observing how individuals change their behaviour in response to changes in the quality of the environment, health or safety. | Based on actual behaviour and expenditures. Relatively easy to estimate. | Not a true measure of economic welfare. Averting expenditures and environmental quality are rarely perfect substitutes. |

### Stated-Preference Approaches

| VALUATION METHOD | DESCRIPTION | ADVANTAGES | DISADVANTAGES |
|---|---|---|---|
| Contingent valuation method (CVM) | Involves directly asking people how much they would be willing to pay for specific environmental services or asking them what amount of compensation they would be willing to accept to give up specific environmental services. | Extremely flexible, allows generating dollar values for virtually everything. Has been widely used, and a great deal of research is being conducted to improve the methodology, making results more valid and reliable. | Potential bias in response, hypothetical market (not observed behaviour). |
| Contingent ranking | Respondents are asked to rank different combinations of environmental quality and costs from most preferred to least preferred. | Easier for respondents to handle conceptually when faced with the situation of putting a money value on a non-market good, relative to the procedure involved in contingent valuation. | Requires a larger sample than CVM, and it produces a measure of economic welfare with difficulty. |
| Choice modelling | Participants are asked to work through a number of choices between different alternatives characterized by the good's main attributes. | Allows the analyst to better understand the complexity of consumer choice behaviour. The repeated question approach may provide additional information on response consistency. | Requires specialized expertise to ensure that choice modelling generates measures of economic welfare. |

## Example of stated-preference approach for estimating benefits of wetland retention and restoration in southern Manitoba

In 2009, researchers from the University of Alberta and Ducks Unlimited Canada estimated the benefits of restoring wetlands in Manitoba.[113] Wetlands in Broughton's Creek watershed, Rural Municipality of Blanshard in southwestern Manitoba, were assumed to adequately represent the status of the wetlands in the entire Prairie Pothole Region of the province.

First, researchers used satellite imagery and GIS analysis to estimate the rate of wetland loss in Manitoba and determined that approximately 7,406 acres of undisturbed wetlands existed in Broughton's Creek watershed in 1968, compared with 5,874 acres in 2005. The overall wetland loss of 1,532 acres (77% of the 1968 level) indicated an average loss rate of 0.57% per year within the watershed. Extrapolated to the entire Manitoba Prairie Pothole Region (1,044,102 acres in 2005), Ducks Unlimited Canada estimated 1,355,977 wetland acres in 1968 declining at approximately 7,700 acres per year.[114]

Second, using wetland monitoring data, researchers established that in Broughton's Creek watershed, wetlands could provide the following benefits (per acre, per year):

- Filter approximately 0.043 kg of nitrogen and 0.009 kg of phosphorus;
- Store 4 tons of carbon dioxide equivalents;
- Control 6.5 tons of soil erosion; and
- Retain 1,200 $m^3$ of floodwater.

Third, these benefits were documented and shared with a group of 1,980 survey respondents who were asked to evaluate their willingness to pay (WTP) to receive respective wetland benefits under five different scenarios of wetland retention and restoration relative to the 1968 base case:

1. Full wetland retention, at 77%;
2. Restoration to 80%;
3. Restoration to 83%;
4. Restoration to 89%; and
5. Restoration to 100%.

The survey respondents were selected as a representative of the provincial population in terms of income, gender ratio, household size and marital status.

As a proxy of their WTP, researchers used an increase in income taxes for a five-year period. Therefore, survey respondents could make an informed decision about the trade-offs between personal income tax increases and wetland conservation benefits.

The table below outlines the results of the survey, where survey participants indicated their willingness to accept an increase in income taxes for various wetland restoration scenarios (in 2009) for the entire Manitoba Prairie Pothole Region.

## Willingness to Accept an Increase in Income Taxes for Various Wetland Restoration Scenarios (Broughton's Creek Watershed, Rural Municipality of Blanshard, southwestern Manitoba)

| | 77% RETENTION | 80% RESTORATION | 83% RESTORATION | 83% RESTORATION | 89% RESTORATION |
|---|---|---|---|---|---|
| **Mean annual WTP per household** | $294.02 | $304.36 | $313.16 | $329.84 | $357.75 |

The stream of payments for restoration (level i) were discounted to the present using the NPV formula:

$$NPV = \sum_{t=1}^{5} \frac{WTP_i^t}{(1+r)^t}$$

where $WTP_i^t$ is the WTP estimate for wetland program *i* in time *t*, and *r* is the discount rate.

The NPV for retention and restoration of wetlands in the entire Prairie Pothole Region of the province was estimated by multiplying the discounted household WTP by the total number of households in Manitoba, discounted at 5% for five years. The resulting estimates ranged from $602 million for retention to $729 million for 100% restoration to 1968 levels.[115]

*Source: Boxall, P. C., Pattison, J. K. and Shane Gabor, S. T. 2009. Estimates of Passive Use Values of Wetland Restoration and Retention in Southern Manitoba. Proceedings from Ecological Goods & Services Technical Meeting, Lord Elgin Hotel, Ottawa, Canada.*

# Appendix C: Decision-Support Tools to Account for Risks and Uncertainty in Cost-Benefit Evaluation of Natural Infrastructure Projects[116]

A wide range of decision-support tools that integrate ecology, economics and geography are available, from simple spreadsheet models to complex software packages. Tools differ in their approaches to economic valuation, spatial and temporal representation of services, and incorporation of existing biophysical models. Many of them are intended to be transferrable to new geographic and decision-making contexts.

The International Institute for Sustainable Development (IISD) is developing an approach for natural infrastructure systems design. The IISD's Distributed Multifunctional Storage (DMFS) model integrates climate change modelling with simulation modelling of naturalized retention ponds and engineered wetlands to estimate the investment case for natural infrastructure regarding climate adaptation.

The DMFS model relies on modern, high-resolution climate and topographic data and simulation modelling principles. At their core, MFS design methods are closely related to classical water resources engineering investment planning based on simulating storage systems (reservoirs) performance with historical or synthesized hydrology.[117] MFS design for climate adaptation, however, requires three major modifications to conventional engineering methods:

- Downscaled global climate modelling data for quantitative climate risk assessment using Monte Carlo simulation techniques;
- High-resolution terrestrial data for identifying sites with high potential for multifunctional storage; and
- Environmental economics methods based on ecosystem service valuation to build a comprehensive investment case of this style of infrastructure.

First, the MFS design for climate adaptation should make explicit use of ensemble climate projections to generate the synthetic, climate-change influenced hydrology necessary for climate risk analysis. Climateatlas.ca is a repository of downscaled ensemble climate modelling data that can be used to generate the necessary synthetic hydrology.

Second, the MFS design relies on high-resolution topographic data derived from LiDAR to identify candidate natural infrastructure sites. The underlying philosophy is that a large number of small wetland-type landscape features can deliver valuable services, such as flood and drought mitigation, which would otherwise be provided by a single, large conventional infrastructure project. The MFS sites can therefore be built into watersheds and landscapes, and exploit natural ecosystem processes. Selecting multiple sites and designing networks can accomplish multiple objectives. LiDAR is the underlying data source that enables the identification and selection of sites.

Third, the MFS design typically includes, to the extent possible, the quantification and monetization of ecosystem service benefits. Ecosystem service quantification is still an evolving practice and a typical criticism is that standard tools for mapping and valuing ecosystem services such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) lack the hydrological detail to be useful.[118] The high-spatial resolution analysis largely avoids this pitfall by using localized hydrological information to drive the ecosystem service quantification and monetization process.

Several of the key analytical innovations necessary for climate-risk-based natural infrastructure systems design and investment planning are described as follows:

### Integrating Synthetic Hydrology with Climate-influenced Extreme Precipitation Events

The time series produced by the high-resolution (downscaled) future climate projections allows for continuous modelling to investigate the performance of natural infrastructure in the long term (up to the year 2100). However, climate models have some limitations when it comes to predicting extreme events – they usually underestimate the magnitude of daily extreme events.[119, 120] To this end, Intensity Duration Frequency (IDF) curves, which provide information on the return periods (frequency) of different storm events based on historical record, are used to model daily extreme events in the hydraulic design of different water-related infrastructures.[121]

To integrate precipitation projections from statistically downscaled Global Circulation Models (GCMs) and climate-modified IDF curves, IISD integrates the University of Western Ontario's tool for generating climate-adjusted IDF curves[vii] with the precipitation time series derived from downscaled GCMs. The fundamental logic is that exposure to higher frequency extreme events is a key consideration for climate adaptation and natural infrastructure design. However, those extreme events should not distort the annual precipitation budget estimated from downscaled GCMs, as this could result in an over-estimate of available precipitation. The following are the key steps of this method:

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[vii] The Computerized Tool for the Development of Intensity-Duration-Frequency Curves under Climate Change (IDF-CC) available at: http://www.idf-cc-uwo.ca/

a) Statistically identify the temporal points of extreme events for different return periods from the 100-year span:

| | | |
|---|---|---|
| i) | $M_5 = 1{:}5$ | (20 events) |
| ii) | $M_{10} = 1{:}10$ | (10 events) |
| iii) | $M_{20} = 1{:}20$ | (5 events) |
| iv) | $M_{50} = 1{:}50$ | (2 events) |
| v) | $M_{100} = 1{:}100$ | (1 event) |

b) Using the Western University developed IDF-CC tool, the magnitude of the events mentioned above will be determined.

c) Calculate the cumulative amount of the projected precipitation (for 100):

   i) $Total\ P = \sum_{i=1}^{100} P_i$

d) Calculate the total amount of extreme events identified in the step above:

   i) $M = 20 * M_5 + 10 * M_{10} + 5 * M_{20} + 2 * M_{50} + M_{100}$

e) Calculate the correction factor:

   i) $K = Total\ P / (Total\ P + M)$

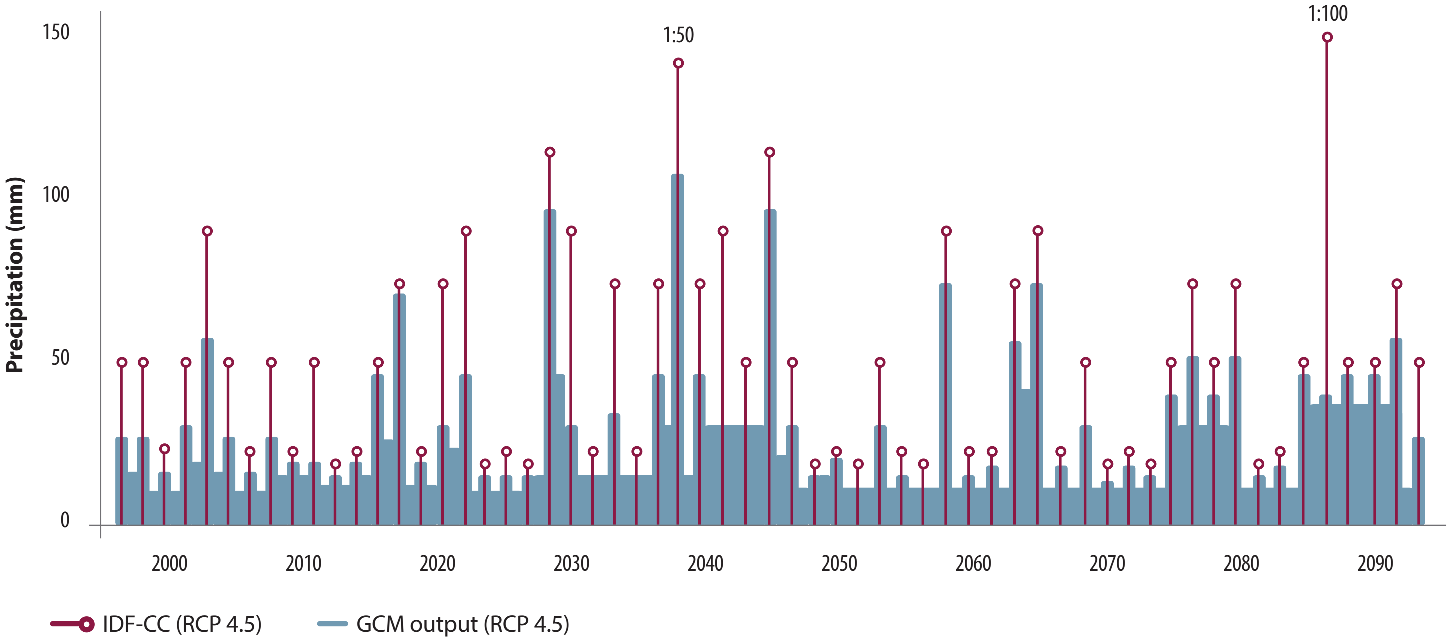
f) Corrected annual precipitation:

   i) $Corr\ Total\ P = P * K$

   ii) Insert the extreme events (from step a) in the new corrected time series (steps f-i)

This approach allows for simultaneous Monte Carlo simulations of the hydrological performance of natural infrastructure in the long term, and under extreme events, without compromising the time series properties generated by the climate model that underlies the downscaled GCM data. The illustration below (Figure C.1) shows the superposition of extreme events derived from IDF-CC and a representative precipitation time series derived from a GCM.

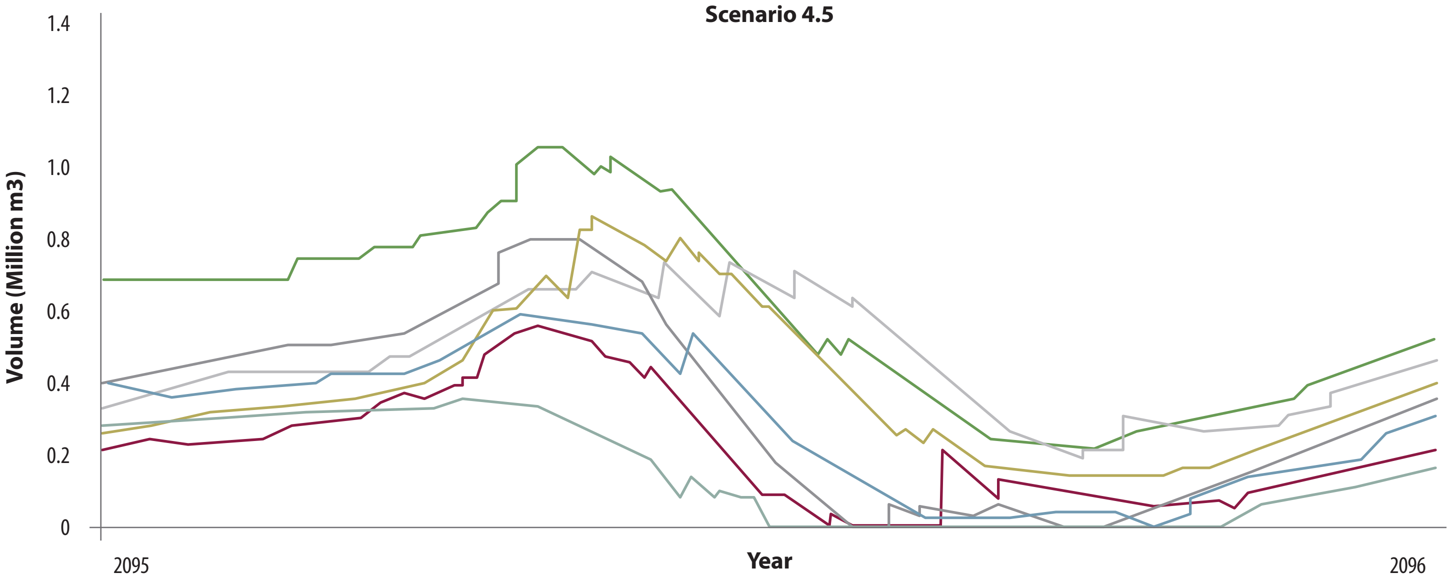
## Figure C.1: Superimposed Extreme Precipitation Events on GCM Output (Example)



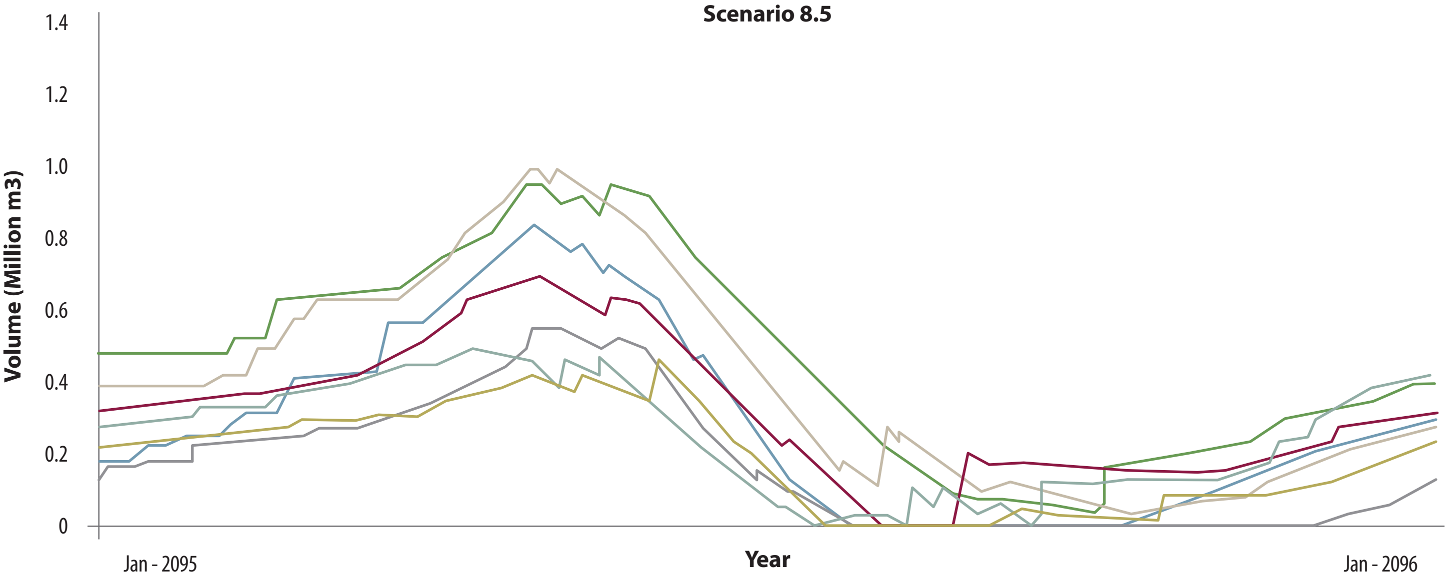
**Note:** This figure is an illustrative example (Virden, Man.) to show how extreme events from IDF-CC can be incorporated into a GCM outputs (RCP 4.5) time series. The figure reveals that projected extreme events may be significantly larger than those generated directly from downscaled GCM outputs. The superimposition of extreme events on the GCM output and the continuous simulation-optimization approach captures future risk of high-frequency oscillation between flood and drought conditions and the modulating effect of natural infrastructure.

Proposed natural infrastructure project designs can then be evaluated using Monte Carlo–based methods that simulate the performance of the system using an ensemble of hydrologic data derived from downscaled GCM data. Figures C.2 and C.3 show examples of multiple traces of daily, simulated MFS behaviour for 12 different GCMs for two different reference climate change scenarios (RCP4.5 and RCP8.5).

## Figure C.2: Monte Carlo simulation of a hypothetical multifunctional site at Virden, Manitoba (storage volume in millions of cubic meters) using output for 12 GCMs (RCP4.5)



## Figure C.3: Monte Carlo simulation of a hypothetical multifunctional site at Virden, Manitoba (storage volume in millions of cubic meters) using output for 12 GCMs (RCP8.5).



Note that the RCP8.5 scenario represents a hotter climate than RCP4.5. The MFS site therefore operates at a lower supply level or is empty more frequently than in the RCP4.5 scenario due primarily to increased evaporation.

The Monte Carlo approach essentially evaluates many simulation years to estimate the probability distribution of future benefits, which is essential for the climate-risk-based estimation of the natural infrastructure investment value proposition.

### Other Tools

The IISD multifunctional storage model utilizes three-dimensional reservoir storage modelling based on LiDAR-derived topography for high spatial resolution modelling that allows modelling of critical ecosystem services such as nutrient interception, biomass harvesting and carbon sequestration.

InVEST and ARIES (ARtificial Intelligence for Ecosystem Services) are other public-domain tools for modelling ecosystem services, key features of which could be integrated into natural infrastructure design methods. Both use a variety of spatial data as model inputs and encode ecological production functions in deterministic models (InVEST and ARIES) and in probabilistic models (ARIES).

EcoServ is a web-based tool under development in the U.S. and Canadian Prairie Pothole Region, with the intent to eventually develop additional case studies, then nationally or globally generalized models.[122] EcoServ links external ecosystem process models and spatial data and will make these accessible to the public via a web tool. EcoServ accounts for temporal climate variability and can provide output maps of service provision under scenarios for climate and land-use change.

ARIES is a software platform that provides an intelligent modelling platform capable of composing complex ecosystem service models from a collection of models specified by the user. These component models can be defined within ARIES using its native modelling language or developed independently in another language or architecture and used by ARIES via its model-wrapping mechanism. Once properly wrapped, ARIES is capable of automatically negotiating the differences in input data, units, modelling paradigms and applicable scales between component models.

# Definitions[123]

**Biodiversity:** the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.

**Carbon sequestration:** the removal and storage of carbon from the atmosphere in carbon sinks (such as wetlands, oceans, forests or soils) through physical or biological processes, such as photosynthesis.

**Drought:** sustained and regionally extensive occurrence of appreciably below-average natural water availability in the form of precipitation, streamflow or groundwater.

**Grey infrastructure (water resources):** human-engineered infrastructure for water resources such as water and wastewater treatment plants, pipelines and reservoirs.

**Flood plain:** an area adjacent to a lake, river or coast, which can be regularly inundated or covered with water. It typically includes two zones:

- **Floodway:** the channel of the river or stream and the adjacent land that must remain free from obstruction so that the regulatory flood can be safely conveyed downstream.
- **Flood fringe:** the remaining portion of the flood plain, where flood depths, flow velocities, or wave energies are relatively low and some development may be permitted, if adequate levels of flood protection are provided.

**Flood mitigation:** a sustained action taken to reduce or eliminate long-term risk to people and property from flood hazards and their effects. Mitigation distinguishes actions that have a long-term impact from those that are more closely associated with preparedness for, immediate response to, and short-term recovery from specific events.

**Flood risk:** flood risk is a combination of the likelihood of occurrence of a flood event (flood frequency) and the social or economic consequences of that event when it occurs (through exposure to the flood hazard).

**Habitat:** an area on which a species depends, directly or indirectly, to carry out its life processes such as reproduction, rearing, hibernation, migration or feeding.

**Hydrologic function:** the occurrence, circulation, distribution, and chemical and physical properties of water in the atmosphere, on the surface of the land, in soil and in underlying rocks; and water's interaction with the environment, including its relation to living things.

# Definitions[123]

**Hydraulic analysis:** an engineering analysis of flow scenarios carried out to provide estimates of the water surface elevations and velocity for selected recurrence intervals.

**Hydrologic analysis:** estimation of flood magnitudes as a function of precipitation.

**Intensity-Duration-Frequency (IDF) curve:** a graphical representation of the probability that a given depth of rainfall will occur, shown in rainfall intensity (e.g., in millimetres per hour) with respect to rainfall duration (e.g., hour).

**Invasive species:** species that are not native to an area and whose introduction or spread threatens the environment, the economy or society, including human health.

**Natural infrastructure:** a strategically planned and managed network of natural lands, such as forests and wetlands, working landscapes, and other open spaces that conserves or enhances ecosystem values, and functions and provides associated benefits to human populations.

**Surface water flooding:** flooding that occurs when runoff water exceeds the capacity of the storm sewer (minor system) and flows along streets and in adverse circumstances onto private properties causing flood damages. It can happen anywhere in the community, independent of an overflowing water body.

**Riparian buffers:** vegetated areas adjacent to waterbodies (e.g., lakes, rivers, streams) that can reduce pollution from stormwater runoff and provide bank stabilization and aquatic and wildlife habitat.

**Riverine flooding:** excess stream flow in a watercourse, such that land outside the normal banks is submerged or inundated. Can be caused by extreme rainfall or snowmelt, or physical conditions (such as ice jams and undersized watercourse crossings) associated with a watercourse.

**Runoff:** the amount of water deriving from precipitation/snowmelt, not otherwise evapotranspirated or stored, that flows across the landscape.

**Watershed:** the area of land that drains into a river, lake or other water body.

**Wetland:** lands that are seasonally or permanently covered by shallow water, as well as lands where the water table is close to or at the surface. In either case, the presence of abundant water has caused the formation of hydric soils and has favoured the dominance of either aquatic or water tolerant plants. The four major types of wetlands are swamps, marshes, bogs and fens.

**Wetland complex:** a group of wetlands that are functionally linked to one another and no more than 750 metres apart.

# Acronyms

ALUS - Alternative Land Use Services
CapEx - capital expense
CLTIP - Conservation Land Tax Incentive Program
DFAA - Disaster Financial Assistance Arrangements
GIS - Geographic Information System
GCMs - global circulation models
GDP - gross domestic product
IBC - Insurance Bureau of Canada
IDF - Intensity Duration Frequency
IFC - Intact Financial Corporation
Intact Centre - Intact Centre on Climate Adaptation
IPCC - Intergovernmental Panel on Climate Change
IRR - internal rate of return
KPI - key performance indicator
LiDAR - light detection and ranging
MNAI - Municipal Natural Assets Initiative
nBCR - net Benefit-Cost Ratio
NPV - net present value
O&M - operation and maintenance
OECD - Organisation for Economic Co-operation and Development
OpEx - operating expense
PwC - PricewaterhouseCoopers Canada
TEV - total economic value
VfM - value for money
WTP - willingness to pay

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