BENEFITS OF ADOPTING NATURAL INFRASTRUCTURE

A Comparison of Natural and Grey Infrastructure Solutions

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HORIZON ADVISORS

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List of Acronyms

CBD	Convention on Biological Diversity
CCME	Canadian Council of Ministers of the Environment
CDC	US Centers for Disease Control and Prevention
CUFN	Canadian Urban Forestry Network
ECCC	Environment and Climate Change Canada
FCM	Federation of Canadian Municipalities
MNAI	Municipal Natural Assets Initiative
NCC	Natural Capital Coalition
NRCan	Natural Resources Canada
PCF	Pan-Canadian Framework on Clean Growth and Climate Change
PHAC	Public Health Agency of Canada
UN	United Nations
UNEP	United Nations Environment Programme
VNCST	Value of Nature to Canadians Study Taskforce
WBCSD	World Business Council for Sustainable Development

Definitions

Benefits – the range of outcomes (economic, social and cultural) provided by solutions in response to infrastructure challenges. A subset of this, co-benefits, are the multiple secondary or ancillary benefits of infrastructure interventions for species, habitats, and ecological processes, separate from the outcomes or benefits (economic, social and cultural) for human communities.

Ecosystem – a dynamic complex of plant, animal and microorganism communities and their non-living environment, interacting as a functional unit.

Ecosystem services – the results of environmental processes, sometimes with human interventions, which provide benefits that humans depend on to support life (e.g., because ecosystems produce air, water, and food) security (e.g., by mitigating extreme weather events), and well-being (e.g., by supporting mental and physical health, cultural identity, spirituality, recreation).

Green infrastructure – an overarching description of physical systems that include natural and/or engineered elements (e.g., dikes, burmes, bioswales, rain gardens, etc.) providing positive environmental outcomes.

Grey infrastructure – elements of the environment that are engineered by humans (e.g., water treatment plants, pipes, dams and tunnels) using concrete, metals and synthetic materials to support services such as transportation, communication, water and waste management.

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

Natural assets – sometimes called 'natural capital assets'; ecosystems or ecosystem components considered in terms of their value to society, particularly for the benefits they provide such as water purification or flood mitigation. These assets can be assessed and managed to ensure ongoing infrastructure outcomes and other benefits to people through the ecosystem services they provide.

Nature-based solutions – employing nature and its processes to address societal challenges such as the need for adaptive infrastructure in the face of climate change, simultaneously supporting human well-being and providing biodiversity co-benefits.

Natural infrastructure – the existing, restored or enhanced combinations of vegetation and associated biology, land and water, as well as naturally occurring ecological processes that generate infrastructure outcomes such as preventing and mitigating floods, erosion and the effects of extreme heat. Sometimes considered a subset of green infrastructure.

Sources: Allen (2013); CBD (2004); ICF (2018); MA (2005); MNAI (2018); Moudrak et al. (2018); Natural Capital Coalition (2015); VNCST (2017); WBCSD (2015); Winkelman et al. (2017).

Executive Summary

This report is intended to inform the decision-making practices of governments, businesses and organizations who are in a position to influence the choice between engineered and nature-based approaches to infrastructure development. Its core focus is to document the benefits of 'natural infrastructure' (NI) used to address three specific infrastructure challenges, and compares these benefits, values and costs associated with conventional 'grey infrastructure' (GI) development. The preparation of the report began with a comprehensive literature review of pilot studies and project reports on three distinct types of NI, targeted to three infrastructure outcomes:

- Inland and riparian wetlands for flood control;
- Coastal ecosystems for flood/storm surge control; and,
- Urban forests for urban heat island control.

Drawing significantly on case studies from across Canada, the authors supplemented these materials with research on the ability of GI to provide comparable infrastructure outcomes and have assessed the differences in order to show how NI can provide GI-equivalent investment returns, as well as additional benefits to human communities and biodiversity. As this report makes clear, in some applications NI elements can protect existing built infrastructure; elsewhere, they can help to offset some of the more damaging environmental impacts of GI. Overall, what distinguishes NI is its ability to provide targeted infrastructure outcomes, supported by additional benefits including biodiversity improvements, habitat protection, climate adaptation, carbon sequestration and ecosystems services supporting the health of human communities and functioning ecosystems.

Taken together, the discussions undertaken of the three types of NI support the case for the wider uptake of NI where proven appropriate, and suggest that natural assets are a financially prudent and socially-desirable investment target.

Inland and riparian wetlands provide flood and stormwater storage during riverine and overland flood events. At the same time, they can supply clean water, store carbon and help to regulate local temperature, provide essential habitat for diverse species, and support recreational, cultural and economic activity.

Coastal ecosystems provide resilience to natural hazards including flooding and storm surges. They also provide adaptation to long-term sea level rise (SLR) and coastal erosion, conserve and enhance biodiversity, and support maritime industries, local recreation, culture and economic activity.

Urban forests figure importantly in efforts to mitigate the urban heat isalnd (UHI) effect in towns and cities. They provide additional benefits for climate mitigation and adaptation, pollution reduction, flood prevention, human health and well-being, biodiversity and economic activity.

The value of NI benefits is critical to the recognition of NI elements as natural assets, valuable to society in both economic and sociocultural terms. Measuring the benefits and value of GI is usually straightforward and often relies on quantitative indicators and metrics for the assessment of singular outcomes. The multipurpose character of NI often leads to more elaborate, qualitative valuations of its full range of additional benefits. This report provides monetary values for the development and maintenance of NI and GI elements where documentation was available, and frequently reports differentiated economic and sociocultural values for the case studies of NI that employed an avoided-cost approach to estimating the value of NI benefits. The primary objective of this information is to enable decision-makers to confidently state the evidence to justify adopting NI by documenting the full range of outcomes and benefits associated with NI and GI alternatives.

1

Introduction

Governments are increasingly developing policies and tools for the adoption of nature-based solutions to environmental and economic challenges, including physical infrastructure objectives.[1] In-line with this global trend and the Pan-Canadian Framework on Clean Growth and Climate Change (PCF), the Government of Canada has made a number of funding and program announcements that support the adoption of natural infrastructure (NI). Most prominently, Budget 2017 includes $21.9 billion in planned investment in green infrastructure. NI projects are eligible under the Resilience, Adaptation and Disaster Mitigation substream of the $9.2 billion Green Infrastructure Fund, and the Disaster Mitigation and Adaptation Fund allocates a further $2.0 billion to large-scale projects including NI that help communities manage the risks of natural hazards.

It is important to note that municipalities own about 57 per cent of Canadian infrastructure, including roadways, bridges, shorelines, recreation sites, as well as stormwater, wastewater and drinking water facilities (Mirza and Ali, 2017), with 30 per cent of these assessed as being in fair or very poor condition (FCM, 2016). Elements of grey infrastructure (GI) (e.g., water treatment plants and dams) that are designed for singular purposes have dominated municipal infrastructure investments. NI, as a basis for comparison, can prove more adaptable over time – providing targeted infrastructure outcomes as well as additional benefits to people and biodiversity. For example, while a wastewater treatment plant's sole function is to pump out clean water, inland and riparian wetlands can perform that function while providing carbon sequestration, recreational capacity and habitats for diverse flora and fauna (Roy, 2018). In this key respect, NI can produce a sustainable and value-added range of benefits that GI cannot.

This report builds on the work of the Canadian Council of Ministers of the Environment (CCME) in defining NI as *the existing, restored or enhanced combinations of vegetation and associated biology, land and water, and naturally occurring ecological processes that generate infrastructure outcomes* (ICF, 2018), such as preventing and mitigating floods, coastal erosion and the effects of extreme heat. NI is often discussed as a subset of the broader category of green infrastructure. In theory, individual infrastructure elements can exist on a continuum between green and grey, and can be more or less 'naturalized' depending on factors such as the extent and direction of human management, the passage of time and changes to ecosystem conditions. In practice, this means that NI is comprised of intact, naturally-existing ecosystem elements that can be subject to varying practices of management, where green infrastructure is engineered to emulate many of the features and functions of NI. Importantly, green initiatives have the capability to evolve in response to natural ecological processes, which distinguishes them from grey solutions.

This report aims to comprehensively describe how intact natural assets that require little or no ongoing human intervention, as well as managed initiatives using natural materials (i.e., water, vegetation, trees and soils), can replace or complement built infrastructure in diverse applications across Canada.

In order to accomplish this, the report addresses three distinct infrastructure challenges and compares the ability of NI and GI to meet the targeted infrastructure outcome in each area; subsequent discussion demonstrates the range of additional benefits associated with nature-based solutions when compared to conventional engineered assets. Stakeholders including municipal governments, watershed agencies, conservation groups and environmental organizations are often interested in clear and context-specific discussions of the full implications of different infrastructure investments (VNCST, 2017: 38). Accordingly, this report aims to inform the work of decision-makers seeking to evaluate and prioritize potential approaches to the planning and implementation of infrastructure projects.

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[1] Noteworthy is Article 7 of the Paris Agreement on climate change, which references the important role of adaptive natural measures in protecting livelihoods and ecosystems (UN, 2016); accordingly, signatories to the Agreement have committed to investing in the conservation and use of natural capital in response to current and future climate challenges.

2

Methodological Notes

The benefits provided by nature can be assigned value based on people's preferences, constraints on resources or the value the market places on products and services derived from ecosystems. NI elements are natural assets – valuable to society, in this view – because they provide infrastructure outcomes, and do so at costs that can be accounted for in monetary terms or non-financial terms (i.e., where market indicators of their value do not exist). This report summarizes the extent of infrastructure benefits and co-benefits, and the associated costs, for NI used in three specific applications:

- Inland and riparian wetlands for flood mitigation;
- Coastal ecosystems for protection from flooding and storm surges; and,
- Urban forests for mitigating the urban heat island (UHI) effect.

The preparation of the report began with a comprehensive literature review of pilot studies and project reports on initiatives that used NI or assessed the potential for NI to meet identified infrastructure needs. These case studies were supplemented with research on the ability of GI to provide comparable infrastructure outcomes, and the differences were assessed to show how using NI can provide GI-equivalent investment returns, as well as additional benefits to human communities and biodiversity.

In the selection of case studies, an effort was made to include examples that estimate the magnitude and value of the targeted infrastructure outcome in both economic and sociocultural terms. The pilot studies and project reports were consistent in portraying outcomes inclusive of a range of benefits, as well as determinations of the value of project development and actual project costs. Accordingly, their conclusions about the benefits of NI are often supported with the use of avoided cost analysis, which assesses the economic and social value of NI by measuring the costs to infrastructure that would occur if the natural asset were lost and that governments would otherwise have to address using GI (*c.f.,* Whiteoak and Binney, 2012). For example, urban wetlands can provide a city with floodwater storage during periods of heavy rainfall; otherwise, dams or canals would need to be built for stormwater control. In analyses such as these, the avoided GI costs can be usefully compared to the total economic and sociocultural value of the NI.

The argument in favour of comprehensive economic and sociocultural valuations of NI is persuasive. In the first place, calculating the monetary value of the benefits provided by NI can be helpful to decisionmakers and the public (Guerry et al., 2015), though it is challenging to attach a price to the infrastructure outcomes derived from natural assets such as stormwater management, water purification and erosion control. At the same time, because NI's value as a municipal or private asset is further enhanced by its benefits beyond the delivery of a singular service (e.g., its tangible and intangible benefits to humans and supporting biodiversity), it is useful for stakeholders to be able to model and measure those additional outcomes and values.

This report provides several case studies as examples of how the relative economic and sociocultural costs of an equivalent infrastructure outcome using NI and GI can be compared, though it is beyond the scope this research to determine exact monetary costs or savings (i.e., due to site-specific variables or where such metrics were not relevant to the pilot study or initiative undertaken). Benefits are reported in economic and sociocultural terms, supported by measures of the biophysical changes (e.g., in the quantity and quality of natural assets) that may result from the use of NI or GI. The reported values may be insufficient for extrapolation to other locations because of differences in project type and/or scale, but the comparisons drawn can assist decision-makers in evaluating the trade-offs that may need to be made when deciding when and to what extent NI should be incorporated into natural asset planning and management.

In each of the following sections, a targeted infrastructure challenge is identified; then, the possibilities for using NI and GI to meet the desired outcome are described. The additional benefits associated with NI are then demonstrated, drawing significantly on examples from important NI initiatives undertaken across Canada. Indicators of the benefits and extent of NI and GI alternatives are presented side-by-side, in both a summary table and graphical table, allowing the reader to draw comparisons at a glance.

3

Infrastructure Challenge

Watershed Management for Flood Control

Integrated approaches to local watershed management will entail a combination of riverine flow monitoring, flood and drought forecasting to enhance the effectiveness of natural floodplain functions. Land use changes including agricultural expansion and residential development on Canadian floodplains have increased vulnerability to riverine flooding caused by intense precipitation, rapid snow-melt and ice-jams in rivers. With the acceleration of climate change, more frequent, severe floods can be expected to exert considerable pressures on water management infrastructure across the country (Moudrak et al., 2018; ICF, 2018; Buttle et al., 2016; PHAC, 2018). Investing in physical infrastructure as an aspect of overall watershed management can be transformational in controlling stormwater and mitigating the effects of overland flooding. Nature-based and engineered solutions can help to regulate river flows while protecting existing infrastructure. NI solutions in the area include the afforestation or reforestation of riparian lands, and the preservation, restoration, enhancement, or construction of wetlands. Engineered alternatives include water source diversions using channels, off-stream floodwater storage in dry reservoirs, wet or dry dams (BC Ministry of Environment, n.d.), berms, levees and dikes.[2]

3.1 Flood Control Solutions

3.1.1 Inland and Riparian Wetlands

Inland (non-tidal) wetlands in Canada are located on riparian lands (i.e., transitional lands alongside rivers and streams), on the natural floodplain of drainage basins, along the margins of lakes and ponds, and in low-lying areas where groundwater contacts the soil surface (i.e., swamps, marshes, and peatlands including fens and bogs). Some wetlands are seasonal, dry for one or more seasons each year, but in all cases the quantity of water they retain determines their ecosystem characteristics (National Wetlands Working Group, 1997). Because of their ability to provision and regulate water quantity (i.e., during times of drought, unpredictable rainfall, riverine flooding or high runoff), intact natural wetlands figure importantly in sustainable and multi-functional watershed management strategies (ICF, 2018; Moudrak et al., 2017). Naturalized or constructed wetlands, too, can provide urban and rural communities with upstream water purification, waste assimilation, stormwater retention and discharge.

Notwithstanding the infrastructure benefits that wetlands provide to Canadian communities, they have been significantly degraded or lost for more than the last century. The City of Calgary, for example, may have lost as much as 90 per cent of its wetlands since pre-settlement (1875) times, and the province has since maintained an annual rate of wetland loss between 0.3 and 0.6 per cent (DUC, 2014). This has culminated in a loss of over 20 per cent of the province's wetland-based water storage capacity since the 1960s, a $2 million CDN annual deadweight loss on the provincial economy when the historic rate of wetlands loss is applied (Government of Alberta, 2011). In southern Ontario, as Moudrak et al. (2018: 16) observe, 72 per cent of original wetlands have been lost to encroaching development and other land conversion. In most places it is still common practice for wetlands to be drained and filled for agricultural production and livestock grazing on natural floodplains. Increases in atmospheric temperature affecting higher latitudes, excess nutrient and chemical runoff, as well as air and water pollution (Junk et al., 2013; Moudrak et al., 2018; Sauchyn et al., 2007) represent significant emerging threats to the future of Canadian wetlands, as does the introduction of GI for water diversion (e.g., dams and canals) that encroach upon natural floodplains. Nevertheless, federal and provincial policies mandating the conservation of wetlands have considerably slowed the rate of area loss. Governments increasingly recognize the full value of wetlands to their future economic, sociocultural and environmental needs and as a result are adopting the protection of wetlands as an integral aspect of overall watershed management.[3]

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[2] GI applications can be characterized as more- or less- dependent on concrete, steel or synthetic components. As an example, berms and levees should be properly distinguished from dikes in that where the former two GI elements identically involve the excavation of land coupled with engineered embankments, dikes are built by digging a ditch and keeping the naturally excavated materials in a mound (Alberta Water Portal Society, nd). This would lead to their categorization as a green infrastructure solution.

[3] Examples of government commitments to protect and invest in wetlands as NI include Ontario's Wetland Conservation Strategy; the Alberta Wetland Policy; 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 (Moudrak et al., 2018: 16).

CASE STUDY 1: FLOODWATER STORAGE WITH RIPARIAN WETLANDS AT GRAND FORKS, BRITISH COLUMBIA

Under the direction of the Municipal Natural Assets Initiative (MNAI), a 2016 pilot study was carried out on the value and benefits provided by the natural floodplain including prominent riparian wetlands near the confluence of the Kettle and Granby Rivers outside of Grand Forks, BC. Hydrological and hydraulic river flow modelling was used for a variety of overland flood scenarios to determine peak flow rates, and floodplain modeling identified the areas susceptible to flood risk greater than 1 per cent – those are, the areas that have high susceptibility to a 100-year flood event (*c.f.*, Lord, 2011). Where this risk can be reduced to less than 1 per cent with the use of NI for flood control, analysts can estimate the range of value provided by the floodplain's risk reduction impact. The results were analyzed using an avoided cost approach – i.e., the value of the preserved floodplain is estimated as the sum value of the damages to buildings in the city if the existing natural assets including wetlands were lost.[a] Assuming variable to full encroachment of buildings on the floodway, the models predicted damage to 55 buildings in Grand Forks, resulting in up to $3,316,000 CDN of total damages in the absence of 111 ha of floodplain. This suggests that each hectare of riparian area and wetland upstream of Grand Forks provides $3,500/ha^2 in flood damage reduction (for buildings only) during high-flow events.

For floodwater storage, Sheaffer et al. (2002) estimate the value of water storage using artificial ponds at $295,000 CDN per hectare, though the approximation is outdated and not directly applicable to the Grand Forks area.[b] Protection of the natural floodplain would serve to maintain the targeted infrastructure outcome while providing important additional benefits (which on balance exceed the value of the flood control outcome provided by the GI alternative), including:

- Floodwater storage, minimizing downstream damage to 55 buildings in Grand Forks (assuming variable to full encroachment);
- Erosion mitigation by minimizing flow velocities during flood events;
- The recharge of the underlying local aquifer with groundwater;
- The improvement of water quality through upstream sediment and chemical sequestering;
- The protection of residential and commercial property value.

Source: MNAI (2018a)

[a] The avoided cost approach for floodplain valuation has been widely advocated as a focus of floodplain and overall watershed management (*c.f.*, Sheaffer et al., 2002; Opperman et al., 2017).

[b] Based on conversion from US to Canadian dollars and assuming an inflation rate of 2.1 per cent.

Most runoff occurs when the input of rainfall or snow-melt exceeds the infiltration capacity of saturated soils. Wetlands in riparian areas store runoff generated by snow-melt and rainfall, slowing its discharge into streams and rivers. This helps to sustain flow-rates and reduce peak flow during flood events, preventing overland flooding or limiting damage where floodwaters extend past the riparian limits. During inundation of the natural floodplain, wetlands can absorb floodwaters and gradually release them (UNEP, 2014). During the assessments leading up to the introduction of Alberta's Wetland Policy in 2013, the Government of Alberta (*c.f.,* 2011) determined that the costs of replacing an important wetlands complex in eastern Calgary and the surrounding region with engineered water storage infrastructure could be as high as $338 million. Ducks Unlimited Canada (DUC), who have played a key stewardship role in the management of protected wetlands across the country, have similarly emphasized that wetlands conservation and restoration compare favorably to GI in terms of the cost-per-cubic-metre of flood and stormwater storage (DUC, 2012; 2014). Maintaining wetlands in their natural state offers a broadly-applicable strategy to offset the costly social and economic impacts of flooding, and inland wetlands can also be constructed to serve as a destination for stormwater runoff, given the appropriate ecological context and financial considerations.

A naturalized stormwater retention pond (City of Moncton) that can evolve to provide natural infrastructure benefits.
Photo ©Ducks Unlimited Canada. Used with permission.

CASE STUDY 2: WATER MANAGEMENT BENEFITS OF PRAIRIE POTHOLES IN THE SHEPARD SLOUGH COMPLEX, ALBERTA

This pilot project was designed to assess the value of benefits from 'prairie pothole' wetlands in the 'White Zone', an expanse of land covering approximately the lower third of Alberta and containing both the Bow River and South Saskatchewan River Basins. These are inland wetlands that do not typically form connections to streams and rivers when water volumes are at average levels (DUC, 2014), of special interest because they are scattered across an area where land use pressures have had a profound impact on the water storage capacity of wetlands. The largest proportion of the prairie potholes comprise the Shepard Slough complex, an area featuring more than 1,300 ha of natural wetlands capable of storing and purifying water, as well as the Shepard Constructed Wetland. This 230 ha natural asset receives, treats and discharges stormwater runoff from a catchment area of nearly 6,000 ha, and is capable of storing up to 27,000 m^3 of water per ha of that area for up to 72 days, up to a maximum storage volume of 7 million m^3.

As a result of the 2013 flooding in southern Alberta's Bow River and South Saskatchewan River basins, the province has sought to explore all options to reduce the risk of future flooding. The Shepard complex can provide flood or stormwater storage for 36.3 million m^3, which if replaced with engineered stormwater ponds would require investment of $338 million CDN to match. Avoiding wetland loss or restoring natural wetlands can provide a wider range of benefits at a lower cost. Wetlands restoration, too, prove to be far less costly than constructing artificial wetlands of the same size; general estimates are that the full cost for restoration of natural wetlands in the White Zone is as low as $10,000/ha, increasing to between $19,000 and $23,284/ha in areas closest to Calgary.

In the Shepard Slough complex, additional benefits have been sought from the use of wetlands to provide clean water, because 57 per cent of the prairie potholes are categorized as having medium to high water purification potential (Government of Alberta, 2011). Restored wetlands demonstrate lower costs for water purification than constructed wetlands or GI water treatment plants can achieve, and the loss of intact wetlands results in estimable annual losses of value for municipal water quality systems in this region of Alberta. The Shepard prairie potholes also show potential as carbon sinks (i.e., the White Zone's wetlands have captured over 160,000 T of CO_2-equivalent since the 1960s), as wildlife habitat, and as settings for scientific research and education. ES benefits for recreation have been given a high priority because tourism linked to the wetlands was found to generate $4.5 million CDN of revenue for the province at a low investment cost. Access and proximity to wetlands in the area also positively impacts property value, increasing the average worth of a house by $4,390 - $5,136 CDN.

Wetlands loss in the White Zone including Shepard Slough results in increased downstream flows for local waterways, due to the loss of water storage capacity provided by prairie potholes during heavy rainfall and riverine flood events. Stormwater infrastructure costs rise with the construction of more GI, which require ongoing maintenance and monitoring to provide an equivalent infrastructure outcome. In the absence of natural wetlands, water treatment for nonpoint-source contamination are higher for municipalities. Clean water may be unavailable to meet local demand at an acceptable cost for agricultural irrigation, and the costs of flood damage, unseeded losses in the spring from excess moisture, and crops lost to flood during fall harvesting all contribute to the increase in insurance costs for agricultural property owners especially. With the degradation of wetlands, residential and commercial property values may decline, owing to the diminished aesthetic qualities of natural landscapes and the decrease in wildlife habitat and recreational space. Decreased revenue from tourism can be expected, since so much of recreational and cultural life in the Bow and South Saskatchewan River basins is dependent on healthy ecosystems and biodiversity. The value of the additional ecosystem benefits provided by the Shepard Slough wetlands were identically recognized by the Government of Alberta and Ducks Unlimited, making a persuasive case for stopping wetlands drainage and ending residential, industrial and agricultural encroachment on intact wetlands in the area.

Sources: Government of Alberta (2011); DUC (2014).

Aerial view prairie potholes. Photo ©Ducks Unlimited Canada. Used with permission.

3.1.2 GI Alternatives

With limited ability to quantify NI's more complex and differentiated dimensions of value, municipalities have often favoured the implementation of single-purpose GI for flood mitigation. For example, engineered diversion channels offer a redirected route for excess stormwater, mitigating the risk of overland flooding and helping local streams and rivers to maintain manageable flows. Typically, diversion channels are built around developed urban or high-value centres to limit the extent of flood damage (Alberta Water Portal, n.d.). They are permanent GI designed to endure under demanding conditions, and so are associated with high initial costs related to construction and materials, as well as ongoing maintenance. A lack of adaptability is a principal weakness of large-scale GI.

Dams are concrete barriers built across streams and rivers to detain water within an engineered reservoir, providing floodwater storage while helping to control flow volumes. Prior to wet seasons, the operators of a dam will lower the level of water in the reservoir to allow for increased flow volume and precipitation. During flood events, the structure will hold water back before releasing it gradually into spillways when levels have become too high. Beyond the infrastructure outcome of flood control, the water stored by dams and reservoirs can provide additional benefits for water management when used for electricity generation or to supply municipalities during periods of increased demand. Importantly however, few major Canadian dams are designed as multi-purpose GI capable of mitigating the effects of both flooding and drought (BC Ministry of Environment, n.d.). Depending on their size, they remain a costly investment for the singular purpose of flood mitigation; the Glenmore Reservoir and Dam in Calgary, for example, was constructed in 1932 at a cost of $3.8 million, and nearly a century later it is possible for large dam projects to cost several billion dollars to construct (Alberta Water Portal, n.d.). Ongoing (2017-2020) upgrades and overhauls of the Glenmore Reservoir are being carried out at a cost of $82 million, including improvements to the steel gate and hoist system as well as the pedestrian bridge deck (City of Calgary, n.d.).

Berms and dikes are examples of engineered green infrastructure used for flood mitigation, though they are smaller and entail lower costs than diversion channels or dams. They prevent riverbank breaches and floodplain inundation by confining water to streams and rivers, but unlike GI flood control structures, they are only semi-permanent solutions because their life expectancy diminishes with each breach. Berms, levees and dikes identically require periodic upgrades to accommodate higher river flows, because their failure could result in considerable damage to property. As an example, Calgary's system of berms was constructed by Drumheller in the 1980s and has since proved beneficial during significant events such as the overland flooding in 2013. Recently the firm has requested $12-15 million from the province to ensure that the lateral berms can mitigate future floods, 30 years after initial construction (Alberta Water Portal, n.d.). Even when functioning as intended, berms and dikes can lead to stream instability and riverbank erosion, because by limiting the space for water to flow they increase its velocity. Like diversion channels and dams, berms and dikes encroach on natural floodplains and have significant impacts on functioning ecosystems at a watershed level, contributing directly to the loss of aquatic and riparian forest habitats.

CASE STUDY 3: PORTAGE DIVERSION, MANITOBA

Constructed between 1965 and 1970 at a cost of $20.5 billion CDN, the 29 km-long Portage Diversion diverts water from the Assiniboine River north into Lake Manitoba, using sets of gates that allow a portion of the river to flow into a concrete channel. In so doing, it redirects up to 25,000 cubic feet of water per second away from the city of Winnipeg and northern areas along the Red River. This provides flood protection to municipalities including Portage la Prairie, Cartier, St. Francis Xavier, Headingley, Woodlands and Macdonald. Combined with the Red River Floodway channel, the Portage Diversion is estimated to have provided communities with $7 billion in avoided damages from flooding, and has been required to operate in more than 30 of the years since its construction. During a major flood event in 2011, its flow capacity was temporarily increased to 34,000 cubic feet/second to prevent inundation of the natural floodplain north of the Assiniboine potentially as far as the Municipality of Morris. During the time since, about $6 million in repairs and upgrades have been completed on various sections of the diversion.

Source: Government of Manitoba (n.d.)

3.2 Additional Benefits of Wetlands

As natural assets, wetlands provide an infrastructure outcome comparable to GI used for flood mitigation such as diversion channels and dams with reservoirs, as well as green infrastructures including berms and dikes. What distinguishes them is that they provide additional benefits, many of which can be categorized as ecosystems services (ES) that humans depend on to support life, security and well-being. The value of the ES provided by wetlands is typically higher than for other NI types, because a large proportion of the natural asset value reported for most types of wetlands come from their additional water-related benefits, including water filtration and groundwater recharge, the regulation of climate and air quality, the preservation of ecosystems and habitat for diverse species, as well as benefits to recreation, culture and the economy. Wetlands also control pests and the spread of disease by supporting water cycling, as well as by regulating microbiota in their local ecosystems. They enable nutrient cycling (e.g., phosphorus and nitrogen) and help to form and transport biomass.

3.2.1 Water Supply and Quality

Inland wetlands have the potential to store water during times of drought, and replenish groundwater aquifers by directing rainwater into the ground. During dry years, wetlands discharge water in excess of that provided by precipitation, and so prove critical to maintaining the volume and flows of streams and rivers. Significant investment in engineered solutions would be required to replace the water provided by wetlands on natural floodplains. Water provisioning using GI such as dams and reservoirs will almost always entail higher costs than the conservation or restoration of natural wetlands. Ozment et al. (2015) observe that NI elements like wetlands can in fact improve the efficiency and longevity of dams by providing storage for sediment and effluents, which might otherwise accumulate in reservoirs or enter hydropower turbines. At the same time, wetlands vegetation can prevent silt and contaminants from entering the streams that supply freshwater to downstream residential and business centers. By acting as natural water filtration plants, regulating runoff and providing sinks for soil erosion, they serve many of the same functions as human-engineered water treatment facilities. Wetlands water, soil and vegetation absorb harmful fertilizers and pesticide runoff, as well as metals and industrial toxins at no cost; water treatment plants designed to provide an identical service may cost millions of dollars to operate and maintain (Statistics Canada, 2013). They also absorb, store and infiltrate stormwater and thus prevent the nonpoint source pollution of local water. In so doing, they complement municipal water treatment services.

3.2.2 Climate and Air Quality Regulation

Wetlands help to regulate local temperatures while sequestering carbon and pollution. They serve as ideal sinks for carbon storage, particularly in long-established peatlands and marshes. The bioretention capacity of wetlands allows them to directly absorb CO_2 emissions from the atmosphere, though this benefit is partly offset by newly-restored or constructed wetlands' status as significant sources of atmospheric methane. The infiltration capacity of wetlands assimilates particulate matter upstream and minimizes the amount of water entering water treatment facilities; this has the added benefit of reducing the downstream energy requirements to treat water, as well the GHG emissions associated with engineered solutions.

3.2.3 Biodiversity

Many of the plant species found in inland wetlands are unique to wetland ecosystems. This vegetation provides nesting materials and permanent habitat for insects, small mammals and nearly all of the world's species of waterfowl. Many other birds use wetlands to breed and feed as part of their migratory patterns. In Canada, much of the food supplied by wetlands is of a lower order on the food chain, but vital to the survival of non-humans – many birds, fish and reptiles depend upon the microscopic zooplankton, insect eggs and larvae found in low-lying surface water and soil. Small and large mammals also use wetland vegetation as a major source of food.

Photo ©Ducks Unlimited Canada. Used with permission.

CASE STUDY 4: CONSERVATION ACTIVITY AT BUTTERTUBS MARSH, NANAIMO, BRITISH COLUMBIA

Supported by the MNAI and the City of Nanaimo, efforts have been undertaken to assign financial value to the NI within Buttertubs Marsh, a human-engineered marsh that hosts the Buttertubs Marsh Conservation Area (BMCA) and bird sanctuary. Adjacent to the Millstone River and Nanaimo's city centre on the coast of Vancouver Island, the marsh is comprised of 55 ha of reclaimed floodplain capable of providing riverine water-flow regulation. An avoided-cost approach was used to assess the value of the flood and stormwater control benefits that would be lost with degradation or loss of the Buttertubs Marsh and the coastal wetlands on its floodplain. Hydrological modelling was carried out to quantify the water storage benefits of the Marsh for water drainage from the city, as well as the attenuation of flows achieved by the Millstone River when overland floodwaters drain into the Marsh. Taken together, these measures were believed to yield evidence of the resilience of the Marsh to escalating coastal flood and storm events.

The MNAI modelled development scenarios for land use changes in the Marsh – left intact, infilled with grass, and degraded for single-home residential development – to accurately reflect the current characteristics of the BMCA, and modelled flood events to demonstrate the flow attenuation capability of the Marsh. Across each scenario, the water storage provided by the Marsh resulted in significant peak flow attenuation before drainage into the Millstone River, as well a demonstrable advantage for water volume retention when compared to circumstances where the marsh vegetation was lost. The value of the present capacity of the East and West Marshes to absorb overbank flows from the Millstone during a historic 1 in 100-year flood event was calculated based on the storage volume between the normal water level and the maximum water level that they can contain without neighbourhood flooding or adverse effects on transportation infrastructure downstream; this storage benefit was valued at approximately $4.7 million dollars when compared to the estimate for replacement off-stream storage using green or grey alternatives. Under a climate change median and upper 90th percentile scenario, the financial value of floodwater storage increases to estimated values of $6.5 million and $8.2 million, respectively.

According to 2004-2015 and 2016-2021 Management Plans for the BMCA, Buttertubs Marsh is comprised of natural assets that yield benefits beyond what can be expected of GI solutions to the challenge of riverine flood- and stormwater storage. Among these are expansive recreation areas, as well as the educational opportunities associated with the landscape and wildlife ecosystems – university research, controlled public access and bird species viewing opportunities at the bird sanctuary. Across the Marsh there are also efforts to monitor, manage, and maintain water control structures by conducting hydrological studies, reviewing options to reduce outflow obstruction from beaver activities, removing beaver material from in front of marsh outlet debris grating. Elsewhere, there are benefits relating to wildlife protection, the control of invasive plant and animal species, maintaining the 'eco-gift' designation of the West Marsh, and the wetlands habitats and riparian zones along the Millstone River that provide habitat for rare species such as the Western Painted Turtle and the American Bittern.

Source: MNAI (2018b)

3.2.4 Recreation and Culture

Wetlands support cultural identity and heritage by fostering a sense of place and supporting human well-being through aesthetic experience and inspiration, especially for people with long-standing ties to the landscape. Wetlands are of significant historical and archaeological value to many cultures and religious communities around the world. They also have high recreational and cultural value for activities including hiking, fishing, bird watching, photography and hunting. Intact natural and restored wetlands provide an ideal context for scientific research in such areas as plant and animal biology, hydrology and sustainable water management, and convene experts to work together in interdisciplinary teams. As a basis for comparison, GI elements like dams can provide useful research and tourism-related benefits, but in ways that are limited depending on their design characteristics.

3.2.5 Economic Benefits

Wetlands contribute to stable insurance costs because they protect residential, commercial and agricultural property from the costs of loss resulting from flood events. There are instances where existing GI is inadequate to prevent overland flooding, as extreme precipitation can be difficult to plan for. Manitoba has implemented a so-called 'flood and compensate' program to address potential failures of the Portage Diversion, involving the deliberate, temporary diversion of riverine floodwater to nearby properties that would otherwise be used for productive activities such as livestock or crop farming. The arrangement provides compensation, for example, when a farmer allows the use of land he or she owns to be flooded when needed, including payment for the loss of agricultural products (Alberta Water Portal, n.d.). By providing upstream floodwater storage, intact riparian areas and wetlands on natural floodplains can help to minimize the costs of compensating people negatively impacted by such adaptive watershed management strategies. What is more, wetlands can be used as a source of food and natural products including stems, leaves, resins, and biomass crops (i.e., cattail) for commercial markets. Markets may exist for sequestered nutrients such as phosphorus, and there may be a potential to measure the value of wetlands for carbon offsets.

CASE STUDY 5: FLOOD COST MITIGATION IN THE CREDIT VALLEY AND LAUREL CREEK WATERSHEDS, SOUTHERN ONTARIO

A 2017 study completed by the Intact Centre on Climate Adaptation at the University of Waterloo makes the economic case for wetlands conservation to achieve the infrastructure outcome of flood prevention and cost mitigation. Using hydrological and hydraulic flood modeling for a rural site (communities in the Credit Valley watershed outside of Mississauga) and an urban centre (downtown Waterloo, in the Laurel Creek watershed), flood scenarios were designed to quantify the flood damage benefits of wetlands maintained in their natural state, as compared to circumstances where they are lost to agricultural land development. The report concludes that under conditions of severe rainfall events, preserved wetlands could reduce the costs of damage to local buildings by between 29 and 38 per cent across the two sites. These values represented a savings of $3.5 million CDN and $51.1 million CDN at the rural and urban pilot sites, respectively (Moudrak et al., 2017: 13, Table 5). Monitoring the cost outcomes of wetlands used to provide inland floodwater storage can prove critical to the sustainability of wetlands conservation efforts. The Intact Centre concluded that cost-benefit analyses carried out as part of a total watershed management approach should include the benefits of protecting specific wetlands, riparian areas and natural floodplains, as well as specific built infrastructure alternatives in order so that such information might be extrapolated to project sites elsewhere.

Source: Moudrak et al. (2017)

CASE STUDY 6: WET AGRICULTURE USING CONSTRUCTED WETLAND AT PELLY'S LAKE, MANITOBA

The Pelly's Lake wetland complex near Holland, Manitoba resides upstream of the Boyne River, a tributary of the Red River system. The wetlands in this area have been heavily drained and filled for agricultural use, turning a natural slough into marginal agriculture land. Pelly's Lake itself is a 121 ha wetland area, frequently flooded and overgrown with the aggressive species Typha (commonly called cattail), which thrives in waters overloaded with phosphorus. In 2015, a retention structure with reservoir was built to provide controlled water releases from the Pelly's Lake complex. During the summer, the gates are opened and the wetland is partially drained to a lower saturation level, providing ideal conditions for the cultivation of emergent plant cover. By the fall, the land has dried suitably for agricultural equipment to access the site and harvest the cattails. Harvesting the cattails produces multiple benefits including improved water retention within the wetland, since dead cattail debris has interfered with the wetland's ability to retain and filter water. By extension, its removal contributes to downstream flood attenuation. Cleaner water is achieved through enhanced capture of excess phosphorus and nitrogen, and improvements to air quality and carbon sequestration are supported. No less significantly, the engineered wetland provides critical wildlife habitat for a diversity of plants, songbirds and waterfowl species.

The unique value of Pelly Lake derives from the harvesting of cattails as a biomass crop, because they can be processed into fuel for bioenergy applications, used as compost or for livestock bedding. This counts as an important exemplar of the growth in 'wet agriculture', quite apart from the additional benefits achieved: flood control for local agricultural lands; carbon sequestration and phosphorus capture; the potential for offsets; river basin recharge, and habitat provision. From an economic perspective, the constructed Pelly Island wetland demonstrates "… the importance of geographic targeting to identify potential natural infrastructure development sites with high hydrologic and low agricultural value to minimize land acquisition costs (Moudrak et al., 2018: 21)." Researchers at the University of Saskatchewan would subsequently determine that the estimated internal rate of return (IRR) for this project, assuming a 20-year life cycle, is approximately 32 per cent, with the consequence that the Pelly wetland has a total value of $3.7 million for the flood reduction, water quality improvement, carbon sequestration and the agricultural products it provides.

Sources: Moudrak et al. (2018); Grosshans (2018).

3.3 Summary of Findings

	NI – Inland and Riparian Wetlands	GI Alternatives
	Intended Infrastructure Outcome	
Flood & Stormwater Control	➢ Prevent floods by regulating river flows ➢ Store and release overland floodwaters	➢ Dams – flood prevention and diversion ➢ Reservoirs – floodwater storage and drainage ➢ Diversion strategies – floodwater control ➢ Stormwater facilities – water storage, treatment and drainage
	Additional Benefits	
Clean Water Reduced Treatment Costs	➢ Improve water quality through sediment and chemical sequestering ➢ Purification carried out at lower cost ➢ Improved water quality for recreation, stock watering and agricultural crop applications	➢ Water treatment plants – water is treated for improved quality/purity by biological, chemical or physical processes
Sustainable Water Supply	➢ Assist with groundwater aquifer recharge	➢ Water catchment areas – water storage ➢ Water distribution systems – transport of water to end-users
Climate Adaptation	➢ Key element of adaptation strategies ➢ Localized temperature moderation	
Biodiversity	➢ Provide ecosystems and habitat allowing diverse species to thrive ➢ Pollination, ecosystem conditions favourable for fertilization of floral plants ➢ Soil formation and nutrient cycling	
Recreation and Culture	➢ Provide setting for scientific research, educational activities ➢ Sustainable recreational space for hiking, hunting and wildlife viewing ➢ Heritage and sense of place ➢ Aesthetic appreciation of nature	➢ Limited use for scientific research and educational activities
Other Economic Benefits	➢ Reduction in insurance costs ➢ Reduction in municipal infrastructure costs ➢ Reduced investment risks ➢ Commercial markets for natural products including stems and leaves; 'wet agriculture' for biomass crops (i.e., cattail) ➢ Markets for carbon and phosphorus ➢ Potential for carbon offsets	

3.4 Benefit Indicators of Flood Control Solutions

		Benefit Indicator	Metric	NI	GI
Water	**Flood Control**	Avoided cost of flood damage	$	●	●
	Storage	Storage of flood / storm water	M_3	●	●
	Treatment	Improvements to water quality	Other	●	●
	Aquifers	Recharge of aquifers	M_3	●	
Biodiversity	**Habitat**	Availability of species' functional habitat	ha	●	
	Wildlife	Diversity and number of species supported	#	●	
	Ecosystem Processes	Quantity and quality of nutrients cycled	Other	●	
	Land Formation	Rate of soil formation and sedimentation	Other	●	
Climate Change	**CO$_2$ Sequestration**	Sequestration of carbon dioxide	Tonnes	●	
	Climate Adaptation	Climate adaptation cost efficiency	$	●	
	Temperature	Improvements to localized air temperature	M_3	●	
Sociocultural	**Science & Education**	Support for scientific research	$	●	
	Recreation	Natural spaces for recreation	ha	●	
	Heritage	Spiritual / cultural / emotional health	Other	●	
	Aesthetics	Appreciation of natural landscapes	Other	●	
Economic	**Municipal Assets**	Long-term resilience	$	●	
	Insurance	Risk and cost reduction from hazards	$	●	●
	Commercial	Value of bioeconomy	$	●	

* This report provides a sample of benefit indicators and possible metrics for their evaluation, while acknowledging that there are various approaches for assessing the outcomes of NI and GI solutions.

○	Low
◐	Medium
●	High

Infrastructure Challenge

Coastal Resilience to Natural Hazards

Canada has 243,000 km of coastline when the North, West and East coasts are considered together, though their ecosystem characteristics vary considerably. Different regions are subject to different weather conditions and levels of water inundation, resulting in different infrastructure needs. Much of the infrastructure in coastal communities was implemented before climate change was recognized as an environmental issue. The effects of climate change do not impact all coastal regions equally; the isostatic increase in elevation of the Pacific coast will offset many of the effects of sea level rise (SLR), though the potential for flooding and storm surges will persist in much of coastal British Columbia (ICF, 2018). The Canadian North, as a basis for comparison, includes about 70 per cent of Canada's coastline but is sparsely populated (Lemmen and Warren, 2016); there, the loss of sea-ice coverage, permafrost thaw and coastal erosion can be expected to have lasting impacts on ecosystems in Inuit, First Nations and Métis communities. The integrity of coastlines in Atlantic Canada is imperiled by SLR, regional subsidence[4] and the loss of Northern Atlantic sea-ice, with the consequence that wave energy can erode exposed cliffs, glacial deposits, sand dunes, sand spits, barrier bars, marshes and other coastal features (Arlington Group et al., 2013: 35). No less significantly, land use changes can have lasting impacts on coastal ecosystems and risk undermining the absorptive capacity of shorelines. In the coming decades, climate-related challenges are expected to exacerbate existing vulnerabilities to natural hazards including flooding and storm surge events. In response, the federal government has devised funding policies such as the $75 million Coastal Restoration Fund, to support a mix of infrastructure solutions to improve coastal resilience.

4.1 – Coastal Flooding and Storm Surge Control Solutions

4.1.1 – Coastal Ecosystems

Coastal ecosystems are found where land meets the sea (UNEP, 2019), along shorelines and land formations such as estuaries, bays and barrier islands. They encompass diverse habitats including tidal wetlands and forests, eelgrass meadows and freshwater transition areas, as well as natural assets created by the interaction of wind, waves and sediment such as sand dunes and beaches. As elements of NI, these ecosystems are naturally resilient to gradual change, evolving in response to storms, SLR and changes in wave climate. But, with the accelerated pace of climate change, improving the resilience of coastal infrastructure to high-intensity flood and storm surge events becomes an ongoing challenge. NI used to protect shorelines requires careful planning and management, and can entail:

- Ecosystem revegetation;
- Stabilization of dunes;
- Maintenance of sediment supplies; and,
- Management of buffer and sacrificial zones.

Taken together, these measures are commonly called 'soft-armouring' approaches and are most appropriate for long-term use under low- to medium-intensity conditions. Engineered GI may be necessary to address coastal flooding and storm surge control in some situations, particularly in urban areas, but 'hard armouring' structures disrupt coastal processes and can worsen localized erosion patterns, leading to the degradation and loss of habitats and ecosystem services (Lemmen and Warren, 2016).

Coastal wetlands occur inland of ecosystems that begin offshore and move inland through estuaries and salt marshes (MA, 2005: 521). Their generally high level of saturation limits floodwater storage, since they either contain freshwater or are inundated with saltwater depending on tidal cycles. However, they can be herbaceous (marshes) or arboreal (swamps), and the vegetation they support can dissipate wave energy, reduce water velocity, flood depths and wave heights, as well as minimize net sediment loss during flood events (ICF, 2018: 10; Arkema et al., 2013). Eelgrass (seagrass) beds and meadows are richly distributed along Canada's Atlantic and Pacific coasts, stabilizing estuarine sediments and supporting the formation of the coastal marshes capable of wave attenuation. Sand dunes contribute to shoreline protection as both natural seawalls and erosional buffers, storing sand which is mobilized during storms and subsequently returned to the dunes by the tide (Atkinson et al, 2016: 57). Beaches provide a buffer zone of erodible material during storm events, dissipating wave and floodwater energy even after fully submerged. Wider beaches and beaches with higher berm elevations can provide targeted flood prevention and damage control

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[4] Subsidence here describes the gradual setting of Atlantic Canada's landmass, caused by the migration of an area of uplift that developed around the margins of the North American ice sheets, as well as by additional water loading on the seabed of the Gulf of St. Lawrence as global SLR has accelerated (Arlington Group et al., 2013: 9).

outcomes (ICF, 2018: 11). Combinations of NI elements along estuaries and coasts can yield benefits beyond those achieved individually; for example, combining a restored oyster bed with marsh vegetation can better dissipate wave energy than either approach by itself (ibid). Elements like pebbles and natural rock can be used in applications like beach nourishment that provide storm surge defense outcomes comparable to those associated with engineered GI such as groynes and seawalls.

CASE STUDY 7: BEACH NOURISHMENT ALONG THE ANSE-DE-SUD SHORELINE, PERCÉ, QUÉBEC

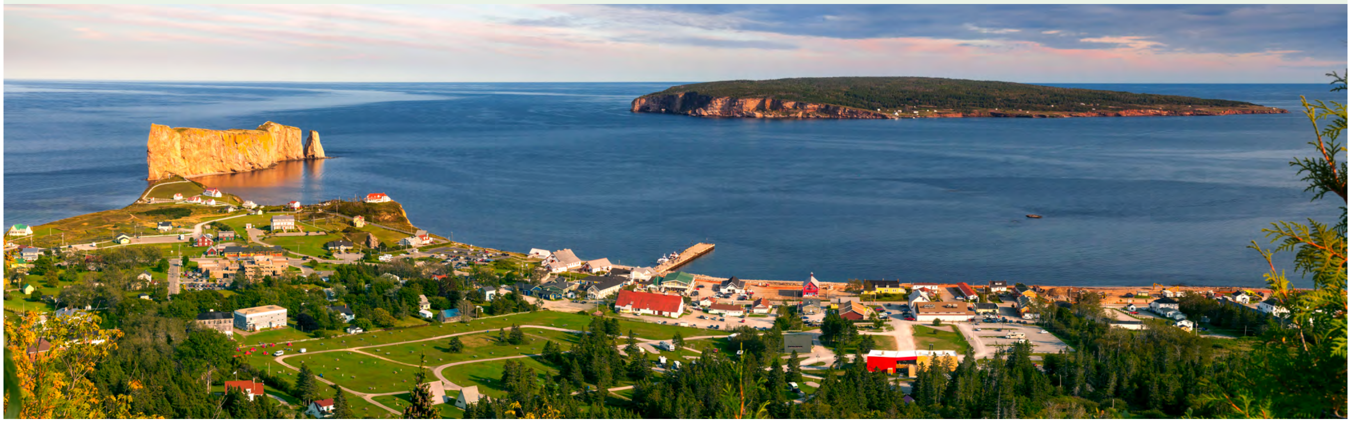
This coastal community near the tip of the Gaspé Peninsula has been impacted by SLR, changing storm patterns, rapid ice-melt and diminished ice cover on the Gulf of St. Lawrence (Circé et al., 2016). At present, the town's Anse du Sud shoreline segment is protected by a seawall supporting a seaside boardwalk, and a wharf surrounding a gravel beach. These waterfront assets are estimated to attract approximately 400,000 visitors to Percé every year. As part of a 2016 initiative of Natural Resources Canada to apply economic assessments to climate-adaptive infrastructure options, the climatology consultants Ouranos investigated alternative methods of protecting the existing shoreline from the effects of intensified erosion. The approaches to infrastructure development evaluated included the naturalized options of beach nourishment with and without groynes, as well as grey alternatives such as rebuilding and extending the existing seawall, constructing a rubblemound, or installing a riprap berm.

Though beach nourishment offers environmental enhancement, protection of recreational areas and hazard reduction benefits, it is not a permanent solution to shoreline erosion. In Percé and elsewhere, it requires regular monitoring and can be prohibitively expensive, depending on the proximity of a supply source of required materials. Authorities in Percé determined that replenishment of the shoreline beach with pebbles could provide net benefits of approximately $773 million over 50 years (discounted at a rate of 4 per cent) when compared to non-intervention, providing a buffer zone for wave attenuation and erosion control for the existing seawall. The projected loss of the wall and boardwalk during the next 50 years, on the other hand, could result in a loss of up to $705 million in tourism and commerce-related revenue for the entire Gaspésie region (Circé et al., 2016). $68 million would be the net gain achieved with a 2 per cent increase in tourism, based on projections of 35 000 overnight stays annually (ibid: 22). This option was judged to be the most cost-effective, producing tourism benefits and lower initial construction costs than further investment in GI, even though beach nourishment may incur high maintenance costs about every 12 years. Costs associated with air and noise pollution during beach replenishment would be generally low-impact compared to those associated with engineered adaptation solutions.

Building a new seawall would identically yield the benefits of wave attenuation, the protection of the economic value of tourism and business assets, and help to preserve the heritage value of the waterfront. With the addition of a deflector to better withstand high-intensity storm events, a new wall would represent nearly $400 million of value added over the next 50 years. Extending foreshore protection with elements like a rubblemound or riprap berm in front of the wall, would estimably detract from the available space for tourist traffic. The Environment Ministry of Quebec advised that in the absence of a newly-constructed berm, the height of the wall should be increased to meet the needs of future SLR, though Percé authorities rejected this option because the integrity of the seawall would remain the same while obstructing sight of the beach. A hybrid solution combining beach nourishment with groynes was rejected in spite of a suggested $753 million return on investment over 50 years, owing to high construction costs and evidence that groynes would prove inadequate to meet the need for sedimentary drift required for the maintenance of the beach.

Local authorities elected to implement beach nourishment with natural elements as the most cost-effective means of protecting against erosion of the existing infrastructure, allowing them to protect local tourism and preserve the heritage value of the waterfront.

Source: Circé et al. (2016).



Aerial view of Percé, Québec

4.1.2 GI Alternatives

Globally, it is estimated that coastal flooding could displace hundreds of millions of people in the current century, with the annual costs for adaptation measures such as new dike construction and maintenance costing up to $25–270 billion USD per year by 2,100 (Wong et al., 2014). Engineered assets are designed for a high level of dependability and to ensure the resilience of high-value developments. In Canadian communities, the most common approaches to providing the infrastructure outcome of coastal flooding and storm-surge defense have been retreat from areas at risk and the use of hard-armour GI. The most costly coastal defense strategy is relocation, which involves removing homes and cottages from an eroding coastline or flood-susceptible area. Planned setbacks which prohibit coastal development are more cost-effective measures, and must increase in response to SLR and other climate change effects or else the protection provided by GI solutions will deteriorate over time (Arlington Group et al., 2015). Alternatively, developers in coastal communities can commit to less costly strategies like adaptive elevation planning, and the wet- and dry-floodproofing of buildings.

Dikes are the primary green infrastructure elements providing defense from flooding and storm surges – linear, compacted earthfill structures with a flatter gradient on the seaward side and a steeper gradient on the landward side intended to protect low-lying shores from inundation by floodwaters. They provide some assurance of land stability and therefore tend to promote shoreline development (Arlington Group et al., 2015). Other engineered elements supporting coastal resilience include berms and levees, floodgates, groynes and breakwaters. Many GI elements such as seawalls and floodwalls require deep foundations and may cause localized erosion. They are expensive to construct and maintain, can be unsightly and restrict shoreline access for people (Atkinson et al., 2016; Arlington Group et al., 2015).

Coastal resilience infrastructure in Canada has begun to incorporate hybrid solutions that combine vegetation with GI to protect coastal communities against higher-intensity natural and climate-related hazards. Examples are engineered and vegetated dunes, as well as living shorelines. Constructed dunes can be used to defend against coastal flooding and erosion by dissipating wave energy and storing sediment; at the same time, they provide ES benefits including public and recreational access to beaches and habitat for species at risk (Lemmen and Warren, 2016). Living shorelines have typically been designed and implemented using a collaborative approach, working with several levels of government, riparian property owners, nature trust organizations and other stakeholders (Arlington Group et al., 2015). They employ a combination of techniques using groynes or breakwaters with sand, marsh grasses and other natural materials to maintain natural shoreline dynamics while minimizing erosion impacts. The benefits associated with living shorelines can include improved water quality (by the capture of sediments and filtering of pollution), greater abundance and diversity of aquatic species, and improved connectivity between aquatic and upland ecosystems (Lemmen and Warren, 2016; Arlington Group et al., 2015).

4.2 Additional Benefits of Coastal Ecosystems

The use of natural assets to protect coastal communities from flooding and storm surge events can be accomplished using NI, GI or combinations of the two; flood damage mitigation and storm surge defense often require complementary interventions, as suggested by the emergence of hybrid applications. NI solutions are nevertheless distinguished by providing communities with additional benefits, such as adaptation to the long-term effects of SLR and coastal erosion, diverse species habitats, and social and economic benefits that depend on aquatic ecosystems such as agriculture and aquaculture production as well maritime industries (fisheries and trousim).

4.2.1 Adaptation to SLR and Coastal Erosion

It is a common misconception that coastal erosion is a gradual process; in fact, storms with elevated water levels and wave action are the most significant agents of coastline change (Atkinson et al., 2016: 36). Adaptation nevertheless entails long-term planning, especially in the context of increasing SLR, and key aspects of coastal erosion can worsen over time. A study completed for the Government of British Columbia (*c.f.,* Ausenco Sandwell, 2011) influentially recommended SLR planning for increases of 50 cm to the year 2050, 1 m to the year 2100 and 2 m to the year 2200, consistent with SLR projections used in the United States and Europe. Where sediment supply and biological productivity are sufficient, NI elements like salt marshes can accrete at rates sufficient to keep pace with SLR, developing thick sequences of organic-rich sediment or peat (Lemmen and Warren, 2016). In general, coastal ecosystems help to dissipate wave and tidal energy, and their root systems act as a trap for sediments, facilitating land formation and reducing erosion. They help to reverse the loss of intertidal land area (the so-called 'coastal squeeze' effect) because in the absence of a barrier to migration, if a wetland or salt marsh is losing area on its seaward side, it is likely claiming area on its landward side (Arlington Group et al, 2015). This is an example of the adaptability that NI routinely demonstrates in comparison to GI, which entails permanent outlays that typically require the continuous input of resources.

4.2.2 Biodiversity

Estuaries and coastal wetlands including marshland are fertile ecosystems for the protection of biological diversity. One of the most important processes supported is the mixing of nutrients from upstream as well as from tidal sources, forming a salinity gradient and helping to maintain freshwater flows into local point-sources (MA, 2005). Salt marshes are the most commonly-restored type of coastal wetland, though the space requirements for restoration in areas with existing development or high development potential may be accompanied by high acquisition costs (Arlington Group et al., 2015).

Wetland construction may not be feasible in many areas due to unsuitable bathymetric conditions or excessive erosion (Arlington Group et al., 2015), though restoration is possible in most places. When adding vegetation, matching local varieties and ensuring location-appropriate designs and materials helps to ensure that wetlands protection projects provide the greatest benefits while avoiding unintended negative consequences, such as blocking species movement or introducing invasive species (Webb, 2018).

Vegetation suited to saltwater such as eelgrass serves to help with nutrient cycling and the transport of biomass offshore. Eelgrass meadows reduce water flow velocity near the sediment surface and promote the settling of organic and inorganic matter, which initiates sulfate reduction and maintains the sulfur cycle; the sulfur cycle is important for the stimulation of plant growth (DFO, n.d.). Further, the anaerobic (i.e., low-oxygen) conditions in the root systems also promote the growth of nitrogen-fixing bacteria, which enhance primary production at the most fundamental level of the food chain (ibid).

Equally as important, coastal ecosystems provide essential habitat and improved water quality for fish and shellfish, mollusks and crustaceans; most commercial fish will breed and nurse their young in coastal marshes and estuaries before departing offshore. Coastal rainforests are rich ecosystems for bird life, breeding and migration. In the example of the Anse de Sud section of Percé, a preserved shoreline with an adequate mix of pebbles, rocks and vegetation was used to support the spawning of capelin, fish that are a food source for larger species of fish, marine mammals and birds including the gannet. Sand dunes and beach complexes also host a range of distinctive mammalian habitats and plant communities, while providing essential nesting grounds for waterfowl and songbirds.

CASE STUDY 8: SALT MARSH RESTORATION IN THE NORTHUMBERLAND STRAIT AND BAY OF FUNDY, NOVA SCOTIA

The Northumberland Strait Coastal Restoration Project is a five-year initiative with the objective of restoring a critical salt marsh habitat covering an area of 15 hectares, advanced collaboratively by the Clean Foundation, the Mi'kmaw Conservation Group and the Confederacy of Mainland Mi'kmaq. The Clean Foundation notes the loss of about 64 per cent of coastal wetlands in the Maritimes as a consequence of land development, the restriction of tidal flow, changes to the terrestrial landscape and increased mixing with freshwater flows.In 2019, the Government of Canada invested $1.2 million over four years to support restoration efforts in the Northumberland Strait and the Bay of Fundy, and its investment is expected to create jobs for the local Indigenous community.

The participation of Indigenous communities is particularly important as the project proponents incorporate traditional knowledge and seek to advance the community's ownership of restoration efforts. The project also incorporates partnerships with academic institutions, local communities and U.S.-based conservancy organizations.

The Clean Foundation is developing an online repository in collaboration with the Coastal and Ocean Information Network Atlantic to facilitate information-sharing and improve capacity-building. Protocols developed through the project are also expected to be used and made available to support future restoration efforts.

Sources: Clean Foundation (2019); DFO (2019).

Participants documenting species observations in a saltmarsh during a 2018 Bioblitz. Photo ©Clean Foundation. Used with permission.

4.2.3 Maritime Industries

SLR and increased erosion from flooding and extreme weather events irremediably impact the built environment that supports coastal agricultural and aquaculture industries such as ports, wharves, piers and fish plants. Higher water temperatures and diminished water quality can result in the loss of aquatic wildlife that people rely upon for food, altering the growth and development of fish as well as their migration, spawning and feeding patterns. NI elements including vegetated shorelines and marshlands can support new capture fisheries, and enable the cultivation of aquaculture and wild foods. Coastal ecosystems can also figure as important sources of products derived from nature, including biochemical and medicinal resources, timber, fibres and resins with estimable commercial value.

4.2.4 Recreation and Culture

Global temperature rise will mean longer seasons for tourist visits and recreation in coastal communities; at the same time, the decreases in water quality and increase in algae blooms that are associated with warmer weather may detract from the aesthetic and recreational qualities of beaches and shorelines (Lemmen and Warren, 2016). Coastal ecosystems contribute to the overall attractiveness of the landscape, while helping to moderate temperature and air quality. Comparable recreational and cultural benefits are achieved with GI initiatives like Vancouver’s Stanley Park seawall, which couples structural protection against erosion with the characteristics of a naturalized recreation corridor. Constructed dunes provide protection from erosion but may conflict with recreational and tourism purposes where the concern is maintaining ‘sea views’; they have a large footprint, require long-term management and may lack the appropriate materials to be replenished locally (Arlington Group et al., 2015). Some GI and hybrid initiatives may not prove adaptable to all coastal landscapes, where NI is considerably more flexible in its potential applications. Many of these promote the aesthetic and cultural value of nature itself, and therefore contribute to the sustainability and attractiveness of recreation opportunities in coastal communities.

4.2.5 Economic Benefits

Given the cost implications, it is anticipated that greater use of hybrid infrastructure elements such as living shorelines with cumulative benefits must be implemented in most Canadian coastal communities, in order to prevent the need for relocation and as a means of coordinating with planned retreat strategies. For GI, the initial capital costs and ongoing maintenance costs of levees, groynes and various barrier types will mean limiting their uptake to selected locations, such as densely populated areas, areas with high natural or cultural importance, and high value infrastructure (Arlington Group et al., 2015). This helps to control insurance costs and protect property values. The report for BC’s Ministry of Environment (Ausenco Sandwell, 2011) calculated the full costs of establishing flood protection for seismic stabilization of the diking system and the SLR projected to take place by 2100 on the Pacific Coast, including land acquisition, engineering, environmental design, relocation of utilities and upgrading of pump stations. The total estimated cost was nearly $9.5 billion, including a 50 per cent contingency factor. The estimated cost to address SLR alone, including associated infrastructure and property acquisition, was estimated at almost $3 billion. There are opportunities for the use of coastal ecosystems and their contained NI elements to offset or avoid such costs in Canada’s coastal regions. Beyond meeting the targeted infrastructure outcome of flooding and storm surge control, NI can be lauded for its ability to mitigate the long-term deterioration of GI and the significant economic costs associated with it.

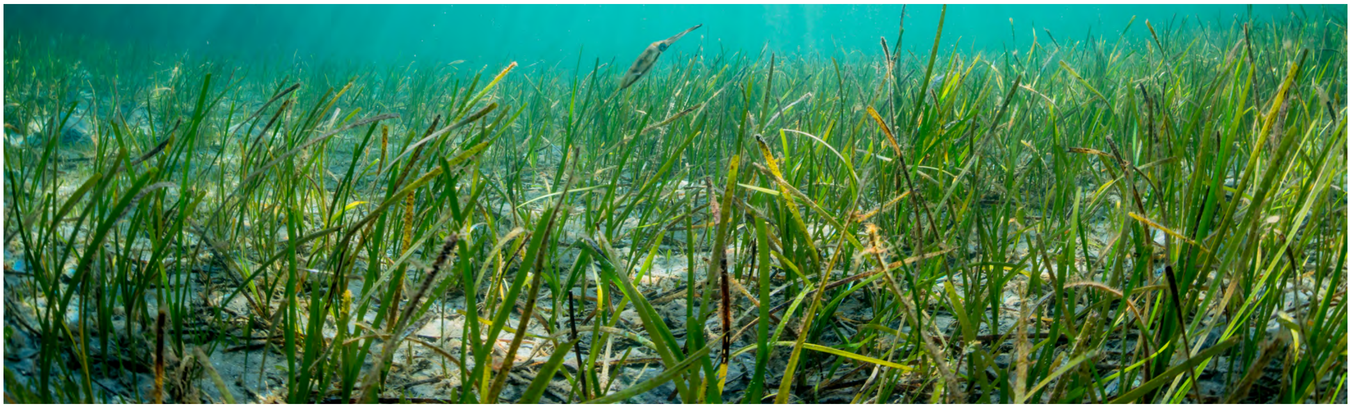


Photo of eelgrass bed

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CASE STUDY 9: EELGRASS REPLENISHMENT IN THE SALISH SEA, BRITISH COLUMBIA

The Salish Sea Marine Survival Project has been studying the nearshore ecosystem health of the region, which it notes is an important habitat for about 3,000 marine species, including several species of salmon that have experienced a tenfold decline in number (Salish Sea Marine Survival Project 2019). Changes to water temperature, acidity, algae growth and the decline of prey fish among other factors, have resulted in negative impacts on the region's marine biodiversity. Through a bottom-up approach, the project aims to restore the region's ecosystem and enhance juvenile salmon habitat in particular. It does this through the monitoring and restoration of critical habitat,which in 2017 resulted in eelgrass recovery in 23 sites throughout the Salish Sea.

SeaChange Marine Conservation Society, a non-profit organization based in British Columbia, has been working, "… to reverse the continual degradation of marine ecosystems through restoration, rehabilitation and/or conservation activities" (SeaChange 2018), and is one of the leading organizations supporting such nearshore restoration efforts in the Salish Sea. In 2018, the organization received $1.3 million over five years under the Government of Canada's Coastal Restoration Fund to support its nearshore debris removal and restoration efforts in four regions of the Salish Sea (DFO 2018).

The organization's conservation and transplanting of eelgrass across an area of near 3km^2 since 2014 is particularly noteworthy (*c.f.*, Schmidt, et al. 2018, 81-3). In 2016, the organization was able to complete eleven eelgrass transplants in the region over an area of near 900m^2, creating new meadows where the others had been degraded due to human activity (i.e., logging, mining, ocean floor disturbances), culminating in a 65 per cent success rate. These efforts also included debris removal, addressing contamination related issues, surveys and monitoring. Significant community involvement also contributed to the success of the projects, with extensive public outreach, including engagement with Indigenous communities.

Sources: Salish Sea Marine Survival Project (2019); SeaChange (2018); DFO (2018); Schmidt et al. (2018).

4.3 Summary of Findings

	NI – Coastal Ecosystems	GI Alternatives
	Intended Infrastructure Outcome	
Flood & Storm Surge Control	➢ Ecosystem vegetation including trees, marsh vegetation and eelgrass contribute to tide and wave attenuation; protect against storm surges and flooding during extreme weather events ➢ Coastal vegetation areas including tree lines, shorelines and wetlands act as storm surge buffer zones, contribute to flood and stormwater storage and discharge ➢ Sand dunes contribute sedimentation to form coastal marshes, which serve to mitigate flooding ➢ Beaches dissipate wave energy even after submerged; provide a sacrificial zone during high-intensity storm events ➢ Protect public infrastructure	➢ Levees provide tide and wave attenuation; protect against low-elevation flooding ➢ Groynes and riprap defense structure (armour stone) comprise flood barriers ➢ Seawalls and storm barriers prevent inundation ➢ GI elements protect public infrastructure ➢ Hybrid infrastructure proffers protection against events in combination with NI
	Additional Benefits	
Adaptation to SLR & Coastal Erosion	➢ Vegetation improves sedimentation and stabilizes beaches and sand dunes ➢ Natural dunes return sediment and recover lost intertidal area in the after-math of storm events ➢ Beaches provide an erosional buffer and sacrificial zone against SLR ➢ Rainforests and wetlands located along estuaries and coasts are home to many high conservation priority species ➢ Nutrient cycling – coastal wetlands provide infiltration, increasing water quality for wildlife; eelgrass supports the sulphur cycle and primary production	➢ Hard armouring strategies stop erosion; can be difficult and costly to adapt or remove ➢ Engineered dunes add sedimentation and minimize coastal squeeze effect ➢ GI contributes to habitat loss for a wide range of species ➢ Hybrid applications including living shore-lines accommodate wildlife habitat
Biodiversity	➢ Rainforests and wetlands located along estuaries and coasts are home to many high conservation priority species ➢ Nutrient cycling – coastal wetlands provide infiltration, increasing water quality for wildlife; eelgrass supports the sulphur cycle and primary production	➢ Hybrid applications including living shorelines accommodate wildlife habitat
Maritime Industries	➢ Capture fisheries, aquaculture and wild foods ➢ Biochemical and medicinal resources ➢ Timber and other wood products – the trees in coastal forests provide wood, fibres and resins	
Recreation and Culture	➢ Aesthetic improvement ➢ Local cultural identity and heritage ➢ Protection of economic value of tourism and business assets	➢ Aesthetic improvement with appropriate planning ➢ Protection of economic value of tourism and business assets ➢ Sense of safety may promote development, recreation and cultural programming
Other Economic Benefits	➢ Protection of property value ➢ Reductions in insurance costs	➢ Protection of property value ➢ Reduction in insurance costs

4.4 Benefit Indicators of Coastal Flood and Storm Surge Solutions

		Benefit Indicator	Metric	NI	GI
Water	**Flood Control**	Avoided cost of flood damage	$	●	●
	Storm Surge Defence	Defence against storm water surge	Other	●	●
	SLR Resilience	Protection of public / private assets	$	●	●
	Coastal Erosion	Preservation of intertidal areas	Ha	●	●
Biodiversity	**Habitat**	Availability of species' functional habitat	Ha	●	
	Wildlife	Diversity and number of species supported	#	●	
	Ecosystem Processes	Quantity and quality of nutrients cycled	Other	●	
	Land Formation	Rate of soil formation and sedimentation	Other	●	
Maritime Ind.	**Agriculture**	Value of agricultural products	$	●	
	Fishing	Value of fish products	$	●	
	Natural Products	Value of other natural resources	$	●	
Sociocultural	**Recreation**	Natural spaces for recreation	Ha	●	◐
	Heritage	Spiritual / cultural / emotional health	Other	●	◐
	Aesthetics	Appreciation of natural landscapes	Other	●	
Economic	**Municipal Assets**	Long-term resilience	$	●	●
	Insurance	Risk and cost reduction	$	●	●
	Commercial	Value of tourism and business assets	$	●	●
	Real Estate	Improvements to real estate value / resale	$	●	◐

* This report provides a sample of benefit indicators and possible metrics for their evaluation, while acknowledging that there are various approaches for assessing the outcomes of NI and GI solutions.

○ Low
◐ Medium
● High

5

Infrastructure Challenge

Thermal Impacts of The Built Environment

Impermeable GI surfaces (e.g., concrete, asphalt and steel) combined with a lack of greenery in municipal landscapes result in increased heat absorption and emittance, or what is known as the UHI effect. In the US, for example, the UHI effect has resulted in an increase to average temperatures in cities of up to 3°C, correlating with a 4 per cent greater demand for electricity for every °C of temperature rise (*c.f.,* Gago et al., 2013: 751; EPA, 2008: 13). A number of factors relating specifically to engineered infrastructure contribute directly to the UHI effect:

- Impermeable surfaces have lower albedo ratings (i.e., the ability of a surface to reflect radiation), leading to the absorption of the sun's radiation by infrastructure elements like roadways, bridges and parking lots;
- Land-use planning has increased the prevalence of spaces within the built environment (i.e., so-called 'urban heat canyons' between densely-spaced buildings) that demonstrate significant heat retention coupled with inadequate air flow;
- Low ratios of green coverage as compared to impermeable surface (including the surface areas of buildings) and the area of visible sky;
- The generally low degree of water permeability associated with pavement coverage;
- Concentrated dimensions of pollution resulting from human activity.

In addition to their role in temperature increase, elements of the built environment concentrate and intensify air and noise pollution in restricted spaces, with negative consequences on human health and urban wildlife. Though there are aspects of GI that can be redesigned to reduce these effects, natural assets like urban forests provide more cost-efficient and effective solutions to the UHI challenge, precisely because the degradation of natural assets has gone hand-in-hand with the growth in GI.

5.1 UHI Control Solutions

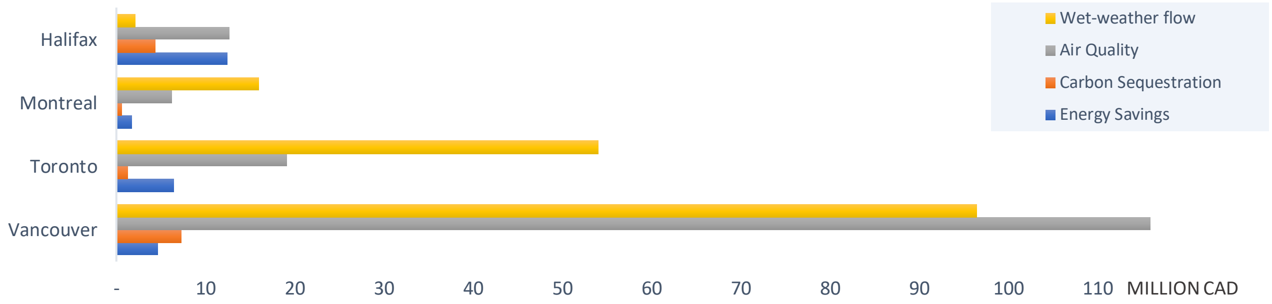
5.1.1 Urban Forests

Urban forests are groups of trees with placement along streets and on rooftops, in parks and woodlands within the municipal boundaries of towns and cities. Together with other elements of urban greenery including grasses, shrubs, gardens and flowerbeds, local tree coverage is managed by authorities to provide people with estimable health and social benefits while storing and filtering stormwater runoff, decreasing electricity demand and energy use, as well as reducing carbon emissions and airborne pollutants. Review of a robust literature in the area also demonstrates the many benefits of urban forests that are difficult to value in quantitative terms, including enhancement of the aesthetic qualities of city landscapes, improved mental health for people, and expanded natural habitats for wildlife.

One of the principal benefits of urban trees is their effect on temperature; they provide the targeted infrastructure outcome of mitigating the UHI effect, where urban spaces consistently reach higher temperatures than rural areas due to elements of the built environment. As a consequence, urban forest strategies can occupy a central role among infrastructure options that enhance the value of natural assets and offer high return on investment. A study of managed trees and vegetation in California's South Coast Air Basin suggests the potential for an overall cooling effect of 2-8 degrees (Taha, 1997), while an evaluation of the climate mitigation ability of parks In Vancouver documents a cooling effect of 5°C when compared to neighbouring areas (Spronken-Smith and Oke, 2010). The cooling effect of a single tree on localized atmospheric temperatures has been estimated as equivalent to that of 10 residential air conditioners continuously operating (Alexander and McDonald 2014, 3). In-line with findings that urban forests can help to offset the UHI effect, it is unsurprising that they in turn reduce energy consumption during peak periods of electricity demand. In this respect, considerations relating to the characteristics of the local climate, the tree species used as well as their placement are important factors (Gago et al., 2013: 751-2). There is also consensus about the relatively greater cooling value of trees placed to the west of built environments, because they provide shade from sunlight for the duration of when the sun's energy is most intense (Hotte et al., 2015: 24). According to a 2014 study, Toronto's urban forests are estimated to have reduced natural gas use by 750 billion BTUs and electricity use by 41 GWH, resulting in annual savings of over $6 million CDN, or about $0.63 per tree (Alexander and McDonald, 2014).

The value of such climate adaptation benefits is estimated below in Figure 5.1, suggesting that economies of scale are achievable with investment in urban forestry (though certain complementary benefit indicators are excluded).

Figure 5.1: Climate Adaptation Benefits of Urban Forests in Major Canadian Municipalities



Data source: Alexander and DePratto (2014) and Alaxander and McDonald (2014).

5.1.2 GI Alternatives

In most urban environments, pavement covers as much as 40 per cent of the physical landscape (Santamouris, 2013; Qin, 2015). Most commonly made of concrete and asphalt material with a low albedo rating and low permeability, paved surfaces contribute significantly to the UHI effect. 'Cool pavements' are a GI solution that can raise solar radiation reflectivity, as well as allow for water to permeate and cool the pavement material. Construction industry analyses estimate that improving the solar reflectivity of pavement by 10 per cent can yield decreases in surface temperature of 4°C, and surrounding air temperature can be reduced by about half a degree centigrade if pavement reflectivity is increased by 25 per cent (EPA, 2008: Ch. 5: 10). Recent evidence has also suggested that incorporating more reflective materials into GI elements (e.g., light-colored aggregate, chip seal, high near-infrared paint, and white concrete components) can moderate the maximum surface temperature reached by surface materials by between 4 and 20°C during intense summer heat (Qin, 2015).[5] A sample of the costs associated with such innovative materials is summarized in Table 5.1.

In 2015, a pilot study was undertaken in Los Angeles where an asphalt-based, light grey coating was applied to pavement at the Balboa Sports Complex; the reported temperature was measured at 10 degrees Fahrenheit cooler relative to neighbouring black asphalt coverage (EPA, 2018). This prompted the uptake of the same technology across 15 other locations at a cost of $40,000 per square mile in order to realize comparable temperature regulating effects (Picazo, 2018). What is more, pavements can be made to absorb more water and achieve temperature reductions of between 5 and 15°C with the use of porous and permeable designs (Qin, 2015: 451), or when used alongside elements of NI.

Table 5.1: Estimated Cost of Innovative Engineered Materials

Engineered Solutions	USD/sq. ft
Hot mix asphalt with light aggregate	$0.10–$1.50
Portland cement, plain-jointed	$0.30–$4.50
Porous asphalt	$2.00–$2.50
Pervious concrete	$5.00–$6.25
Paving blocks	$5.00–$10.00
Grass/gravel pavers	$1.50–$5.75
Chip seals with light aggregate	$0.10–$0.15
Microsurfacing	$0.35–$0.65
Ultra-thin whitetopping	$1.50–$6.50

Source: Adapted from EPA (2008): Ch. 5, p. 25

Gago et al. (2013: 755) compile evidence of the considerable potential for urban planning strategies to increase air flow (e.g., reducing high-rise development to facilitate the vertical and horizontal transport of air pollutants, positioning buildings in-line with primary wind current direction, and the strategic use of urban geometry in architectural planning). They conclude that dense outlays of high-rise structures coupled with narrow streets reduce airflow, trap pollutants and contribute to the formation of heat canyons.

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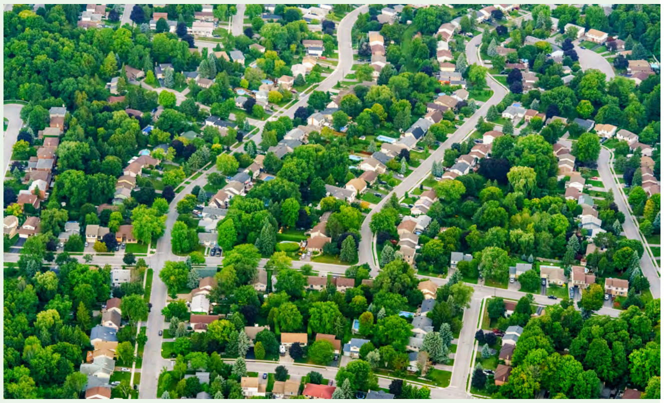
[5] An unintended consequence of the use of reflective pavements is a possible rise in ambient temperatures in surrounding buildings, though the net benefits for temperature regulation are likely to offset this effect.

CASE STUDY 10: URBAN FOREST STRATEGY IN TORONTO, ONTARIO

Toronto's urban forests are comprised of 10 million trees from over 100 different species, covering a quarter of the city. Over the course of a decade (2012-2022), the city plans to expand this coverage to 40 per cent, as a means of improving the overall liveability of local communities and neighbourhoods. Considered together, the city's urban forests are estimated to have a value of about $7 billion, with an annual functional value of near $30 million derived from the environmental benefits associated with the removal of air pollution, energy savings from UHI mitigation and carbon sequestration. Though canopy expansion is subject to constraints from the emergence of invasive forest insects and diseases, the city's 40 per cent target is judged to be achievable but will require stringent tree conservation bylaws and improved long-term planning.

At the core the municipal tree strategy is the move to optimize the conditions for planting (i.e., below and above ground), in order to support mature growth, resilience and diversity of tree species. Authorities employ several technologies to assess opportunities to increase its forest canopy, and notable among these is the use of big data to monitor tree coverage, support maintenance efforts and improve city planning. A collaborative arrangement with the USDA Forest Service has resulted in the cost-effective aerial imaging of 10,000 geo-referenced points to assess trends over time. In addition, the city has shifted from its historical approach of reactive maintenance to a more systematic assessment of upkeep in order to reduce the risk of tree mortality partially supported by improved geospatial data. Finally, big data is also identified as a useful tool to ensure that growth can be integrated into improved planning that supports the city's 40 per cent tree canopy target.



Aerial view of a neighbourhood in Toronto, Ontario

Source: City of Toronto (2013)

CASE STUDY 11: CANOPY ACTION PLAN IN MONTRÉAL, QUÉBEC

Montreal's Canopy Action Plan is a comprehensive municipal strategy designed to increase the city's tree coverage from about 20 per cent to 25 per cent by 2025. As part of the preparation for the city's 375th anniversary, the non-profit organization Jour de la Terre set an ambitious goal to plant 375 000 trees in the Greater Montreal area over the course of three years. The project was expected to increase urban tree canopy coverage by 3 per cent, a significant contribution to the city's urban forest target. Two years into its implementation, the initiative has resulted in the planting of over 226,000 trees.

The project is jointly supported by the provincial government, the David Suzuki Foundation, la Fondation Cowboys Frignants, and the Compagnie Cabot-Champagne. The cost of participating in the project is only $10 per tree, and it allows private citizens and companies to self identify on the project website, creating a promotional medium. The project also receives public and private sector support, including from Caisse de Dépôt, an institutional investor, which has provided funding for 250,000 of the required trees.

In addition to supporting the city's urban forestry strategy, the Canopy Action Plan seeks to improve biodiversity, increase ecosystem connectivity, and facilitate the creation and maintenance of the Montreal Green Belt. Tree selection has been supported by scientific assessment for the appropriate species, and advice has been sought to achieve suitable dimensions of ecosystem integration and resilience. In addition, stakeholders able to invite larger-scale participation have been able to submit project ideas for review by a scientific committee that meets twice a year.

Urban forest in Montréal, Québec

Sources: Hanes (2017); Jour de la Terre (n.d.)

5.2 Additional Benefits of Urban Forests

Urban trees facilitate evapotranspiration, provide shade, and help to cool the air; in so doing, they support climate mitigation and adaptation efforts while reducing energy demand during peak, high-temperature periods. The additional benefits of urban trees include carbon sequestration and pollution control, improved human health and well-being, as well as expanded recreational space and wildlife habitats (CUFN, 2015). What is more, the cumulative effect of trees with other urban green spaces provides important stormwater management benefits, by retaining excess precipitation during heavy rain events, reducing runoff and helping to limit erosion by stabilizing soil (Moudrak et. al., 2018; Green Infrastructure Ontario Coalition, 2016). These outcomes enhance the intangible aesthetic qualities of Canadian towns and cities, while providing the tangible economic benefit of increased property value. GI solutions reliant on technological innovation have sought to offset the UHI effect with varying measures of success, but do not offer comparable additional benefits. NI in this area proves capable of protecting engineered GI, and in many instances provides a means of offsetting the environmental impacts of GI.

5.2.1 Climate Mitigation and Adaptation

Gago et al. (2013: 753) suggest that the use of reflective materials in building construction can result in energy savings of up to 70 per cent. Improving the reflective characteristics of pavement albedo globally (i.e., from 35 to 39 per cent) could result in GHG reduction savings of approximately $400 billion USD (EPA 2008, Ch. 5: 23).

Urban forests in the US are estimated to store 700 Mt of carbon, sequestering about 23 Mt per year (Hotte et al., 2015: 28-9). Using a social cost of carbon of $40 tonne,[6] the economic value of such carbon storage can be estimated at about $28 billion CDN while sequestering about $920 million of carbon per year. Proceeding on the premise that Canadian towns and cities have approximately 27 per cent tree canopy cover, this equates to carbon storage of approximately 34Mt and 2.5 Mt of sequestration attributable to urban trees (Pasher et al., 2014). Using the same social cost of carbon value, the economic value of the stored carbon in Canadian urban forests is $1.36 billion, with carbon sequestered valued at approximately $100 million annually. Though the economic value of urban forests for community-based climate adaptation will vary based on local conditions and characteristics of the built environment, their benefits are reported consistently across local projects.

5.2.2 Pollution Reduction

According to a recent Health Canada (2017) study, air pollution contributes to 14,400 deaths per year. The primary human health effects of air pollution are traceable to emissions of carbon monoxide, nitrogen dioxide, particulate matter and ground-level ozone, and Canadians in cities demonstrate higher rates of exposure to these pollutants than rural residents. Urban forests contribute to the improvement of overall air quality by removing airborne effluents, depending on factors such as tree coverage area, seasonal variability and local environmental conditions (Hotte et al., 2015: 25). The same changes to the built environment that address temperature rise can also directly improve air quality. Altering pavement colour to boost albedo ratings results in a corresponding reduction in ozone concentration by 7 per cent (*c.f.,* Taha, 1997). Urban forests provide a wider range and value of pollution reduction benefits, however, and can be positioned as a key target for NI investment.

A study of 86 Canadian municipalities found that trees remove over 16 Mt of air pollution annually, leading to human health benefits valued at $227 million CDN (Nowak et al., 2017). The same study suggests that these benefits corresponded with the prevention of 30 human deaths and the avoidance of 22,000 incidents of acute respiratory illness for the baseline year of 2010 (ibid). The urban forest canopy removes about one-quarter of industrial air pollution within the Greater Toronto Area's boundaries, representing a value of about $19 million (or $1.87/tree) of pollution offset (Alexander and McDonald, 2014). The proportion of pollution reduction attributed to urban forests has the greatest value in relation to ozone and particulate matter reduction (Nowak et al., 2017), depending on such factors as total area of tree coverage, variations in precipitation and the concentration of pollutants. Total value estimations for urban trees and variations across selected municipalities are depicted in Figures 5.2 and 5.3, respectively.

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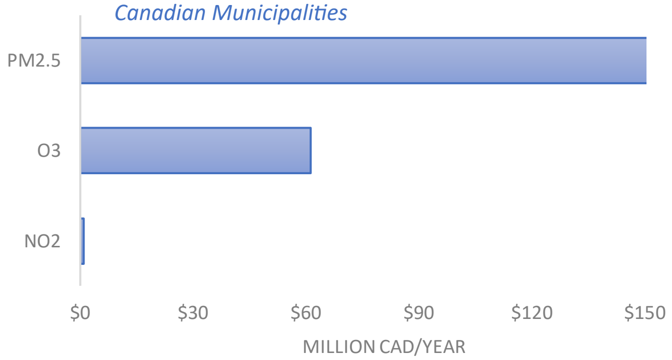
[6] This approximates the 2016 ECCC metric on the social cost of carbon, which can be much higher and is expected to increase in future years.

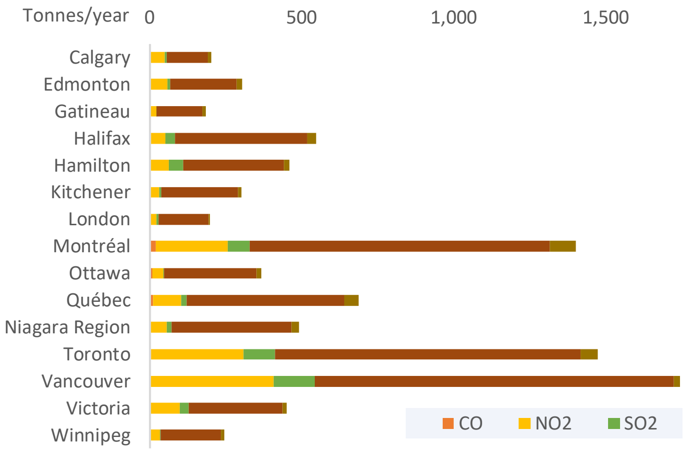
Figure 5.2: Total Value of Pollution Removed by Trees in Major Canadian Municipalities



Source: Data reported in Nowak et al. (2018).

Not insignificantly, urban forests can also help to alleviate noise pollution from human activity, particularly in travel/transit corridors and near industrial operations (Hotte et al., 2015: 28).

Figure 5.3: Air Pollution Removed by Trees by Municipality



Source: Data reported in Nowak et al. (2018).

5.2.3 Flood Prevention

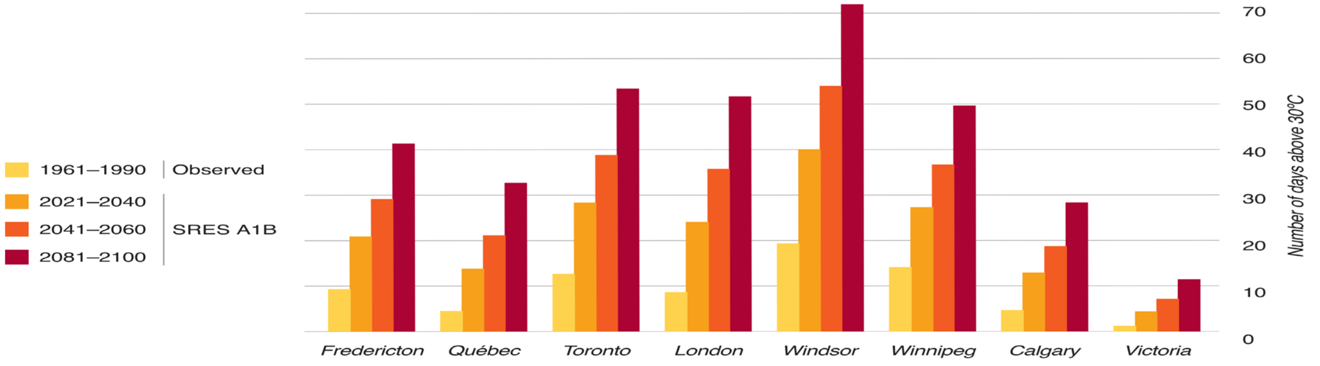
Stormwater runoff is collected and processed using municipal water management systems comprised of GI elements, which can become overloaded during intense rainfall events. Urban forests can play a crucial role in regulating rainwater flows, improving water retention and releasing runoff gradually via tree root systems. The magnitude of flood-mitigation benefits achieved will inevitably depend on tree species selection, local environmental conditions and overall design of municipal urban forest strategies (Hotte et al., 2015: 24), though trees are capable of contributing to the retention of stormwater and the related cycling of waste particulates (Gago et al., 2013: 753).

5.2.4 Human Health and Well-Being

The benefits of urban tree coverage for human health have become increasingly important in the context of global climate change, where additional stress on the health of populations vulnerable to heat-related illness can be anticipated, including people with chronic conditions, children and older adults (Graham et. al., 2016; Kabisch et. al., 2017). A study examining the relationship between tree canopy coverage and ambulatory calls during extreme heat events in Toronto suggests that even a modest increase in urban tree coverage (from <5% to >5%) correlates closely with a reduction in heat-related emergency calls of up to 80 per cent (Graham et al., 2016). 93 heat-related deaths in Montreal during a protracted heat wave in 2018 served to focus attention on city temperature as a public health problem (The Weather Network, 2018).

As a basis for comparison, according to the CDC (2004), heat exposure was the cause of 8,015 deaths in the United States over the course of two decades (1979 to 1999), a number that exceeded the combined total fatalities resulting from hurricanes, tornados, floods, lightning and earthquakes.

Figure 5.4: Number of Extreme Hot Days in Selected Cities



Source: Health Canada (2011)

There are additional health benefits provided by urban trees, as the public spaces they occupy are commonly used for recreation and physical activity. Further, there is evidence that the presence of trees where people live and work supports psychological and spiritual well-being. A study conducted in Vancouver, for example, points to a strong association between urban green environments and positive birthing experiences for women (Hystad et al., 2014). During working years, people given a view of natural spaces have reported fewer sick days, lower absenteeism and occupational stress levels, and expressed preferences for a view of large trees over manicured greenery (Hotte et al., 2015: 40).

5.2.5 Biodiversity

Urban forests can help to mitigate ecosystem fragmentation, as well as reverse some of the more deleterious effects of urban development on plant and animal habitats. The habitat-supporting benefits of urban forests will depend in important respects on variations in overall ecosystem connectivity, the diversity and maturity of plant life, and the extent of urban density (Hotte et al., 2015: 27). Trees represent something of a unique natural asset, insofar as their use is often directed to offset the negative impacts of GI. The urban agricultural landscape, from this perspective, is also noteworthy for its role in supporting human nutrition needs while supporting biodiversity through habitat creation for insects and pollinators.

5.2.6 Economic Benefits

Urban forests increase in value over time as the canopy matures (Hotte et al., 2015), and increase the value of municipal assets and private property in their proximity. Considered as a landscape amenity, Vancouver's network of street trees has an estimated worth of one half-billion dollars, and Edmonton's are valued at nearly $1 billion CDN (Farr, 2004: 38). In Toronto, where the municipal urban forest initiative is valued at over $16 billion CDN, each dollar invested in the maintenance of the tree coverage returns nearly $3.20 in benefits to city residents (Alexander and McDonald, 2014). With respect to residential and commercial property values, buildings adjacent to parkland or green spaces demonstrate values of up to one-fifth higher, and the presence of trees leads to an increase in value of approximately 7 per cent in most residential housing markets while improving resale potential (Hotte et al., 2015: 47-8).

Photo of a heron in Vancouver, British Columbia

5.3 Summary of Findings

	NI – Urban Forests	GI Alternatives
Intended Infrastructure Outcome		
UHI Mitigation	➢ Urban forests help to significantly mitigate the UHI effect	➢ Innovative GI materials reduce the contribution of the built environment to the UHI effect
Additional Benefits		
Climate Mitigation & Adaptation	➢ Trees store and sequester carbon pollution through their lifetime ➢ The cooling benefits of evapotranspiration and shade provides by trees reduce energy demand during peak periods	➢ Innovative GI materials marginally improve the albedo effect of the build environment, reducing energy demand
Pollution Reduction	➢ Urban forests and other vegetation help to remove air pollutants ➢ Tree canopy coverage helps to mitigate noise pollution	
Flood Prevention	➢ Diversion of rainwater runoff, reducing demand on municipal water treatment	➢ Permeable GI materials reduce rainwater runoff, reducing demand on municipal water treatment
Human Health & Well-Being	➢ Mitigating UHI effects reduce heat related illnesses, especially in vulnerable populations ➢ Access to green spaces provide recreational opportunities that contribute to physical and mental health ➢ Exposure to urban forests can reduce mortality and morbidity	
Biodiversity	➢ Green spaces create habitant for urban wildlife, supporting nesting, feeding and habitat for migratory species	
Economic Benefits	➢ Urban green spaces increase property value and resale potential	

5.4 Benefit Indicators of Urban Heat Island Control Infrastructure Solutions

		Benefit Indicator	Metric	NI	GI
Climate Change	Temperature	Improvements to ambient air temperature	°C	●	◐
	CO$_2$ Sequestration	Sequestration of carbon dioxide	Tonnes	●	
	Climate Resiliency	Climate adaptation cost efficiency	$	●	○
	Energy Use	Reduction in energy demand	GWH/BTU	●	
Pollution	Air Pollution	Reduction in air pollutants	Tonnes	●	
	Road Salt Use	Avoidance of increased salinity of water	PPM	◐	
	Noise Pollution	Reduction in anthropogenic noise	dB	◐	
Water	Water Pollution	Improvements to water quality	Other	●	
	Ground Water	Ground water recharge	M_3	●	○
	Flood	Attenuation of flooding	$	●	
Human Health	Physical Health	Heat stress, mortality and health insurance	Other	●	○
	Mental Health	Improvements to human well-being	Other	●	
	Recreational	Improvements to physical health	Other	●	○
Biodiversity	Habitat Availability	Availability of species' functional habitat	ha	●	
	Habitat Connectivity	Connectivity of green spaces	Other	●	
	Wildlife	Diversity and number of species supported	#	●	
Economic	Commercial	Value of tourism and business assets	$	●	○
	Agriculture	Local food production	Other	●	
	Real Estate	Improvements to real estate value / resale	$	●	○

* This report provides a sample of benefit indicators and possible metrics for their evaluation, while acknowledging that there are various approaches for assessing the outcomes of NI and GI solutions.

○ Low
◐ Medium
● High

Concluding Remarks

Under the broad category of green infrastructure, NI is comprised of existing, restored or enhanced combinations of vegetation and associated biology, land and water, and ecological processes that generate infrastructure outcomes (ICF, 2018). This report has documented case studies where NI was used or assessed for its potential to provide the sought-after infrastructure outcomes of riverine flood and stormwater storage, coastal flood and storm surge defense, and UHI effect mitigation. It has also taken stock of GI alternatives in these areas, and concluded that NI projects can be cost-effective and viable replacements for (or complements to) engineered solutions. In many instances, NI elements can protect existing built infrastructure; elsewhere, they can help to offset some of the more damaging environmental impacts of GI.

What distinguishes NI from GI is that it provides additional benefits to Canadian communities; many of these benefits are valuable ES, and still others yield identifiable co-benefits supporting the biodiversity of unique ecosystems. When compared to engineered assets designed for singular purposes, NI can be managed to maximize several objectives. Canada's wetlands, for example, reduce the need for engineered flood control infrastructure while providing a range of additional benefits for overall watershed management. Coastal ecosystems provide benefits for resilience to natural hazards including flooding and storm surges, while supporting culture, recreation and maritime industries in coastal communities. Urban forests help to mitigate the increased temperatures in towns and cities, while providing important benefits for climate adaptation, human health and well-being, as well as essential habitat for wildlife.

Where the benefits provided by NI can be assessed for their sociocultural and economic value, its elements should be properly understood as natural assets. The benefits and value of natural assets are important considerations for local land-use planning and infrastructure investment decisions. There are government funding sources to support the development, maintenance and enhancement of NI projects; in some communities, development cost charges may be able to support the preservation and rehabilitation of natural assets (MNAI, 2018c). Superior knowledge and transparency of measurable costs and benefits on a case-by-case basis is necessary for advancing NI solutions to infrastructure challenges (ICF, 2018: 35; WBCSD, 2015). With decision makers coming to understand the full range of benefits associated with nature-based solutions, the wider adoption of NI can help Canada to address its current infrastructure needs and prepare for emerging environmental challenges.

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