Best Practices and Resources on Climate Resilient Natural Infrastructure



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Executive Summary

Natural infrastructure practices have the potential to play a critical role in making coastal, riverine, rural, and urban communities more climate resilient. The purpose of this research report is to summarize the current state of practice, including existing projects, programs, strategies, co-benefits, best practices, key resources, knowledge gaps, implementation challenges, and lessons learned. Research was conducted through a literature review and a series of interviews with experts across the natural infrastructure field, including landscape architects, engineers, and city planners. This report is intended to aid local, provincial, territorial, and federal decision makers with designing, implementing, or investing in natural infrastructure solutions.

In the context of this report, **natural infrastructure** refers to existing, restored, or enhanced combinations of vegetation and associated biology, land, and water, and their naturally occurring ecological processes that generate infrastructure outcomes such as preventing and mitigating floods, erosion and landslides, mitigating effects of extreme heat, and purifying groundwater.

This is distinct from **green infrastructure**, which refers to any environmentally based infrastructure.

Natural infrastructure in the context of this report focusses on four key climate hazards[1]:

- Coastal storms and flooding
- Riverine flooding
- Urban and rural stormwater (overland flooding)
- Urban heat islands

Natural infrastructure options can be specifically designed to address these types of hazards. Because natural infrastructure options typically evolve naturally over time, there is also an opportunity to consider designing natural infrastructure for projected extremes and hazard conditions under future climate scenarios rather than under current climate conditions.

Natural infrastructure solutions or a hybrid approach are usually more cost-effective than grey infrastructure approaches. This is due in part to the variety of economic, environmental, and social co-benefits they provide—such as improving, purifying, and decontaminating water, air, and soils; creating recreational green spaces; improving the quality of human health and wellbeing; and enhancing biodiversity and ecosystem services.

However, a number of knowledge gaps and implementation challenges have limited the adoption and implementation of natural infrastructure to date. These include:

- Limited institutional capacity, especially at the local level, to develop and train staff in practices and processes that are unknown or unfamiliar
- Limited number of qualified experts with technical knowledge and skill to design, implement, and maintain natural infrastructure
- Limited awareness of natural infrastructure and its benefits across all stakeholders

[1] Note that while this report focuses on mitigation of climate hazards as the main impetus and goal for implementing natural infrastructure, natural infrastructure can also be employed to reap a variety of benefits, such as providing fresh water, improving recreational opportunities, and fostering biodiversity. These and other benefits are discussed further in Chapter 3: Business Case for Natural Infrastructure Investments.

- Limited location-specific data necessary for natural infrastructure design and evaluation
- Limited awareness of opportunities among decision-makers at federal, provincial, territorial, and local levels
- Policy and regulatory barriers that tend to favour grey infrastructure
- Gentrification of neighbourhoods that benefit from natural infrastructure investments
- Institutional and technical limitations regarding maintaining natural infrastructure
- Lack of capacity within municipal decision-making entities to assess natural infrastructure options
- Lack of existing lines of communication between ecologists and engineers

A number of lessons learned have emerged from the implementation of natural infrastructure projects in Canada and other jurisdictions. The following actions and considerations can help overcome the barriers described above and create successful natural infrastructure projects and initiatives:

- Identify a champion to lead and promote natural infrastructure efforts
- Develop an interdisciplinary team to design and implement natural infrastructure projects
- Train and educate professionals and community members to increase awareness and technical skills
- Focus on community leadership, goals, and values, including those of Indigenous Peoples, to ensure participatory visioning and design of projects
- Develop regulatory and financial incentives to support natural infrastructure options
- Employ natural infrastructure-proactive criteria in funding opportunities, such as the Integrated Bilateral Agreements under the Investing in Canada Plan
- Consider long-term changes in climate

Natural Infrastructure Application Definitions

Bank vegetation and seeding: Stabilize soil and the riverbank to prevent erosion while increasing habitat and the aesthetic quality of the area (FEMA, 2017).

Beaches: In a storm event, beaches (including fine sand, coarse sand, and cobbles) initially act as a volume of erodible material. Once the beach is submerged during a storm, the beach still serves to dissipate wave energy. Wider beaches and beaches with higher berm elevations provide more protection to upland infrastructure (Webb, 2018).

Bioretention pond: Bioretention ponds are designed to collect and hold excess water and allow slow filtration back into the soil, recharging groundwater supplies (American Society of Landscape Architects, 2018).

Bioswale: Bioswales are long, narrow depressions or channels designed with absorbent soils or other substrates, and planted with deep-rooted vegetation. They provide a way to filter, retain, and route excess stormwater away from where it is not wanted. They are particularly suitable along streets and parking lots (EPA, 2014a).

Dunes: Sand dunes provide protective benefits during storm events by eliminating or reducing storm surge flooding and wave action behind them (Webb, 2018).

Flood setbacks: Setbacks are used to shield development from exposure to hazards. Setback standards set minimum distances at which structures must be positioned (or set back) from river channels and coastal shorelines. (FEMA, 2017).

Floodplain preservation: The most efficient strategy for natural riverine flood protection is conserving the natural floodplain. This option involves preserving existing natural ecosystems that are already serving to absorb and otherwise attenuate floods (Sabine Dietz, personal communication, May 18, 2018).

Green roof: Roofs covered with growing media and vegetation capture rainfall, where it can be absorbed by root systems or retained for evapotranspiration later. U.S. EPA research has shown such roof systems are economically effective in urban areas where property costs and stormwater management costs are high (EPA, 2014a).

Hybrid solutions: Nature-based features are most effective at mitigating hazards under low- to moderate-intensity events. Combining nature-based approaches with grey infrastructure may enhance the resilience of both the infrastructure and the ecosystem to higher intensity events (Webb, 2018).

In-stream structures: Engineered riffles, boulder terraces, sills, vanes, and other in-stream structures can divert flow to prevent erosion (FEMA, 2017).

Living shoreline: This approach uses coastal ecosystems to provide stabilizing ecosystem services (Ecology Action Centre, Undated). Note that the "living shoreline" umbrella may include other strategies that involve preserving, restoring, and/or creating coastal ecosystems.

Maritime forests: Maritime forest refers to an upland coastal forest of trees and shrubs, not mangroves or marshes. Maritime forests are effective at reducing wave heights and the inland extent of flooding (Webb, 2018).

Rainwater harvesting: A system that collects and stores rainwater from a roof that would otherwise be lost to runoff and diverted to storm drains and streams (EPA, 2014a).

Rain garden: Rain gardens (i.e., bioretention or bioinfiltration cells) are shallow, vegetated basins that collect and absorb runoff from rooftops, sidewalks, and streets. They mimic natural hydrology by absorbing and retaining water. Rain gardens are versatile features that can be installed in almost any unpaved space (EPA, 2014a).

Reefs: Reefs possess some capacity to reduce wave energy. They do not contribute substantially to reductions in storm surge, but can contribute to changes in the mean water level due to wave breaking (Webb, 2018).

Relief channels: Constructing additional channels to increase flood conveyance capacity while enhancing habitat (FEMA, 2017).

Restoration of inland wetlands: An important strategy for riverine flood mitigation due to the ability of wetlands to collect and hold floodwaters, then gradually release it. Wetlands can absorb floods and regulate water flows (Kumar, 2017). Inland wetlands can also be created in areas in need of flood protection, given the appropriate ecological context and considerations.

Saltwater marshes: Saltwater marshes provide many benefits during storm and non-storm conditions. Depending on the water level, marsh vegetation can be effective at dissipating wave energy, reducing water velocity, reducing flood depths in the marsh, reducing wave heights, reducing the extent of flooding, and minimizing net sediment loss (Webb, 2018).

Two-stage channels: An upper channel provides flood conveyance and a low-flow channel provides habitat and improved sediment transport (FEMA, 2017).

Urban trees: Trees provide natural water filtration. In addition, during heavy rain events, trees can reduce and slow stormwater by intercepting precipitation in their roots, leaves, and branches, thereby reducing and slowing stormwater runoff and helping to limit erosion by stabilizing soil. Tree canopies also provide shade, reducing the urban heat island effect (EPA, 2014a).

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Chapter 1: Introduction

There is growing interest across Canada, as well as around the world, in using natural infrastructure to help communities become more resilient to extreme events and reduce the risk of climate hazards. Natural infrastructure uses natural ecosystems and other naturalized solutions that collectively provide society with a multitude of economic, environmental, and social benefits (Green Infrastructure Ontario Coalition, 2016a). Natural infrastructure provides flexible solutions for enhancing resilience in a changing climate in a variety of settings (e.g., coastal, riverine, urban) and applications (The Chicago Metropolitan Agency for Planning, 2016).

Despite these potential benefits and a recent increase in popularity, the implementation of natural infrastructure has been limited in Canada and elsewhere. Although there are several examples of success stories at the local scale (e.g., the asset management strategy adopted by the Town of Gibsons, BC), uncertainty regarding performance and cost-effectiveness and the absence of political support remain key barriers to widespread implementation (Canadian Institute for Environmental Law and Policy, 2011).

Climate change is affecting communities and regions in many ways, from compounding the urban heat island effect to increasing inland and coastal flooding risk (EPA, 2018a). Similarly, sea level rise and heavy storms can result in erosion and flooding of sensitive ecosystems, threatening existing natural habitats.

Natural infrastructure can play a key role in increasing resilience to the impacts of climate change and extreme events. Many natural infrastructure strategies have the ability to physically stabilize landscapes, provide buffers against hazards, absorb water, and create cooler ambient temperatures. For example, tree roots hold soil in place, preventing erosion (FEMA, 2017). Dunes, reefs, and tree walls protect landscapes against high winds and storm surges (Webb, 2018). Permeable surfaces and plants have a high capacity to take in, hold, and slowly release water, preventing flooding (EPA, 2018b). Green roofs and tree canopies cool their surrounding environment, mitigating the effects of extreme heat events (EPA, 2008). Beyond these ecosystem adaptation benefits, natural infrastructure can provide local environmental and social benefits, such as reduced air pollution and expanded recreation areas (Terton, 2017).

This report provides infrastructure decision makers and practitioners with a compilation of best practices in the design and application of natural infrastructure, information on social and economic benefits, and promising solutions for overcoming barriers to implementation. The research used to develop this report involved reviews of existing literature as well as interviews with experts in the field of natural infrastructure.

Key Terms

Within this report, "natural infrastructure" is the prevailing term used to describe existing, restored, or enhanced combinations of vegetation and associated biology, land and water, and naturally occurring ecological processes that generate infrastructure outcomes such as preventing and mitigating floods, erosion, and landslides; mitigating effects of extreme heat; and purifying groundwater. Natural infrastructure uses natural ecosystems and materials (such as trees, sand, stone, etc.) to produce ecosystem service outcomes and contribute to climate resilience. These ecosystems and materials can be existing natural features or human-made and constructed.

The field of natural infrastructure at large uses several terms to describe this practice: "natural infrastructure," "green infrastructure," and "low-impact development" are often used interchangeably and are not universally defined.

- **Green infrastructure** is sometimes used to refer to natural infrastructure, although it is also used more broadly for things such as rain gardens or even water meters and energy-efficient equipment (Allen, 2014).
- **Low-impact development (LID)** is also associated with natural infrastructure, often in reference to environmentally and hydrologically functional landscapes that mimic natural hydrologic functions (Coffman, 2000).
- **Hybrid solutions** are a result of nature-based approaches that are combined with grey infrastructure to enhance the resilience of both the infrastructure and the surrounding ecosystem to higher intensity events.

Natural infrastructure relies more on existing and/or restorable natural landscape components such as natural floodplains, wetlands, and forests to provide an array of economic, social, and environmental benefits (Association of State Wetland Managers, 2018). Green infrastructure and LID are most often used in urban and developed areas and involve a more engineered solution: examples include bioswales, permeable pavement, and green roofs. In Canada, there are additional variations: the Government of Canada has included clean energy in its definition of green infrastructure, and uses the term "living green infrastructure" for the more common definition of natural infrastructure (Municipal Natural Assets Initiative, 2017).

In contrast, built or "grey" infrastructure refers to traditional (or traditionally constructed) infrastructure, such as wastewater treatment plants, seawalls, pipes, and levees. Grey infrastructure is traditionally the most common option in addressing the climate hazards discussed in this report. Although significant expertise exists on how to design, build, and maintain grey infrastructure, it is less able to adapt to changing conditions such as increases in extreme precipitation events, and has a limited lifespan (Sutton-Grier, 2015). There is also growing recognition that hybrid solutions, incorporating both natural and grey infrastructure, will be needed to address future climate conditions.

Chapter 2: Opportunities for Natural Infrastructure Solutions

This chapter provides background information, examples, and best practices in natural infrastructure design and applications for addressing four prominent climate hazards:

1. Coastal storms and flooding
2. Riverine flooding
3. Urban and rural stormwater (overland flooding)
4. Urban heat islands

Figure 1 from the United Nations Environment Programme (UNEP)'s *Green Infrastructure Guide for Water Management,* provides a summary of many of the green and natural infrastructure solutions for coastal storms and flooding, riverine flooding, and urban and rural stormwater described in this chapter (United Nations Environment Programme, 2014).

Water management issue (Primary service to be provided)		Green Infrastructure solution	Location				Corresponding Grey Infrastructure solution (at the primary service level)
			Watershed	Floodplain	Urban	Coastal	
Water supply regulation (incl. drought mitigation)		Re/afforestation and forest conservation	■				Dams and groundwater pumping Water distribution systems
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Water harvesting*	■	■	■		
		Green spaces (bioretention and infiltration)			■		
		Permeable pavements*			■		
Water quality regulation	Water purification	Re/afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (bioretention and infiltration)			■		
		Permeable pavements*			■		
	Erosion control	Re/afforestation and forest conservation	■				Reinforcement of slopes
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
	Biological control	Re/afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
	Water temperature control	Re/afforestation and forest conservation	■				Dams
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (shading of water ways)			■		
Moderation of extreme events (floods)	Riverine flood control	Re/afforestation and forest conservation	■				Dams and levees
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Establishing flood bypasses		■			
	Urban stormwater runoff	Green roofs			■		Urban stormwater infrastructure
		Green spaces (bioretention and infiltration)			■		
		Water harvesting*	■	■	■		
		Permeable pavements*			■		
	Coastal flood (storm) control	Protecting/restoring mangroves, coastal marshes and dunes				■	Sea walls
		Protecting/restoring reefs (coral/oyster)				■	

Figure 1. Summary Table of Natural and Green Infrastructure Solutions from the UNEP's *Green Infrastructure Guide for Water Management* (United Nations Environment Programme, 2014)

Coastal Storms and Flooding

Higher global temperatures lead to rising sea levels and more frequent and intense coastal storms. Given that Canada has an extensive coastline with many small and a few large communities, where valuable economic activities and culturally significant resources are located, coastal storms and flooding are of great concern. Coastal impacts will vary across the country depending on geography and population density (Government of Canada, 2016). Canada has three distinct coastal regions: East Coast, North Coast, and West Coast. Some coastal regions will be subject to greater rates of temporary and permanent inundation and erosion, while others may experience little impact from sea level rise due to increasing land elevation through glacial isostatic adjustment (Government of Canada, 2016).

For example, on the West Coast in British Columbia, vertical land movement will reduce the effect of global sea level rise. However, storm surges and flooding still pose a significant risk to coastal BC. The North Coast has experienced some of Canada's most rapid rates of climate change to date, exacerbating existing vulnerabilities (such as coastal erosion) of the small, remote Indigenous populations that primarily reside there (McClearn, 2018). In addition, sea-ice melt and its consequences are a serious concern for this region. On the East Coast, ocean acidification, impacts of sea level rise on coastal erosion and storm surges, and sea-ice coverage are prominent concerns (Government of Canada, 2016). The appropriate natural infrastructure solutions will therefore vary by coastal region and local conditions.

A range of natural infrastructure strategies can be applied in a variety of locations and contexts to mitigate coastal climate risks. These strategies can improve community resilience to climate hazards and risks (e.g., by stabilizing soils and attenuating waves), while providing co-benefits such as increased habitat and beautification. Natural infrastructure can also support local coastal adaptation to sea level rise (DG Blair, personal communication, May 1, 2018 referencing (Lamont, Readshaw, Robinson, & St-Germain, 2014)).

The following sections provide more details and case study examples on natural infrastructure practices for reducing the risks associated with coastal storms and flooding.

Opportunities for climate risk mitigation

Approaches to enhancing coastal resilience via natural infrastructure can range from ecosystem restoration (e.g., living shorelines) to hybrid approaches (e.g., fortified dunes) to localized approaches (e.g., managed retreat and replacement). Common types of nature-based coastal resilience strategies include (Webb, 2018):

- **Saltwater marshes:** Saltwater marshes provide many benefits during storms as well as under non-storm conditions. Depending on the water level, marsh vegetation can be effective at dissipating wave energy, reducing water velocity, reducing flood depths in the marsh, reducing wave heights, reducing the extent of flooding, and minimizing net sediment loss.
- **Maritime forests:** Maritime forest refers to an upland coastal forest of trees and shrubs, as opposed to mangroves or marshes. Maritime forests are effective at reducing wave heights and the inland extent of flooding.
- **Reefs:** Reefs possess some capacity to reduce wave energy. Reefs do not contribute substantially to reductions in storm surge, but they can contribute to changes in the mean water level due to wave breaking.

- **Beaches:** In a storm event, beaches (including fine sand, coarse sand, and cobbles) initially act as a volume of erodible material. Once the beach is submerged during a storm, the beach still serves to dissipate wave energy. Wider beaches and beaches with higher berm elevations provide more protection to upland infrastructure.
- **Dunes:** Sand dunes provide protective benefits during storm events by eliminating or reducing storm surge flooding and wave action behind them.
- **Combinations of solutions:** Appropriate combinations of nature-based solutions may yield benefits beyond those achieved individually. For example, combining a restored oyster bed with marsh vegetation can have a greater impact on reducing wave energy than either approach by itself.
- **Hybrid solutions:** Nature-based features are most effective at mitigating hazards under low- to moderate-intensity events. Combining nature-based approaches with grey infrastructure may enhance the resilience of both the infrastructure and the ecosystem to higher intensity events.

Living Shorelines

The living shoreline approach recreates coastal ecosystems to provide stabilizing ecosystem services. Common practices include reducing the slope grade, adding biomass to the bank, and establishing plant cover. These strategies stabilize soil, foster plant growth, attenuate waves, and create and enhance habitat. Depending on site specifics such as geographic area, local climate, and primary hazard concerns, living shoreline ecosystems can range from oyster reefs to salt marshes to vegetated slopes (Ecology Action Centre, Undated).

In Nova Scotia, the Ecology Action Centre has implemented the living shoreline approach in four locations along the coast. One location for the Centre's project was Caribou Island, where the primary climate-related risk was erosion. The Ecology Action Centre planted stakes (cuttings from salt-tolerant and erosion-controlling tree species), placed hay on exposed soil, and made and staked alder mats over the hay. These strategies reduced erosion immediately while also improving conditions for future plant growth and subsequent further erosion control (Ecology Action Centre, 2014).

In the Bay of Fundy area, restoration of a saltwater marsh started in 2010 when an old dyke had to be breached, allowing tides back in. The restoration project was prompted by concerns both for mitigation of erosion and sea level rise and for the disappearance and degradation of saltwater marshes in the region. The project has been monitored so that future restoration efforts can learn from its example (New Brunswick, 2010; Calnan, 2015).

A 2014 study in British Columbia compared the cost of grey infrastructure to that of natural approaches to improving resilience to sea level rise, and found that natural approaches cost 30-50% less to construct. (Lamont, Readshaw, Robinson, & St-Germain, Greening Shorelines to Enhance Resilience, An Evaluation of Approaches for Adaptation to Sea Level Rise, 2014)

Wetlands

Kumar et al. (2017) found that wetlands in general are an effective option for reducing disaster risk in both riverine and coastal environments. Coastal wetlands, such as salt marshes, can buffer against storm surges, reduce wave energy, increase sedimentation, and reduce erosion and sediment movement (Spalding, 2014; Kumar, 2017). Other coastal ecosystems, such as coral reefs, beaches, dunes, barrier islands, seagrass beds, and shellfish-built reefs can have effects similar to those of wetlands. These natural infrastructure options have been shown to dissipate wave energy, settle and trap sediment, and attenuate currents. Another significant benefit to coastal ecosystems is the ability of some of these options to grow so that they remain functional when faced with sea level rise (Spalding, 2014).

New Brunswick has formally recognized such benefits and sought to capture them through policy. In 2002, the province released the New Brunswick Wetlands Conservation Policy, which aims to prevent the loss of Provincially Significant Wetlands (PSW) as well as attain no net loss of wetland function for all other wetlands. In New Brunswick all coastal marshes are considered PSW under this policy and only activities the rehabilitate, restore, or enhance a PSW or activities deemed to provide necessary public function would be permitted within 30 meters of a PSW. The Policy cites the importance of wetlands in their ability to protect human and ecosystem health, enhance habitat and support biodiversity, and give protection from flooding and storm surges while stabilizing shorelines. Wetlands are also noted for the ability to provide provisioning, recreational, scientific, aesthetic, spiritual, and cultural services. The Policy also makes the business case for preserving wetlands, stating that historical loss of wetlands has led to costly flood damage and "significant impacts on local and provincial economies" (New Brunswick Natural Resource and Energy, Environment and Local Government, 2002).

Dunes and Beaches

Dunes can be used— on their own and through modifications—as natural infrastructure solutions for mitigating hazards such as erosion and flooding. For example, adding dune and beach grasses, restoring via sand topping, or creating hybrid "fortified dunes" with riprap rock covered in sand and Marram grass or beach grass are all viable strategies (Department Official, New Brunswick Department of Environment). This hybrid approach can be particularly useful from both an operational and political standpoint: the rock provides protection and the sand and grasses are easily maintained, while including some degree of grey infrastructure increases the chances of support from the engineering community. It is particularly important to increase buy-in from engineers, as they are the professionals called upon to implement all manner of infrastructure solutions. Finding ways for engineers to support natural infrastructure can help increase uptake across sectors and projects (Department Official, New Brunswick Department of Environment).

Beaches are also important forms of coastal natural infrastructure. The U.S. Federal Highway Administration (FHWA) studied several examples of using natural infrastructure to protect coastal highways (Webb, 2018). In one example, in Yorktown, Virginia, the creation of pocket beaches stabilized by rock headlands has created a storm-resistant front that protects the nearby coastal infrastructure from flooding and damage, and was shown to be resilient (experiencing some sand losses but no damage to the rock breakwaters) in the face of Hurricane Isabel's 100-year storm event in 2003. Additional co-benefits of these pocket beaches include improved tourism and additional intertidal and shorebird habitats.

Small-Scale Approaches

Coastal protection can also come in the form of smaller-scale natural infrastructure projects. For example, The Nature Conservancy (2014) implemented several natural infrastructure case study projects in coastal California. At one of the case study locations, Surfers Point, managed retreat of vulnerable infrastructure (a bike path and parking lot) and replacement of aging assets with natural cobble and dunes led to less erosion and continued aesthetic value. At another case study location, Aramburu Island, installing gravel and cobble along the island's beach improved its resistance to erosion at a lower cost than installing riprap.

Best practices in design and applications

Experts have identified several best practices for promoting and implementing natural infrastructure to reduce the impacts of coastal storms and flooding. Spalding et al. (2014) advocate for the inclusion of ecological options in resilience decision making, as doing so will increase the adoption of natural infrastructure in coastal protection. They also recommend specific management approaches for natural infrastructure planning. These include targeting marine protected areas to protect on-site habitat, implementing habitat restoration, managed realignment to re-connect coastal lands to the tidal system, and grey-green hybrid infrastructure (Spalding, 2014).

In its studies of pocket beaches and other interventions, FHWA found that monitoring was an important strategy for continued success of natural infrastructure, as it allows for adjustments to be made over time based on performance data. Indeed, the federal, provincial, and territorial working group on biodiversity, Biodiversity Canada, includes performance monitoring and reporting as a fundamental step in its adaptive Biodiversity Outcomes Framework (Environment and Climate Change Canada, 2016)

FHWA also found that incorporating local ecosystem characteristics in natural infrastructure project design could avoid pitfalls in implementation. By using local vegetation and addressing site-specific physical coastal processes, ecological needs, and location-appropriate designs and materials, coastal protection projects can provide the greatest benefits while avoiding unintended negative consequences such as blocking species movement or introducing invasive species (Webb, 2018).

Riverine Flooding

Riverine flooding is typically caused by factors such as intense precipitation, rapid snowmelt, and ice jams in rivers. These risks are expected to increase as climate change brings more varied and intense precipitation and seasonal temperature changes to Canada. Most regions in Canada are expected to see higher daily and extreme precipitation. More severe flooding will impact human health and wellbeing and infrastructure (Public Health Agency of Canada, 2018).

The following sections provide information and best practices for using natural infrastructure to reduce risks associated with current and future riverine flooding.

Opportunities for climate risk mitigation

Common natural infrastructure solutions for riverine flooding focus on enhancing the capacity of the natural floodplain to absorb and otherwise reduce flooding. This can be accomplished by protecting existing natural floodplains, restoring the floodplain to a more natural ecosystem, and creating new ecosystems in flooded areas. Smaller modifications below the ecosystem level can also be made to divert, block, and attenuate floodwaters. Common nature-based approaches to mitigating riverine flooding include:

- **Floodplain preservation:** The most efficient strategy for natural riverine flood protection is conserving the natural floodplain. This option involves preserving existing natural ecosystems that are already serving to absorb and otherwise attenuate floods (Sabine Dietz, personal communication, May 18, 2018).
- **Restoration of inland wetlands:** Inland wetlands are an important resource in riverine flood mitigation due to their ability to collect and hold floodwaters, then gradually release them. They effectively absorb floods and help regulate water flows (Kumar, 2017). Inland wetlands can be created in areas in need of flood protection, given the appropriate ecological context and considerations.
- **Flood setbacks**: This strategy removes infrastructure in the floodplain and restores the channel to its historical configuration (FEMA, 2017).
- **Two-stage channels**: An upper channel provides flood conveyance and a low-flow channel to provide habitat and improved sediment transport (FEMA, 2017).
- **Relief channels**: This approach includes constructing additional channels to increase flood conveyance capacity while enhancing habitat (FEMA, 2017).
- **Adding in-stream structures**: These structures (such as boulder terraces and engineered riffles) can divert flow to prevent erosion (FEMA, 2017).
- **Bank vegetation and seeding:** Vegetation can stabilize the soil and riverbank to prevent erosion and mitigate flooding while increasing habitat and the aesthetic quality of the area (FEMA, 2017; Native Plant Solutions, 2016).

Conservation

Acknowledging the benefits of existing natural floodplains and preserving them through conservation efforts is a passive strategy that avoids development of natural areas. For example, The Nature Conservancy acquired easements on agricultural land in the Santa Clara River floodplain in California for preservation purposes. This allowed natural flooding to continue in the undeveloped floodplain, mitigating risks and potential costs and damages (The Nature Conservancy, 2014). Conservation is often less costly than remedial measures such as restoration or creation of ecosystems, as restoration often has significant upfront cost resulting from clearing away existing barriers to the ecosystems' regeneration; furthermore, restoration activities are often not initially successful and may require multiple interventions (Florence Daviet, personal communication, May 8, 2018).

Conservation is also often much less costly than grey infrastructure alternatives. For example, the Town of Gibsons, BC, was considering an engineered option to manage stormwater. When the Town compared the costs of the proposed project to those associated with the cost of a natural alternative that relies on restoring and expanding a local park area, it found that the natural solution provided the same level of service, or better, at lower capital and maintenance costs (Emanuel Machado, personal communication, May 4, 2018).

Floodplain Restoration and Inland Wetlands

Restoring floodplains and inland wetlands can be a very effective strategy for reducing riverine flooding while providing a range of other benefits. The examples below describe how several Canadian jurisdictions have applied this approach.

Alberta's Watershed Resiliency and Restoration Program has identified flooding and drought as major watershed issues, and is working to mitigate these hazards through "watershed mitigation approaches," which "focus on the creation and/or enhancement of natural systems such as wetlands and riparian areas to improve watershed functioning" (Alberta Government, 2017). This is an example of a jurisdiction using natural infrastructure solutions for climate-related hazard mitigation.

In Ontario, the Toronto and Region Conservation Authority (TRCA) focused on the restoration and preservation of wetlands and the natural floodplain in its efforts to restore the former Brock North and South landfills. The TRCA acquired the landfill sites with the goal of creating self-sustaining natural systems that contributed to the health of the Duffins Creek watershed. The authority developed a restoration plan that clearly laid out the planning context, including existing and planned conditions of the site and adjacent area (e.g., natural heritage, ecological habitat, cultural heritage and archaeological resources, adjacent land uses and socioeconomic conditions, road networks, and potential on-site land uses), and the targets of relevant regional and local plans and strategies (e.g., Terrestrial Natural Heritage System Strategy, Duffins Creek and Carruthers Creek Watershed Management Plan, City of Pickering Official Plan, Province of Ontario Clean Water Act, etc.).

The restoration plan lays out the project's goals, methodology, site selection and restoration zones (split into terrestrial and drainage restoration), and implementation plan. The team used geographic information systems and on-site field work to identify restoration opportunities, and then prioritized the opportunities to focus their efforts on those sites that were highly altered and degraded, demonstrated a major impairment to proper natural functioning, and/or where restoration would yield significant benefits.

The strategies themselves involved terrestrial, wetland, hydrologic, river, and riparian restoration, as well as the installation of essential wildlife habitat. Drainage in riparian zones was to be enhanced by planting species of trees and shrubs that were native to the area and suitable to wet soil. Other restoration methods included regrading and recontouring topography, additional soil applications, and infrastructure removal to enhance natural drainage. Old agricultural tile drains were to be removed to allow the soil to saturate and return to wetlands (Toronto and Region Conservation for the Living City, 2011).

Alberta Environment and Parks has a Watershed Resiliency and Restoration Program designed to address flooding and drought through conservation, restoration and enhancement, education and stewardship, and research and data. In establishing this program, Alberta identified watershed resiliency as a provincial priority and identified priority watershed areas (Alberta Government, 2016). There have been five rounds of grant approvals through the Program thus far. Projects supported via these grants have included riparian restoration in the Modeste Creek subwatershed (North Saskatchewan River Basin), Bow River Basin, Red Deer River Basin, and other locales (Alberta Government Environment and Parks, 2018).

Restoration work can also occur on a smaller scale. For example, in St-Adolphe, Manitoba, Manitoba Infrastructure and Transportation oversaw the revegetation of a 100-meter segment of the Red River that was prone to erosion. Willow cuttings were installed, along with tree plantings and native grasses, with the goal of stabilizing the vulnerable riverbank (Native Plant Solutions, n.d.).

Creation of New Natural Areas

Another major project by the TRCA and partners was the Lower Don River West Remedial Flood Protection Project, which resulted in the construction of a flood protection landform to mitigate flooding in a high-risk area for assets and stakeholders. Waterfront Toronto constructed a large berm along the river that would present a physical barrier to floodwaters. This berm was constructed over former industrial land, taking clean soil from regional construction sites to transform the brownfield into an attractive park with recreational amenities and natural habitat (TRCA, 2015). This project was complemented by a nearby grey infrastructure project, in which a bridge over the river was widened to accommodate a greater water flow and further reduce risk of flood damage. Similarly, Toronto naturalized the mouth of the Don River to return the area from a polluted, industrialized site to a thriving natural habitat with enhanced flood protection (TRCA, 2018).

Best practices in design and applications

This section presents best practices and lessons learned in using natural infrastructure to reduce riverine flooding, based on projects implemented by governments and communities.

Maintaining existing natural infrastructure and ecosystems is generally the most efficient and cost-effective method for capturing and preserving the benefits of natural infrastructure to limit riverine flooding (Emanuel Machado, personal communication, May 4, 2018). This approach mitigates the need to create new on-site natural infrastructure and has immediate results in reducing flood risks.

When designing new natural areas, practitioners have found it best to keep broader habitat needs in mind. In its restoration plan, the TRCA recommended that when restoring the former Brock landfills, the resulting natural habitat should create larger habitat blocks and increase habitat connectivity while managing invasive species. Incorporating these types of considerations in project design can lead to a healthier ecosystem that is more resilient to increased user pressure and local development of the land (Toronto and Region Conservation for the Living City, 2011).

Including infrastructural components that allow access to the natural areas along waterways can increase stakeholder and community engagement. For example, the berm constructed along the Lower Don River in Toronto was transformed into a local park with amenities for local residents (TRCA, 2015). In another case, involving a flood mitigation project along the Napa River in California, the local community and water quality regulators selected a “living river” approach over grey infrastructure options. This restored habitat created a riverfront promenade and improved the social aesthetics of the river. While this project had higher capital costs than the grey infrastructure options, local stakeholders showed strong support for the natural infrastructure option—illustrating the value of natural infrastructure co-benefits (The Nature Conservancy, 2014).

Urban and Rural Stormwater

As urban and rural populations continue to grow and develop, the area of hard surfaces impermeable to rainwater expands and water flow patterns change, affecting watershed hydrology (Water Canada, 2017). Permeable surfaces, such as open lands and forests, are replaced by impermeable, human-made surfaces such as parking lots and highways. An increase in impermeable surfaces leads to an increase in runoff, since less rain soaks into the soil or is taken up by vegetation (City of Vancouver, 2018b).

As a result of urbanization, peak flows in Canada rose steadily between 1969 and 2010 and also became more variable (Water Canada, 2017). This pollutant-laden runoff flows into storm drains and eventually into waterways, and can cause flooding, ponding, and health and safety risks (City of Vancouver, 2018b). Excessive amounts of runoff can erode stream banks, cause localized flooding, contribute to sewer overflows, and can facilitate the spread of mosquito-borne diseases or cause leaks or damage to buildings and other infrastructure (e.g., in the case of excess ponding on a green roof) (American Rivers, Water Environment Federation, American Society of Landscape Architects & ECONorthwest, 2012; Credit Valley Conservation and Toronto and Region Conservation Authority, 2010).These effects are exacerbated by climate change, which also contributes to increasing flooding, more variable water flows, and an increased prevalence of vector-borne diseases.

Natural infrastructure mitigates excess stormwater and pollution by promoting evapotranspiration, filtration, and infiltration, as well as preventing excessive runoff of impervious surfaces that can negatively affect local waterways, buildings, property, and oceans. To increase the function of natural infrastructure that mitigates overland flooding, measures should be taken to help remove pollutants such as petroleum products from the water before it is filtered through natural infrastructure (Department Official, New Brunswick Department of Environment).

It is also important to note that appropriate natural infrastructure practices will vary by locality and local needs. For example, a community that experiences flooding from excess stormwater may be interested in approaches that focus on capturing and evaporating excess moisture, whereas another community that relies on groundwater supplies for drinking water may be interested in approaches that support infiltration to recharge aquifers (Jenny Hill, personal communication, May 9, 2018).

The following sections provide case study examples and more details on natural infrastructure practices for stormwater management.

Opportunities for climate risk mitigation

Natural infrastructure solutions for stormwater management can include (EPA, 2018b):

- Green roofs
- Bioswales
- Bioretention ponds
- Rain gardens
- Urban trees
- Vegetative swales

Natural infrastructure practices can also be complemented by green infrastructure practices such as permeable pavements that help to control stormwater through physical means.

Green Roofs

Green roofs are contained areas of vegetation on the roofs of buildings, used to capture rainwater, reduce runoff, and counter the urban heat island effect (Green Infrastructure Ontario Coalition, 2016b; City of Vancouver, 2016). Green roofs are also beneficial for helping to decrease energy use and improve air quality, and they do not require the additional land space needed by other stormwater management strategies (EPA, 2008; City of Vancouver, 2016). Green roofs can also provide natural spaces for community interactions, agriculture, and biodiversity in an urban setting (Green Infrastructure Ontario Coalition, 2016b). Green roofs require routine maintenance such as weeding, and may also require repairs over time, although the U.S. EPA estimates that the expected life of a green roof is about twice that of a conventional roof (EPA, 2008).

The Green Roof Innovation Testing Laboratory (GRIT Lab) at the University of Toronto conducts research on the latest green roof technologies. This research includes quantifying the degree of stormwater management and evaporative cooling of green roofs, which vary by growing material, depth, vegetation, and irrigation (University of Toronto, Undated).

Bioswales

Bioswales use grass, other vegetation, rocks, and a sloped surface to capture and direct excess stormwater back into the soil (American Society of Landscape Architects, 2018; Green Infrastructure Ontario Coalition, 2016d). Bioswales are often implemented along streets to keep stormwater away from sensitive infrastructure, and are often used in conjunction with bioretention ponds (American Society of Landscape Architects, 2018; Georgetown Climate Center, 2018). In addition to their stormwater benefits, they can reduce pollutants, reduce temperatures, recharge groundwater, and improve air and water quality (American Society of Landscape Architects, 2018; Georgetown Climate Center, 2018; Green Infrastructure Ontario Coalition, 2016d). Finally, bioswales are often aesthetically pleasing and potentially increase property values (Georgetown Climate Center, 2018).

Bioretention Ponds

Bioretention ponds are designed to collect and hold excess water and allow slow filtration back into the soil, recharging groundwater supplies. Evapotranspiration also occurs, removing some of the collected stormwater, and the vegetation helps to remove pollutants from stormwater

(American Society of Landscape Architects, 2018). Bioretention ponds are typically designed to hold water for 24-48 hours to avoid ponding and facilitate slow filtration back into the soil (Credit Valley Conservation and Toronto and Region Conservation Authority, 2010). The size and depth of the bioretention pond will vary depending on the local hydrology conditions.

Rain Gardens

Rain gardens can help retain stormwater runoff through infiltration (Green Infrastructure Ontario Coalition, 2016d; City of Vancouver, 2016). The gardens should be placed in areas where stormwater currently overwhelms drainage capacity, and can capture and filter stormwater with vegetation and constructed soil and subsoils in a limited amount of space (Georgetown Climate Center, 2018; City of Vancouver, 2016). Rain gardens can be easily implemented by communities of any size and often serve as the first step in a long-term commitment to attenuating stormwater (Department Official, New Brunswick Department of Environment). Rain gardens are also appropriate for private properties and can generate buy-in for using best management practices, while increasing public awareness of natural infrastructure (Department Official, New Brunswick Department of Environment).

Rainwater Harvesting

Rainwater harvesting systems capture and store runoff from roof surfaces, which can be used for non-potable purposes such as landscaping (City of Vancouver, 2016). Rainwater harvesting systems can be particularly useful in arid, drought-prone areas, where they can reduce demands on water supplies (Adham, Riksen, Ouessar, & Ritsema, 2016). Incentive programs such as the New York City Rain Barrel Giveaway Program have proven to reduce sewer overflows by capturing and storing stormwater that falls on rooftops. (New York City, Department of Environmental Protection, 2018).

Urban Trees

The cumulative effect of urban trees provides an abundance of stormwater management benefits to municipalities (Green Infrastructure Ontario Coalition, 2016e). Tree roots are essential to mitigating overland flooding by drawing up and retaining excess water and stabilizing soil. Natural infrastructure projects related to urban trees focus on retaining, restoring, or creating forested spaces, such as parks, and planting and maintaining street trees. The success of urban trees as a stormwater mitigation strategy is dependent on species selection, planting conditions, and maintenance, all of which will depend on the local conditions and resources of the municipality.

Best practices in design and application

A growing number of Canadian municipalities are implementing natural infrastructure programs to reduce local water pollution and better control stormwater runoff. This section presents lessons learned from programs and projects implemented by governments and communities.

<u>Case Studies: Toronto, Ontario</u>

According to a study by the Michigan Urban Land Institute in 2017, Toronto has become widely recognized as a natural infrastructure leader for its green roof program. So far, this program has resulted in 1.2 million new square feet of vegetation; a reduction of 435,000 cubic feet of stormwater annually; 1.5 million kWh in annual energy saving for building owners; the creation of over 100 jobs related to the manufacture, design, installation, and maintenance of the green roofs; and a reduction in polluting sewer overflows (Carlson & White, 2017).

The City has also implemented a number of Green Streets Pilot Projects, including Fairford Parkette and South Station Street, which are both focused on mitigating stormwater with public-realm improvement projects (Toronto and Region Conservation Authority, 2017; Park People, 2017; Sheila Boudreau, personal communication, May 3, 2018). Fairford Parkette uses bioretention areas to capture excess stormwater runoff. The City also developed a series of evaluation criteria to assess the quantity of runoff reduction, vegetation health, and degree of public awareness. The proposed Raindrop Plaza pilot will use a mixture of permeable pavements, rain gardens, trees, and an infiltration trench to mitigate stormwater. The pilot is also unique in that creating social benefits was a key design objective: Grade eight students from a local school and a Toronto artist created a tree graphic for the permeable paving in the central seating area; and high school students from the First Nations School of Toronto created traditional Indigenous bead work inspired by "sacred water," to be photographed and created into large art panels for the west entrance to the plaza (Sheila Boudreau, personal communication, May 3, 2018). Now Senior Landscape Architect at the Toronto and Region Conservation Authority, Sheila Boudreau, who orchestrated the Raindrop Plaza pilot activities, continues to look for ways to involve First Nations as collaborative partners in natural and green infrastructure programs, and planning and design initiatives, a meaningful way to implement the Truth and Reconciliation Commission's Calls to Action (Sheila Boudreau, personal communication, May 3, 2018).

Case Studies: Vancouver, British Columbia

The City of Vancouver rainwater management plan provides a long-term natural infrastructure strategy to protect and improve water quality in the waterbodies surrounding the city. The program aims to capture and treat 90% of Vancouver's average annual rainfall through natural infrastructure and amended design guidelines, including rainwater harvesting, infiltration swales, infiltration trenches, rain gardens and infiltration bulges, green roofs, daylighted streams, and tree well structures (City of Vancouver, 2018a).

At the University of British Columbia in Vancouver, the Centre for Interactive Research on Sustainability (CIRS) building serves as a model and source of research for sustainable design. The building was completed in 2011 and continues to serve as a living laboratory for innovative designs. The building includes natural infrastructure features such as a "living roof" of native plants, a "living wall" of vegetation to provide shade, a reclaimed water treatment system, and a rain harvesting system. The building is also adjacent to a natural infrastructure project that includes native plants, stormwater retention, bio-filtration, and ground water recharge (Centre for Interactive Research on Sustainability, Undated).

Case Study: Town of Gibsons, British Columbia

The Town of Gibsons, north of Vancouver, has developed a strategy that could contribute to the efforts of municipalities across Canada and elsewhere to improve climate resilience. The Gibsons Eco-Asset Strategy is a financial and municipal management approach that complements strategies to maintain, replace, and build both grey infrastructure (e.g., roads, storm sewers) and natural infrastructure (e.g., rain gardens, parks, bioswales) (van Ham & Klimmek, 2017). The approach focuses on “identifying existing natural assets (forests, green space, topsoil, aquifers, creeks) that provide municipal services (e.g., storm water management) measuring the value of the municipal services provided by these assets; and making this information operational by integrating it into municipal asset management” (van Ham & Klimmek, 2017). The town has found this approach to be a cost-effective strategy for improving its climate change adaptation and resilience efforts (van Ham & Klimmek, 2017; Town of Gibsons, 2015).

Case Study: Waterloo, Ontario

The Cora Building—scheduled to be completed in the summer 2018—is a commercial office building project that integrates natural infrastructure such as bioswales and rainwater collection. Rainwater will be collected and used to flush toilets and irrigate the grounds. Bioswales will be placed along parking lots to hold and clean storm water runoff to reduce impacts on municipal storm water infrastructure (Queen’s Printer for Ontario, 2018).

Case Study: Lakeside Park, Mississauga, Ontario

Lakeside Park, located in Mississauga, Ontario, was redeveloped in 2012 with the goal of integrating more natural features. The new park incorporated several types of natural infrastructure applications, including bioswales, native vegetation, a reclaimed water irrigation system, and green roofs to mitigate climate change impacts while increasing aesthetic value (Green Infrastructure Ontario Coalition, 2017).

Urban Heat Islands

Urban heat islands are defined as built-up areas that have higher temperatures than local rural areas due to the urban landscape’s reduced ability to reflect sunlight and reduced transpiration (EPA, 2008; Government of Canada, 2010). As grey infrastructure continues to replace vegetation, more impervious and dry surfaces are created. These surfaces absorb more solar radiation, resulting in urban heat islands (EPA, 2008).

According to Health Canada, 80% of Canadians live in cities where the urban atmosphere is impacted by human changes to the environment through urban design and development (Government of Canada, 2010). For example, urban canyons of trapped solar radiation can occur along narrow streets due to the arrangement and size of buildings, resulting in higher temperatures. Other surfaces such as paved roads, concrete sidewalks, and parking lots absorb solar radiation as well, resulting in higher temperatures. When vegetation is replaced by buildings, cooling through evapotranspiration is reduced as is the ability to circulate cooler air to city centres (Government of Canada, 2010).

Urban heat islands aggravate the impact of extreme heat events, including increasing GHG emissions and air pollution, which puts additional stress on the health of vulnerable populations such as young children, older adults, homeless individuals, and people with chronic illnesses (Minister of Health, Canada, 2015; Komali Yenneti, 2017).

In addition to the public health risks, urban heat islands increase energy use. The increased summer cooling energy demand associated with urban heat islands can cause blackouts or brownouts, which in turn can have an impact on emergency response (Komali Yenneti, 2017).

A number of natural infrastructure strategies can be applied in a variety of locations and contexts to reduce urban heat island effects while providing a range of other energy, economic, public health, and quality-of-life benefits to urban residents.

The following sections provide more details and case study examples on natural infrastructure practices for reducing the risks associated with urban heat islands.

Opportunities for climate risk mitigation

Many communities are taking actions to reduce urban heat islands using strategies such as increasing tree and vegetative cover. These natural infrastructure strategies can be complemented by green or grey infrastructure that focuses on reflecting or absorbing solar radiation, such as installing green or cool roofs and reflective roofs or pavements.

Each of these mitigation strategies is discussed below, using examples that communities are implementing and findings in the literature.

Trees and Other Vegetation

Trees and other types of vegetation help reduce the impacts of heat islands by increasing the amount of shade and cooling the air by evapotranspiration (EPA, 2008; Green Infrastructure Ontario Coalition, 2016e). Canada's forests and trees are fundamental to creating and maintaining healthy and resilient communities, including by limiting impacts associated with heat island effect. As a result, the value of urban forests as a landscape amenity has been estimated at over $500 million for Vancouver's street trees, over $800 million for Edmonton's boulevard and park trees, and over $16 billion for Toronto's urban forest (Farr, Undated). In addition to reducing the heat island effect, urban trees also provide services to the community such as increasing air and water quality, and decreasing energy use, among other benefits that add immense value to urban forestry (Farr, Undated). For example, approximately 75% of community drinking water supplies flow through forested ecosystems, which moderate water quantity and improve water quality through natural filtration (Food and Agriculture Organization of the United Nations, Undated). Given that Canada has a considerably greater land base in forested watersheds, this figure could be at least 80% or greater (Department Official, Natural Resources Canada). In addition, forests play a significant role in mitigating the impacts of climate change by removing carbon from the atmosphere (Green Infrastructure Ontario Coalition, 2016e).

Recognizing these benefits and services, several Canadian communities have established tree planting programs; for example, in Hamilton, Ontario, 2,100 trees have been planted on city streets since 2006; in Kelowna, British Columbia, from 600 to 1,400 trees are planted annually; and London, Ontario plans to have a tree in front of every home (Forkes et al., 2009; Government of Canada 2010).

The tree canopy in the City of Toronto currently covers 20% of the City. The City's goal is to have 35% average tree canopy coverage by 2020. Planting and conservation are two strategies implemented by the City to achieve this 35% goal to reduce the heat island effect. Toronto requires new trees to be planted on both public and private property. Other programs, such as the Toronto Tree Canopy Grant, continue to provide incentives to land owners who wish to plant trees on their properties (City of Toronto, 2016).

The impacts of catastrophic events on forests, however, can be particularly damaging to communities located near or within forested landscapes (Krishnaswamy, Simmons, & Jospeh, 2012). For example, forests in interior British Columbia have been affected by insect epidemics, which result in stressed and dead trees that then lead to massive wildfires across millions of hectares of forests (Krishnaswamy, Simmons, & Jospeh, 2012). As a result, without the natural water-holding capacity of a healthy forested landscape, communities such as Kelowna, BC are experiencing more intense flooding, which causes damage to highways, roads, and other critical infrastructure. In addition, these impacts affect the local economy and ability to get natural resources to market, fish and wildlife habitat, environmental values, and the public health and safety of nearby communities.

Green Roofs

As discussed in the urban and rural stormwater section, green roofs are ideal for dense urban areas that do not otherwise have space for trees or parks. (The Trust for Public Land, 2016). Additional benefits of green roofs include reducing ambient temperature, enhancing quality of life, noise reduction, aesthetic value, and food production (Healthy Air Living, 2011).

Hybrid Approach (Green and Cool Roofs)

As a complement to green roofs, roofs can also use reflective materials that lower building and ambient air temperatures. These materials can remain approximately 28–33°C (50 to 60°F) cooler than standard materials during peak summer weather (EPA, 2008). Cool roofs help reduce energy use when temperatures are high, and as a result also reduce GHG emissions, save consumers air-conditioning costs, and improve air quality by reducing pollutant emissions. When enough are installed on a citywide scale, green and cool roofs can also reduce the urban heat island effect by lowering temperatures across communities (NRDC, 2012). On the other hand, cool roofs may lead to higher heating energy costs in winter, especially in areas where roofs are not ordinarily snow-covered during the winter months.

Best practices in design and applications

This section presents lessons learned from heat island mitigation strategies implemented by governments and communities in Canada and elsewhere.

Trees and Other Vegetation

To maximize the benefits of trees in reducing the urban heat island effect, the selected species should be low-pollen emitters, low-volatile organic compounds (VOC) emitters, drought tolerant, and planted in appropriate locations to maximize heating and cooling effects. According to Tree Canada, large deciduous trees should be planted on the southeast, southwest, and west sides of a home or other structure to provide shade and cooling in the summer without obstructing the low winter sun (Tree Canada, Undated). Exposure to winter sun is important for heating the home or structure during the winter. In addition, planting evergreen trees along the north side of a home or structure blocks cold winter winds and helps to reduce energy use for heating homes (Tree Canada, Undated). The Trust for Public Land found that planting trees in an east-west pattern in groups of three (one east two west) created the greatest potential for cooling (The Trust for Public Land, 2016). However, for the majority of Canadians, staying warm in the winter is more problematic and costly than staying cool in the summer. As a result, deciduous trees are more advantageous than coniferous trees because they provide shade in the summer and sun in the winter when the leaves fall (The Trust for Public Land, 2016).

In addition, it has been found that mature trees provide more significant cooling benefits than immature trees (The Trust for Public Land, 2016). Site selection for new trees should therefore consider how best to support the longevity of the tree (The Trust for Public Land, 2016).

When selecting urban street trees to plant, it is also important to select varieties known to be tolerant of road salt for melting snow and ice during the winters so that the tree can survive to maturity (Bassuk, Curtis, Marranca, & Neal, 2009). Trees also need regular watering and after-planting care for the first few years until the roots are well-established (Michelle Sawka, personal communication, May 22, 2018). Sidewalk grates should be designed to allow a sufficient amount of water penetration to meet the tree's current and future water demands. These efforts greatly increase the chances of the tree surviving to maturity.

Some potential adverse effects include increased water demand and possible damage to sidewalks, power lines, and other infrastructure from roots or falling branches (EPA, 2008; Tree Canada, Undated).

Green Roofs

A study by the National Research Council of Canada modelled the heating and cooling energy savings of an approximately 32,000-square-foot (2,980 m^2) green roof on a one-story commercial building in Toronto. The analysis estimated about 21,000 kWh in total savings annually (EPA, 2008).

The City of Toronto, Ontario, has adopted a bylaw to require and govern the construction of green roofs on all new developments above 2,000 m^2 of gross floor area (Government of Canada, 2010).

Hybrid Approach (Green Roofs, Cool Roofs and Pavements)

The city of Windsor, Ontario, is in the process of installing five green roofs and two reflective roofs on municipal buildings to reduce urban heat islands. The city is also replacing dark roofing shingles with lighter coloured alternatives. (Government of Canada, 2015).

<u>Case Study: Measures to reduce the urban heat island effect in Montréal, Québec</u>

In April 2011, the Rosemont–La Petite-Patrie borough council revised its comprehensive zoning bylaw to include four regulatory measures that aim to tackle urban heat island effects: a green roof, a white roof, a highly reflective roof or some combination of the three must be installed on all new buildings; for all new parking lots of 10 or more spaces, at least 15 percent of the area must be open ground landscaped with vegetation; the paving material in all new parking, loading, and storage areas must meet a minimum solar reflectivity index rating of 29 and, when a new building is built, at least 20 percent of the building site must remain open ground and be landscaped with plants, bushes and trees. Note this provision does not apply to commercial arteries (Government of Canada, 2014).

The four measures apply to all renovations and new construction on both public and private property throughout the borough. Although it is too early to measure the effect of the new zoning regulation, the number of roof permits granted to date is a good indicator of the impact of the new law (Government of Canada, 2014).

Chapter 3: Business Case for Natural Infrastructure Investments

As demonstrated in this report, unlike grey infrastructure, which is typically designed to serve one specific purpose, natural infrastructure can provide a variety of economic, social, and environmental benefits, such as providing freshwater to urban populations, in addition to increasing the resilience of an asset or area to a specific climate-related hazard. Due to these co-benefits, natural infrastructure (alone or as a hybrid approach) is often also the more cost-effective solution. The following sections detail the economic, environmental, and social co-benefits of natural infrastructure investments as well as tools and resources for evaluating those co-benefits.

Co-Benefits: Environmental, Social

One important reason for the increasing popularity of natural infrastructure has been the co-benefits that it offers to the environment and for communities. Examples of benefits include the reduction of energy and water consumption, biodiversity enhancement, and improvements in public health and wellbeing.

By understanding the co-benefits of natural infrastructure, practitioners can more easily garner broad support for projects. In many cases, co-benefits affect the community in ways that address multiple perspectives (e.g., public health (both physical and mental), public safety, business, etc.).

Co-benefits related to ecosystem services

The following examples detail ecosystem services provided by natural infrastructure. These are inherent in natural infrastructure’s existence as natural systems and can be reasons for and outcomes of natural infrastructure in and of themselves. Because this report focuses on the climate resilience outcomes of natural infrastructure, brief descriptions of ecosystem services are provided here as supplementary information. These ecosystem services are a key component when evaluating natural infrastructure, in addition to resilience outcomes.

Natural infrastructure improves water quality.
Wetlands can function as filters, trapping sediments and pollution and thereby increasing water quality for the surrounding area. More generally, increased vegetation reduces soil erosion and

protects riverbeds (Terton, 2017). Furthermore, increasing water features and catchment in an area can lead to the recharge of aquifers (The Nature Conservancy, 2014).

Natural infrastructure provides habitat and supports biodiversity.
Increasing natural habitat area and diversity via natural infrastructure supports increased biodiversity. Greenways and other habitat connections facilitate the movement of wildlife and allow continued ecosystem processes (City of Edmonton, 2013). With urban biodiversity comes a plethora of additional benefits, including pollination, nutrient cycling, genetic resources, food production, and positive outcomes for health and wellbeing (Local Governments for Sustainability, 2014).

The Yolo Bypass along the Sacramento River in California is an excellent example of a flood mitigation project that resulted in multiple environmental benefits. By allowing for a natural floodplain, the bypass land not only manages a greater volume of floodwater than there is capacity for in the main river channel, but also provides habitat for native fish and an additional route for migratory fish. The bypass land also provides migratory bird habitat (The Nature Conservancy, 2014).

Natural infrastructure contributes to climate regulation and carbon sequestration.
Natural infrastructure has the environmental benefit of carbon sequestration, which can aid in climate change mitigation efforts. Both soil and vegetative biomass store carbon, as do peatlands (Terton, 2017; Kumar, 2017).

Social and economic co-benefits

The following examples detail social and economic co-benefits provided to communities by natural infrastructure. Social benefits highlight positive outcomes to local communities and populations, and economic benefits focus on direct and indirect financial benefits.

Natural infrastructure can provide communities with a sense of identity and stewardship.
Promoting native species in an area and creating unique natural amenities such as parks, greenways, and green roofs can enhance the local character of a region and provide gathering places and landmarks. Well-known natural infrastructure amenities, such as New York City's High Line, can attract visitors and offer a range of amenities, including art installations, stargazing and other educational programming, and dances and other cultural programming. Additionally, providing outdoor gathering spaces increases communities' environmental awareness and sense of stewardship (Terton, 2017). These open, outdoor gathering areas support community activities and provide aesthetically pleasing destinations, which can aid in building a sense of community and pride in a local area (City of Edmonton, 2016).

Natural infrastructure supports human health and wellbeing.
Interacting with nature has been shown to improve and support human health and wellbeing via reduced mortality and improved physical and mental health, with a number of studies demonstrating these benefits (Tzoulas, 2007; Elmqvist, 2015). For example:

- The air- and water-filtration and pollution capture services provided by plants provide a cleaner, healthier living environment (Terton, 2017).
- Trails and other green spaces can provide the option for active transportation to community members, which supports health (City of Edmonton, 2013; Natural Infrastructure for Business, 2015).
- Moving to greener urban areas can lead to sustained mental health benefits (Alcock, 2014).

Specific types of natural infrastructure, such as trees and forests, can carry particular benefits. For example, the Japanese practice of forest bathing, in which people take non-strenuous walks through forests, has been shown to decrease blood pressure. One study found that viewing forests reduced stress hormones, blood pressure, and pulse rate, and increased feelings of being relaxed and refreshed when compared with viewing urban landscapes (Lee, 2009). Breathing in tree-produced compounds (phytoncides) can reduce concentrations of stress hormones and boost white-blood cell activity (Aubrey, 2017).

Additionally, natural infrastructure often requires less labour to build and maintain than grey infrastructure, reducing workforce safety risks (Natural Infrastructure for Business, 2015).

It is often the case that “greener is better,” such that benefits are increasingly accrued with greater applications of natural infrastructure and systems. Studies have demonstrated this association across different measures of health. For example:

- Exposure to the “greenest environment” was associated with the lowest levels of health inequality related to income deprivation (Mitchell, 2008).
- Self-perceived health increased with higher percentages of green space in people’s living environment (Maas, 2006).
- Psychological benefits of green space increased with higher levels of biodiversity (Fuller, 2007).

While natural infrastructure can potentially result in unintended negative health effects associated with increased exposure to biodiversity, such as the introduction and survival of host organisms for infectious pathogens as well as increased pollen counts in urban areas (National Institutes of Health, 2015), these risks can usually be mediated with awareness building and public education efforts.

Natural infrastructure aligns with Indigenous community values.
Preserving and maintaining natural systems is often a key component to upholding Indigenous rights and ways of life, as Indigenous communities have strong ties to the natural environment (Eriel Deranger, personal communication, May 8, 2018). By valuing and respecting Indigenous knowledge systems, natural infrastructure practitioners can learn much from the long history of natural stewardship by Indigenous communities while promoting reconciliation, biodiversity, and conservation (Indigenous Circle of Experts (ICE), 2018). With thoughtful, inclusive and participatory implementation, natural infrastructure can be used by Indigenous Peoples to achieve resilience outcomes and goals.

Natural infrastructure promotes outdoor recreation.
Natural infrastructure such as greenways, parks, and paths around wetlands and other ecosystems provides opportunities for community members to interact with nature and pursue outdoor recreation (City of Edmonton, 2013). Increased access to nature allows for outdoor physical activity, nature-based activities such as birdwatching, and provides spaces for children to learn and play (Natural Infrastructure for Business, 2015).

Natural infrastructure cuts down on energy costs.
Natural infrastructure can capture and naturally treat stormwater, reducing energy consumption and operational costs through avoided stormwater collection and treatment at wastewater facilities (Winkelman, 2017).

Natural infrastructure such as green roofs, tree planting, and rainwater harvesting can reduce energy use and costs by decreasing temperature in buildings; providing shading, wind blocking, and evaporation benefits; and reducing potable water use (EPA, 2014b).

Researchers at Ryerson University found that a Toronto-wide green roof installation program led to energy savings, urban heat island mitigation, and other benefits, together valued at an estimated $313 million (Green Infrastructure Ontario Coalition, 2016c).

As noted above, urban trees, green roofs, and cool roofs and pavements can reduce the heat island effect. In the United States, one study estimated that investing in natural infrastructure can reduce national energy use for air conditioning by about 20%, with national monetary energy savings estimated to be US$10 billion per year (Green Infrastructure Ontario Coalition, 2016c).

Natural infrastructure increases property value
A report by the Urban Law Institute (ULI), released at its 2017 Spring Meeting in Seattle, examines how water management mechanisms using natural infrastructure can create value for real estate projects. The ULI found that rain gardens, bioswales, and green roofs, and other natural infrastructure, accompanied by water storage and recycling tools such as cisterns, are sustainable and efficient solutions that can also provide health benefits for the local population (Urban Land Institute, 2017).

Greenfill developments, in which underutilized urban lots are transformed into natural infrastructure sites, can increase the property value of the area, attract visitors and residents, and reverse urban population decline (City of Edmonton, 2016). However, it is important to consider the effect that natural infrastructure has on raising property values, as it can lead to gentrification that may drive out the very residents that the infrastructure was originally intended to support.

Natural infrastructure increases employment
Investing in natural infrastructure generates employment opportunities. New positions can be created, such as urban planners, architects, landscape architects, designers, ecologists, foresters, engineers, gardeners and construction workers. New jobs can also be created in the tourism industry (Green Infrastructure Ontario Coalition, 2016c).

Cumulative impacts

The cumulative impacts of natural infrastructure (and of any kind of development) are rooted in the confluence of land-use decisions in the past, present, and future and in the spatial context of the development (Chris Buse, personal communication, May 30, 2018). While the abovementioned co-benefits of natural infrastructure are commonly recognized, it is important to consider how previous land-use patterns set the stage for the natural infrastructure at hand, and how the natural infrastructure project will fit into the context of future communities. It is also important to consider the ecology of the area and work to predict ecological interactions so that the natural infrastructure survives well and can continue to provide important ecosystem and social services (Chris Buse, personal communication, May 30, 2018). Monitoring and adaptively managing the natural infrastructure are best practices for ensuring the continued success of the natural infrastructure in serving the community (Chris Buse, May 30, 2018).

Cost-Benefit Resources for Natural Infrastructure

Quantifying co-benefits and their associated costs can be challenging (see Chapter 4 for more information). The following sections detail existing resources that can assist with conducting cost-benefit analyses. There remains a need, however, for more targeted tools to ensure communities are better supported to complete these assessments in a consistent way across jurisdictions and scales.

Cost-benefit tools

The following tools can be used to evaluate the costs and benefits of natural infrastructure. These tools assess a variety of metrics and considerations, including social, economic, and environmental aspects of natural infrastructure.

The Center for Neighborhood Technology (CNT) Calculator
This tool can be used for quickly comparing the performance, costs, and benefits of natural infrastructure to those of conventional stormwater practices (Center for Neighborhood Technology, 2010). The CNT has proposed a two-step framework approach to measure and value natural infrastructure's multiple ecological, economic, and social benefits (Center for Neighborhood Technology, 2010). The first step involves quantifying the benefit in terms of its resource unit (e.g., kilowatt hours). The second step involves determining a monetary value for that benefit, if possible.

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Tool
The InVEST tool provides a suite of free, open-source software models designed for mapping and assigning value to ecosystem services (Natural Capital Project, 2018). InVEST currently includes 18 ecosystem service models covering terrestrial, freshwater, marine, and coastal ecosystems. The available models cover services such as carbon storage and sequestration, habitat quality, scenic quality, and water purification. The toolset also includes a number of "helper tools" designed to help with data collection, input, and visualization. A new Urban InVEST model is in development to help integrate nature into urban design (Natural Capital Project, 2018).

Ontario Residential Tree Benefits Estimator

This calculator predicts future benefits of a new tree and estimates the current and accumulated benefits of an existing tree by modeling reduced electricity demands and carbon sequestration based on local characteristics (LEAF - Local Enhancement & Appreciation of Forests, 2018).

U.S. Department of Agriculture (USDA) i-Tree Tools

The USDA developed a suite of forest analysis and benefits assessment tools to help professionals better manage urban and rural forests, as well as community trees. These tools are designed to help quantify forest structure, environmental effects (e.g., air quality, water quality, streamflow), environmental and aesthetic benefits, and land and canopy cover (U.S. Department of Agriculture, 2006).

Sustainable Technologies Evaluation Program (STEP) Life Cycle Costing Tool (Ontario)

The Toronto and Region Conservation Authority STEP program has a number of resources available to practitioners, including its own Life Cycle Costing Tool in Microsoft Excel, which is specifically built for use in Ontario. The decision-support tool allows professionals to estimate the capital and life cycle costs of site-specific low-impact designs, including input costs, maintenance requirements, and rehabilitation costs (Toronto and Region Conservation Authority, 2018a).

Value of Nature to Canadians Study Taskforce Ecosystem Services Toolkit

This toolkit is useful in calculating the benefits that can be used as part of a cost-benefit analysis of natural infrastructure. The toolkit, released in 2017, provides interdisciplinary technical directions for conducting an ecosystem services assessment. Nine practical worksheets are included in the tool, to be used for defining, screening, prioritizing, characterizing, and assessing ecosystem services and synthesizing the results (Value of Nature to Canadians Study Taskforce, 2017). The toolkit is meant to be comprehensive but flexible and scalable, so that while it provides everything needed for a thorough, scientific assessment, it also provides resources for organizations that do not wish to or cannot conduct a full assessment (Department Official, Canadian Wildlife Service). The toolkit does not specifically call out natural infrastructure as providing ecosystem services, but can be applied to natural infrastructure, which does provide ecosystem services.

Forthcoming: Framework based on INTACT Centre research

The INTACT Centre on Climate Change Adaptation is an applied research centre at the University of Waterloo with a focus on climate adaptation and flood risk reduction. The Intact Centre has been developing a high-level methodological framework for cost-benefit analysis of natural infrastructure. The goal of this framework is to help practitioners and investors to quantify the “value-for-money” for natural infrastructure conservation and restoration projects. The framework can be used to articulate the business case for (1) retaining/conserving existing natural infrastructure features (e.g., ponds, wetlands and vegetated areas), (2) restoring natural infrastructure features that may have been lost to development, and (3) building net new “naturalized” infrastructure features. The framework offers a standardized approach for implementing natural infrastructure projects, as well as outlines economic cost benefits analysis approaches for natural infrastructure valuation, which will enable an easier comparison of natural infrastructure projects implemented across the country. A report detailing this framework is expected to be published in the Summer of 2018 (Natalia Moudrak, personal communication, May 9, 2018).

Cost-benefit analysis in practice

The key to an effective and informative cost-benefit analysis is to focus on a specific means for achieving a specific goal. While most Canada-based cost-benefit analyses to date have been broad in focus, there are many examples with a narrower scope and specific driver that can serve as useful examples to Canadian municipalities, especially those that have similar climate conditions (Michelle Sawka, personal communication, May 22, 2018). For example, Michelle Sawka at the Toronto Region and Conservation Authority often looks to detailed cost-benefit analyses completed in New York City, as the climate is relatively comparable to that of Toronto. One such example is a cost-benefit analysis by New York City on implementing natural infrastructure to address water quality regulations for combined sewer overflow. The following are some examples of Canada-based cost-benefit analyses.

<u>Series of Case Studies on Natural Capital and Valuation of Ecosystem Services</u>

TD Bank Group and the Nature Conservancy of Canada produced 11 case studies across Canada's eight different forest regions on valuing ecosystem services from forests. The report, *Putting a Value on the Ecosystem Services Provided by Forests in Canada: Case Studies on Natural Capital and Conservation*, provides background on each forest region as well as a methodology for valuing ecosystem services (TD Bank Group and the Nature Conservancy of Canada, 2017). Across the 11 case studies, services were valued between $5,800 to $46,000 per hectare, per year in natural capital benefits, with an average benefit of $26,382 per hectare per year (TD Bank Group and the Nature Conservancy of Canada, 2017). The individual case study results are summarized below:

Case Study	Forest Region	Valuation (per hectare per year)
Long Tusket Lake, Nova Scotia	Acadian Forest Region	$26,250
Maymont Property, Saskatchewan	Boreal Forest Region	$5,800
Kurian Property, Manitoba	Boreal Forest Region	$26,800
Salmonier Conservation Project, Newfoundland & Labrador	Boreal Forest Region	$26,300
Backus Woods, Ontario	Carolinian Forest Region	$19,353
Gullchucks Estuary, British Columbia	Coastal Forest Region	$33,700
Midgeley, British Columbia	Columbia Forest Region	$46,000

Kenauk, Québec	Great Lakes-St. Lawrence Forest Region	$20,000
Crane River, Ontario	Great Lakes-St. Lawrence Forest Region	$19,400
Lusicich, Alberta	Montane Forest Region	$42,000
Enchantment Property, British Columbia	Subalpine Forest Region	$24,600

Case Studies: City of Mississauga and the City of Waterloo, Ontario

The Intact Centre on Climate Adaptation evaluated "wetland" and "no wetland" scenarios to calculate the return on investment for losses averted. The report, *When the Big Storms Hit: The Role of Wetlands to Limit Urban and Rural Flood Damage*, assesses the potential for wetlands to affect the financial impacts associated with rural and urban flooding (Intact Centre on Climate Adaptation, 2017). These findings have national applicability, albeit the research focused on two Southern Ontario pilot sites, one rural and one urban. For both sites, computer models simulated a major fall flood to compare flood damages under conditions where wetlands were maintained in their natural state and where they were replaced with agricultural land use. The researchers found that flood damages were lower if wetlands were maintained in their natural state, with financial cost savings of 29% and 38% in rural and urban areas, respectively.

Case Study: Toronto, Ontario

The Canadian Impact Infrastructure Exchange conducted a triple bottom line (financial, environmental, social) cost-benefit analysis of Raindrop Plaza in Toronto, Ontario during the project's design phase (Canadian Impact Infrastructure Exchange, 2017). Raindrop Plaza is a Green Streets Pilot Project for the City of Toronto planned for 2018 construction focused on managing stormwater runoff with permeable pavement, rain gardens, an infiltration trench, and a substantial volume of high quality soil to grow healthy native and drought-tolerant trees (with soil stored in an engineered soil cell system below the paving). In addition to stormwater management with urban forest creation, the project is intended to provide recreational space for community enjoyment and environmental education opportunities (Sheila Boudreau, personal communication, May 3, 2018). An associated cost-benefit analysis evaluated the financial, social, and environmental benefits of the project over a 40-year period compared with a baseline scenario in which the project was not implemented. The analysis revealed that while the benefits would not completely offset the financial cost of the project, they would significantly reduce the net cost. The report provides a detailed methodology for this process as well as further details on the specific Raindrop Plaza analysis (Canadian Impact Infrastructure Exchange, 2017).

Chapter 4: Knowledge Gaps and Implementation Challenges

A number of knowledge gaps and implementation challenges have emerged as natural infrastructure projects and programs have grown. Common gaps and challenges revealed through the literature and a series of interviews with experts from across the natural infrastructure field are detailed below. Our research in this Chapter and in Chapter 5 draws from expert interviews from natural infrastructure researchers and practitioners.

Institutional Capacity

There is a lack of institutional capacity in Canada to oversee and strategically implement natural infrastructure. The cross-cutting nature of several co-benefits of natural infrastructure make it hard to classify responsibilities (water managers, energy managers, engineers, etc.) (Steven Peck, personal communication, May 4, 2018). Miscommunication about natural infrastructure goals between multiple jurisdictions and levels of government has occurred: in one case, for example, existing wetlands were cleared to construct a highway while a contentious manmade flood defence system was approved nearby without full consultation between implicated levels of government (Craig Stewart, personal communication, May 8, 2018). In addition, local municipalities often have limited resources (funding, staff, expertise, etc.) and many responsibilities, making it challenging to change existing practices and adopt natural infrastructure.

The capacity for including natural infrastructure considerations into planning and development varies among municipalities. Rural areas, for example, can have little to no capacity, but have significant potential for enhancing resilience through natural infrastructure (Sabine Dietz, personal communication, May 18, 2018). There are also no simple tools for municipalities to use. This is a challenge because decision makers at the municipal level approve funding, but may not understand natural infrastructure and may not have clear resources to aid them in understanding and making appropriate decisions (Sabine Dietz, personal communication, May 18, 2018). Funding match requirements, which are often stipulated for federal funding, also may result in larger-scale projects receiving awards while leaving gaps for smaller, possibly more strategic projects (Craig Stewart, personal communication, May 8, 2018).

Solutions that may help to address institutional capacity challenges include:

- Forming new entities at the provincial, regional, and federal levels to help address the multifaceted and multi-sector aspects of natural infrastructure, as well as to ensure a more strategic approach for implementation at regional or national levels (Steven Peck, personal communication, May 4, 2018). This would hopefully reduce miscommunication and create opportunities to work through any conflicting goals across different levels of government and with stakeholders.
- Providing federal or provincial funding opportunities to local municipalities to build capacity. Although many studies have concluded that natural infrastructure is cost-effective, adopting and implementing natural infrastructure requires training staff and

changing operations and maintenance processes, which can be difficult for municipalities to support (Sara Jane O'Neill, personal communication, May 2, 2018).

- Expanding NGO-led capacity building to bridge the gap between local communities and federal funding, and to help money flow to landowners to incentivize restoration of natural infrastructure such as wetlands. Effective results from federal funding requires a pull from the bottom up rather than a push from the top down (Craig Stewart, personal communication, May 8, 2018). NGOs can provide ecological, biological, and environmental knowledge, which is critical to natural infrastructure considerations.
- Developing technical reports and guidance documents that are user-friendly, cost-effective, and rely on publicly available data. Given the limited capacity of municipalities, one method is to tailor resources and methods toward decision-making needs to ensure that data collection and analyses efficiently address the concerns of decision-makers and the public (Sara Jane O-Neill, personal communication, May 2, 2018).
- Providing easy-to-understand educational tools and trainings to municipal staff to help with data collection, data analysis, and decision making.
- Supporting communities of practice. For example, the Canadian and American coastal community is developing a bi-national community of practice on Cold Regions Living Shorelines (Coastal Zone Canada Association, 2018).

Technical Knowledge and Skill

Local governments, engineers, and planners are only going to fund and adopt natural infrastructure if they are aware of its benefits and options. There is currently a shortage of trained professionals who have the familiarity with the concept and the methods of implementation for natural infrastructure projects. There is, therefore, a strong need to educate more planners, government leadership, and community members about nature-based solutions and to train more engineers in nature-based approaches (DG Blair, personal communication, May 1, 2018; Department Official, Canadian Wildlife Service). Developing natural infrastructure expertise can also be difficult as design, and implementation can require ecological and engineering professionals to work together—which they may not be accustomed to doing.

In addition, many municipalities and practitioners are hesitant to change current standards and practices. For municipalities, there is a lack of understanding about how natural infrastructure works and how management processes and tools may change (Sara Jane O-Neill, personal communication, May 2, 2018). For practitioners, there is hesitancy to learn new skills, integrate new research-based knowledge into practice, and apply new standards. New science and research regarding natural infrastructure has therefore been slow to translate into practice (Danielle Dagenais, personal communication, May 3, 2018).

Several interviewees mentioned that there is a lack of training for the professional design, construction and landscape community on proper design, implementation, and maintenance of natural infrastructure. This results in a lack of professionals who can actually work with local communities and residents to successfully implement and maintain natural infrastructure practices (Christine Zimmer, personal communication, May 2, 2018; Nathalie Bleau, personal communication, May 7, 2018; Department Official, Canadian Wildlife Service).

In addition to engineers and planners, there is also a lack of knowledge within permitting agencies, such as conservation authorities. Permitting agency staff could be trained and educated on the latest technologies and skills so they are better able to give and support permits for more innovative projects (Jenny Hill, personal communication, May 9, 2018).

Finally, a few participants indicated that post-secondary institutions should teach more about the benefits and challenges of natural infrastructure and encourage engineers and landscapers to use those natural solutions. (Department Official, Infrastructure Canada).

One solution that may help to address technical knowledge and skill challenges is pilot projects combined with peer-to-peer learning, which can build technical expertise among communities in a region. This helps practitioners learn about methods to analyze risks, costs, and benefits and develop approaches to integration within existing systems. Many of the examples provided in the case studies throughout this report are pilot projects, or at least started out that way.

Awareness of Benefits in Developing the Business Case

Increasing public awareness about the benefits of natural infrastructure can increase support for future projects as well as potential opportunities for private property owners to install their own natural infrastructure, such as rain gardens. Effective communication strategies such as presentations and workshops, media campaigns, and websites can relay that information to the public to build support and buy-in (Roy Brooke, personal communication, April 30, 2018; Nathalie Bleau, personal communication, May 7, 2018; Maija Bertule, personal communication, May 8, 2018; Department Official, Canadian Wildlife Service). Educational resources such as the Maritime Natural Infrastructure Collaborative (MNIC)'s *How to Talk about Ecosystem Services* guidebook, provide communication strategies and guidance on how to frame the benefits of natural infrastructure and increase awareness and support (The Maritime Natural Infrastructure Collaborative, 2018a).

<u>Building the "Business Case"</u>

Monitoring and reporting of the actual costs and actual performance benefits realized through natural infrastructure projects implementation would be highly beneficial to advancing the practice and raising awareness. A body of knowledge and transparency on the measured costs and benefits as observed on-the-ground is required to build robust business cases for natural infrastructure conservation/restoration in Canada (Natalia Moudrak, personal communication, May 9, 2018; Department Official, Infrastructure Canada).

Without raising awareness or sharing tangible progress of the benefits natural infrastructure can provide, it can be difficult to gain community and political support, especially with many competing priorities. Adopting new practices requires a strong will to change as well as a strategic interest in the benefits of natural infrastructure. Raising community awareness and cross-sectoral communication may reveal that natural infrastructure can address a number of strategic priorities simultaneously. Community interest and political will are ultimately key to carrying natural infrastructure projects and initiatives forward (Maija Bertule, personal communication, May 8, 2018).

Solutions that may help to raise awareness of the benefits in building a business case for natural infrastructure include a multifaceted approach to communicating with relevant stakeholders including through the use of webinars, town halls, media campaigns, and workshops within the community. To accompany these communications efforts, resources such as brochures, guidebooks and toolkits can be developed and distributed to support decision-makers and in raising the awareness of the potential uses of natural infrastructure in the community.

Data Needs/Lack of Data

One challenge regarding data is that natural infrastructure decisions are very location-specific and require specific localized data that may not be available or that a municipality may not have the capacity to gather (Danielle Dagenais, personal communication, May 3, 2018; Sara Jane O'Neill, personal communication, May 2, 2018; Hope Parnham, personal communication, May 7, 2018; Luke Sales, personal communication, May 1, 2018; Department Official, Infrastructure Canada). Quantifying the benefits of natural infrastructure, and particularly accounting for the wide array of co-benefits, can require considerable resources for data collection and processing (Maija Bertule, personal communication, May 8, 2018). In addition, evaluating multiple aspects and benefits of natural infrastructure requires different tools and data sources, which may be difficult to obtain or compare (Sara Jane O'Neill, personal communication, May 2, 2018). Under existing practices, a variety of tools and methods have been used to investigate stormwater capacity, wildfire implications, ecosystem impacts, etc. Without a standard methodology in place for data collection, it will be difficult to scale up or translate results to different projects. Natural systems have distinct location-specific differences, and as a result these differences cannot be overcome without losing a lot of information in a high-level approach. Including local ecologists and biologists in the conversation is critical to understanding and accounting for local characteristics (Sabine Dietz, personal communication, May 18, 2018). To help address this challenge, the Maritime Natural Infrastructure Collaborative is currently assessing local needs and approaches to develop a toolkit to aid in awareness, data collection, and decision making (The Maritime Natural Infrastructure Collaborative, 2018b).

Another challenge to consider is that, unlike valuing grey infrastructure—where the metrics are mainly quantitative and straightforward to assess—natural infrastructure and its co-benefits can be difficult to measure and rely more heavily on qualitative assessments (Emanuel Machado, personal communication, May 5, 2018; Sara Jane O'Neill, personal communication, May 2, 2018; Luke Sales, personal communication, May 1, 2018; Department Official, Infrastructure Canada). Caution should be exercised when using the benefit-transfer technique for estimating monetary benefits of natural infrastructure projects. This technique relies on borrowing unit values developed to assess the value of natural infrastructure features at one location and applying these unit values to another location. However, no two ecosystem sites are identical and the relationships between the total areas and benefits produced are not linear. As well, each community will value benefits of natural infrastructure projects differently, so it is important to survey local residents regarding the value they attribute to natural infrastructure features being evaluated. Transparency in how these economic benefits are calculated for various natural infrastructure projects is key to increasing the acceptance of natural infrastructure project benefit valuations (Natalia Moudrak, personal communication, May 9, 2018).

One solution would be to start quantifying benefits and incorporating more natural asset management policies. An example to look to is the Town of Gibsons, BC, which has an effective asset management program. The “Gibsons approach” could be transferred to other municipalities (Luke Sales, personal communication, May 1, 2018; Department Official, Infrastructure Canada). The Town’s approach is defined by identifying, cataloguing, and maintaining natural assets in much the same way that the municipality does so for hard assets. For example, its aquifer is seen as a key natural asset that provides water to the town. By including the aquifer in its asset management plans and by developing an eco-asset strategy, the Town is able to explicitly value natural capital and maintain its natural assets as part of standard operations (Emanuel Machado, personal communication, May 4, 2018). This practice allows the municipality to justify maintenance costs for natural infrastructure in the same way it does for grey infrastructure projects (Natalia Moudrak, personal communication, May 9, 2018).

Municipalities must comply with asset management requirements, creating an opportunity for municipalities to expand their asset management efforts (e.g., scheduling, budgeting, project prioritization) to include natural assets. Gibsons became the first municipality in North America to pass a municipal asset management policy that “explicitly defines and recognizes natural assets as an asset class; and creates specific obligations to operate, maintain and replace natural assets alongside traditional capital assets” (Town of Gibsons).

The work in Gibsons proved to have many benefits. For instance, the Town determined that “the stormwater services provided by ponds in White Tower Park have a value of $3.5-$4.0 million if they had to be replaced by an engineered asset, a cost that can be avoided through regular maintenance in the Park” (Sahl 2016; Town of Gibsons, 2017). Additionally, in 2015, at a stakeholder meeting to review the Town’s experience and its applicability elsewhere, participants concluded that “its approach could—and should—be replicated” (Town of Gibsons, 2017). The City of Grand Forks, BC; City of Nanaimo, BC; District of West Vancouver, BC; Town of Oakville, ON; and Region of Peel, ON, are currently considering the “Gibsons approach” as part of their asset management programs (Town of Gibsons, 2017).

Several participants also mentioned the need to quantify the health benefits of natural infrastructure, and the need for a standardized cost-effectiveness methodology to prioritize work (Department Official, Infrastructure Canada).

Monitoring natural infrastructure carries data challenges, particularly around identifying indicators for measuring the health of natural assets. Such measurement is important, as healthier natural assets (e.g., mixed forest) confer greater impact and benefits than unhealthy assets that have low ecological function (e.g., planted monoculture). Similarly, it is important to understand thresholds of natural assets: that is, how much surrounding development and disruption natural assets can experience before their ability to function is diminished or negated. At this time, however, information on these indicators and thresholds—particularly region-specific information—still needs to be developed.

Political Environment

The political environment often favours what is widespread and has known economic and technical data (grey infrastructure) over less prevalent solutions (natural infrastructure).

In cases where the economic system is focused on short-term investment returns, it is difficult to make natural infrastructure—such as the preservation of wetlands/riparian forest systems—politically important (Steven Peck, personal communication, May 4, 2018).

Solutions that may help to address an adverse economic-political environment include:

- Develop new economic instruments that recognize the value of nature and support conservation (Dan Kraus, personal communication, May 3, 2018).
- Incentives for keeping wetlands on the landscape (Dan Kraus, personal communication, May 3, 2018; Craig Stewart, personal communication, May 8, 2018).

In addition, natural infrastructure and the maintenance and preservation of natural resources are tied deeply to Indigenous rights, culture, and wellbeing, which have historically received lower political priority (Eriel Deranger, personal communication, May 8, 2018).

Strategies and initiatives that may elevate the priority of these concerns include:

- The Indigenous Circle of Experts, which is an initiative that works to recognize Indigenous rights while protecting natural systems—goals that are mutually supportive (Eriel Deranger, personal communication, May 8, 2018).
- Valuing Indigenous science, which has been developed over generations, at the same level as Western science. Indigenous science often includes deep knowledge of ecological processes that are fundamental to ensuring healthy functioning of natural systems, and has a history of practicing adaptation and resilience (Eriel Deranger, personal communication, May 8, 2018).

Policy and Regulatory Barriers

The complexity of the regulatory environment is one of the largest barriers to implementing natural infrastructure (DG Blair, personal communication, May 1, 2018). The existing regulatory framework is based on standard engineering approaches that are not necessarily supportive of natural infrastructure projects (DG Blair, personal communication, May 1, 2018; Sara Jane O'Neill, personal communication, May 2, 2018). Also, there is no standard national approach for natural infrastructure; the policies and regulations that do exist vary across municipalities and provinces and territories (Sara Jane O'Neill, personal communication, May 2, 2018; Department Official, Canadian Forestry Service).

In addition, there is currently a perception of limited federal and provincial funding to support natural infrastructure projects and programs and to identify areas of particular importance for ecological services (DG Blair, personal communication, May 1, 2018; Dan Kraus, personal communication, May 3, 2018). Complicating matters is the fact that while the federal government provides resources, provincial and territorial governments are the land managers, and the effects are often felt by municipalities and local communities. This means that proponents of natural infrastructure must work with multiple levels of decision makers to support and implement nature-based solutions (Florence Daviet, personal communication, May 8, 2018).

Federal, provincial, or territorial policy changes and incentives that may encourage more implementation of natural infrastructure include:

- Setting aside a designated proportion of federal funding specifically for natural infrastructure (Dan Kraus, personal communication, May 3, 2018).
- Reviewing and revising current regulations and policies that may reduce the effectiveness of existing natural infrastructure, such as land clearing and agricultural drainage practices (Dan Kraus personal communication, May 3, 2018). Similarly, existing policies and regulations can inadvertently prevent the development of natural infrastructure projects (e.g., separating nature from the built environment or only having intensively managed landscapes), so governments at all levels could reassess their land-use policies and associated regulations to identify and remove such barriers (Department Official, Canadian Wildlife Service).
- Developing a federal freshwater strategy for addressing nonpoint pollution that prioritizes impaired watersheds for action (Dan Kraus personal communication, May 3, 2018).
- Building capacity and support for land trusts and other conservation organizations to partner with private land owners to establish strategic, long-term conservation easements on lands that provide key watershed services (Dan Kraus, personal communication, May 3, 2018).
- Offering incentives for natural infrastructure options such as fast-track permitting and tax incentives (DG Blair, personal communication, May 1, 2018; Hope Parnham, personal communication, May 7, 2018). Combining incentives with regulation so that the option to support natural infrastructure is taken more seriously. A benefit for adhering to the regulation can be a useful strategy (Department Official, Canadian Wildlife Service).

Local policy changes and incentives may also encourage more implementation and better protection of natural infrastructure, such as:

- Community building standards should incorporate natural infrastructure from the start in the build-out phase (Craig Stewart, personal communication, May 8, 2018). Similarly, requiring development permits for new grey infrastructural projects, and making sure that these permit applications undergo robust review with respect to their impact on natural processes and ecosystems, can elevate the importance of existing natural assets and ensure that they are properly maintained and protected (Emanuel Machado, personal communication, May 4, 2018).
- Incorporating natural asset considerations into existing policies and practices. Creating new policies and practices can be challenging and resource-intensive. Municipalities should instead review their existing policies and practices and enhance them with natural infrastructure considerations (Sara Jane O'Neill, personal communication, May 2, 2018).
- Evaluating existing problem areas or projects to identify opportunities for a hybrid approach with natural infrastructure considerations (Danielle Dagenais, personal

communication, May 3, 2018). Rather than seeking out new natural infrastructure projects, municipalities could instead assess existing projects, such as replacing a culvert, for opportunities to add natural infrastructure components.

- Using existing operational funding streams to cover the cost of natural infrastructure. For example, the Town of Gibsons includes the costs of monitoring their aquifer, which it considers a critical natural asset, in the cost they charge for water so that maintaining this asset is financially sustainable (Emanuel Machado, personal communication, May 4, 2018).

Societal Impacts

Natural infrastructure makes neighbourhoods healthier and more aesthetically attractive, which can increase property values and housing costs. Ultimately, this may create environmental gentrification. Thus, when cities are implementing natural infrastructure, they must ensure that they are inclusive of low-income urban communities (Department Official, Infrastructure Canada).

Similarly, for urban heat island considerations, more prosperous neighbourhoods tend to have a greater tree canopy than less prosperous neighbourhoods. As a result, the urban heat island effect disproportionally affects these neighbourhoods and may exacerbate existing vulnerabilities. Municipalities should prioritize planting trees in neighbourhoods where they will have the greatest impact increasing the tree canopy and decreasing the urban heat island (Michelle Sawka, personal communication, May 22, 2018).

Maintenance Challenges

Maintenance of natural infrastructure is another critical barrier to increased adoption. Grants to fund natural infrastructure often stop at implementation without funding for maintenance. Natural infrastructure maintenance primarily focuses on caring for vegetation over time so that the natural infrastructure reaches its maximum potential. Urban trees, for example, would benefit from a watering budget for the first five years until their roots are well established (Michelle Sawka, personal communication, May 22, 2018). Without funding for long-term maintenance, the functionality and aesthetic appeal of a "green project" decreases, resulting in lack of public support (Department Official, Infrastructure Canada; Nathalie Bleau, personal communication, May 7, 2018; Danielle Dagenais, personal communication, May 3, 2018).

Another part of the maintenance challenge arises from the fact that natural infrastructure often needs adequate space to function (e.g., a wetland must be of a certain size to maintain habitat integrity). However, areas that have already been developed have little available space, and land surrounding the edges of these natural infrastructural projects is subject to disturbance and development that can then affect the natural infrastructure. If the assessment and implementation of natural infrastructure does not properly account for these needs such as adequate space, the natural infrastructure may not function at its full potential.

Chapter 5: Lessons Learned and Opportunities

The following sections detail lessons learned and keys to success from existing natural infrastructure initiatives, projects, and programs. The insights in this chapter, similar to those in Chapter 4, are based on interviews with a variety of natural infrastructure experts.

Identify a Champion

Identifying a champion within the region or community can be key to the success of natural infrastructure initiatives and programs. A champion is willing to push projects forward and take chances in order to achieve the goals of the initiative or program (Danielle Dagenais, personal communication, May 3, 2018; Michelle Sawka, personal communication, May 22, 2018). For example, researchers from Polytechnique Montréal and the University of Montréal worked closely with the City of Trois-Rivières to implement a series of natural infrastructure projects along the street of Saint-Maurice and attributed the completion of the overall project to having a local champion (Danielle Dagenais, personal communication, May 3, 2018). The pilot project consisted of incorporating raingardens, bioswales, and trees and other vegetation along the 1.3km street to reduce stormwater runoff and decrease heat island effects (Trois-Rivières , 2018). The City has indicated that performance studies will be conducted once the work is completed. If these infrastructure projects prove to be effective, the pilot may serve as an example to other municipalities to replicate this type of development elsewhere in the province of Québec.

The City of Toronto's urban designer similarly acted as a designated champion for innovative natural infrastructure initiatives to meet the Toronto Green Standard. With the support of an engineer from Toronto Water and the Chief Planner, the effort culminated in the development of Toronto's Green Streets Technical Guidelines (Schollen & Company Inc. et al., 2017; Sheila Boudreau, personal communication, May 3, 2018).

Develop an Interdisciplinary Team

Due to the multifaceted nature of natural infrastructure, there are multiple interests and perspectives involved. Successful implementation of natural infrastructure therefore requires a dedicated and diverse team of stakeholders and professionals, including landscape architects, engineers, planners, environmental scientists, foresters, community members, and others. (Danielle Dagenais, personal communication, May 3, 2018; Jenny Hill, personal communication, May 9, 2018). Different team members have different skills and perspectives to contribute to the project which can lead to greater project richness and success. For example, engineers are fundamental to the design and functionality of natural infrastructure projects, whereas landscape architects are fundamental to social and environmental aspects such as ensuring the project provides ecosystem services, improves quality of life, and enhances neighbourhood aesthetics (Danielle Dagenais, personal communication, May 3, 2018).

Given the status quo, these practitioners often operate in silos, with limited communication between one another. To ensure that best practices, data, and other resources are shared openly across disciplines to work toward the best solutions, it is important to have open lines of communications between these fields and to facilitate collaboration (Florence Daviet, personal communication, May 8, 2018; Hope Parnham, personal communication, May 7, 2018; Maija Bertule, personal communication, May 9, 2018). There may also need to be discussion about changing the behaviour of certain stakeholders, such as upstream farmers' impact on downstream water quality (Maija Bertule, personal communication, May 8, 2018).

Developing these sorts of partnerships is fundamental to successful implementation. The Town of Gibsons found that the partnerships it had established with stakeholders and supporters such as private and non-profit organizations, including the David Suzuki Foundation through a Memorandum of Understanding with clearly defined roles and visions, was important to realizing its goal of properly recognizing and managing critical natural assets. These partnerships allowed the small town to increase its capacity to evaluate its natural assets and develop an eco-asset strategy. The success from the Town of Gibsons has been translated into the Municipal Natural Assets Initiative (MNAI), which the Town co-founded and which now provides expertise and resources to other municipalities seeking to incorporate natural asset management strategies into their financial planning and asset management operations (Emanuel Machado, personal communication, May 4, 2018).

In the City of Toronto, there is a disconnect between city departments about roles and responsibilities in implementing the Green Streets Technical Guidelines (Sheila Boudreau, personal communication, May 3, 2018). Assigning clear roles to each department is key to moving forward with this work, which is required to achieve the Toronto Green Standard and the City's Official Plan policies.

Train and Educate Professionals and Community Members

Seeing natural infrastructure projects in practice in other locations can be a more effective way to accelerate and improve the implementation of natural infrastructure than providing municipalities with the latest research findings (Danielle Dagenais, personal communication, May 3, 2018). Pilot projects and guided tours are other useful strategies for educating and encouraging communities to implement natural infrastructure projects (Danielle Dagenais, personal communication, May 3, 2018). Developing positive, empirical examples from cases where natural infrastructure has been successfully implemented is important for adding credibility to the argument for implementing natural infrastructure solutions. These examples can also be used to train practitioners in lessons learned and best practices (Florence Daviet, personal communication, May 8, 2018.)

The RAIN program, a Green Communities Canada urban stormwater education program, delivered in Waterloo Region by Reep Green Solutions, attributes the success of its RAIN Smart Neighbourhoods project to a comprehensive engagement strategy that includes a "RAIN coach" on staff, who provides ongoing support during the design phase of projects to participants in the program (Reep Green Solutions, 2018; Patrick Gilbride, personal communication, May 23, 2018). The RAIN coach works with participants to identify their goals for their outdoor space and low-impact development strategies and best practices that can be incorporated into the site plan that can help reach those goals. In addition, signage is used on demonstration projects to raise awareness among neighbourhood homeowners about the program and stormwater management possibilities for their own properties (Patrick Gilbride, personal communication, May 23, 2018). The RAIN program has also supported initiatives for businesses and individual homes.

Another form of education is information sharing. For example, the Town of Gibsons found that many of its natural assets, such as its watershed and aquifer, extend beyond the town boundaries. When the town mapped the watershed and aquifer, it included their full geographic range and shared the resulting information with neighbouring stakeholders with the aim of helping these other relevant parties amend their processes to more fully protect this vital and shared asset (Emanuel Machado, personal communication, May 4, 2018). In addition, communities of practice are a very effective network to share information. For example, the Cold Regions Living Shorelines Community of Practice is currently being developed by Coastal Zone Canada, with the goal of providing information to public and private stakeholders based on science and engineering principles tailored to our northern climate (Coastal Zone Canada Association, 2018).

The Municipal Natural Assets Initiative (MNAI) provides resources for local municipalities interested in including natural assets in their asset management plans and strategies. The Initiative started with the Town of Gibsons, which developed an Eco-Asset Strategy in order to secure sustained support for its valued natural assets and to mainstream natural asset management into the town's general practices (Town of Gibsons, 2015). The MNAI site provides resources for communities interested in undertaking similar initiatives.

An example of a training and education program in action is Green Shores, a successful British Columbia shoreline natural infrastructure initiative of the Stewardship Centre for BC that lays out design standards, best practices, and credits and rating systems for shoreline development projects to achieve Green Shores certification (DG Blair, personal communication, May 1, 2018). The voluntary program includes the *Green Shores for Coastal Development Credits and Rating Guide* for municipal parks, mixed use residential, and institutional shoreline properties and the *Green Shores for Homes Credits and Rating Guide* for residential shoreline property owners (Stewardship Centre for British Columbia, 2010; Stewardship Centre for British Columbia, 2015).

Training and education have been critical to the success of this program (DG Blair, personal communication, May 1, 2018). To increase awareness and use of the program, the Stewardship Centre for BC developed a series of training curriculum and courses to educate communities and engineers about the Green Shores certification process and criteria. There has since been an increased interest in the program, including the development of local working groups, partnerships with universities, and continued expansion of the training series. In addition, having the credit and rating system guidance in place has encouraged the use of best practices in more coastal development projects. The Green Shores credit and rating systems, training series, and partnerships and community engagement activities have all helped to facilitate growth and awareness of nature-based solutions and the Green Shores program.

Another example of technically driven trainings are those accompanying the Sustainable Technologies Evaluation Program (STEP) low-impact development resources (Toronto and Region Conservation Authority, Undated). STEP is a collaborative program between Toronto

Region Conservation Authority, Lake Simcoe Conservation Authority, and Credit Valley Conservation Authority. Together they hold regular training events on the content of the Low-Impact Development Stormwater Management Planning and Design Guide to help decrease the technical knowledge gap mentioned previously (Jenny Hill, personal communication, May 9, 2018; Toronto and Region Conservation Authority, 2018b). There is strong interest in these TRCA programs; as a result there are plans to develop an enhanced online forum for professionals to post comments and communicate with one another (Jenny Hill, personal communication, May 9, 2018; Toronto and Region Conservation Authority, 2018b). Having resources and knowledge about what others are doing, as well as a way to communicate directly with those involved, can be very helpful for those who want to implement similar strategies (Jenny Hill, personal communication, May 9, 2018).

Focus on Community Goals and Values

Natural infrastructure provides an array of added environmental, social, and economic benefits, in addition to its main purpose of water or heat management. Focusing the conversation on how natural infrastructure can help achieve community goals and values, such as public health, social wellbeing, aesthetic value, recreational spaces, increased property values, or resilience is a useful tool for increasing community interest in nature-based solutions (Patrick Gilbride, personal communication, May 23, 2018). The public health services and values of urban forests, for example, are becoming a key municipal interest (Department Official, Canadian Forestry Service).

Articulating the costs of maintaining urban forests as well as the cost savings and benefits of healthy trees can help facilitate the conversation for nature-based solutions and natural asset management at the municipal level (Michelle Sawka, personal communication, May 22, 2018). Similarly, communications with businesses about natural infrastructure tend to be more effective when focused on the bottom line or how a nature-based solution could help operations, such as harvesting and recycling rainwater for a production mechanism (Patrick Gilbride, personal communication, May 23, 2018).

In addition, actively engaging the community and developing robust processes of outreach and participation can not only increase chances of community buy-in and support, but can also mitigate potential negative consequences of the proposed natural infrastructure, such as gentrification, inadequately addressing community needs, or not considering the impact on future generations. The Indigenous planning concept of considering the impact of decisions on seven generations into the future is well suited to this sort of thoughtful, robust, community-oriented, long-term planning (Chris Buse, personal communication, May 30, 2018).

Indigenous co-management

In many cases, natural infrastructure can go hand-in-hand with upholding Indigenous rights and sovereignty (Eriel Deranger, personal communication, May 8, 2018). Currently, the standard practice is to consult Indigenous communities when it comes to land-use decisions (Eriel Deranger, personal communication, May 8, 2018). As outlined in “Aboriginal Consultation and Accommodation – Updated Guidelines for Federal Officials to Fulfill the Duty to Consult - March

2011", land use planning and development decisions will sometimes trigger a legal duty to consult Indigenous communities. That said, greater benefits can be accrued when the process moves from consultation under legal duty to engagement and full co-management of projects integrating Indigenous values and traditional knowledge. Recently, the Squamish Nation worked with a liquefied natural gas company that wanted to build on the Nation's land. The Squamish Nation conducted its own environmental assessment (EA) in tandem with the standardized default EA and issued its own certificates for the project. In doing so, the Nation had the decision-making power to relocate the compressor station out of downtown Squamish and to eliminate any industrial disturbance in the Skwel'wil'em Wildlife Management Area—power that wasn't inherent in the default process. While this example arises from industrial land-use development, the same process can be applied to natural infrastructure planning to ensure equitable and holistic decision making (Chris Buse, personal communication, May 8, 2018).

Develop Regulatory and Financial Incentives

Developing regulatory incentives is an important strategy to creating a policy and financial environment that is conducive to natural infrastructure. It is also important to include natural infrastructure in local, provincial, and national policies and practices. Similar to the *Benefit Cost Analysis Guide* produced by the Treasury Board of Canada Secretariat, which guides the assessment of regulatory and non-regulatory proposals by departments and agencies in Canada (Treasury Board of Canada Secretariat, 2007), there should be a national Natural Infrastructure Benefit Cost Analysis Guide. Without a standard guide, there is a hodge-podge of valuation approaches implemented across the country to value natural infrastructure assets and it is difficult for institutional investors, corporate sponsors and foundations to incentivize wider adoption of natural infrastructure projects / unlock further investment into natural infrastructure. Creating such a guide and investing further into natural infrastructure solutions would align strongly with natural infrastructure preservation commitments Canada has made under *The Paris Agreement* (United Nations Climate Change, 2016), the United Nations' *Sendai Framework for Disaster Risk Reduction* (United Nations Office for Disaster Risk Reduction, 2015), and the *Pan-Canadian Framework on Clean Growth and Climate Change* (Government of Canada, 2018) (Natalia Moudrak, personal communication, May 9, 2018).

Financial incentives can help spur investment in new approaches such as the use of natural infrastructure to reduce the financial risk to communities. These incentives can support pilot projects or small scale installations for longer term projects.

Ouranos, for example, funded research on large-scale stormwater management projects worldwide, which revealed that fines from a higher level of government are particularly effective incentives for cities to control and implement large-scale stormwater projects (Danielle Dagenais, personal communication, May 3, 2018; Dagenais, Paquette, Thomas, & Fuamba, 2014).

At a local scale, the RAIN Smart Neighbourhoods Project has seen great success in part due to setting aside $43,000 in financial incentives for participants who use rain gardens, infiltration galleries, permeable pavement, cisterns, or rain barrels to manage stormwater on their properties (Reep Green Solutions, 2018). In addition, RAIN projects completed in Kitchener, Ontario are also eligible for stormwater credits from the City. Residential and non-residential property owners who qualify for stormwater credits receive a reduction on the stormwater portion of their utility bill (City of Kitchener, 2017).

Tax incentives to conserve and manage natural areas in Ontario have garnered increasing participation, and subsequently led to more natural land under protection. The Conservation Land Tax Incentive Program protects important natural areas by qualifying certain privately owned lands with “eligible natural heritage features,” such as wetlands and habitats of endangered species, for 100% property tax exemption (Ontario Ministry of Natural Resources and Forestry, 2018a). The Managed Forest Tax Incentive Program protects forested land by allowing property owners of “managed forest” to pay only 25% of the municipal tax rate set for residential properties, so long as they prepare and follow a 10-year Managed Forest Plan and provide progress reports and plan updates (Ontario Ministry of Natural Resources and Forestry, 2018b).

Utilize Available Funding Opportunities

Natural infrastructure is eligible under both the Integrated Bilateral Agreements (IBAs) and the Disaster Mitigation and Adaptation Fund (DMAF), both components of the Investing in Canada Plan that is managed by Infrastructure Canada. IBAs could be an important source of funding for natural asset rehabilitation (Roy Brooke, personal communication, April 30, 2018). The Canadian government has set aside billions of dollars through IBAs for green infrastructure, divided into climate change mitigation; adaptation, resilience and disaster mitigation; and environmental quality funding streams. The DMAF has set aside $2 billion for large-scale infrastructure projects that will better prepare communities for natural hazard-based disasters (Infrastructure Canada, 2018). Projects funded under these streams must be large scale (i.e., over 20 million) or bundled together in order to achieve the threshold. Therefore, this funding, if utilized more by proponents for natural infrastructure projects could maximize benefits and outcomes for natural solutions for large-scale projects.

Consider Long-Term Changes in Climate

Although many natural infrastructure projects do have a climate resilience benefit in addition to the main purpose of water or heat management, natural infrastructure projects should actively consider the implications of long-term changes in climate. For example, in addition to looking at the areas that currently flood, projected future changes in rainfall patterns and the frequency or intensity of extreme events should also be considered for the area of interest (Maija Bertule, personal communication, May 8, 2018). Project design should consider these projections as well as the effect of the future climate on the vegetation and ecosystem services intended through the natural infrastructure option. Vegetation should be chosen based on its ability to survive under a range of potential future climate conditions (Department Official, Canadian Forestry Service). The risks associated with natural infrastructure under climate change should also be considered—such as whether natural infrastructure will provide the same ecosystem services in the future under climate change and whether it may create new risks, such as the spread of more vector-borne diseases due to the presence of standing water (Maija Bertule, personal communication, May 8, 2018). Pests could also pose a risk in the future. A past example is the spread of Emerald Ash Borer, which resulted in huge removal costs and devastation to urban ash trees (Department Official, Canadian Forestry Service).

Appendices

A. Research Methodology for Literature Review and Interviews

For the literature review, resources were collected from CCME as well as through targeted internet searches using terms, such as:

- Natural infrastructure
- Green infrastructure
- Nature-based solutions
- Living shorelines
- Engineering with nature
- Building with nature
- Working with nature
- Specific examples of natural infrastructure (e.g., bioswales, retention ponds, green roofs)

Searches were specifically focused on the four hazards profiled in this report: coastal storms and flooding, riverine flooding, urban and rural stormwater, and urban heat islands.

For the interviews, potential interviewees were either provided by CCME or identified through presentations, guidance documents, and relevant membership organizations. A total of 25 interviews were conducted between April 30 and May 30, 2018.

B. List of Interviews

1. Roy Brooke, Municipal Natural Assets Initiative, interviewed by Tiffany Michou, ICF on April 30, 2018.
2. DG Blair, Green Shores Stewardship Centre for British Columbia, interviewed by Amanda Vargo, ICF on May, 1 2018.
3. Luke Sales, Town of Qualicum Beach, interviewed by Tiffany Michou, ICF on May 1, 2018.
4. Sara Jane O'Neill, Smart Prosperity, interviewed by Amanda Vargo, ICF on May, 2, 2018.
5. Christine Zimmer, Credit Valley Conservation, interviewed by Tiffany Michou, ICF on May 2, 2018.
6. Danielle Dagenais, Université de Montréal, interviewed by Amanda Vargo, ICF on May 3, 2018.
7. Dan Kraus, Nature Conservancy Canada, interviewed by Jamie Genevie, ICF on May 3, 2018.
8. Sheila Boudreau, Toronto and Region Conservation Authority and formerly the City of Toronto, interviewed by Amanda Vargo, ICF on May 3, 2018.

9. Steven Peck, Green Roofs for Healthy Cities and the Green Infrastructure Ontario Coalition, interviewed by Jamie Genevie, ICF on May 4, 2018.
10. Emanuel Machado, Town of Gibsons, interviewed by Samantha Heitsch, ICF on May 4, 2018.
11. Hope Parnham, Atlantic Provinces Association of Landscape Architects, interviewed by Samantha Heitsch, ICF on May 7, 2018.
12. Nathalie Bleau, Ouranos, interviewed by Tiffany Michou, ICF on May 7, 2018.
13. Sylvain Perron, David Suzuki Foundation, interviewed by Tiffany Michou, ICF on May 7, 2018.
14. Maija Bertule, United Nations Environment Programme – DHI Partnership, Centre on Water and the Environment, interviewed by Amanda Vargo, ICF on May 8, 2018.
15. Craig Stewart, Insurance Bureau of Canada, interviewed by Jamie Genevie, ICF on May 8, 2018.
16. Eriel Deranger, Indigenous Climate Action, interviewed by Samantha Heitsch, ICF on May 8, 2018.
17. Florence Daviet, Canadian Parks and Wilderness Society, interviewed by Samantha Heitsch, ICF on May 8, 2018.
18. Natalia Moudrak, Intact Centre on Climate Change Adaptation, interviewed by Samantha Heitsch, ICF on May 9, 2018.
19. Jenny Hill, Toronto and Region Conservation Authority, interviewed by Amanda Vargo, ICF on May 9, 2018.
20. Ken Farr, Natural Resources Canada, Canadian Forestry Service, interviewed by Amanda Vargo, ICF on May 10, 2018.
21. Susan Preston, Environment and Climate Change Canada, Canadian Wildlife Service, interviewed by Samantha Heitsch, ICF on May 11, 2018.
22. Chad Nelson, François Levesque, and Jade Monaghan, Infrastructure Canada, interviewed by Tiffany Michou, ICF on May 11, 2018.
23. Michelle Sawka, Toronto and Region Conservation Authority and Green Infrastructure Ontario Coalition, interviewed by Amanda Vargo, ICF on May 22, 2018.
24. Patrick Gilbride, Reep Green Solutions, interviewed by Amanda Vargo, ICF on May 23, 2018.
25. Chris Buse, University of Northern British Columbia, interviewed by Samantha Heitsch, ICF on May 30, 2018.

Robert Capozi, New Brunswick Department of Environment; Sabine Dietz, Aster Group Environmental Services Co-operative; and Winnifred Hays-Byl, Natural Resources Canada are also cited as personal communications dated May 18, 2018, based on written comments provided to the project team.

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