CCME

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NATURAL INFRASTRUCTURE FRAMEWORK: KEY CONCEPTS, DEFINITIONS AND TERMS

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NOTE TO READER

The Canadian Council of Ministers of the Environment (CCME) is the primary minister-led intergovernmental forum for collective action on environmental issues of national and international concern. The 14 member governments work as partners in developing nationally consistent environmental standards and practices.

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EXECUTIVE SUMMARY

In 2018 the Canadian Council of Ministers of the Environment (CCME) developed *Best Practices and Resources on Climate Resilient Natural Infrastructure*. In addition to outlining best practices and key resources available to support natural infrastructure (NI) solutions, several challenges were identified which limit their uptake. These included a lack of awareness on natural infrastructure and its benefits, and inconsistent use of terminology across sectors to describe the related opportunities and key concepts.

To respond to these gaps, this *Natural Infrastructure Framework* has been developed to offer a common vocabulary for diverse users, including federal, provincial and territorial governments, interested in NI, and broader nature-based solutions (NBS).

NBS refer to nature-based measures that protect, repair and sustainably manage natural or human-modified ecosystems, with the aim of maintaining or enhancing the services provided to human communities and benefits to biodiversity. Whereas NI refers to a specific segment of NBS that uses preserved, restored or enhanced ecosystem features and materials (e.g., water, native species of vegetation, and sand and stone). to meet targeted infrastructure outcomes, while providing a range of co-benefits to the environment, the economy, community health and well-being**.**

Given the growing interest in using NBS to help governments meet the emerging infrastructure challenges, especially in light of increased pressures from changing climatic conditions, this Framework was developed to support decision-makers and practitioners. The Framework aims to communicate the wide range of NI and related NBS, using common agreed upon terms, and to improve understanding of the suite of NBS that can be implemented across jurisdictions, and their benefits.

This Framework outlines key concepts and terms that address four distinct climate-related infrastructure challenges: coastal hazards, riverine floods, municipal storm water, and extreme heat. Examples of how NBS can be used to address these challenge areas are also provided. While select infrastructure solutions may be more suitable for application in specific geographic locations (e.g., those intended to address coastal erosion are most suited for coastal regions, including the Great Lakes), the Framework is intended to be applied across jurisdictions, including Canada's rural and northern areas. The Framework does not provide specific emphasis on use of NBS for fire risk management, droughts, or remote and northern communities, outside of the four distinct challenge and solution areas listed above. While many of the NBS can be applied for those areas and purposes, further work is needed.

A summary of the four challenge and solution areas is provided below.

1 *Challenge Area:* Coastal Hazard Management | *Solution Area:* Building Coastal Resilience

Coastal Hazards

Building Coastal Resilience is becoming increasingly important in climate adaptation efforts in Canada's Northern, Pacific, Atlantic, lake and freshwater coastal regions. The heightened risk of coastal flooding from the loss of sea ice, storm surges, and changes in water level linked to shifting patterns of shoreline erosion, are key drivers of the degradation of vulnerable aquatic and terrestrial ecosystems, along with demonstrable threats to property in coastal communities.

NI features (e.g., coastal marshes, restored beaches, sand dunes and seagrass beds) typically function in tandem with hybrid infrastructure (e.g., living breakwaters) and built defenses (e.g., dykes and seawalls) in coastal settings to provide indispensable coastal hazard management.

2 *Challenge Area*: Riverine Flood Management | *Solution Area*: Overall Watershed Management

Riverine Floods

Overall Watershed Management can figure importantly as part of a climate-adaptive response to the riverine (fluvial) flooding that impacts the towns and cities, rural communities, agricultural croplands and other managed landscapes located on natural floodplains.

NI features (e.g., riparian areas and shorelines, forests, grasslands, wetlands, ponds and streams) through protection or enhancement efforts can provide upstream flood management and damage mitigation functions, while supporting hydrological and ecosystem processes beneficial to downstream communities (e.g., rudimentary water purification, aquifer recharge andnutrient cycling). At a watershed level, conserved areas (e.g., protected wetlands) are key sites for the preservation, restoration and enhancement of NI features.

3 *Challenge Area:* Municipal Stormwater Management | *Solution Area:* Green Stormwater Infrastructure

Municipal Stormwater

Green Stormwater Infrastructure has been implemented by municipalities to achieve the active and everyday management of the full rainfall-runoff spectrum. In future scenarios, it is anticipated that climate-related hazards (e.g., pluvial/overland flooding from rainfall or snowmelt, flash flooding from intense rainfall and fast runoff) will exert new pressures on storm sewer capacity, drainage and conveyance systems.

NI features (e.g., rain gardens, vegetated swales and distributed depression storage) and grey elements (e.g., reservoir, and ditch and culvert systems) work together to help restore the pre-development balance of hydrological functions in urban sites, with co-benefits to local water quality, landscape-level naturalization and wildlife habitat.

4 *Challenge:* Extreme Heat Conditions and Events | *Solution*: Urban Forestry and Greening Projects

Extreme Heat Conditions

Urban Forestry and Greening Projects can enable and help restore the ability of land and water assets to mitigate the effects of more frequent and severe heat events. Conventional approaches to urban planning have increased the amount of impermeable and low albedo surfaces in towns and cities, exacerbating the impacts of temperature rise (e.g., the creation of urban heat islands).

NI features such as street trees, soil cells, green spaces, green roofs and resilient landscaping can enhance temperature regulation in high-density settings while providing benefits for the management of soils and sediments, storm and floodwater drainage, groundwater quality and infiltration, as well as human health, food security and recreation. The greening of Canadian communities (e.g., depaving initiatives and the suitable placement of native species of vegetation), helps to achieve multifunctional land use and can create opportunities for people to interact with the natural environment.

NI has the potential to contribute to Canadian climate policy and programming, at a range of different scales and orders of government. It offers nature-based solutions to complex infrastructure challenges, including those resulting from a changing climate, often at a lower cost and with increasing returns on investment when compared to grey infrastructure. Whether ecosystems are intact and high functioning or have been negatively impacted by the effects of climate change, using preserved, restored or enhanced features of nature as infrastructure, supports their conservation as well as a sustainable flow of benefits to biodiversity and human communities.

This document provides a framework of key concepts, definition and terms to advance knowledge of infrastructure solutions that are characteristically closer to nature.

ABBREVIATIONS

CSO	Combined Sewer Overflow
DWN	Design-With-Nature
EBA	Ecosystem-Based Adaptation
EIA	Effective Impermeable Area
ES	Ecosystem Services
GI	Green Infrastructure
GOSs	Green Open Spaces
GSI	Green Stormwater Infrastructure
IPCAs	Indigenous Protected and Conserved Areas
LID	Low Impact Development
MPAs	Marine Protected Areas
NBS	Nature-Based Solutions
NCS	Nature-Based/Natural Climate Solutions
NI	Natural Infrastructure
OECMs	Other Effective Conservation Measures
PPAs	Parks and Protected Areas
SCMs	Stormwater Control Measures
SLR	Sea Level Rise

1.0 INTRODUCTION

Infrastructure planning and development approaches have traditionally been concerned with the hard and grey elements in urban or otherwise high-value settings. While these will continue to be the focus of asset management in many Canadian communities, new pressures have emerged for public and private infrastructure to achieve resilience to the effects of climate change, including:

- more variable precipitation
- earlier spring peak river- and stream-flows
- shorter snow and ice-covered seasons
- the thawing of permafrost and sea-ice
- intensified impacts of sea level rise
- conditions of increased heat and more extreme heat events.

Natural Infrastructure (NI) and other Nature-based Solutions (NBS) can incorporate or complement engineered or built assets, extend the lifespan of built infrastructure against accelerated climate-related deterioration, and help to offset some of the more damaging environmental impacts of existing grey infrastructure.

While NI initiatives have already been successfully implemented by governments and organizations across the country, there is room for increased uptake to build resilience to climate change. Decision-makers (e.g., governments, conservation authorities, and private property owners) share an interest in clear and context-specific discussion of the full implications of different infrastructure investments, including NBS, however, they may be unlikely to fund and adopt NI unless they are aware of its full spectrum of applications, associated benefits, and costs (Guerry *et al*. 2015). For example, CCME (2018) cites inconsistent terminology as a significant barrier to NI's wider uptake. As part of any communication, however, care must be taken to ensure that NBS is not communicated as a catchall solution, but as a set of proven interventions focused on the management of risk and improvement of Canadians' preparedness for a changing climate.

In what follows, a framework is outlined for understanding NI as a subset of NBS. Section 2.0 of the framework presents general terminology and concepts, providing necessary distinctions in the use of key overarching terms, and instances where different professions may use identical terms for different purposes. Section 3.0 addresses specific NI applications, techniques and practices used alone, or in combination with other related NBS, to provide or support infrastructure functions. It is important to note that as NI and NBS continue to expand, new terms, technologies and evidence of benefits will emerge.

As a means of situating NBS on Canada's evolving climate agenda, the specific applications are categorized as forms of response to four key infrastructure challenge areas, with corresponding solution areas that have been identified for each.

	Infrastructure Challenge Areas	Nature Based Solution Areas
1	Coastal Hazard Management	Building Coastal Resilience
2	Riverine Flood Management	Overall Watershed Management
3	Municipal Stormwater Management	Green Stormwater Infrastructure
4	Extreme Heat Conditions	Urban Forestry and Greening Projects

The Terminology Framework is a high-level introduction to NI and broader NBS, and it includes applications capable of contributing to climate adaptation efforts in Canada. As decision-makers and practitioners work to incorporate new technologies, investment and management approaches, the scope of terminology to solution areas may expand beyond what is included in this report.

2.0 GENERAL TERMINOLOGY

NBS have strong potential to enhance responses to climate change risks and related infrastructure challenges throughout Canada's rural, urban and northern regions. To set the context, this section defines foundational terms, demonstrates their linkage to climate resilience and NBS, and discerns the differences and interactions between key concepts.

2.1 Contextual Terminology

Climate Change Adaptation

Climate change adaptation describes the adjustments made by human and natural systems to actual or expected climate conditions and their effects (IPCC 2018; Bush and Lemmen 2019). While some climate change impacts can be avoided, reduced or delayed by mitigation, adaptation is necessary to address the effects of changing climatic conditions which are already unavoidable due to past emissions. In human systems, adaptation means moderating or avoiding harm (e.g., avoidance of development), or exploiting beneficial opportunities (e.g., meeting conservation goals). Some natural systems, as a basis for comparison, will require human intervention to achieve positive adaptation outcomes (e.g., preserving biodiversity). NBS (including green infrastructure and NI) can contribute directly to adaptation efforts by moderating the effects of climate change and improving the resilience of the built and natural environments to climate-related impacts.

Climate Change Mitigation

Broadly, mitigation efforts are interventions intended to reduce negative or unsustainable uses of the environment, ecosystems and biodiversity (IPBES 2018). Mitigation measures addressed specifically to climate change include the range of actions undertaken to reduce or prevent greenhouse gas (GHG) emissions, whether these result from natural processes or human-caused activities. They also entail reducing emissions of other substances that have a warming effect on the climate, as well as efforts to enhance the effectiveness of GHG sinks.[1] Mitigation activities often require the measurement and reporting of GHG removals along a set baseline and according to specific accounting rules. Although NI contributes mainly to efforts aimed at climate change adaptation, certain applications may produce positive mitigation outcomes as a supporting co-benefit, such as when wetlands, grasslands and forests provide temporary or long-term carbon storage.

Climate Resilience

Climate resilience refers to the capacity of a system, community or society exposed to climate-related hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This includes successful planning, development and ongoing management of assets so they can withstand, respond to and recover rapidly from damage and disruptions caused by changing climate conditions. The OECD (2018) observes that climate risks to infrastructure can be reduced by locating infrastructure assets in areas that are less exposed to climate hazards (e.g., avoiding new construction on natural floodplains), as well as by enhancing the ability of infrastructure assets to cope with climate impacts when they materialize (e.g., using stormwater retention areas to mitigate the risk of sewer overflows).

Nature-Based Solutions and Natural Climate Solutions

The Organisation for Economic Co-operation and Development (2020) and International Union for Conservation of Nature (2016) identically define NBS as measures that protect, restore and sustainably manage natural or modified ecosystems, with the aim of maintaining or enhancing the services provided to human communities and benefits to biodiversity. It is a concept that connects previously segregated bodies of knowledge on a wide variety of interventions and perspectives on what qualifies as nature-based. In specific policy contexts, it is typically used in connection with allied terms such as ecosystem-based adaptation (EBA), eco-disaster risk reduction, and notably green infrastructure (OECD 2020), because in practice NBS can fulfill needed infrastructure functions such as regulating water flows, protecting shorelines, cooling cities, and complementing built infrastructure (GCA 2019).

Nature-based or natural climate solutions (NCS) can be used synonymously to respond to challenges of food security, water supply and quality, disaster risk management, and

[1] Carbon sources include the natural processes and human activities that produce carbon – for example, the burning of coal, oil, natural gas and methane hydrate – and release of GHGs into the atmosphere. Carbon sinks include natural or artificial reservoirs that absorb and store atmospheric carbon – forests, oceans, the vegetative biomass found in wetlands and peatlands, as well as soils. Importantly, NI elements including trees and urban vegetation, parklands and wetlands are all notable carbon sinks, as are GI applications such as green roofs and urban tree canopies.

socioeconomic development under the pressures of climate change. Both green infrastructure and NI count as NBS and NCS, since they share a general focus on supporting societies' development goals with measures that enhance the resilience of ecosystems, their capacity for renewal and the provision of services. Crucially, climate-adaptive infrastructure solutions cannot come at a cost to the biological diversity that underpins the condition and resilience of the environment; solutions that protect against the social and economic costs associated with natural disasters but are negative for biodiversity, for example, are neither NBS nor NCS.

The value of NBS to the climate challenge for Canadian stakeholders can be realized as part of both adaptation and mitigation efforts, since nearly all interventions that reduce climate impacts also increase carbon uptake and storage. What is more, many NBS and NCS are rooted in Indigenous traditional knowledge as well as local knowledge and can be incorporated into the design of sustainability science and conservation planning to reduce risks and prepare for an uncertain future. Equally as significant, they align with global conventions supporting sustainable development, habitat and biodiversity protection (e.g., United Nations Sustainable Development Goals).

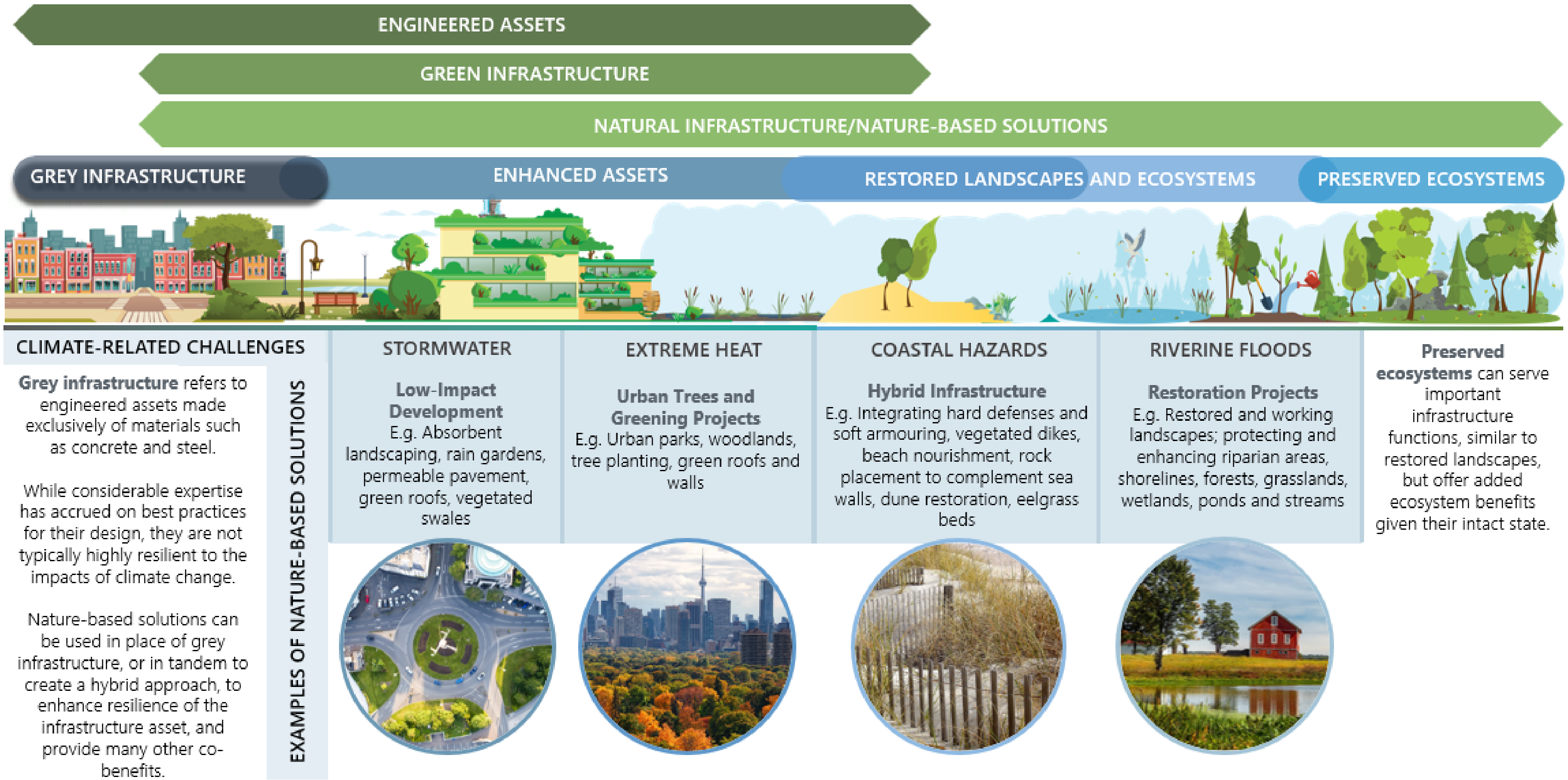
2.2 Infrastructure Types

Infrastructure

Infrastructure refers to the managed elements of interrelated systems that provide goods and services essential to enabling, sustaining or enhancing the living conditions of human communities. They include elements such as water and waste systems, utilities, transportation and recreational amenities. Scientists and conservationists alike have advanced the idea that ecosystems comprise an important and valuable type of infrastructure. Since the 1980s, terms such as 'ecological', 'natural', 'green', and 'blue' have been coupled with that of 'infrastructure' to describe a range of loosely connected and evolving approaches to development planning and asset management. The proliferation of terminology, however, has fragmented understanding of potential solutions to existing and emerging infrastructure challenges. Similarly, a lack of knowledge mobilization has also been observed.

There are varying perspectives on the comparative characterization of infrastructure types. Figure 1 provides a high-level perspective on the typology of infrastructure types, with increasing use of NBS within the mix of infrastructure elements as one moves closer to preserved ecosystems. This depiction also provides a comparison on the relative position of infrastructure applications. In this regard, it is important to note that each application could have more or less nature-based elements that would accordingly move such application closer or farther from preserved ecosystems, respectively.

Figure 1. Typology of Infrastructure Types



Natural Infrastructure

NI refers to the use of preserved, restored or enhanced elements or combinations of vegetation and associated biology, land, water and naturally occurring ecological processes to meet targeted infrastructure outcomes (CCME 2018), such as coastal hazard management, riverine flood management, local stormwater management and mitigation of the effects of extreme heat. It can be differentiated from the related category of green infrastructure based on its composition exclusively of natural ecosystem features and materials (e.g., water, native species of vegetation, sand and stone, etc.), and from grey infrastructure because it provides a range of co-benefits to the environment, the economy, community health and well-being that grey infrastructure usually cannot.

The concept of NI has origins dating to the 1980s, when it was used by nature conservationists to highlight the importance of preserved wetlands in the management of freshwater systems. In the time since, it has been discussed in academic and policy circles in relation to natural capital, natural assets, natural heritage systems and related terms mainly to do with the preserved and restored portion of green infrastructure. At the same time, the preservation, restoration or enhancement of NI elements is often incorporated into green infrastructure applications, and many features of the latter can count as NBS.

Like green infrastructure and many NBS more broadly, NI often requires managed interventions, whether this entails ecosystem conservation or the modification of landscapes (in the case of restored functional areas, or constructed assets that incorporate natural features). Beyond the infrastructure purposes for which they are used, NI elements can improve the climate resilience and overall lifespan of grey infrastructure, and deliver co-benefits including biodiversity enhancement, habitat protection, ecosystem services, support for recreation and culture, improved air and water quality, job creation and stimulation of rural economies (Roy 2018). The multipurpose character of NI often leads to more elaborate, qualitative valuations of its full range of benefits than is possible for grey infrastructure projects, when assessing cost-benefit ratios and other performance indicators such as GHG reductions (e.g., carbon sequestration and storage, avoided emissions). NI can be implemented directly using established approaches to asset management, or indirectly through supporting policies, by-laws, plans and guidelines (MNAI, 2017). For example, in a Canadian context, NI initiatives have been supported through federal programming such as the Investing in Canada Infrastructure Program's Green Stream (delivered through Integrated Bilateral Agreements with provinces and territories) and Disaster Mitigation and Adaptation Fund (DMAF), and going forward there will be opportunities for Canadian authorities to better align their land-use regulations, infrastructure investments, and fiscal policies around nature-based climate adaptation objectives.

Green Infrastructure

Green Infrastructure refers to the natural vegetative systems, engineered and built features, and green technologies that collectively provide society with a multitude of economic, environmental and social outcomes (GIO 2020; Stanley *et al*. 2019). Some experts from different backgrounds describe green infrastructure as mainly enhanced natural assets, incorporating land, water and vegetation features alongside human-made elements to sustain ecosystem functions and services. Others may use the term interchangeably with NI, or in a more global sense to discuss natural assets and capital of all kinds. Across most usages, green infrastructure is distinguished from grey infrastructure based on its ability to emulate many of the functions of NI.

A commonly used definition of green infrastructure, first devised by urban stormwater management practitioners in the United States during the early 1990s, describes the concept as the strategic use of 'vegetation, soils, and other elements and practices to restore the natural processes required to manage water and create healthier urban environments'.

The European Union's preference during the same time period was for a broader concept and use of the term 'green infrastructure' by the EEA (2015) and notably the European Commission (2013) aligns more closely with a combination of NI with green infrastructure: "… a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned), and other physical features in terrestrial (including coastal) and marine areas. On land, green infrastructure is present in [both] rural and urban settings". In both North America and Europe, the multiple co-benefits of green infrastructure have been emphasized in comparisons with single-purpose grey infrastructure elements.

At present, green infrastructure is still associated strongly with the planning philosophy of low-impact development (LID) and technologies that support the ecological and hydrological processes needed to manage rain- and stormwater in towns and cities (MNAI 2017; Chenoweth *et al*. 2018; di Marino and Lipintie 2017; Government of Ontario 2014). For urban stormwater practitioners, green infrastructure refers to the enhancement of conventional grey infrastructure (e.g., piped, ditch and culvert, dam and reservoir systems) with nature-based elements, in order to achieve the active and everyday management of the full rainfall-runoff spectrum. In these applications, green infrastructure must provide functions and services beyond a singular response to an extreme weather event (e.g., a flood or drought), and is usually reliant on grey infrastructure innovations (e.g., the reconstruction of river systems for flood management with reinforced and specialized concrete). These are not NI features *per se*, but they do restore natural *functions* (e.g., distributed depression storage for flow rate and volume control), while providing additional ecosystem benefits (e.g., improvements to water quality).

The use of green infrastructure as an overarching descriptor for clean technology, clean energy infrastructure, climate-resilient infrastructure at large risks bringing many grey infrastructure assets under its banner. This has led to confusion in the terminology, particularly when the intent of green infrastructure is to expand the green category to take account of how living materials (e.g., vegetation) can be used in combination with abiotic natural elements (e.g., sunlight, wind, rock and sand) to meet targeted infrastructure outcomes. As a corrective, the term 'living green infrastructure' is used by certain stakeholders to distinguish the natural assets portion of green infrastructure (e.g., urban tree coverage) from other environmental technologies (e.g., electric vehicle infrastructure).

Grey Infrastructure

Grey infrastructure describes features of the built environment made exclusively of materials such as concrete and steel, including bridges, dams, water treatment plants, culverts, ditches and storm drains. Grey infrastructure solutions can be compared to NBS based on their differentiated design principles, management practices, costs and benefits. Grey infrastructure elements are generally designed for singular purposes, and although considerable expertise has accrued over time on best practices for their design and management, they are not highly adaptable to changing conditions such as extreme precipitation events and have a limited lifespan (Sutton-Grier *et al*. 2015). Further to this, grey infrastructure has a large carbon footprint given the emissions associated with manufacturing concrete and steel structures (Bataille 2019). Measuring the benefits and value of grey infrastructure is usually straightforward and often relies on quantitative indicators and metrics for the assessment of singular outcomes.

3.0 INFRASTRUCTURE CHALLENGE AREAS: NATURAL INFRASTRUCTURE AND NATURE BASED SOLUTION AREAS

NI applications using preserved, restored or human-enhanced features have been used across the country, including in urban, rural and northern areas, in response to diverse climate-related infrastructure challenges, notably as defenses for vulnerable coastlines, to protect against floods, manage water resources, and mitigate the effects of rising temperatures.

While no single inventory exists to track NBS implemented across the country, there are many examples that highlight their role, and increasing opportunities, for building climate resilience. There is significant room to expand on the work that has been done to-date, and these cases can be modified to suite other needs across the country. For example:

- To protect vulnerable coastlines, coastal dune restoration work has been undertaken in New Brunswick, intertidal reefs have been developed in Prince Edward Island, living shorelines have been promoted in British Columbia, and salt marsh restoration work has been advanced in Nova Scotia.
- To protect against flooding, watershed restoration and floodplain reclamation efforts have been undertaken in Ontario, and a Rain City Strategy was developed for the City of Vancouver, using NBS to reduce risks of floods.
- To manage water resources, work has been undertaken in the Prairie Provinces to improve watershed resiliency, including to support agriculture.
- To mitigate the effects of rising temperatures, urban forestry projects and protected areas have been implemented across the country, including Ontario. Further to this, the Standards Council of Canada released a report on designing thermally comfortable playgrounds, which looks at ways to reduce the urban heat island effect in public parks.
- Further to this, parks and protected areas have received increased attention, and have been implemented to achieve a number of cross cutting objectives across the country. The Northwest Territories, for example, has made significant progress in establishing Indigenous Protected areas, which supporting resilience through their biodiversity benefits, maintaining local cultural practices, and providing a range of community services.

In what follows, some key climate-related infrastructure needs are described, and examples of NI and related NBS are discussed which can be developed and scaled up to provide an effective and cost-efficient alternative or complement to built and engineered assets.

3.1 Coastal Hazard Management

Coastal ecosystems are found where land meets the sea, along shorelines and land formations such as estuaries, bays and barrier islands. Certain types of environmental change, such as sediment deficit, reduction in ice cover, and sea level rise (SLR)[2] increase the sensitivity of Canada's coastal shorelines to weather and climate-related hazards. For example, permafrost thaw, shoreline erosion and retreat[3] can be expected to have lasting impacts on Inuit communities in the Canadian North, which includes about 70 per cent of Canada's coastline (Atkinson *et al*. 2016), as well as important coastal ecosystems like fens and tundra areas. The integrity of coastlines in Atlantic Canada is imperiled by SLR, regional subsidence[4] and the loss of Northern Atlantic sea-ice, with the consequence that wave energy can erode exposed cliffs, glacial deposits, sand dunes, sand spits, barrier bars, marshes and other coastal features (Arlington Group *et al*. 2013). The effects of climate change do not impact all regions equally, however. The increase in elevation of the Pacific coast (due to glacial isostatic rebound), for example, is expected to offset some of the magnitude of SLR and lessen the impacts on shoreline ecosystems, though the potential for flooding and storm surges will persist in much of coastal British Columbia (CCME 2018).

In the coming decades, climate-related pressures such as changing water levels and shoreline dynamics will exacerbate the existing Atlantic and Pacific coasts' vulnerability to natural hazards including flooding and storm surge events. At the same time, land use changes using grey infrastructure can contribute to the 'coastal squeeze' effect and risk undermining the overall absorptive capacity of our oceanic shorelines. The cities, towns and Indigenous communities on the northern coasts of Ontario and in the territories will be at increasing risk of damage to their aquifer-derived water supplies, roads and bridges, as well as residential and commercial waterfront developments. Shoreline erosion and recurrent flooding also threaten the vitality of the sensitive aquatic ecosystems in estuaries filled with brackish water (i.e., mixed freshwater and seawater systems where our rivers meet the sea). Many of Canada's largest freshwater systems also (e.g., the Laurentian Great Lakes region) have coastline lengths and populations comparable to the oceanic coasts (Gronewold *et al*. 2013), and the degradation of aquatic ecosystems in lake systems across the country threatens the nursery and migratory grounds for many species of birds, fish and other animals.

It is increasingly recognized that climate change adaptation and biodiversity conservation should form the combined basis of marine management and coastal land/seascape protection (Tittensor *et al*. 2019). As part of coastal protection efforts, non-structural measures such as horizontal and vertical setbacks

[2] SLR is the phenomenon whereby the combination of warming of the ocean waters with the accelerated melting of land ice results in increased height of the water. Both causes originate with the increased atmospheric heat from anthropogenic carbon emissions, which the oceans absorb. Adaptation planning by governments globally is being refocused to incorporate consideration of global SLR of up to 1m by 2100 (Atkinson *et al*. 2016), which will increase the height and penetration of storm surges. Adaptation to SLR generally falls into three categories: protect (build infrastructure to protect development), accommodate (build with the water, such as elevating houses), or retreat (move people away from the shore) (Kousky 2014).

[3] Coastal erosion is both a gradual and acute process; on one hand, average water levels and landside factors – including surface and subsurface drainage, loss of shoreline vegetation, and the loading and weight of buildings on coastal and lakeside shores – all negatively impact the nearshore substrate. On the other hand, rapid shoreline change can be instigated by storms with elevated water levels and wave action (Atkinson *et al*. 2016). SLR and storm surges can lead to the erosion of narrow shorelines especially, where the shoreline is unable to migrate landward in response to rising water levels. This can lead to irreversible impacts such as the loss of habitat for birds, fish, plants and other organisms that use the beach for all or part of their life cycle.

[4] Subsidence is the gradual loss of elevation for some coastal regions due to post-glacial crustal adjustments. Atlantic Canada, for example, is undergoing subsidence of its landmass caused by the migration of an area of uplift that developed around the margins of the North American ice sheets, as well as by additional water loading on the seabed of the Gulf of St. Lawrence as global SLR has accelerated (Arlington Group *et al*. 2013). For Canada's Eastern coast, this compounds the effects of SLR.

provide alternatives to grey infrastructure, and hybrid applications can protect existing infrastructure and high-value assets from high-intensity weather events. While these are likely to be prioritized in overall asset planning and management for coastal communities, there is general agreement that coastal ecosystems with natural features can provide significant dimensions of resilience to the effects of storm surges and associated flooding. For example, NI elements including vegetated shorelines and buffer/sacrificial zones help to stabilize soils and provide erosion protection. Related NBS can include sand dune reconstruction using an armour rock core, shoreline armouring with large rocks to prevent tidal pressures from undercutting sea walls, and soft sediment slopes installed to protect seaside boardwalks (e.g., as Schafer (2018) documents in Summerside and Charlottetown, P.E.I.). Such combinations of measures proffer benefits for adaptation to long-term SLR, conserve and enhance biodiversity, and support maritime industries, local recreation, culture and economic activity.

3.1.1. Solution Area: Building Coastal Resilience

Coastal Defenses

In Canadian communities, coastal flooding and coastal erosion defense has traditionally taken the form of 'coastal defenses' or 'defensive strategies' – retreat from the areas at risk, or investment in forms of grey infrastructure called 'hard armour'. Compared to inland regions, these coastal areas are likely to be subject to higher-intensity weather and climate conditions. One of the most complex coastal defense strategies is relocation, also referred to as planned retreat, which involves removing homes and cottages from an eroding coastline or flood-susceptible area - this was undertaken in Tuktoyaktuk in 2020 due to shoreline erosion. Planned setbacks, which prohibit coastal development, are often more cost-effective and must increase in response to SLR and other climate change effects, or else the protection provided by grey solutions will deteriorate over time (Arlington Group *et al*. 2013). Alternatively, developers in coastal communities can commit to less costly strategies like adaptive elevation planning, and the wet and dry-flood proofing of buildings. Beyond flood and storm surge defense, building resilience to coastal hazards means ensuring the integrity of coastal ecosystems in the face of increasing climate-related risks.

Hard Defenses

Used interchangeably with the term hard armour, hard defenses describe conventional grey infrastructure applications for coastal resilience – breakwaters, berms, seawalls, groynes, dikes and levees. Often implemented in high-value areas, hard defenses are highly effective locally at absorbing storm surges and redistributing tidal pressures along the shoreline. While many erosion control measures dissipate the energy on the coast, they are often not designed to block flood waters like a berm or levee. Further to this, hard defences have the potential to shift erosion pressures to adjacent, rural or potentially impoverished areas. For those coastal communities, options to address the physical challenges with hard defenses may require government supports, even though at a household level some people already incur costs of their own for flood and storm surge protection (Vasseur *et al*. 2017). In that context, nature-based and hybrid applications can serve to protect existing built infrastructure and preserve homes and businesses. Importantly, the presence of extensively developed hard defenses can promote a false sense of security and exacerbate the potential for poor planning and inappropriate siting of grey infrastructure.

Soft Armouring

Soft armour refers to NI elements, such as vegetation and natural materials, used to protect coastal and lake shorelines and marine ecosystems. Coastal landscapes and seascapes encompass diverse habitats including tidal wetlands and forests, eelgrass meadows and freshwater transition areas, as well as natural assets created by the interaction of wind, waves and sediment such as sand dunes and beaches. As elements of NI, these ecosystems are naturally resilient to gradual change, evolving in response to storms, SLR and changes in wave climate. However, with the accelerated pace of climate change, improving the resilience of coastal infrastructure to high-intensity flood and storm surge events becomes an ongoing challenge. Soft armouring applications include:

- shoreline/ecosystem revegetation
- stabilization of dunes
- beach nourishment and maintenance of sediment supplies
- management of buffer and sacrificial zones

Taken together, soft armouring approaches prove to be most appropriate for long-term use under low to medium intensity conditions. While engineered or grey infrastructure solutions are necessary to address coastal flooding and storm surge control in some situations, particularly in urban areas, these hard defenses (outlined above) can also disrupt coastal processes and can worsen localized erosion patterns, leading to the degradation and loss of habitats and ecosystem services. NI and complementary NBS, as a basis for comparison, can help to mitigate the long-term deterioration of grey infrastructure and the significant economic costs associated with it. What is more, as Sutton-Grier *et al*. (2018) observe, soft armouring applications demonstrate co-benefits such as improvements to water quality, support for biomass transport and nutrient cycling, the creation of species habitat, improved aesthetics, and access to natural seascapes that can increase tourism and recreation.

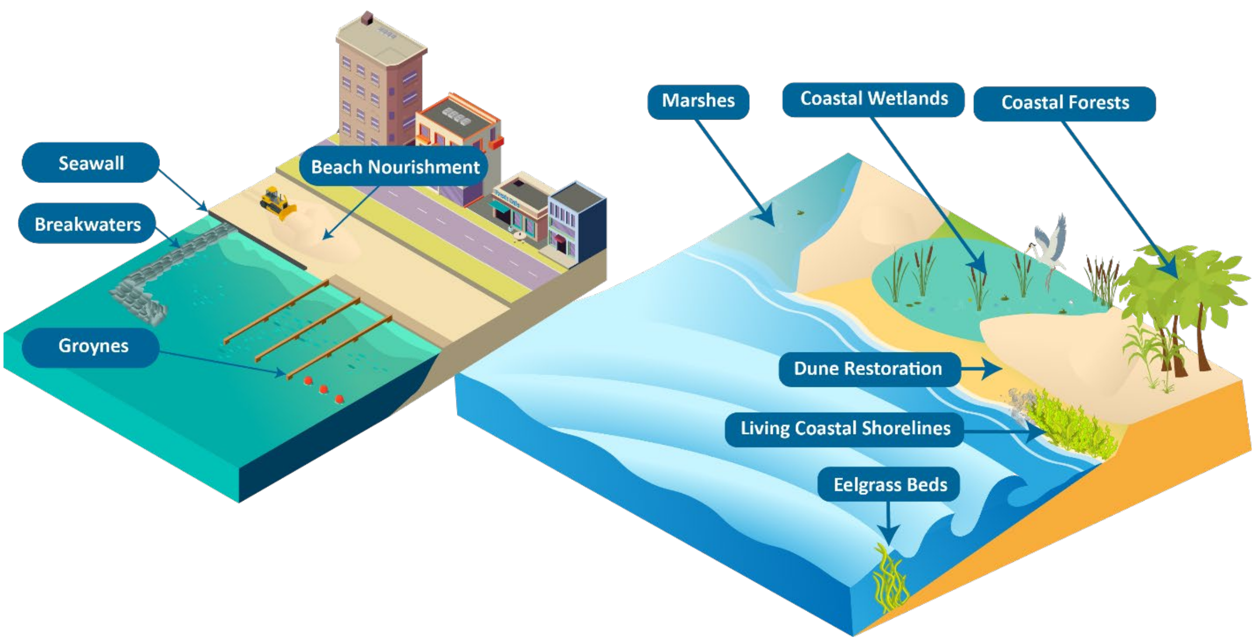
Hybrid Infrastructure

Hybrid infrastructure projects combine nature-based elements with grey infrastructure to enhance the resilience of both the infrastructure and ecosystem features to higher-intensity events (CCME 2018). In coastal regions in particular, hybrid applications will have an increasing role in defending against extreme climate change-related hazards and include a combination of hard defenses with soft armouring. Applications of this type are often capable of achieving superior outcomes and benefits in comparison to NI or grey projects by themselves. For example, the use of sand and natural rock in beach nourishment applications can complement the ability of an adjacent seawall, riprap rock or set of groynes to dissipate wave energy.

Beach Nourishment

Beach nourishment refers to the replenishment of sand and stones in targeted areas of beach to provide a sustained buffer zone of erodible material. Under storm conditions, adequately nourished beaches can help to dissipate wave and floodwater energy even after fully submerged. Wider beaches and beaches with higher berm elevations can provide targeted flood prevention and damage control outcomes (CCME 2018). Beach nourishment requires the transport of compatible sand and rock (e.g., fine sand, coarse sand, and/or cobbles) to the targeted area, as well as annual (or more frequent) maintenance to remain effective. Sufficiently wide and elevated beaches provide a feasible NI alternative to the grey infrastructure elements such as dikes, breakwaters and groynes that are commonly constructed along low-lying coastlines. Beyond their flood-wave attenuation function, beach complexes provide the setting for recreational activity, and host a range of distinctive animal habitats while providing essential nesting grounds for waterfowl and songbirds. Beaches with vegetation will also provide some measure of stabilization from active processes of shoreline erosion.

Figure 2. Building Coastal Resilience - Examples of Natural Infrastructure and Nature Based Solutions



Note: The image on the left is a combination of hard defences and hybrid applications, e.g., beach nourishment as NI, and a sea wall as grey infrastructure. The image on the right depicts only NI solutions. When it comes to coastal resilience, hybrid approaches are often used to incorporate both hard defences and soft armouring.

Blue and Blue-Green Infrastructure

Blue-green infrastructure describes the common elements, linkages and connected spaces formed between water and land, whether in a coastal or inland, rural or urban context. It includes such features as lakes, ponds, marine waterways, rivers and creeks, as well as engineered or built water features in developed areas.

Blue infrastructure is a term used mostly to refer to the conservation and management of freshwater and coastal-marine ecosystems (da Silva and Wheeler 2017), and is sometimes linked to discussions of the climate mitigation potential for so-called 'blue carbon' storage. It has partly displaced the concept of 'coastal green infrastructure', which has been defined as "… natural or nature-based systems that mimic natural areas of dynamic coastal landforms, vegetation, and reefs that naturally provide coastal protection services as well as various ecosystem health, maintenance of natural processes (e.g., temperature regulation) and biodiversity, and social and economic benefits to communities" (Conger and Chang 2019: 54).

Coastal Forests

Coastal forests include upland forests of trees and shrubs, while excluding salt marshes and vegetated estuaries with brackish water. Although considered alone coastal forests only minimally control the extent of landscape inundation, their vegetation can enhance the flood mitigation capabilities of dikes, retaining walls and embankments, limiting both wave height and the rate of peak floodwater flows.

Coastal Wetlands

Coastal wetlands occur inland of ecosystems that begin offshore and move inland through estuaries and salt marshes (MA 2005). Their generally high level of saturation limits floodwater storage, since they either contain freshwater or are inundated with saltwater depending on tidal cycles. However, they can be herbaceous (marshes) or arboreal (swamps), and the vegetation they support can dissipate wave energy, reduce water velocity, flood depths and wave heights, as well as minimize net sediment loss during flood events (CCME 2018; Arkema *et al*. 2013). Other benefits of coastal wetlands, including coastal marshes, include providing support for nutrient cycling and biomass transport, and the provision of essential habitat and improved water quality for fish and shellfish, mollusks and crustaceans. In addition, most commercially valuable fish will breed and nurse their young in coastal marshes and estuaries.

Dune Restoration

Dune restoration refers to a NBS using vegetation, sand and sometimes engineered or built features like fencing to stabilize sand dunes and prevent dynamic migration of the shoreline. Preserved sand dunes contribute to shoreline protection as both natural seawalls and erosional buffers, and storing sand that is mobilized during storms and subsequently returned to the dunes by the tide (Atkinson *et al*. 2016). Schafer (2018) documents dune stabilization projects using salt-resistant grasses in Cavendish, PEI as a means of decreasing the rate of storm wave and wind erosion. Other technologies in the area include sand-topping and creating hybrid fortified dunes with riprap rock covered in sand and grasses. It is important to note the risks associated with using non-native plants to stabilize dunes; these can spread rapidly and slowly displace the native plant species that are adapted to this environment, demonstrating the need for careful planning and use of native species.

Eelgrass Beds

Eelgrass is a variety of seagrass suited to saltwater and capable of cycling nutrients and transporting biomass offshore. Eelgrass beds and meadows are richly distributed along Canada's Atlantic and Pacific coasts, stabilizing estuarine sediments and supporting the formation of the coastal marshes capable of wave attenuation (Horizon Advisors 2019). More expansive meadows reduce water flow velocity near the sediment surface and promote the settling of organic and inorganic matter; this initiates sulfate reduction and maintains the sulfur cycle, which is important for the stimulation of plant growth. Further, the anaerobic (i.e., low-oxygen) conditions in the root systems also promote the growth of nitrogen-fixing bacteria, which enhance primary production at the most fundamental level of the food chain.

Living Coastal Shorelines

Living coastal shorelines, or living shorelines, encompass a range of strategies using coastal vegetation and seeding for preserving, restoring or creating shoreline ecosystems, to improve sediment stabilization, maintain shoreline dynamics and minimize erosion. Typically, living coastal shorelines have been designed and implemented using a collaborative approach, working with several orders of government, property owners, marine conservation organizations, ecologists, landscape architects and engineering professionals (Arlington Group *et al*. 2013). They employ vegetation and related biotic material to provide sediment stabilization benefits, along with hybrid applications using groynes or breakwaters with sand, marsh grasses and other natural materials to maintain shoreline dynamics while minimizing erosion impacts. Their benefits include improved water quality (by the capture of sediments and filtering of pollution), greater abundance and diversity of aquatic species, and improved connectivity between aquatic and nearshore ecosystems.

Coastal Marshes

Coastal marshes (including salt and saltwater marshes) are the most common type of coastal wetlands, characterized by vegetation unique to seawater, or brackish waters in some estuaries. They help to regulate flood depths, wave height and velocity, and therefore minimize sediment loss and the extent of storm-related flooding. Preserved salt marshes have the ability to grow and remain resilient to the effects of SLR, developing thick sequences of organic-rich sediment or peat (Atkinson *et al*. 2016). In general, coastal wetlands help to dissipate wave and tidal energy, and their root systems act as a trap for sediments, facilitating land formation and reducing erosion. By helping to claim area on the landward side, salt marshes help to reverse the loss of intertidal land area (the coastal squeeze effect) in which beaches, dunes, and vegetation zones that cannot migrate inland (due to hard defenses or other barriers) are eventually squeezed out and contract, caught between the tides and immovable shoreline structures. This is an example of the adaptability that NI often demonstrates in comparison to grey infrastructure, which entails permanent outlays that are typically inflexible and require the continuous input of resources. Coastal marshes provide additional environmental benefits such as habitat for species of wildlife, and support for ecological processes like nutrient cycling. One of the most important processes supported is the mixing of nutrients from upstream as well as from tidal sources, forming a salinity gradient and helping to maintain freshwater flows into local point sources (MA 2005).

Restored or Preserved Ecosystems

Restoring or preserving ecosystems, such as salt marshes, coastal forests, dunes and wetlands, (referenced above) can also support coastal resilience. For example, Marine Protected Areas (MPAs) can also be used as a NBS to support coastal resilience. In Canada, this refers to conserved marine ecosystems that are protected by law and subject to limits on use due to biodiversity conservation concerns. The changing climatic influences of seasonality and marine pollution threaten these delicate ecosystems, but NI planning can be targeted to MPAs to protect or restore vulnerable habitats. Zoning practices and management plans should be revised to account for climate-displaced species and habitats, and there is a need to ensure that vulnerable marine ecosystems retain their functions and services under future climate scenarios (Tittensor *et al*. 2019).

3.2 Riverine Flood Management

Canada's rivers make up 25 major watersheds – the areas of land that collect precipitation on natural floodplains and return it through networks of streams and rivers to common bodies of water; these are comprised of more than 100 smaller sub-watersheds (WWF Canada n.d.). Pollution, overuse of water, introduction of invasive species, and degradation of habitat all represent significant threats to the health of Canada's freshwater. At the same time, the alteration of flows and excess ice melt resulting from climate change have increased seasonal water levels in many parts of Canada and heightened the risk of catastrophic riverine (fluvial) flooding.[5]

Flooding of this type happens when water flows over properties as a result of excess volumes in rivers and creeks, from backups due to ice jams, or excess groundwater. Residential flooding, as Moudrak and Feltmate (2019) summarize, has been an important driver of rising home insurance premiums, mental health stress for homeowners impacted by flooding, higher rates of residential mortgage default, and lawsuits directed to builders and municipalities that fail to anticipate and mitigate flood risk. Common NBS for riverine flooding focus on enhancing the capacity of natural floodplains to absorb water and regulate peak flows. This can be accomplished with comprehensive approaches to overall watershed management, which entail a combination of:

- preservation and/or restoration of inland wetlands and other NI elements (e.g., grasslands, riverine foreshores, creeks and in-stream features) capable of providing flood mitigation
- ongoing riverine flow monitoring, flood and drought forecasting to enhance the effectiveness of natural floodplain functions
- the installation of naturalized channels on floodplains for improved floodwater conveyance and habitat protection
- riverbank and riparian (i.e., transitional areas alongside rivers and streams, between the water and untouched, cultivated or developed land) vegetation initiatives, such as living shorelines
- planned setbacks whereby infrastructure is removed from the floodplain and the landscape is restored to its historical configuration (CCME 2018).

Comprehensive approaches to overall watershed management have emphasized the preservation and/or enhancement of NI elements such as wetlands and riparian areas to improve aspects of watershed functioning beyond an exclusive focus on flood management. Specific applications in the area include terrestrial and hydrologic process restoration, or nature-based projects like constructed wetlands, which can provide a range of ecosystem goods and services as well as essential wildlife habitat. Planning and governance for watershed management is increasingly undertaken as part of

[5] It should be noted that lake systems (e.g., the Great Lakes region) are equally susceptible to increased flood risk due to factors such as decreasing seasonal ice cover, as well as floodwater impacts such as accelerated shoreline erosion.

integrated watershed management (IWM), and this is the focus of much current policy and programming in the area (CCME 2016).

3.2.1 Solution Area: Overall Watershed Management

Overall Watershed Management

Overall watershed management describes an adaptive, comprehensive, integrated, and multi-resource management planning process that seeks to balance ecological, economic, and sociocultural conditions at a watershed level (Red Deer River Watershed Alliance n.d.). The aims of this comprehensive approach to planning are to recognize and take into account the interaction of water, plants, animals and human land use found within the physical boundaries of a watershed when developing and managing natural floodplain landscapes. These include infrastructure solutions (as noted below), other non-structural measures (e.g., planned setbacks of residential developments on natural flood plains), as well as the relocation of buildings or avoidance of urban development in flood plain areas.

Integrated Water Management

CCME (2016) defines integrated water management as the "… integration of environmental, social and economic decisions and activities through an inclusive decision-making process to manage the protection, conservation, restoration and enhancement of aquatic and terrestrial ecosystem features, functions and linkages." In practice, integrated approaches to water management often involve interdisciplinary, collaborative projects, including NBS and NI, which include local citizen participation. Governance and management at the watershed level, supports the formation of interdisciplinary teams and facilitates the reporting of performance outcomes against predefined targets.

Forests

Forested land may consist of either closed or open forest formations, and demonstrate the absence of other predominant (e.g., agricultural) land use. Although forests located in riparian areas and on natural floodplains cannot stop catastrophic, large-scale inland floods, they are important NI elements that help attenuate and delay peak floodwater flows, while supporting other hydrological processes at the watershed level including filtration and the recharge of local aquifers. Discussion of the additional benefits of forests commonly points to their vegetation and soils as valuable carbon sinks, and their ecosystems as vital habitat for diverse species of animals and birds. Less-cited environmental benefits include the provision of forest litter layers and standing dead wood, which stabilize soils and limit the rate of soil erosion. International definitions dictate that a forest occupies land area of more than 0.5 ha, with tree crown cover (or equivalent stocking level) of more than 10 per cent; trees in a forest should have the potential to reach a minimum height of 5 m at maturity in situ to meet the canopy cover requirement (IPBES 2018; CBD 2006).

Living Shorelines

Living shorelines is an umbrella term that describes restorative applications for shoreline ecosystems. In riverine and riparian areas, the term is commonly associated with soil bioengineering, which uses combinations of vegetation and seeding; these practices enable the stabilization of soils and riverbanks to prevent erosion (UNEP 2014)**.** The same managed interventions are capable of expanding existing species habitat, and it is generally agreed that naturalizing shorelines and riparian areas is beneficial for a wide variety of species and simultaneously improves aesthetic qualities.

Wetlands

Non-tidal wetlands in Canada are located on riparian lands, on the natural floodplains of drainage basins, along the margins of lakes and ponds, and in low-lying areas where groundwater contacts the soil surface (e.g., swamps, marshes, and peatlands including fens and bogs). The quantity of water wetlands retain determines their ecosystem characteristics. Some are seasonal, dry for one or more seasons each year. Other landscape attributes will determine their hydrological functions, with the consequence that each type of wetland (e.g., a salt marsh, peat bog, Arctic fen, etc.) will operate differently and support different processes. Drainage for agricultural development (e.g., in the Prairie provinces); conversion of land to residential development (e.g., on settled landscapes such as Southern Ontario); excess nutrient and chemical runoff; as well as air and water pollution, represent significant emerging threats to the future of Canadian wetlands. The introduction of grey infrastructure for water diversion, such as dams and canals, also poses risks to wetlands as these can encroach on natural floodplains.

Because of their ability to regulate water quantity (e.g., during times of drought, unpredictable rainfall, peak floodwater flows or high runoff), wetlands can be an important asset for riverine flood mitigation, as they absorb and hold floodwaters before gradually releasing them. Naturalized or constructed wetlands, too, can provide urban and rural communities with improved flood management, upstream water purification, waste assimilation, stormwater retention and discharge (Horizon Advisors 2019). The potential for wetlands to attenuate peak floodwater flows, and the extent of inundation is, however, highly contingent on local conditions. This includes subtle differences in hydrological functions, landscape location, configuration and topography (e.g., whether a wetlands complex is upland, at the headwater source of a river or tributary, or located on the inland-floodplain), soil characteristics including moisture, as well as management status (Acreman and Holden 2013). As a consequence, their influence on flooding magnitude is variable – even wetlands of the same type can reduce or increase flooding depending on the precise characteristics of an individual preserved or restored wetland. Enhanced or constructed wetlands must be initiated with informed placement criteria to ensure a positive influence on floodwater flows and damage. As a rule, floodplain wetlands can help to control the extent of riverine and inland flooding.

Ducks Unlimited Canada (DUC) assessed the extent to which municipalities are opting to combine wetlands with their built infrastructure to reduce the risk of flooding. Their findings are that wetlands in combination with traditional infrastructure can be more cost-effective for flood mitigation than using built infrastructure on its own. The cost savings of employing wetlands can be calculated by estimating 1) avoided costs of built infrastructure needed to replace wetland flood-mitigation services or 2) avoided costs of damages if the flooding is controlled (DUC 2020). Beyond their flood management benefits, floodplain wetlands make a vital contribution to ecosystem functioning at the overall watershed level, which results in a wide range of benefits including the filtration of pollutants from stormwater, support for downstream groundwater recharge and discharge, sediment stabilization, carbon sequestration, and nutrient cycling. In so doing, they reduce the need for new grey infrastructure and support low-impact development of land.

Managed Landscapes

Managed landscapes include livestock grazed/grazing lands, farming lands and orchards. When located on natural floodplains, these landscapes can help prevent large-scale damage and reduce the financial impact of inland floods. Managed landscapes including agricultural lands can support food security, carbon sequestration and biodiversity objectives. Care must be taken in the area of land use planning, however, because certain land use practices including the drainage of historical wetlands for agricultural development can increase susceptibility of some areas to overland flooding (Moudrak and Feltmate 2019). Additional benefits of using managed landscapes as an NBS include critical support for natural processes such as pollination; patches of semi-natural habitat, when distributed throughout productive agricultural landscapes, provide the nesting and floral resources needed for pollinator-dependent crops (IPBES 2018).

Daylighting Rivers

Daylighting is the term for removing concrete, culverts and other obstructions that are covering original rivers, streams, creeks and drainage paths and restoring them to more natural conditions (Wild *et al*. 2011). Sometimes called ‘deculverting’, the practice is part of a larger approach to water management, coupling flood management measures with water treatment functions. Daylighting can entail opening up watercourses in either rural or urban sites, and can vary from the simplest form – removing the ‘roof’ of a culvert and retaining existing bank walls and natural bed material – to the major reconstruction of both riverbed and riverbanks using soft-bioengineering measures and river restoration techniques (*ibid*). River restoration through daylighting is accomplished in two dimensions – the natural, and the cultural. In the natural dimension, the aim is to restore some or all of a river to its pre-development ecology and habitat status; examples of practices can include urban, suburban or rural stream renaturalization, to improve drainage flow in riparian corridors and on natural floodplains. In the cultural dimension, the aim is to celebrate a river’s hydrological and ecological role in the delivery of services or benefits to the community, through the strategic placement of heritage markers, public art and education activities to inform the public of the watercourse’s historic path and infrastructure functions.

During the 20th century, urban planning practices buried rivers and streams under concrete or incorporated them into storm sewer infrastructure under roads, or beneath residential, commercial and industrial developments. Burying rivers has interrupted the natural connectivity of waterways, increased pollution and the associated costs of water treatment. The earliest stream daylighting projects were implemented in Europe and the United States by landscape architects beginning in the 1980s; they were designed to address concerns about rainwater runoff and pollution from sewage and chemicals. In the time since, daylighting has become more of a multipurpose NI practice aimed at replacing or protecting the aging hydrological infrastructure in towns and cites that have traditionally diverted their watercourses below ground. As with many types of river restoration projects, the outcomes linked to daylighting initiatives can vary in relation to local hydrological conditions and landscape features, but most indications are that daylighted waterways benefit flood management by helping to attenuate peak storm- and floodwater flows. In addition, they can reduce water treatment costs by providing rudimentary quality improvements and contribute to the regulation of local temperatures. More consistently reported benefits include: the provision of revitalized habitats for native species of vegetation, birds, fish and other wildlife; beautification and increased property values; enhanced connectivity with the creation of new green belts and green spaces, as well as cultural benefits such as volunteer engagement in daylighting projects.

<u>Restored and Preserved Ecosystems</u>

There are a range of opportunities to use restored and preserved ecosystems, as an NBS, to support watershed management. This includes through Indigenous Protected and Conserved Areas (IPCAs)[6], Parks and Protected Areas (PPAs)[7], and Other Effective Area-Based Conservation Measures (OECM)[8].

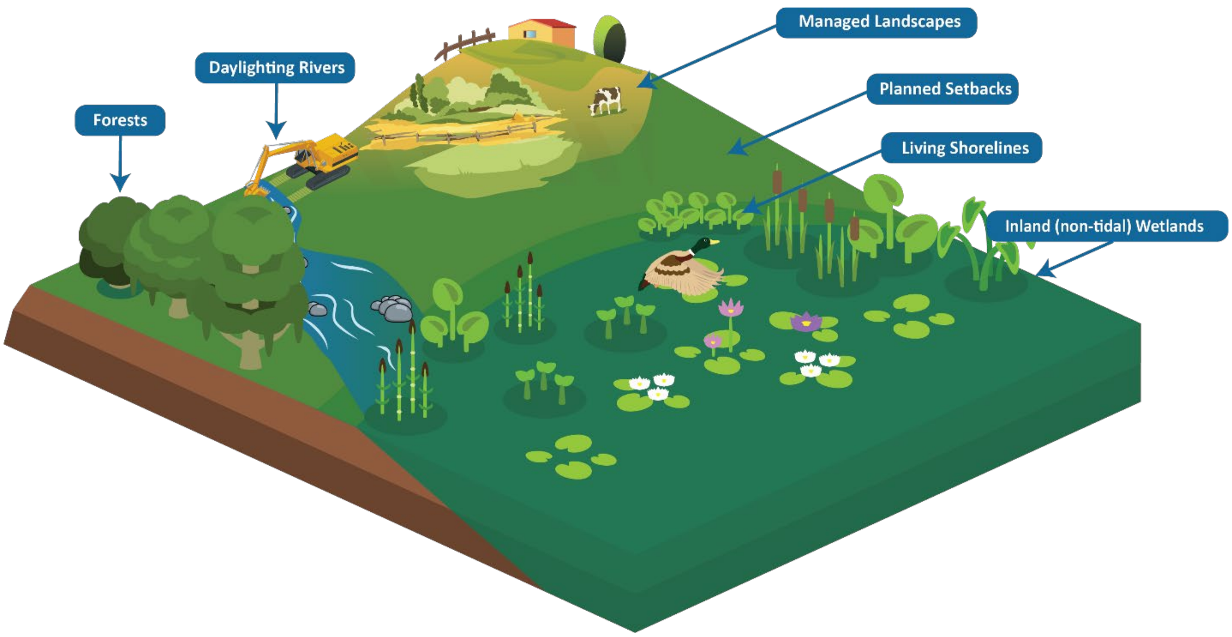
They can help protect biodiversity in light of changing climatic conditions, which can entail conserving NI elements such as freshwater features, plants, forests, wildlife, natural habitats, corridors and heritage systems. In order to support the resilience of plant and animal habitats to the effects of climate change, as well as adjacent municipalities, there are opportunities to explore NI applications suitable to the local conditions. At present, restored and protected ecosystems are a key setting for the conservation of NI and help to maintain networks between diverse ecosystems and landscapes (Canadian Parks Council Climate Change Working Group 2018), ensuring that natural systems are more resilient to change, or adapt as they are supposed to.

[6] IPCAs refer to lands and waters that Indigenous governments protect and conserve through Indigenous laws, governance and knowledge systems (ICE, 2018). Elsewhere in the world, similar conserved areas are called Indigenous and Community Conserved Areas (ICCAs). They provide an instructive model for land and water management that supports both ecosystems and human use of natural features and processes. In IPCAs, efforts are made to safeguard Indigenous rights to the goods and services provided by nature, and to practice Indigenous ways of life while protecting biodiversity.

[7] PPAs include national and provincial parks, designated wildlife areas and bird sanctuaries, and the terrestrial and aquatic ecosystems present in these areas comprise an important focus of Canadian conservation activity. The Government of Canada (Government of Canada 2018: 38) has advanced a definition of a PPA that is consistent with that of the CBD and the IUCN's categories of protected areas: "A clearly defined geographical space, recognized, dedicated and managed, though legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values."

[8] In Canada, an OECM must meet all requirements of a: "… geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socio-economic, and other locally relevant values" (Government of Canada 2018: 40). The federal government implemented this additional legal category for conserved areas, terrestrial or aquatic landscapes that do not meet the formal definition of a PPA but which the federal, provincial and territorial governments can recognize and report as being managed with measures that allow for the conservation of biodiversity. OECM sites are populated by a range of significant species-at-risk, and include mixed grasslands, inland water systems and most notably marine refuges, which have traditionally fallen outside the reach of conservation governance in Canada and around the world.

Figure 3. Riverine Flood Management - Examples of Natural Infrastructure and Nature Based Solutions



3.3 Municipal Stormwater Management

When rainfall volume exceeds the capacity of the drainage system and stormwater starts to flow overland, pluvial flooding occurs in towns and cities. In rural environments, it is generally caused by heavy rains or snowmelt on frozen ground, such that the water cannot be absorbed (PBO 2016). With the acceleration of climate change, more frequent, severe floods can be expected to exert considerable pressures on water management infrastructure across the country. Effective drainage and conveyance are required to protect existing infrastructure, homes and businesses from risks to property and public health. Investing in infrastructure can be transformational in regulating peak flows during higher-volume overland flooding, as well as during flash flooding with fast runoff. In older communities without dedicated storm sewers, complementary nature-based and engineered or built assets help to prevent combined sewer overflow (CSO) of runoff with sanitary wastewater.

Where traditional grey infrastructure solutions for flooding and drainage, such as water source diversions using channels, dry reservoirs and sewers are designed to perform only one function, NBS shift the focus of local stormwater management. Runoff is not treated as a waste product to be disposed of, rather a multipurpose water resource captured in place. An established body of structural and non-structural stormwater control measures are already widely implemented in Canadian communities, but urban water managers have also moved towards the active and everyday management of the full rainfall-runoff spectrum, using combinations of NI and green infrastructure. This includes rain gardens, vegetated swales, and distributed depression storage, alongside grey elements such as reservoirs, ditches and culvert systems to restore the pre-development balance of hydrological functions in urban sites.

Beyond meeting the targeted outcome of enhanced stormwater management, nature-based applications here provide a range of direct and indirect co-benefits, including economic, environmental and social outcomes. Direct co-benefits include improved local water quality, enhanced erosion and sediment control, along with potential for stormwater capture and reuse (e.g., rainwater harvesting). Indirect co-benefits include the provision of recreational space through landscape-level naturalization, mitigation of the damages and costs associated with flood insurance claims, aesthetic improvement, and enhanced connectivity and wildlife habitat.

3.3.1 Solution Area: Green Stormwater Infrastructure

Green Stormwater Infrastructure (GSI)

Although grey and other engineered or built infrastructure is often required to meet the targeted outcomes for local water management, urban watershed stakeholders have moved to plan holistically for their infrastructure needs and have sought to incorporate natural assets into their planning and management practices. Moreover, green stormwater management has included NBS since its inception as a specialized discipline focused on rain and stormwater drainage and conveyance. GSI describes the combinations of nature-based and grey infrastructure elements used strategically to manage the full rainfall-runoff spectrum. The term is sometimes used interchangeably with green infrastructure and LID, but in practice describes an approach to local water management focused on preserving or restoring a site's pre-development balance of hydrological functions (TRCA 2019).[9]

During storm events, peak runoff flows can quickly exceed the capacity of storm drains, waterways, and combined sewers (in communities with older infrastructure), resulting in flooding and the potential spread of toxic pollutants. Excess runoff of poor quality can inundate permeable surfaces and pollute aquifers and groundwater supplies. GSI is able to capture and convey stormwater on site, redirecting runoff or storing it for evapotranspiration. Stormwater control measures can be structural or non-structural, and the controls on runoff volume and stormwater quality can be differentiated as either conveyance (while the flow is in the drainage system) or end-of-pipe (at the outlet of drain systems, before stormwaters reach their receiving waterway). The EPA (1999) notes that when rainfall is managed as a resource at the site level with conservation, storage, infiltration and usage for irrigation, the need for traditional curb-and-gutter storm drainage can be reduced. As a consequence, the use of GSI reduces the need for capital-, land and maintenance-intensive management of large stormwater flows from developed watersheds (*ibid*).

Relatedly, GSI mitigates the damages caused by pluvial flooding by adding the control of stormwater runoff volume and rudimentary improvements to runoff water quality to the conventional management requirements for control of drainage rates and conveyance. Different GSI practitioners include various NBS under the banner of NI, such as absorbent landscaping, rain gardens, natural permeable pavements, green roofs, vegetated swales, constructed wetlands, and retention and detention areas. By encompassing certain of the principles that it shares with green infrastructure applications (like biomimicry and eco-design), GSI is often identified as a key principle of 'one water' or integrated water infrastructure. It also serves as a key area for hybrid infrastructure applications in the management of water resources in urban settings.

[9] This means the balance between precipitation and other water inputs, and the outflow of water through runoff, evapotranspiration, groundwater recharge and stream-flow.

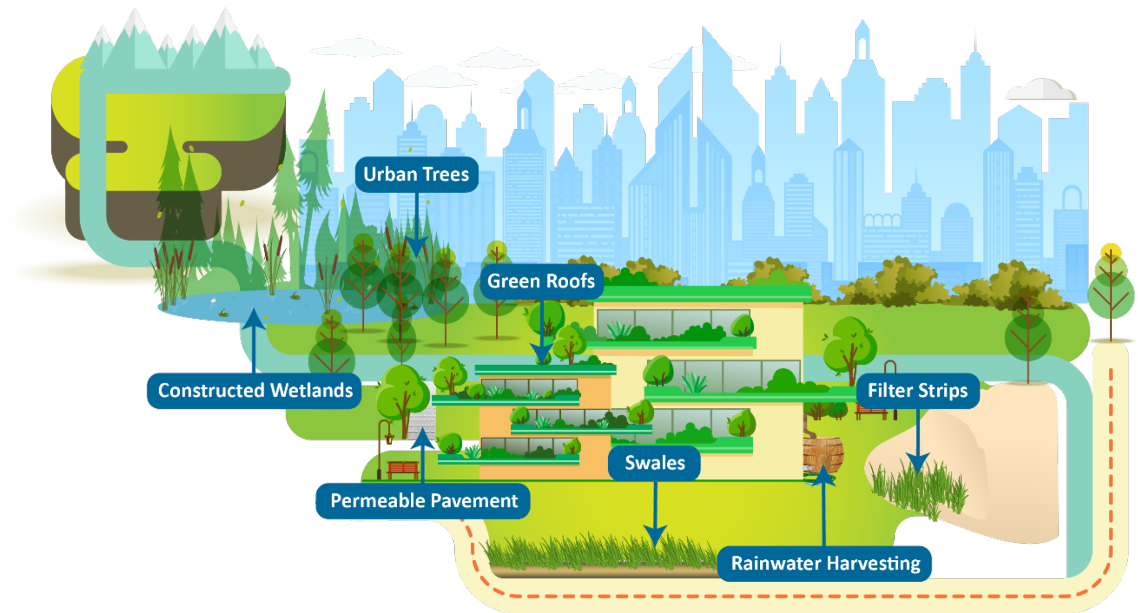
Considered together, the NI applications used as part of GSI can demonstrate benefits for adaptation to severe weather patterns, flood damage mitigation, water cycling, air quality, water quality and urban aesthetics. In addition, there is a persuasive business case for NBS for stormwater control. Many applications have lower construction costs than comparable grey infrastructure, while offering reduced maintenance and extended lifespans (GIO 2016c). The methods used will vary according to community needs; where one community vulnerable to flood damage may focus on capturing and diverting excess rainwater, one reliant on groundwater for its drinking supply might focus on infiltration (CCME 2018).

Low-Impact Development

LID is a broad-based urban planning approach usually used for stormwater management applications, and sometimes to wider practices of minimizing ecosystem impacts in the design and development of municipal water services in particular. In the stormwater management arena, it entails strategies for mitigating increased runoff and stormwater pollution by managing runoff as close to its source as possible (STEP 2019). In this respect, GSI should be considered a subset of LID, comprised of the mixed natural and engineered or built assets that make LID possible. In practice, LID embraces NBS including:

- the conservation of ecosystem features such as wetlands, natural drainage courses, vegetation and soils
- the use of effective erosion and sediment control and soil management during construction
- optimized urban site planning to reduce impervious surfaces, lengthen stormwater flow paths, and increase runoff time
- a focus on non-structural management practices and pollution prevention
- distributed micro-scale detention and retention features
- overall increased vegetation cover and soil depths
- applications and practices enabling water evapotranspiration, infiltration and treatment as needed
- prioritization of green or otherwise NBS over grey alternatives wherever possible, throughout the landscape.

Figure 4. Municipal Stormwater Management - Examples of Natural Infrastructure and Nature Based Solutions



Detention and Retention Applications

Detention areas (typically ponds or depressions) provide short-term stormwater storage (e.g., 24-48 hours) with a controlled release rate, meaning that the discharge volume of stormwater is equal to its inflow volume (CSA Group 2018). Although not NI, they are nature-based stormwater infrastructure, allowing for sediments to settle before runoff is released for conveyance to the watercourse. Retention areas provide similar temporary storage, but with an outflow volume that is *smaller* than the inflow volume (*ibid*). Evapotranspiration occurs for some retained stormwater, and some can be directed for groundwater recharge. Retention ponds are considerably adaptable in design and can be naturalized using vegetation, providing species habitat and multipurpose green spaces. They can be designed with native vegetation to remove pollutants from stormwater, in addition to grey infrastructure elements (e.g., drainage pipes) that mimic natural hydrological functions. In all cases, the size and depth of retention ponds will depend on the drainage catchment area and local hydrological conditions.

Stormwater Capture and Use/Reuse

In stormwater capture and use or reuse, runoff that is collected in wet ponds is used (usually with treatment) to irrigate landscapes to fulfill runoff volume reduction targets and to assist in achieving water quality objectives. Vegetation is selected that is not dependent on this additional water source, but rather is enhanced by it. For regions and communities prone to periods of drought, this is a popular stormwater control measure. With appropriate treatment, other uses can extend beyond urban irrigation.

Swales

Swales are GSI elements designed as vegetated, linear water conveyance channels that may be wet or dry, typically dug along streets and parking lots for retaining runoff and routing stormwater (GIO 2016c; CCME 2018). 'Bioswales' are a subtype of a dry swale with components comparable to bioretention systems**.** They have a low slope (typically 2% or less) to maximize opportunities for infiltration and treatment. In addition to their stormwater management benefits, bioswales help regulate temperature, recharge groundwater and contribute to urban beautification. The performance of swales in general for stormwater management can vary, depending on vegetation type and height, mowing practices, soil type and depth, longitudinal slope, shape, size and features of the contributing catchment area.

Constructed Wetlands

Constructed wetlands are green infrastructure designed to mimic the terrestrial and aquatic features of natural wetlands, and are designed to support similar ecological and hydrological functions. In the context of developed areas such as towns and cities, they regulate and treat stormwater runoff by filtering and cycling sediments and pollutants. These processes prevent the infiltration of contaminants into local waterways and aquifers. In order to provide ancillary benefits such as habitat for wildlife, constructed wetlands can be naturalized to integrate elements like vegetation native to local ecosystems. For this reason, some experts consider them to be examples of GSI, although their actual ecological value is reduced due to poor water quality and negative impacts on resident biota.

Filter Strips/Buffer Strips

Primarily used on agricultural land, these are planted strips of grass or dense vegetation embedded on a gentle slope, designed to filter excess runoff of sediments. They can be likened to simplified vegetated swales, without natural or synthetic substrate media or drainage systems.

Resilient Landscaping

This term originated with landscape architects as a descriptor for techniques aimed at eliminating reliance on potable water for irrigation while attenuating runoff flows and supporting ancillary benefits. Some practitioners include rain gardens as an application of this sort, but more typically, the practices included are xeriscaping, inclusion of the right plant in the right place, use of native plant species, deeper or amended soils for increased rainfall and runoff absorbency, and downspout direction and dispersion onto deeper or amended soils. Some practitioners refer to the overarching category as absorbent landscaping or fusion landscaping; others distinguish absorbent landscaping as the sub-practice of deeper topsoil with downspout direction and dispersion, while some regard the practice of amended, deeper soil on its own as absorbent landscaping. Standardization of terms in this category is likely due to varying climate, soils, vegetation, and associated stormwater management objectives, as well as the target audience. At the core is the acknowledgement of the role of soil and plants to attenuate stormwater runoff rate and volume, along with improvement to runoff quality. Programs are emerging that tie these practices to other ecological goals such as pollinator habitat, biodiversity and habitat connectivity.

Green Roofs

A green roof is a contained green space that extends a conventional roof, partially or completely covered with a growing medium and vegetation planted over a waterproof membrane (CNT 2010). It is designed to use the vegetation to capture rainwater and store runoff in the substrate for gradual transpiration and evaporation (Johns 2018; Rowe 2011) and can reduce stormwater runoff by 50 to 100 percent depending on the roof slope, plant species selection and depth of the substrate (Rowe 2011; Kumar *et al*. 2019). Far more popular in Europe and the United States than across Canada to date,[10] there is growing recognition of the benefits of green roofs for the management of runoff and pollution abatement especially. Applications are available as retrofits or as new installations and can be characterized as either extensive (allowing for sloped roof variations, lighter weight and a shallower depth) or intensive (with substantial depth to the soil layer and greater abundance of vegetation) (Berardi *et al*. 2014). By delaying the time at which runoff occurs, green roofs help to reduce the risk of rainwater flooding, sewer overflow and potential downstream erosion (Rowe 2011).

The additional functions of green roofs include air temperature regulation; filtration of dust, particulate matter and noxious gases; carbon sequestration; and the provision of habitat for birds, small mammals and insects. They also contribute co-benefits to the quality of human lives, including increased and aesthetically enhanced amenity space and noise reduction. Estimable economic benefits accrue from the uptake of green roofs as well, including job creation related to fabrication, installation and maintenance, along with reduced energy expenditure on cooling and heating systems. They are not always among the most cost-effective green infrastructure elements, as buildings must be designed to support their weight in accordance with established construction standards. In addition, they may require the support of grey infrastructure solutions (systems of irrigation pipes, pumps and reservoirs) during periods of drought or intense heat in order to survive. However, they do not require the additional land space required by alternative natural stormwater management systems and may demonstrate longer lifespans than conventional roofs (CCME 2018), while diverting waste though the use of recycled materials.

Permeable Pavement

Permeable pavements can include combinations of nature-based and grey infrastructure to improve water absorption and drainage capabilities of hard surfaces (e.g., parking lots, walkways and private driveways) during periods of high rain and stormwater runoff. They work by allowing stormwater to runoff into underlying reservoirs, where it is either infiltrated to underlying soils or removed by a subsurface drain (CRD n.d.). There is a range of pavement techniques using green infrastructure elements to allow stormwater to infiltrate the subsurface aggregate and soil layers (e.g., permeable interlocking precast concrete pavers, and grid systems filled with sand, gravel, or plants). Grey

[10] The slow uptake of urban roof phenomena in Canada is beginning to change, however. Toronto was the first North American city to adopt a green roof by-law (Section 108 of the City of Toronto Act), which since 2010 has required that green roofs be installed on new commercial, institutional and high-density residential buildings (Johns 2018).

infrastructure generally implies impervious surfaces, and alternative applications have been developed including specialized mixtures of permeable asphalt and concrete. Permeable pavements help to manage peak runoff volumes while providing environmental benefits, such as the regulation of runoff water quality and temperature (i.e., reduction of thermal pollution to receiving water bodies), the recharge of groundwater, and reduction of what is often called overall effective impermeable area (EIA).

Rain Gardens

Rain gardens are shallow, vegetated basins that mimic natural hydrology and work on the principle of bioretention. They absorb runoff from areas that have poor infiltration (e.g., roofs, and alongside hard surface areas such as parking lots, sidewalks and streets). As examples of nature-based GSI, they filter, store, infiltrate, and evapotranspirate stormwater using filter beds comprised of plant material and bioretention media (e.g., a substrate of specialized soils) (CSA Group 2018). In many jurisdictions, they are favoured as a flood mitigation retrofit for older residential lots, notably where subsoils are freely infiltrating, and the primary objective is infiltration. The US EPA (n.d.) notes that stand-alone varieties are a versatile GI application suitable for installation in almost any paved or unpaved space, and on public or private properties of any size.

Rainwater Harvesting

This term describes applications typically using barrels or cisterns to collect and store rainwater runoff that would otherwise be diverted into storm drainage systems, waterways and bodies of water (CNT 2010). This is an age-old practice that has been used in drought-prone communities seeking to reduce demand on their water supply. In addition to its targeted outcome of controlling stormwater runoff volumes and mitigating overland flooding, rainwater-harvesting practices increase the available water supply available for irrigation, accelerating groundwater recharge and reducing energy use.

Urban Trees

Urban trees are an example of NBS, contributing to water management in towns and cities, when planted and managed strategically. To begin with, trees have cumulative effects beneficial for local stormwater control, helping to mitigate flood magnitude and damage by stabilizing soils and absorbing excess water. These capabilities depend on factors such as species selection, planting conditions and maintenance practices (CCME 2018). In urban and rural communities across Canada, the impacts of catastrophic events such as forest fires have damaging consequences for developments reliant on (or located close to) forested lands. Communities that lose the natural climate adaptation benefits of a healthy forested landscape will be more vulnerable to severe storm events, and risk losing the benefits of trees and forests for water infrastructure, local economies, public health and safety.

Underground Infiltration Systems

Underground infiltration systems are green infrastructure applications that collect and hold stormwater, allowing the gradual infiltration of water into the underlying soils. Infiltration systems can include rock trenches, infiltration galleries, dry wells, perforated pipe systems, and sewerless roads. They are ideally suited for placement under paved surfaces like parking lots and roadways and require an upstream pre-treatment device to ensure adequate sediment removal.

3.4 Extreme Heat Conditions and Events

Land use planning in Canadian towns and cities has exacerbated the effects of temperature rise due to climate change.[11] Impermeable and low albedo (i.e., the ability of a surface to reflect radiation) grey infrastructure surfaces (e.g., concrete, asphalt, steel and glass) – combined with concentrated air pollution and a lack or loss of greenery in municipal landscapes – increase heat absorption by elements of the built environment and directly contribute to the urban heat island (UHI) effect.[12] Increases in temperature are usually associated with a corresponding rise in demand for electricity, increasing GHG emissions and intensifying climate change impacts.

Urban trees and other vegetation figure importantly in efforts to mitigate the UHI effect in developed areas, based on evidence that trees can reduce energy consumption during peak periods of demand (e.g.: lower temperature can reduce demand for air conditioning). In this respect, considerations relating to the characteristics of the local climate as well as the choice of plant species and their placement are important factors. Trees and greening projects (e.g., green roofs, green walls and permeable surfaces) provide benefits for climate mitigation and adaptation, pollution reduction, flood prevention, human health and well-being, conservation activity and local economies. In addition, the use of native species can serve to protect and support biodiversity. Perhaps most significantly, urban greenery projects comprise an NBS capable of offsetting some of the more damaging environmental impacts of the grey infrastructure elements with which they co-exist.

3.4.1 Solution Area: Urban Forestry and Greening Projects

<u>Urban Forests</u>

Urban forests are groups of trees with placement along streets and on rooftops, in parks and woodlands within the municipal boundaries of towns and cities, rural communities and on private and public lands. They are ecosystems encompassing shrubs and other greenery, as well as the soil and water that support vegetation. Nature-based projects using urban trees include preserving, restoring or creating forested spaces, and planting and maintaining street trees, those in parks, as well as municipally managed conservation areas. Private trees and vegetation include those in private front and backyards, around apartment buildings, in parking lots, and on commercial and industrial lots. Because the concept of urban forestry (used in conjunction with community forestry in some places) has a well-established record of accomplishment supported by highly cited peer-reviewed literature, it can provide a toolbox for the uptake of NI and NBS more broadly (Escobedo *et al*. 2019).

[11] This infrastructure challenge area is discussed with an exclusive focus on urban (i.e., town and city) sites, in order to maintain a narrow scope. It does not address important impacts of temperature rise such as the potential for drought in rural or arid regions, or contributions to the increase of forest fires in Northern regions of the country.

[12] UHIs are defined as city areas that consistently reach higher temperatures than rural areas, due to heat absorption and emittance from impermeable surfaces (e.g., concrete, glass, asphalt and steel) in the built environment. A closely related phenomenon, urban canyons, are the spaces between densely spaced buildings that demonstrate inadequate air flow; as a consequence, they trap pollutants and cause a decline in local air quality.

In the area of temperature regulation, urban forests and tree canopies (TCs) reduce air temperatures through evapotranspiration and by providing shade, thus combatting the UHI effect by keeping buildings and open spaces cooler. They comprise an important climate adaptation measure while supporting human health and reducing energy demand during peak, high-temperature periods. There is an array of supporting benefits derived from urban trees, dependent on species selection and placement factors; these include benefits for:

- Stormwater management: the cumulative effect of large numbers of trees with other green spaces is improved retention of excess precipitation, which is absorbed by leaves, branches and root systems. By reducing runoff, erosion is limited and local soils are stabilized (GIO 2016d).
- Water purification: trees (but also grasses, shrubs, gardens and flowerbeds) provide effective natural water filtration and support the infiltration of cleaner groundwater.
- Air quality: urban NI applications involving trees (including green roofs) help remove pollutants including carbon monoxide, ground level ozone and airborne particulate matter from the air (Hotte *et al*. 2015).
- Carbon sequestration: trees remove carbon dioxide from the atmosphere.
- Reduced noise pollution: urban tree coverage helps to buffer excess noise from traffic and construction, which can be difficult to value in monetary terms but likely enhances the quality of life in developed areas.
- Human health and well-being: there is evidence that living and working close to trees improves mood, focus and psychological health (Kardan *et al*. 2015). In addition, forested spaces promote outdoor recreation, increasing physical activity when suitably designed and managed for those purposes, as well as food security when fruit trees are used.
- Habitat and the protection of biodiversity: for wildlife, urban forests represent a critical form of natural habitat to species living in or migrating through urban areas.
- The economy and value of property: because urban forests and trees enhance the aesthetic qualities of Canadian towns and cities, they increase property value.

Conventional grey infrastructure solutions reliant on technological innovation (e.g., applications that reflect or absorb radiation, such cool roofs and reflective pavements) have sought to offset urban temperature rise with varying measures of success, but do not offer comparable additional benefits as those from urban forests.

Soil Cells

Sometimes called structural cells, soil cells are rigid polypropylene structures of fixed shape and size, designed with a void space to accommodate soil (Ow and Ghosh 2017). The cells are used to grow healthier trees (i.e., trees with greater biomass) in limited space, by providing a compacted surface that protects uncompact soil underneath. Resembling plastic tabletops in appearance, the cells create long soil vaults between trees, and bridges underneath sidewalks to allow root systems to reach deeper. Because uncompact soil provides additional rooting space, urban trees grown with soil cells can develop to their fullest potential. Cell systems have no need for stone (i.e., planters), as they are sufficiently strong to accommodate the load from the surrounding pavement. This green infrastructure innovation enables the growth of a mature urban tree canopy, which helps to regulate temperature, reduce stormwater runoff, support infiltration, increase oxygen, and absorb air pollution.

Urban Greening

This term describes a performance-based approach to urban land use planning, based on the core principle of integrating multiple low-impact land uses in complex socio-ecological urban systems where diverse social networks and actions interact with natural ecosystem elements (Dorst *et al*. 2019). In all cases, its use in the NBS literature is restricted to urban (i.e., town and city) settings where greater dimensions of population and development density can be found, compared to those that characterize smaller rural or remote communities. Urban trees, green roofs/ walls, and de-paving initiatives are examples of land use multi-functionality. Vegetation, land and water can support local climate adaptation in the critical areas of flood and stormwater management and temperature regulation, while providing discernible co-benefits.

Green Open Spaces (GOSs)

GOSs or simply green spaces are terms used to describe city or town parks, conservation areas, ravines, woodlots, riparian areas, provincial and federal parks, playing fields, as well as schoolyards and golf courses (GIO 2016b). The extensive pavement coverage in most towns and cities is associated with a generally low degree of water permeability, contributing to an increase in temperature. Green spaces with trees, shrubs and soils help to slow localized temperature rise through processes such as evapotranspiration and shading. The same vegetation can attenuate stormwater flows during severe weather events, filter sediment, and remove pollutants from rainwater.

GOSs provide a range of other environmental and sociocultural co-benefits. For instance, they provide valuable habitat for native plant species and for birds migrating through urban corridors. Pollination parks can be preserved to allow bees to carry out the pollination required by local farmers for food production, as well as provide the venue for the pollination of native vegetation types. Many GOSs are designated for recreational purposes and promote people's social interaction and physical activity. This delivers a subset of important benefits to human health and well-being, including contributions to improved motor abilities in children, lower risks of obesity and generally improved levels of mental health. Finally, residential properties adjacent to parks and GOSs may be valued higher than comparable real estate elsewhere.

Green Roofs

In response to rising temperatures, green roofs are a type of green infrastructure that helps to regulate temperature through saturation and evapotranspiration, shading and the reflection of solar radiation. In urban settings, there is a low ratio of green overhead coverage compared to impermeable surfaces and the area of visible sky. Conventional roof surfaces comprise a large proportion of the impervious overhead cover, essentially trapping heat because they are dry and absorb solar radiation. Exacerbating the UHI effect is the construction of buildings in close proximity along city streets, as a part of high-density commercial and residential development. Green roofs have the capability to counter the UHI effect through evaporative cooling, providing insulation that regulates the internal temperature of buildings (Filazzola *et al*. 2019; Moss *et al*. 2019). Maximized roof surface coverage is a key factor in the ability of a green roof to regulate temperature, because an abundance of foliage provides shading, enables thermal heat exchange, and absorbs thermal energy during the vegetation's photosynthesis (Berardi *et al*. 2014).

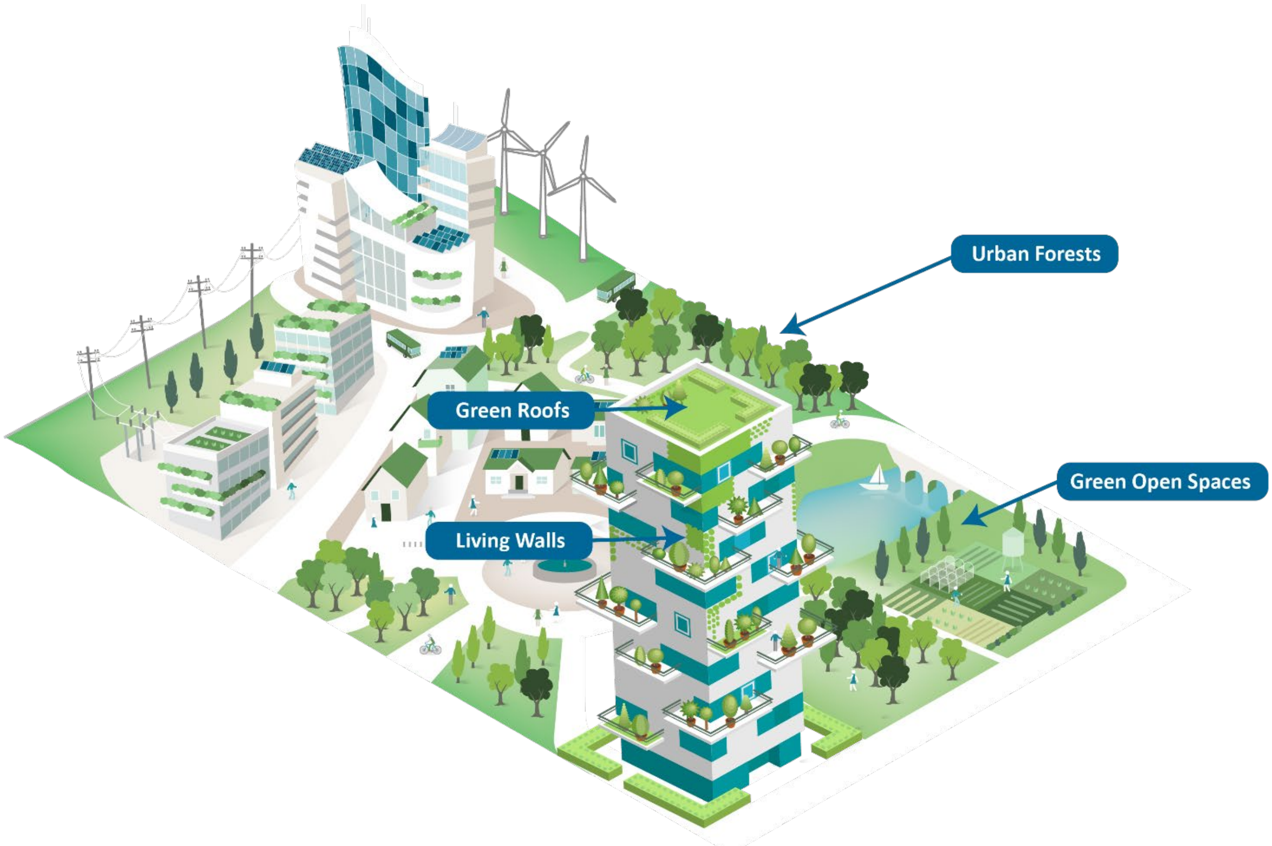
The principal ancillary benefits of green roof applications are reductions in energy use in both the winter and summer seasons, and reduced air pollution by filtering ground level ozone and particulate matter (Rowe 2011; Kumar *et al*., 2019). Green roofs require lower investment in construction and maintenance costs than their main engineered counterpart, cool roofs, because they shield the main roofs below from ultraviolet radiation, temperature extremes and physical damage from precipitation. Roofs with sufficiently deep substrates are able to sequester significant carbon (Whittinghill *et al*. 2014). What is more, a green roof can be used for vertical gardens and urban agriculture, providing a food source for human communities, pollinating insects and birds (GIO 2016a). They convert what may have been under-utilized urban space into supportive habitat for urban wildlife (Parkins and Clark, 2015), diminish nose pollution, and enhance the aesthetic features of high-density urban spaces.

Living Walls

Sometimes referred to as eco-walls, bio-walls or green walls, a living wall is a green infrastructure application in which vegetation is grown on the side of a building and relies on support structures (Filazzola *et al*. 2019). At its simplest, a living wall is a vertical garden in which vines and climbing vegetation grow up from planters and are secured by stainless steel cables, metal grids and trellises. In its more complex forms, there are specialized and engineered envelope systems where vegetation is planted, grown and irrigated in modular elements which are secured to or integrated with the wall of a building (CRD n.d.). For any application, structural weight, moisture retention, nutrient supply and water distribution are important design considerations (*ibid*).

During the summer season and during extreme heat events, living walls protect the exterior walls of buildings from intense solar radiation, transforming it into latent heat and allowing surface temperatures to remain comparatively cooler. Living walls equally help to reverse the urban canyon phenomenon, by trapping airborne pollutants that would otherwise diminish local air quality (Abijith *et al*. 2017). The high ratio of wall to roof area in urban spaces suggests the potential to generate exponentially greater environmental benefits from green walls than from green roofs, though combining both increases the overall efficacy of each type of installation (Alexandri and Jones 2008). Green roofs offer superior drainage, however, and since green walls are constantly wet, care must be taken to ensure mold is controlled. Suitable native plants should comprise the vegetation in all instances except where there is a risk of the overproduction of pollens, which can be an irritant to some people living and working near living walls.

Figure 5. Extreme Heat Conditions and Events - Examples of Natural Infrastructure and Nature Based Elements



4.0 CONCLUSION

NI and related NBS offer solutions to complex infrastructure challenges under current and future climate scenarios. They have the ability to meet targeted infrastructure outcomes in urban and rural settings, including remote and northern communities across the country.

Simply re-labelling the business as usual infrastructure planning and development as nature-based, however, risks limiting opportunities to implement new NI projects and scale up existing interventions. Care must be taken to prioritize solutions that qualify as nature-based because they offer valuable and increasing returns on investment. This includes benefits to climate change resilience through increasing adaptive capacity to the impacts of climate change, but also extends to include multiple other benefits such as supporting biodiversity, nature conservation, the health of human communities, and can also stimulate clean economic growth.

This Terminology Framework serves as an important resource to provide clarity on the broad suite of NBS and their benefits. For example, it can be used to inform officials and practitioners across all jurisdictions, who design or deliver programs related to NBS. It can also help to help facilitate dialogue and disseminate information to the broader public. Given the Framework is focused on clarifying terminology; it does not provide specific case studies on how NBS have been implemented across jurisdictions. It acknowledges, however, the widespread benefits and opportunities for NBS, which can be applied to urban, rural, northern, coastal and inland areas. Is serves as a tool for officials and practitioners across jurisdictions to understand the range of NBS options available, and to use this to inform planning and development decisions. The Framework does not provide specific emphasis on fire risk management, droughts, or remote and northern communities, given this was outside of the four distinct challenge and solution areas covered in the report. While many of the NBS can be applied for those areas and purposes, further work is needed in that area.

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APPENDIX: ADDITIONAL RELATED TERMINOLOGY

This appendix describes key terms that relate to, and intersect with, NBS. The terms have been divided into two groupings: (1) assets, and (2) principles and practices.

Assets

Eco-Assets

A term used in the context of the successful municipal-level NI initiatives undertaken in the town of Gibsons, British Columbia and integrated into the community's asset management programming.[13] It is used interchangeably with natural assets and municipal natural assets, and refers to the features of ecosystems and landscapes that provide services to humans. While picked up by some advocates for NBS across Canada and elsewhere, founding partners of the Gibsons initiative have discouraged its wider adoption because it suggests a focus on environmental outcomes rather than on ecosystem service delivery. NBS including green infrastructure and NI, importantly, seek to meet defined service delivery goals while supporting the achievement of associated benefits to biodiversity, the environment and climate.

Engineered Assets

An umbrella term for human-made infrastructure features. Under this broad category, there is a spectrum of elements running from grey infrastructure at one end, to green infrastructure features such as permeable pavements, green roofs and green walls at the other. Engineered or built assets can be designed to emulate many of the functions of ecosystems and landscapes, and it can be more or less naturalized depending on factors such as the extent and direction of human management, the passage of time and changes to localized ecosystem conditions. They constitute assets insofar as their costs and benefits can be made subject to assessment and evaluation.

Enhanced Assets

Under the banner of NBS in North America and Europe, enhanced assets occupy a mid-point on the spectrum between assets representing NI (ecosystem and landscape elements on the preserved or restored end) and constructed green infrastructure, providing comparable or complementary outcomes**.** To illustrate the sometimes finely-drawn distinctions here, the category of natural assets includes forests, wetlands, rivers and creeks, lakes, fields and soils; enhanced assets include restored or otherwise human-constructed green infrastructure elements such as strategic urban tree planting, rain gardens, bioswales and stormwater ponds (MNAI 2019).

[13] The Gibsons, BC pilots overseen by the Municipal Natural Assets Initiative (MNAI) and founding partners including the David Suzuki Foundation provide some of the best available evidence of the successful local management of linked NI applications. See MNAI (2018).

Municipal Natural Assets

Municipal natural assets are the stock of natural resources and ecosystem elements that are (or could be) relied upon and managed by a municipality, regional district, or other form of local government for the sustainable provision of one or more municipal services (MNAI 2017). Governance and management of natural assets is usually undertaken at the watershed, regional or local level in Canada, as is the practice for conventional infrastructure elements. Uptake remains limited, however, and there persist considerable disparities between the provinces in how authority over natural assets is conferred upon municipalities. This is because the enabling legislation for the municipal level of government across Canada does not explicitly confer authority over nature conservation practices. While designating something as a natural asset can help to emphasize its value as infrastructure, ultimately local governments have to rely on the use of NI and green infrastructure terms to demonstrate the delivery of municipal services using natural systems and processes.

Natural Assets

Sometimes called natural capital assets, these describe ecosystems or ecosystem components (e.g., shorelines, wetlands, green spaces) in terms of their value to society, particularly for the benefits they provide such as nutrient cycling, rainwater drainage and flood mitigation. Nature provides many services that fall under local authority and management structures; these can be assessed and managed to ensure ongoing infrastructure outcomes and other benefits. Because the services provided by natural landscapes and seascapes may differ from those provided by engineered or built assets, natural assets have not been historically considered on equal footing or included in municipal asset management plans (MNAI 2017). The governance and management of natural assets can require collaborative arrangements because many of them pass through or overlap with private properties.

Where integrated successfully into management plans, natural assets can be made subject to valuation – the process of estimating their relative importance, worth or usefulness to human communities, in qualitative, quantitative or monetary terms, or in some combination of these. Where qualitative valuation in this context might be based on people's preferences or constraints on resources (i.e., when market indicators are inapplicable or do not exist), quantitative approaches may take stock of resources, and the monetary value of products and services derived from nature is determined by the market. Calculating the monetary value of the benefits provided by NI can be helpful to decision makers and the public (Guerry *et al.* 2015), though it is challenging to attach a price to co-benefits. At the same time, because NI's value as a municipal or private asset is further enhanced by its benefits beyond the delivery of a singular service (e.g., its tangible and intangible benefits to humans and supporting biodiversity), it is useful for stakeholders to be able to model and measure those additional outcomes and values.

To date, efforts at valuing NI and NBS have had mixed success quantifying the value of co-benefits and their associated costs. Comparisons to grey infrastructure outcomes proffers one method, and avoided cost methodologies (i.e., measuring the costs to infrastructure that would occur if the natural asset were lost and that governments would otherwise have to address using grey infrastructure) represent another. The quantification of the range of social benefits related to comparable economic values are also commonly undertaken (termed triple bottom line) as part of cost-benefit analyses.

Natural Capital

Often used interchangeably with natural assets, natural capital is another term for the stock of renewable and non-renewable, physical and biological resources (e.g., air, water, soils, minerals, plant and animal species and more) that combine to yield a flow of benefits to people (Natural Capital Coalition, n.d. Chenoweth *et al*. 2018). The concept is based on an economic metaphor – the idea that the natural environment provides valuable goods (e.g., timber) or services (e.g., nutrient cycling) which, if used sustainably, can enable human communities to flourish.

Natural Capital Accounting (NCA)

NCA is the umbrella term for efforts to use an accounting framework to systematically measure and report on stocks of natural capital (Turner *et al*. 2019)**.** The principle upon which these are based is that natural assets are important to society and provide comparable infrastructure outcomes to engineered assets; thus, their quantity, condition and value should be managed and monitored, with a long-term goal of full integration into a country's system of national accounts. It is typical for NCA to cover stocks of natural resources, both biotic (e.g., fish, timber) and abiotic (e.g., water, minerals), ecosystem elements (e.g., forests, wetlands), biodiversity levels and ecosystem services.

Principles and Practices

Biodiversity

The United Nations-led Convention on Biological Diversity (CBD) defines biodiversity as "… the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (UN 1992). The dimensions of biodiversity, in this view, include variations in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space, within and among species, biological communities and ecosystems (IPBES 2018).

Biodiversity underpins natural systems and processes; in so doing, it supports the health of vegetation and wildlife native to local ecosystems (CPAWS 2018), and its preservation is integral to the management of NI, green infrastructure and NBS in the widest possible sense. Canada is home to globally significant biodiversity such as the boreal forest, millions of migratory birds, and animal species including caribou and polar bears that are notably imperiled by climate change impacts (ECCC 2019). The effects of climate change have and will continue to impact the overall condition and resilience of biodiversity.

Biomimicry

In the context of NBS, biomimicry refers to a design principle wherein green infrastructure is engineered to emulate many of the features and functions of natural systems and processes. The concept was popularized with the publication of American biologist Janine Benyus's 1997 book

Biomimicry: Innovation Inspired by Nature. Foundational work in the area emphasizes two main aspects of how natural systems adapt successfully and provide evidence for the superior design of human systems (Arsenault and Sood 2007): first, features found in nature are appropriate to their local ecosystem conditions, and so are able to sustain the diversity of elements required to improve their chance of survival. Second, they demonstrate resilience over time – they succeed because they last, and last because they are successful.

Co-Benefits

The positive outcomes achieved by NI beyond a specified infrastructure function. These benefits are both quantitative and qualitative; some of them are ecosystem goods, and others can be formally categorized as ecosystem services, which support the environment, the economy and human health to varying degrees.

Design-with-Nature (DWN)

A concept traceable to the origins of landscape architecture, and since the 1960s, as a core principle of sustainable urbanism movements in the United States and Europe. Today it persists in discourses on design and planning that emphasize the creation of green urban spaces and dimensions of continuity between development and nature (Douglas 2019). In one influential version, Farr (2011) describes it as urbanism based on a combination of active transportation, together with energy-efficient buildings and high-performance green infrastructure. Green infrastructure remains integral to sustainable urban planning and design and can include nature-based applications for natural heritage beautification, nature-based drainage and management of stormwater flows, as well as the elimination of unnecessary paving.

Ecological Infrastructure

A concept linked to discourses of sustainable development in the 1980s and 1990s, specifically as a guiding principle for conservation planning in so-called ecological cities.[14] It refers to the natural or semi-natural structural elements of ecosystems and landscapes that are important in delivering ecosystem services, and so is sometimes described as similar to green infrastructure. By the turn of the millennium, the term was linked to ecosystem and landscape-level applications such as greenways, ecological networks, nature corridors, conservation corridors, multiple use modules and other areas of natural habitat (da Silva and Wheeler 2017) that support processes such as species movement, reproduction and pollination. These applications cover most of the natural features that provide benefits to people living in cities. More recently, it has been used more interchangeably with NI, described as a combination of structures and spatial patterns that preserve ecosystems and landscapes, provide sustainable ecosystem services, and protect cultural heritage and recreational experiences (Yu 2012).

[14] Planned cities of this sort were developed at Dongtan, China and Masdar in the United Arab Emirates beginning in 2005-06, and were received enthusiastically by many conservationists and urban planners globally.

Eco-Based Adaptation (EBA)

EBA is "… the sustainable use of biodiversity and ecosystem services into an overall adaptation strategy to help people to adapt to the adverse effects of climate change [that] can be cost-effective and generate social, economic and cultural co-benefits and contribute to the conservation of biodiversity … (CBD, 2009). In this usage, NBS and/or NCS, applied to climate adaptation, are both subsets of EBA, a strategic approach to ensuring that the climate resilience of human communities is mutually-reinforcing with the sustainable use of resources and protection of biological diversity.

Ecosystem

A dynamic complex of plant, animal, and microorganism communities, along with the non-living environment interacting as a functional unit (MA 2005)**.** An ecosystem can be an intact environment, such as a natural forest, a landscape with mixed patterns of human use, or an area intensively modified and managed by humans, such as agricultural land.

Ecosystem Goods

Ecosystem goods include all of the tangible products and materials derived from the natural environment, such as food, water, fibers and pharmaceutical ingredients. They are typically measured in the physical quantities (e.g., number, volume, weight or flow) that an ecosystem produces over a specified time period (e.g., the quantity of water produced per second, or board-feet of timber cut in a 40-year rotation), and may require various levels of human intervention to be maintained (Molnar *et al*. 2012).

Ecosystem Services (ES)

ES are the conditions and processes through which natural ecosystems (and the species that make them up) sustain a flow of direct and/or indirect benefits to people (Molnar *et al*. 2012). They include the benefits resulting from ecosystem processes (e.g., flood management, nutrient cycling, water filtration and climate regulation) as well as sociocultural benefits (e.g., recreation, aesthetics, cultural heritage and practices).

A number of organizations globally are active in standardizing the concepts, classifications and rules for the assessment and evaluation of natural assets and the services they provide. For these organizations, nature is comprised of assets comparable in value to grey infrastructure elements, and this can be adequate justification for the implementation of NI in many instances.

The best-known model of classification[15] distinguishes ES of four main types (TEEB n.d.; UNEP 2014):

- *Provisioning services* that make direct material and energy contributions to humans, such as fish, biomass, or plants used in pharmaceutical manufacture.

[15] Other high-profile examples of modern ES classification protocols include the Common International Classification of Ecosystem Services (CICES) developed by the European Environmental Agency (to support including ecosystem services into national accounts), along with the Final Ecosystem Goods and Services Classification System (FEGS-CS), and the National Ecosystem Services Classification System (NESCS) both developed by the U.S. EPA.

- *Regulating services,* which result from ecosystems' ability to regulate ecological, hydrological and biochemical cycles, such as when wetlands absorb, filter and purify rainwater, sequester carbon or help to regulate local temperature.
- *Habitat/Supporting services*, which provide habitat for diverse species of plants and animals, preserve genetic diversity, and support processes such as pollination and the migration of birds, fish and insects.
- *Cultural services*, delivered by ecosystems and landscapes to human communities in the form of recreational, intellectual and symbolic benefits to health and well-being, knowledge and spirituality.

Many ES count prominently among the benefits of adopting NI solutions, and still others represent valuable co-benefits.

Habitat

A habitat is a place or type of site where an organism or population naturally occurs (IPBES 2018). It is also used to refer to the environmental attributes directly or indirectly required by resident species to carry out their life processes such as reproduction, hibernation, rearing, migration and feeding.

Natural Heritage System

A natural heritage system is a system made up of natural heritage features and areas, and linkages intended to provide connectivity (at the regional or site level) and support natural processes which are necessary to maintain biological and geological diversity, natural functions, viable populations of Indigenous species, and ecosystems (Government of Ontario 2014). These systems can include designated natural heritage areas, federal and provincial parks and conservation reserves, other natural heritage features), lands that have been restored or have the potential to be restored to a natural state, areas that support hydrologic functions (e.g., lake systems), and working landscapes that enable ecological functions to continue. The concept makes an important contribution to NI terminology by emphasizing the role of large-scale natural systems and landscape-level features (such as nature corridors and greenways).

Nature Corridors

This geographic term is well-established in the NBS literature and is sometimes used interchangeably with greenways to describe habitat connections that facilitate the movement of wildlife and ensure the overall continuity of human communities with the natural environment or a larger 'natural heritage system' (di Marino and Lapintie 2017; Koc *et al*. 2017). It serves as a catchall term for natural spaces that link ecosystems, landscapes and species habitats – watershed, escarpment and ravine systems, as well as interconnected water bodies such as lake systems. Nature corridors provide benefits supporting human health and well-being, and related sociocultural benefits such as spaces for individuals and families to participate in nature-based recreation, as well as transportation routes essential to local and regional economies.