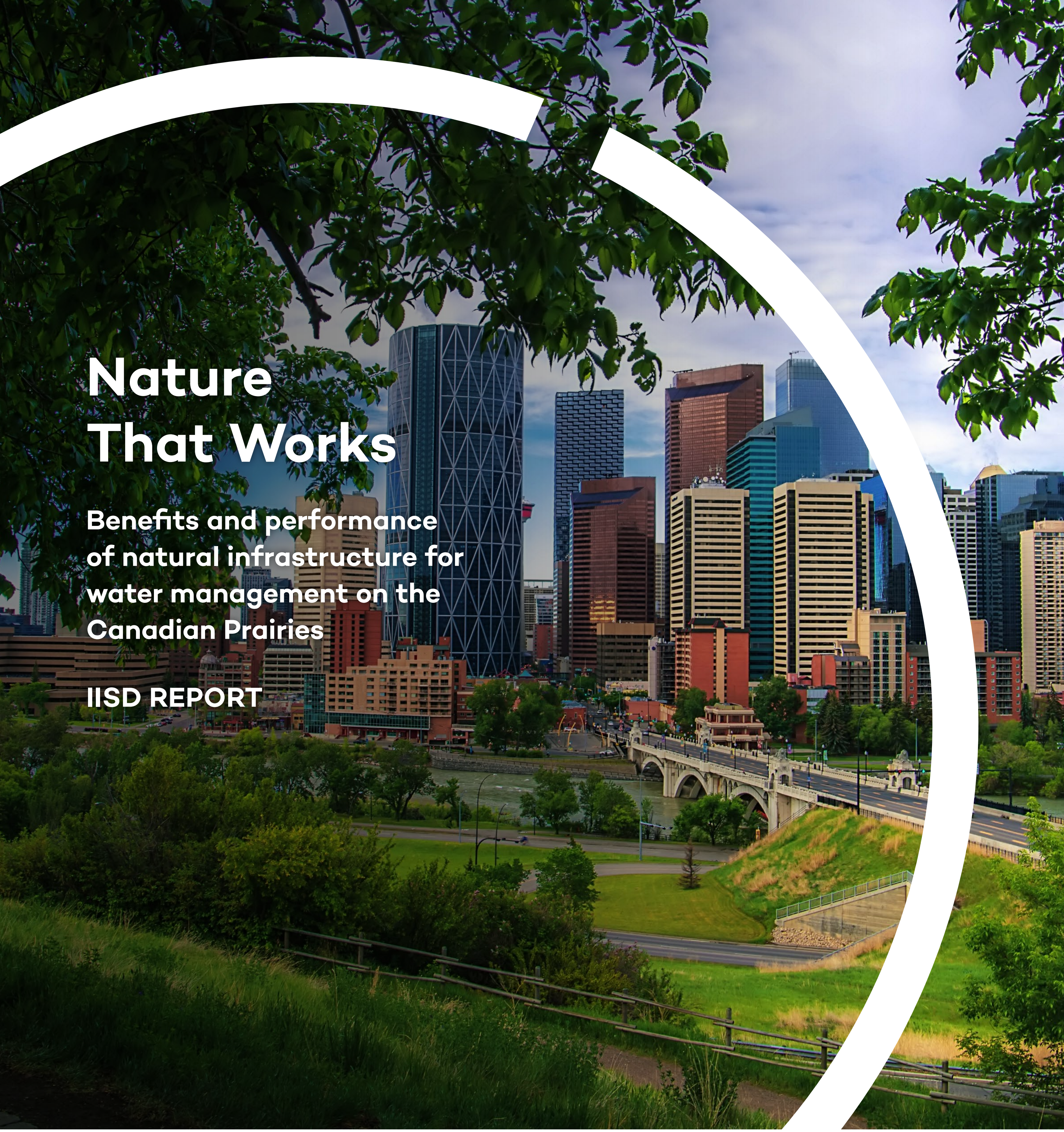

Nature That Works

Benefits and performance of natural infrastructure for water management on the Canadian Prairies

IISD REPORT

IISD | Natural Infrastructure for Water Solutions

ALIDP Alberta Low Impact Development Partnership

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While science and policy are the foundation for this work, IISD is also taking a systems view—looking for opportunities and creative approaches to achieve real impact across the region, working with a network of champions, partners, and decision-makers.

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The Alberta Low Impact Development Partnership (ALIDP) is an incorporated non-profit, membership-based community of practice that promotes the use of natural features and processes to minimize the disruption caused by urban land development to the water cycle, while maximizing economic, environmental, and social benefits. A Low Impact Development approach seeks to prevent and manage runoff as close to its source as possible and views runoff as a resource rather than a nuisance. Since 2008, the ALIDP has been working closely with municipalities, academia, stormwater professionals, industry and citizens to identify and remove barriers to implementation and support the evolution of stormwater management in Alberta, across the country, and in cold climates around the world.

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BHP | Foundation

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Indigenous Lands and Cultures

The region we refer to as the Canadian Prairies is home to an incredible diversity of Indigenous cultures. Indigenous Peoples of the Prairie region are rightsholders with robust knowledge and close connection to their traditional lands and with jurisdiction over their territories.

The region of focus for IISD's Natural Infrastructure for Water Solutions (NIWS) initiative spans over 200 traditional territories and homelands across the provinces we call Alberta, Saskatchewan, and Manitoba—including the Indigenous territories of the Nêhiyaw-Askiy (Plains Cree), Woodland Cree, Iyarhe Nakoda (Stoney Nakoda), Anishininiimowin (Oji-Cree), Niitsítapi (Blackfoot), Tsuut'ina, Očhéthi Šakówiŋ, Nakoda Oyadeb (Nakota), Lakota, Dakota, Anishinaabe (Ojibwe), Anisininew (Ojibwe Cree), and Salteaux, alongside Métis Nations, including the Otipemisiwak Métis, Métis Nation–Saskatchewan, and Red River Métis.

At IISD, we uphold the agency and autonomy of Indigenous Peoples, supporting their efforts to revitalize and engage with their heritage across traditional, contemporary, and future contexts. We offer respect to those who have long lived with and stewarded lands and waters across the Prairies and recognize the ongoing leadership of First Nations and Métis communities.

We encourage everyone to visit native-land.ca to learn more about traditional lands and treaties across the Prairies.

Disclaimer

Executive Summary

As calls increase to harness the power of natural infrastructure to meet infrastructure needs globally and in Canada, so too do questions about the benefits and performance of natural infrastructure. Across the Canadian Prairies, natural infrastructure can contribute to meeting water infrastructure needs while providing social, economic, and environmental benefits. However, more work is needed to build a better business case for natural infrastructure in the context of prairie water management. Evidence increasingly shows clear benefits for both natural and constructed assets to deliver infrastructure services related to water quality and quantity, along with co-benefits. This report provides an accessible entry point for those wanting to learn more about these benefits and how natural infrastructure can be applied to support water management needs across the Canadian Prairies.

Two foundational questions necessary for building a better business case for natural infrastructure in the context of prairie water management are addressed in this report, informed by desktop research and engagement with natural infrastructure experts and practitioners in Canada:

- **What are the benefits of natural infrastructure for water management?** Natural infrastructure can support (i) flood mitigation, (ii) water supply and drought mitigation, and (iii) water quality (e.g., stormwater, wastewater). It can also concurrently provide co-benefits related to climate mitigation and adaptation, environmental integrity and biodiversity, and beneficial social, health, and well-being outcomes.
- **What are some prominent types of water-related natural infrastructure, and how do they perform on the Prairies?** In this report, natural infrastructure is organized into four functional families, including *cover*, *basins*, *watercourses*, and *groundwater*. Within these families, natural assets are introduced and discussed first, setting the stage to explore examples of constructed analogues. The performance of natural infrastructure is shaped by many factors, including design, infrastructure type, position on the landscape (spatial context), season, and maintenance and operations, among others.

The report concludes by framing the next steps for building a better business case for natural infrastructure in the context of water management on the Canadian Prairies, particularly recognizing calls to sharpen the evidence base and strengthening decision-support tools for the holistic valuation of natural infrastructure.

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Abbreviations and Acronyms

AAFC	Agriculture and Agri-Food Canada
ALIDP	Alberta Low Impact Development Partnership
BOD	biological oxygen demand
BMP	beneficial management practice
CCME	Canadian Council of Ministers of the Environment
CVC	Credit Valley Conservation
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
IISD	International Institute for Sustainable Development
I/P ratio	ratio of contributing impervious area to pervious basin area
NbS	nature-based solutions
NIWS	Natural Infrastructure for Water Solutions
NRCan	Natural Resources Canada
PPWB	Prairie Provinces Water Board
SCS	Soil Conservation Service
SEEA	System for Environmental-Economic Accounting System for Environmental-Economic
TN	total nitrogen
TP	total phosphorus
TRCA	Toronto and Region Conservation Authority
TSS	total suspended solids
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture

1.0 Introduction

1.1 Purpose

Communities of all sizes across the Canadian Prairies are weighing infrastructure options regarding flooding, drought, stormwater management, wastewater treatment, and water supply. While there will always be a need for conventional "grey" water infrastructure (e.g., dams, water treatment plants, pipes, and conventional stormwater ponds), natural infrastructure is increasingly recognized as a complementary approach to meeting water infrastructure needs, with added benefits for ecosystems and people. Natural infrastructure is a way to plan and work with nature to meet infrastructure needs (Méthot et al., 2023), enlisting natural features and processes to reduce flood risks, improve water quality, reduce urban heat, add recreational space, and more (Federal Emergency Management Agency [FEMA], 2021).

> "Natural infrastructure solutions are increasingly seen as win-win investments that support traditional infrastructure outcomes, such as stormwater management, and deliver valuable co-benefits to communities, such as climate change resilience, reduced pollution, and carbon sequestration." —Canada's National Adaptation Strategy (Government of Canada, 2023b, p. 26)

This report is designed as an accessible entry point for those wanting to learn more about how natural infrastructure can support water management needs across the Canadian Prairies, with a focus on the benefits and performance of natural infrastructure for water management. Specifically, this report

- frames the benefits and co-benefits of natural infrastructure in relation to prairie water management (Section 2);
- reviews the water-related performance for key natural infrastructure types across the Prairies (Section 3); and
- recommends key considerations to guide the protection, planning, and deployment of natural infrastructure (Section 4).

This report is informed by a scan of literature pertaining to the performance of select natural infrastructure types relevant to the Canadian Prairies. While there are many examples of natural infrastructure projects, evidence of their performance is typically not widely available or easily accessible (Coalition for Disaster Resilient Infrastructure, 2023). This report helps respond to this need, compiling some of the locally relevant evidence base behind natural infrastructure to better equip key groups with the information needed to champion, design, implement, and evaluate natural infrastructure in the context of prairie water management.

Importantly, this report is not a comprehensive literature review or meta-analysis. Also, while this report focuses on the benefits and co-benefits of natural infrastructure, it is also important to consider the potential for trade-offs, disbenefits, and the distribution of benefits through an equity lens. These latter points are outside the scope of this report.

1.2 Defining Natural Infrastructure

1.2.1 What Is Natural Infrastructure?

Natural infrastructure can be a conserved ecosystem (e.g., wetland), a restored ecosystem (e.g., replanted riparian area), or even a constructed asset (e.g., green roof) (Figure 1). The common thread? Natural infrastructure is managed to provide specific infrastructure benefits, with the potential for many associated social, economic, and environmental benefits. These systems differ from "plain old nature" in that they are specifically designed and/or managed to support infrastructure service delivery (Roy, 2018) or acknowledged and accounted for in terms of infrastructure service delivery.

Figure 1. Categories and examples of natural infrastructure

Conserved Ecosystems	Restored Ecosystems	Constructed Assets
Conserving existing natural ecosystems to prevent their loss and/or optimizing their function to enhance infrastructure outcomes	Restoring or enhancing degraded ecosystems to deliver infrastructure outcomes	Engineering and constructing new assets that incorporate ecosystem features to deliver infrastructure outcomes
Examples Wetland, grassland, floodplain, and forest conservation, riparian buffers	**Examples** Wetland, grassland, floodplain, and forest restoration, riparian buffers	**Examples** Constructed wetlands, water retention sites, floating treatment wetlands, soil cells, green roofs, and bioswales

Source: Adapted from Méthot et al., 2023.

Box 1. Glossary of terms used in this report

There are many similar concepts and definitions around natural infrastructure. This report uses the following terms.

Nature-based solutions (NbS): "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" (Canadian Council of Ministers of the Environment [CCME], 2021, p. 3).

Natural infrastructure: "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" (CCME, 2021, p. iv). Natural infrastructure is considered a subset of the broader field of NbS. Natural infrastructure is used in this report to refer to the application of NbS to address water infrastructure needs.

Natural asset: a type of natural feature (e.g., a wetland) that provides one or more outcomes that contribute to the health, well-being, and long-term sustainability of a community (e.g., water storage and filtration). When pluralized, natural assets are the stock of natural resources and ecosystems that contribute to community outcomes (Natural Assets Initiative & Dark Matter Labs, 2024).

Constructed asset: combines both natural ecosystem processes and engineered systems to help manage water but also provides co-benefits like aesthetics and habitat (e.g., green roofs, soil cells, permeable pavement) (Minnesota Pollution Control Agency, n.d.). Similar concepts include engineered ecosystems, low-impact development, and green stormwater infrastructure.

Grey infrastructure: "human-made structures, such as dams, roads, ditches, pipes, water treatment facilities, storm drains, and bridges, that are often (but not exclusively) constructed from materials such as concrete and steel. Grey infrastructure is typically intended to meet targeted infrastructure outcomes" (Méthot et al., 2023, p. viii).

Hybrid infrastructure: "the use of natural infrastructure to complement or augment grey infrastructure to achieve more resilient infrastructure outcomes" (Méthot et al., 2023, p. viii).

Impervious/pervious (I/P) ratio: the ratio of contributing impervious area to pervious basin area (I/P ratio); used for the design of urban stormwater infrastructure.

Natural infrastructure can help meet the growing water-related infrastructure gap in stormwater management, wastewater treatment, flood and drought mitigation, and water supply, among other areas, while also playing a key role in climate adaptation efforts (Government of Canada, 2022). According to the *Canadian Infrastructure Report Card for 2019*, 30% of Canada's water-related grey infrastructure (e.g., pipes, water treatment plants) is in fair, poor, or very poor condition—and its

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replacement will cost taxpayers billions (BluePlan Engineering, 2019). Natural infrastructure can help to bridge the infrastructure gap by delivering reliable, cost-effective infrastructure services and additional co-benefits,[1] either on its own or with grey infrastructure.

Across the Canadian Prairies, land use and land cover continue to expand and intensify, often at the expense of natural systems like remaining native grasslands, forest remnants, and wetlands. According to Moudrak and Feltmate (2020), the most efficient approach to natural infrastructure, in order of priority, is to (i) retain and maintain what you have, (ii) restore what you have lost, and (iii) build what you must.

However, across this spectrum of options, context matters. For example, in urban areas, conserved or restored natural assets are often not located where they need to be to provide the necessary infrastructure benefits. In addition, increased urbanization generates increased loading (both in terms of quantity and quality), and the assimilative capacity of natural assets can easily be exceeded under these conditions. For these reasons, constructed natural assets for water management generally take priority in urban areas, although it is still important to conserve and restore natural assets in urban areas and to protect them from degradation under these challenging conditions.

1.2.2 How Natural Infrastructure Efforts on the Prairies Have Changed Over Time

There is a long history of efforts to conserve, protect, and restore nature across the Prairies. In recent years, momentum for NbS and natural infrastructure has introduced new terminology and cast longstanding efforts in a new light, with a specific focus on infrastructure service delivery. IISD's *The State of Play Report for Natural Infrastructure on the Canadian Prairies* outlines several examples of natural infrastructure projects from across the region (Méthot et al., 2023), spanning a spectrum of conservation efforts, restoration efforts, and actively building with nature. In Canada, NbS and natural infrastructure are integral parts of the federal government's National Adaptation Strategy, which emphasizes the power of nature to support more resilient communities (Government of Canada, 2022). Provincial and local governments have also emphasized NbS in climate change action plans and asset management strategies to varying degrees.

Importantly, Indigenous Peoples have long cared for their lands and waters, guided by their traditional ecological knowledge and governance systems across generations (RAD Network, 2023). Indigenous-led efforts, including Indigenous Guardians programs and Indigenous Protected and Conserved Areas, among others, highlight important intersections between concepts of NbS and natural infrastructure, as well as broader, more holistic knowledge systems.

[1] CCME (2021) defines co-benefits as "the positive outcomes achieved by natural infrastructure 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" (p. 42).

Across the Prairies, many groups have been working to conserve and restore prairie wetlands and grasslands for decades to protect habitat and biodiversity. Similarly, beneficial management practices (BMPs) in rural and agricultural settings have been implemented and extensively studied over the last several decades for improved surface water management (Li et al., 2011; Ryan & Elizabeth, 2015; South Saskatchewan River Watershed Stewards, 2019). Over the past 15 years or so, a growing body of research and pilot projects has been undertaken to support the implementation of constructed assets—or green stormwater infrastructure (e.g., rain gardens, soil cells, green roofs)—on the Prairies. These efforts are slowly becoming more mainstream. For example, in Edmonton, Alberta, EPCOR's Stormwater Integrated Resource Plan will cost over CAD 1.6 billion over 20 years, with approximately 59% (CAD 940 million) dedicated to low-impact development[2] (Credit Valley Conservation [CVC], 2021).

1.3 Characteristics of the Canadian Prairies

1.3.1 Extent

The 466,500 km^2 Canadian Prairies Ecozone extends from the end of the Montane Cordillera Ecozone in the Rocky Mountains in Alberta to where the Boreal Shield Ecozone starts, just east of Winnipeg, Manitoba (Government of Canada, 2016). The northern extent is the Boreal Plains Ecozone, which runs in a southeasterly direction from just north of Edmonton, Alberta, to the southern extent of Lake Winnipeg. The U.S. boundary delimits the southern extent of the region in Canada.

1.3.2 Land Cover and Loss

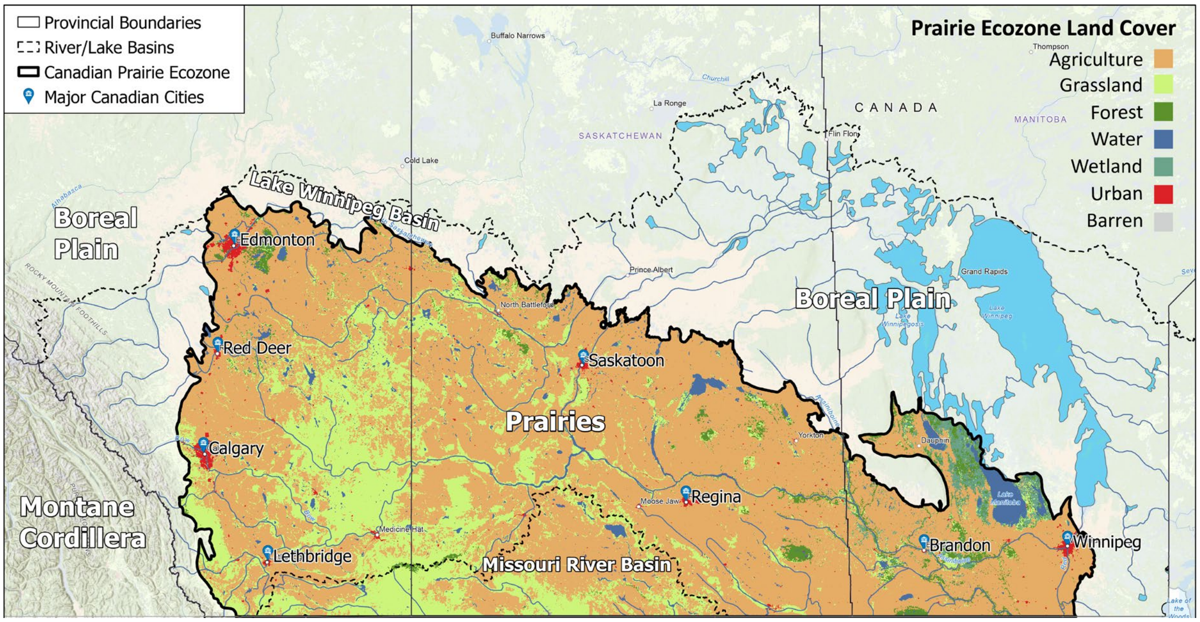
The Prairie Ecozone includes a variety of land-cover and land-use types but is predominantly composed of agricultural (64%) and grassland (22%), with the remaining area including a mix of forest (4%), various waterbodies (3%), wetland (3%), and urban land (3%), as shown in Figure 2. The Canadian Prairies have lost and continue to lose ecosystems, primarily due to agricultural expansion, resource development, and urban development. For example, estimates suggest a 40% to 70% loss of wetlands by area (Davidson, 2014, as cited in Baulch et al., 2021). Native grasslands also face ongoing conversion (Briere, 2022), and it is estimated that approximately 80% of prairie grasslands have been lost, largely due to annual cropland and urban expansion (Bailey et al., 2010).

These conversions contribute to a decline in the population and habitat range of many species, such as the loss of 60% of grassland birds in Canada since 1970 (North American Bird

[2] Dry ponds are one solution that EPCOR is using as part of their holistic approach to mitigate flooding in Edmonton. A dry pond is "a depression in the landscape that is usable for recreation, but when storms and floods occur, they act as catchments for excess water, diverting it away from the drainage network" (EPCOR, 2023, p. 28). In addition to flood mitigation, dry ponds can provide greenspace for soccer fields, pathways, tobogganing hills, or naturalized wildlife habitat (EPCOR, 2023).

Conservation Initiative Canada, 2019). The Prairies contain a disproportionate number of threatened and endangered species (McGill University, n.d.). Approximately 6% of the area within the Prairie Ecozone is under some form of protection (Government of Canada, 2021a).

Figure 2. Canadian Prairie land cover and ecoregions



Source: Based on Agriculture and Agri-Food Canada [AAFC], 2013, 2024a; Government of Canada, 2016, 2017.

1.3.3 Weather and Climate

The mountains to the west block the moderating influence of the Pacific Ocean, contributing to a continental climate with cold winters and hot summers throughout the ecozone. The mountains block precipitation in the southern part of the region, resulting in a rain shadow and semi-arid conditions for southern Alberta and Saskatchewan, as well as warming Chinook conditions closer to the mountains, especially in southern Alberta (Bailey et al., 2010). Humid conditions increase as you move eastward.

Most of the rainfall occurs during the spring and early part of the summer, with winter snowfall contributing about one third of total precipitation (Akinremi et al., 1999). Annual precipitation varies widely, ranging from 250 mm in the arid grassland regions of southwest Saskatchewan and southeast Alberta to almost 700 mm on the plains of Lake Manitoba (Government of Canada, 2013a). Chinooks, also known as snow eaters, diminish snow cover and deplete soil moisture, altering recharge patterns and exacerbating drought vulnerability (MacDonald et al., 2018).

Rainfall occurs in two distinct patterns: severe summer thunderstorms, which are intense and short in duration (convective), and synoptic storms of longer duration and lower intensity. In addition, the prairie climate oscillates between periods of extreme wet and dry weather (Kerr et al., 2021), resulting in large variations in water availability between years and seasons.

The impacts of climate change are anticipated to shift weather and climate from the predictable patterns of the past, as described in the next section.

1.4 Climate Change and Projected Impacts on the Prairies

While the Canadian Prairies have long experienced weather extremes, like reoccurring drought and catastrophic flooding, climate change is predicted to make these even worse. Across the southern Prairies, the traditional weather patterns and water cycle will shift, leading to hotter summers and warmer winters, with drier summers and wetter winters and springs (Loxley, 2022).

> "It is not unlikely that floods and droughts could occur at the same time in different parts of the region, and sometimes one after the other in quick succession" (Loxley, 2022, p. 21).

A Snapshot of the Changing Prairie Climate (Loxley, 2022) provides a detailed description of how climate change is anticipated to impact the prairies and the availability of water, including in the following ways:

More frequent and intense rainfall events. Although the amount of precipitation over the summer is projected to decrease, there will be more heavy rainfall events, with an increased chance of flash floods, inundating existing stormwater infrastructure and threatening roads and homes. Additionally, there is limited improvement in soil moisture with heavy rainfall in dry conditions, meaning that this type of precipitation may do little to alleviate drought.

Lower snowpack but greater precipitation in winter and spring. Snowpack is expected to be less, as the warmer winter weather means that more precipitation falls as rain instead of snow. This may lead to earlier spring runoff and peak flow, changing hydrological patterns with less groundwater recharge and lower river levels. These conditions could place water availability at risk for household, industrial, and irrigation use during the drier summer months. More precipitation in winter and spring would also increase the risk of flooding during snowmelt (Sauchyn et al., 2020).

Hotter summers and warmer, shorter winters. Warmer and shorter winters may lower snowpack and accelerate spring runoff and peak flow, while hotter summers will increase evapotranspiration of surface water, further lowering water levels in rivers, reservoirs, and lakes—and, subsequently, water availability. Above-average temperatures further exacerbate water supply that is already limited by the shrinking glaciers and reduced contribution to streamflow. The risk of wildfire may also increase.

More weather whiplash on the Prairies, with alternating extremes between wet/dry and hot/cold. When these events occur in the shoulder seasons, woody species may have already leafed out in a false spring and suffer dieback or be subject to damage from ice and snow in an early snowfall (Casson et al., 2019, as referenced in Loxley, 2022). Climate change models project dramatic changes in vegetation types, including the northward movement of grasslands that will accompany drier summers and the decline of woody species (Stralberg et al., 2018).

More frequent and more severe floods and droughts. Hotter summers and lower precipitation may increase the risk of drought, while more winter/spring precipitation and heavy rainfall events may increase the risk of flood.

These climate change impacts are also projected to challenge the delivery of services (like stormwater management, flood protection, and supply and quality of drinking water and irrigation), existing infrastructure (like roads, homes, hospitals, and wastewater treatment facilities), and resource production (like hydroelectricity and crop and livestock production). Natural infrastructure is gaining momentum to maintain and enhance the resilience and reliability of these services, infrastructure, and resource production internationally and in Canada (Méthot et al., 2023; United Nations Environment Programme [UNEP], 2023). Given that the Canadian Prairies are projected to warm more quickly than the rest of Canada (outside of the Arctic [Laforge et al., 2021]), natural infrastructure should be considered and implemented with some urgency to adapt Prairie communities to hotter, drier summers; shorter, warmer winters; and wetter springs.

2.0 Framing the Links Between Natural Infrastructure and Water

Research and practice increasingly show that natural infrastructure can support improved water management outcomes while simultaneously delivering benefits for climate change mitigation and adaptation, agriculture, disaster risk reduction, health, economic prosperity, biodiversity, and societal well-being (Seddon et al., 2020). While there is no-one-size-fits-all framework to consider the benefits and co-benefits of natural infrastructure, this section introduces a multi-benefit framework for those interested in the application of natural infrastructure for water solutions.

2.1 Primary Benefits

Figure 3, developed for this report, identifies three water management areas that natural infrastructure can address: (i) flood mitigation, (ii) water supply and drought mitigation, and (iii) water quality. Natural infrastructure can support infrastructure service delivery in these areas in multiple ways and to varying degrees via the core functions of directly delivering infrastructure services, enhancing grey infrastructure services, and protecting grey infrastructure services, as outlined below (UNEP, 2023). Beyond water benefits, natural infrastructure provides a multitude of social, environmental, and economic benefits, as illustrated in Figure 3 and described in Section 2.2.

The Natural Infrastructure for Water Solutions (NIWS) framework is informed by the Pacific Institute's *Multi-Benefit Framework for Water Management* (Diringer et al., 2020), the *Benefit Accounting of Nature-Based Solutions for Watersheds Guide* (Brill et al., 2022), and UNEP's *Green Infrastructure Guide for Water Management* (UNEP, 2014).

"The benefits of NbS have been found to outweigh the costs of implementation and maintenance in a range of contexts, including disaster (mainly flood) risk reduction along coasts and in river catchments. There is also growing evidence that NbS can be more cost effective than engineered alternatives, at least when it comes to less extreme hazard scenarios" (Seddon et al., 2020, p. 7).

Functions of Natural Infrastructure[3]:

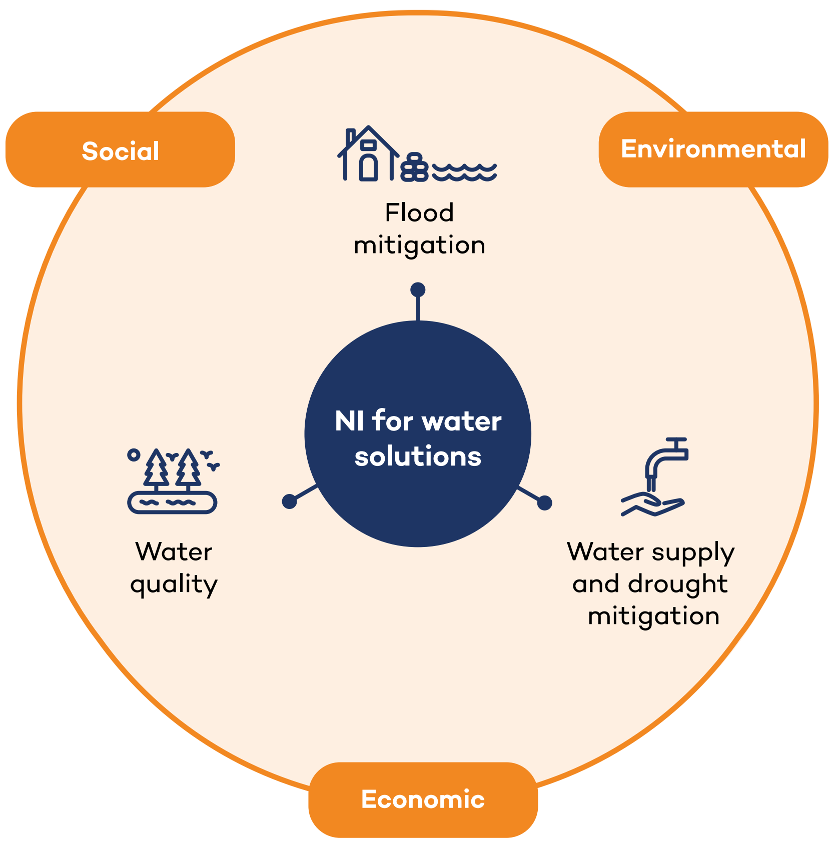
Function 1: Deliver the service directly, with the ability to entirely or partially substitute for the grey infrastructure asset.

Function 2: Enhance the service delivered by a grey infrastructure asset to support the functioning, quality, and efficiency of service provision. This function can reduce the need for maintenance and inputs.

Function 3: Protect the service delivered by a grey infrastructure asset, for example, from extreme climate events.

Function 4: Multiple benefits, or co-benefits, in addition to the primary infrastructure service. Co-benefits may be social, economic, or environmental—for example, boosting jobs, improving health, or supporting biodiversity.

Figure 3. Natural infrastructure benefits framework for water management in the Canadian Prairies region



Source: Author diagram.

3 Adapted from UNEP (2023), where the workforce benefits are grouped with Function 4: Multiple benefits.

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The following section provides more information about how natural infrastructure can support flood mitigation, water supply and drought mitigation, and water quality, alongside the relevant regulatory and policy context.

Natural Infrastructure in Practice

As an example, a community seeking to reduce overland (pluvial) flooding might consider investments in rain gardens to reduce and slow the flow of stormwater. Rain gardens can enhance or protect existing grey stormwater systems. In turn, the assets may provide additional co-benefits to the community, such as supporting local biodiversity, enhancing wellness from greening, and providing pollinator habitat. Such an investment is particularly attractive in older communities, where

- there may not be a stormwater pipe at all or a pipe on every street;
- stormwater and wastewater are both collected in the same pipe (known as a combined sewer), risking backup into people's homes and overflow into water bodies as wastewater treatment facilities are overwhelmed during heavy rainfall;
- infill construction creates more runoff than the stormwater infrastructure was originally designed for; or
- the size of the pipes that were originally installed is smaller than what would be installed today.

Without incorporating natural infrastructure, such as rain gardens, the alternative is to install new pipes or replace existing pipes with bigger ones. Similarly, in newer communities, natural infrastructure can supplement an existing conventional pipe-and-stormwater pond system to provide the additional storage requirements anticipated under climate change.

2.1.1 Flood Mitigation

The Prairies are at risk for both localized overland flooding (pluvial flooding) and riverine flooding (fluvial flooding) (Moudrak et al., 2018). Impacts will be determined by the intensity, duration, and extent of the rainfall event, as well as watershed conditions (e.g., land use and cover, soil type, time of year, etc.).

Flood risks on the Prairies are increasing in the context of climate change (Sauchyn et al., 2020). The report *Canada in a Changing Climate: Regional Perspectives Report for the Canadian Prairies* highlights that rainfall intensity is expected to rise, with more frequent and intense precipitation events. Farmland and infrastructure in the Prairies could be periodically inundated by excess precipitation across seasons, which in future decades is increasingly likely to fall as rain (Sauchyn et al., 2020).

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Communities experience different types of flooding. In urban areas, prolonged or intense rainfall can cause pluvial flooding, generating large volumes of stormwater that floods streets, damages buildings, and can overwhelm drainage systems and sewer capacity. Along rivers, heavy precipitation can cause water to overflow riverbanks, resulting in fluvial flooding that is also influenced by upstream and adjacent land uses. In some cases, communities can experience coincidental flooding, where multiple types of flooding occur simultaneously, exacerbating the impacts on communities (GSI Impact Hub, 2024). Floods represent 37% of disaster costs since 1970 in Canada, and the costs per weather-related disaster have surged from CAD 8.3 million per event in the 1970s to an average of CAD 112 million between 2010 and 2019—a 1,250% increase in public and private costs (Canadian Institute for Climate Choices, 2020).

Human interventions over time have increased flooding and erosion in urban areas and along rivers by

- expanding areas of impermeable surfaces that prevent rainfall from soaking into the ground or evapotranspiring;
- degrading natural habitats, like wetlands, forests, and floodplains, that help to slow down, store, and reduce the volume of surface water runoff;
- straightening, widening, and deepening river channels so that a greater volume of water stays in the channel and is transported more quickly downstream, where it may cause flooding issues;
- hardening riverbanks, which restricts natural channel movement and can make bank instability worse elsewhere; and
- accelerating bank erosion, for example, by removing trees and vegetation whose roots naturally stabilize banks or allowing livestock to trample vegetation along the banks.

Increased runoff from hard surfaces and degraded natural areas has exacerbated consequences for small streams. In this report, we consider two additional types of flooding impacts: small stream flood risk and hydromodification impacts. High peak flows disproportionately increase flood risk adjacent to small streams, as the capacity of this type of receiving water body is relatively small and less able to absorb peaks than larger rivers. Hydromodification impacts are longer-term consequences for small streams from increased, repeated, non-flooding-type storm events that lead to accelerated erosion and a tendency for channels to move to match their new flow regime. Downcutting of the channel may eventually disconnect the stream from its floodplain, reducing its capacity and increasing the likelihood of flooding.

"Flood risk is mounting across Canada from fluvial sources, such as rivers and lakes; pluvial sources, such as intense rainfall inundating urban environments; and coastal sources, such as storm surges compounded by rising sea levels" (Moudrak et al., 2018, p. 4).

How Natural Infrastructure Helps

In Canada and internationally, there is a trend toward the use of flood-management solutions that work *with* rather than *against* nature to manage fluvial and pluvial flood risk. Historically, "grey" engineering techniques, such as flood walls and underground drainage systems, have been used to attempt to control urban and river flooding. These techniques were often designed to address localized issues without considering natural systems or long-term cost effectiveness.

In contrast, natural infrastructure uses natural processes to intercept, soak up, store, or slow down water to reduce peak flows, water volume, and water levels downstream (UNEP-DHI et al., 2018), ultimately reducing risk (United Nations Water, 2018). Multiple types of natural infrastructure can support flood risk management (GSI Impact Hub, 2024; UNEP et al., 2014), and flood risk management can occur at multiple levels, including (i) buildings (residential), (ii) communities, and (iii) watersheds (Eyquem & Monnerat, 2024).

In 2018, IISD and partners, including the Insurance Bureau of Canada and the Intact Centre on Climate Adaptation, published research on how natural infrastructure can cost-effectively address risks associated with flooding (Moudrak et al., 2018). Natural infrastructure approaches for river flooding are typically most effective when they are implemented based on a watershed-scale understanding of the underlying causes of flooding (Eyquem, 2023). Grey and natural infrastructure solutions can often effectively be combined to provide flood and erosion management while protecting sensitive habitats and delivering multiple benefits, such as recreational opportunities, improved water quality, carbon storage, and restored habitats and biodiversity.

Regulatory and Policy Context

Federal, Indigenous, provincial, watershed-scale, and local governments share responsibility for flood risk management in Canada.[4] However, regulations and policy tools are fragmented, making successful flood risk management challenging.

While the federal government plays a key coordinating role through programs (i.e., by supporting flood hazard mapping or infrastructure funding programs), provinces have more authority over policy tools, including land-use planning and building standards.

Provinces set the regulatory flood standard (meaning the return period of a flood) that is used as a baseline for land-use planning and protecting public infrastructure (Golnaraghi et al., 2020). These minimum design standards vary across the Prairie provinces—1:100 flood in Alberta, 1:500 in Saskatchewan, and 1:100 in Manitoba—but there are emerging considerations for more extreme scenarios due to the impacts of climate change. The degree to which watersheds are used as a basis for flood risk management also varies significantly across the country and between provinces, which can hinder the effective use of natural infrastructure flood solutions

[4] See Golnaraghi et al., 2020, for a summary of key roles.

across jurisdictions. An up-to-date overview of watershed management within Canadian Prairie provinces is provided in Eyquem (2023).

While there are examples of interjurisdictional collaboration on flood mitigation, watershed-scale management organizations play a limited formal role in flood management in Alberta (Watershed Planning and Advisory Councils), Saskatchewan (Watershed Associations), and Manitoba (Watershed Districts). Coordination between municipalities at the watershed level has been seen in the context of mitigating impacts related to small streams in rapidly urbanizing regions. For example, the Nose Creek Watershed Partnership recommends runoff volume control targets for municipalities in the Calgary region to adopt (Palliser Environmental Services Ltd., 2018).

Local governments are responsible for most land-use regulation at local scales, implement provincial legislation on land use, and enforce standards for buildings and infrastructure (CSA Group, 2022). As such, municipal land-use plans, stormwater guidelines, and more can affect the effectiveness of local flood risk management practices.

2.1.2 Water Supply and Drought Mitigation

The Canadian Prairies face significant challenges related to both water supply and drought, which, while interrelated, have distinct implications for the region.

Water Supply

Across the Prairies, the availability of water is crucial for various human and ecological needs, including municipal, industrial, and agricultural purposes. Some regions within the Prairies experience limited and variable water supply, exacerbated by climate change and spatial and temporal mismatches between water supply and demand (Sauchyn et al., 2020). For example, irrigation practices often require substantial water during the late summer months, a period when many areas experience lower or even absent flows. This discrepancy creates a pressing need for effective water storage to help manage supply throughout the year (WaterSMART Solutions Ltd., 2020), particularly when surface supplies become overallocated and reliance on groundwater increases (International Association of Hydrogeologists, 2024).

Variable streamflows, amplified by climate risks, also pose challenges to water supply and treatment systems (Howard et al., 2016). In the case of drinking water systems, for example, variable water supplies from rivers, lakes, and groundwater can affect the operations of source water systems (e.g., intakes and storage ponds) and treatment systems (e.g., buildings and pump stations) (Associated Engineering, 2020). Groundwater is a critical source of water for many, providing domestic water for 80% of rural Canadians and supplying more than 50% of the water in the systems supplying First Nations (International Association of Hydrogeologists, 2024).

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"Ultimately, water shortages would be the most damaging [climate impact], resulting in social and environmental impacts, along with economic losses from lost productivity in the agricultural, forestry, energy and mining sectors (i.e., extraction of oil sands and solution potash mining)" (Sauchyn et al., 2020, p. 19).

Drought Mitigation

Drought is a complex and pervasive issue that has multiple impacts on the Canadian Prairies. Its severe effects on food security and water supply make it the costliest type of climate hazard in the region (Bonsal et al., 2010; Sauchyn et al., 2020). A notable example is the drought of 2002, which resulted in billions of dollars in crop losses (Wheaton et al., 2008). Drought is not sudden like a flood event, but rather builds up gradually and can persist over multiple years (Bonsal et al., 2010; Natural Resources Canada [NRCan], 2021; UNEP-DHI et al., 2018; United Nations Water, 2018). A worst-case scenario for the Prairies is "the reoccurrence of consecutive years of severe drought, such as those that occurred in the 1930s" (Sauchyn et al., 2015).

The following different types of droughts impact the Canadian Prairies (National Drought Mitigation Center, n.d.; Wilhite & Glantz, 1985):

- **Meteorological drought** is defined by the degree of dryness or precipitation deficit and the duration of the dry period.
- **Agricultural drought** occurs when meteorological conditions affect agricultural productivity; it is dependent on plant species, growth stage, water demand, and soil conditions.
- **Hydrological drought** occurs when low precipitation affects surface and/or groundwater hydrology, impacting water supply. This process often takes longer than meteorological and agricultural droughts.
- **Ecological drought** occurs when a shortage of natural water supply causes ecosystem stress; it can be caused by natural or managed water supply systems.
- **Socio-economic drought** occurs when the supply and demand of an economic good is affected by the various droughts listed above.

How Natural Infrastructure Helps

Natural infrastructure can strengthen the resilience of water supply systems and aid in drought mitigation through multiple mechanisms (The Nature Conservancy, 2023). By conserving and restoring natural assets, like wetlands and floodplains, or constructing assets, like small water retention sites and beaver dam analogues, natural infrastructure can enhance water availability through increased surface water storage capacity. Natural infrastructure can also slow the flow of water, increase soil moisture and infiltration, decrease evapotranspiration, boost low flows in streams, and recharge groundwater when configured appropriately (Prairie Climate Centre, 2017; Seddon et al., 2020; Vigerstol et al., 2023). Natural infrastructure complements traditional methods of water supply storage and management, such as on-channel reservoirs and off-stream storage, by maintaining and enhancing natural water retention.

Natural infrastructure also supports drought mitigation by providing additional water storage and retention, which can be crucial during dry periods. Although it does not immediately influence the occurrence of meteorological droughts, it can mitigate their effects and other forms of drought by providing water from natural retention and storage sources (e.g., groundwater, wetlands) (Peñailillo et al., 2022; UNEP-DHI et al., 2018). Importantly, natural infrastructure can also boost resilience in the face of drought. For example, native species of grasses and forbs have deep root systems that do not require irrigation (as opposed to turf grass), are tolerant to drought, and help absorb precipitation (World Wildlife Fund, 2024). Trees in urban areas can be sustained with harvested rainwater and stormwater,[5] increasing their resistance to drought impacts. The contribution of natural infrastructure to drought resilience also depends on the type, scale, and length of natural infrastructure deployment, with the benefits of either water retention or reduced evaporative loss typically accruing across landscapes (Arthur & Hack, 2022; Peñailillo et al., 2022).

Regulatory and Policy Context

Water supply and drought management in Alberta, Saskatchewan, and Manitoba involve complex and distinct regulatory and policy frameworks, reflecting each province's approach to handling water resources. The Prairie Provinces Water Board (PPWB) supports interprovincial water management, with the *Master Agreement on Apportionment* stating that each province is entitled to approximately half of the natural flow from interprovincial rivers, though actual volumes vary yearly (PPWB, 2021). Many Prairie water bodies are extensively managed by dams, diversions, and allocated withdrawals, which can mask water variability and the impacts of climate change from year to year (Sauchyn et al., 2020). Each province has legislation that oversees its approach to allocating water alongside policies and initiatives that emphasize sustainable water and agricultural management.

Alberta

Governed by the Water Act, Alberta uses a priority-based surface water licensing system where the earliest water licence holders are legally entitled to their water first (known as the principle of "prior allocation"). In practice, senior and junior licensees may coordinate to share available water volumes. This is particularly significant in the South Saskatchewan River basin, which is

[5] Rainwater is water that falls on the roof of a building, which is harvested or collected in a storage tank before making contact with the surrounding land. Stormwater is water from rain or melting snow that falls on land, creates runoff, and is typically directed into drainage infrastructure for treatment or conveyance (Minnesota Pollution Control Agency, n.d.). Rainwater is typically better quality, as stormwater can accumulate contaminants when exposed to sediment, fertilizer, and oil while it moves across the land. Rainwater is only exposed to the roof where it is harvested.

effectively closed to new surface water licences in three sub-basins, making way for Canada's first market-based approach to trading water licences. Alberta manages drought through five Water Shortage Management Stages, with Stage 5 enabling emergency measures under the Water Act (Alberta Government, 2023). During a recent Stage 4 drought, the Alberta Government (2024a) released a new Drought Response Plan outlining regulatory and non-regulatory tools, including conservation plans, water-sharing agreements, and strengthened partnerships (Alberta Government, 2024b).

Saskatchewan

Surface water allocations are regulated by the Water Security Act, with about 77% allocated to irrigation and municipalities (Government of Saskatchewan, n.d.-b). In 2012, the Water Security Agency released the 25-Year Saskatchewan Water Security Plan, which outlines a plan for sustainable water use (Government of Saskatchewan, 2012). Under the 25-year plan, which acknowledges the role of natural areas in flood and drought protection, the Saskatchewan Agricultural Drought Preparedness Plan (Government of Saskatchewan, n.d.-a) was developed to provide a framework to assess current and future drought risk and outline a drought plan based on three stages: adequate moisture, moderate moisture deficit, and extreme moisture deficit.

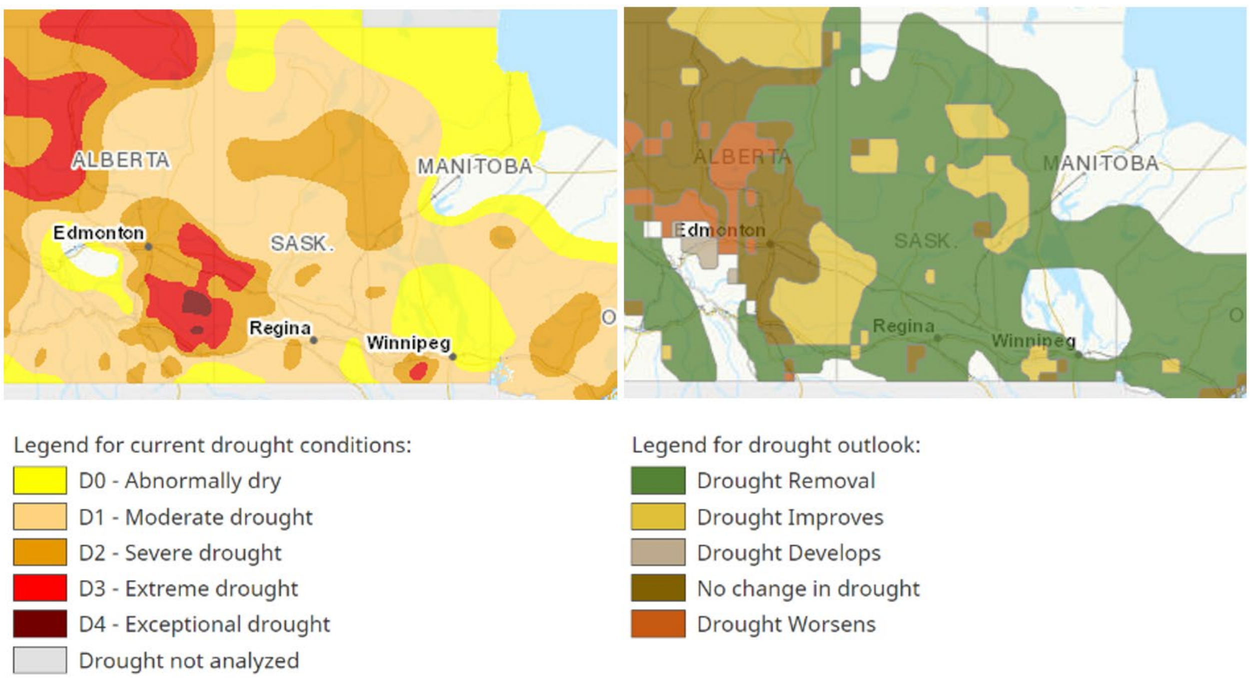
Manitoba

Surface and groundwater allocations are regulated by the Water Rights Act, primarily for municipal, agricultural, industrial, and irrigation use. The Government of Manitoba has the Drought Management Strategy (Government of Manitoba, 2016) and provides monthly reports on water availability and drought conditions throughout April and May. The Government of Manitoba's (2002) Water Protection Act requires the development of Integrated Watershed Management Plans, which outline goals and actions to manage land and water resources on a watershed basis and often include drought preparedness studies.

Federally, the Canadian Drought Monitor, delivered by the AAFC, develops monthly maps that show the extent and intensity of drought across the country based on five categories (AAFC, 2024b). AAFC also hosts the Canadian Drought Outlook,[6] which predicts if drought conditions will intensify, stay the same, or improve for the upcoming month (AAFC, 2025) (Figure 4). Both tools help producers, government planners and policy-makers, emergency preparedness agencies, and others to proactively plan and respond to drought.

[6] Canadian Drought Outlook: https://agriculture.canada.ca/en/agricultural-production/weather/canadian-drought-outlook

Figure 4. Example of the Canadian Drought Outlook for the Canadian Prairies, with drought conditions as of March 31, 2024 (left) and drought outlook for the end of April 2024 (right)



Source: AAFC, 2025.

2.1.3 Water Quality

Water quality issues across the Prairies vary and can include phosphorus and nitrogen loading, industrial and agricultural chemicals, and sediment and turbidity issues, among others (Carson & Hudson, 1992; PPWB, 2016). In addition, emerging pollutants, such as pharmaceuticals and pesticides, pose significant new challenges for managing and treating water (Talib & Randhir, 2016; United Nations Water, 2018). Water pollution from both point and non-point sources is a major challenge for water management across the Prairies, influencing infrastructure decisions related to water and wastewater treatment, as well as broader policy and regulatory considerations related to the health of aquatic ecosystems.

Table 1 highlights the typical concentrations of various contaminants in surface water, stormwater, and wastewater, showing significant differences in total suspended solids (TSS), biological oxygen demand (BOD), and nutrient levels, with wastewater consistently having higher values than surface water and stormwater. Natural infrastructure can contribute to meeting water quality objectives, either on its own or working alongside grey infrastructure.

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Table 1. Typical characteristics of surface water, stormwater, and wastewater

Contaminant	Surface water	Stormwater	Wastewater
TSS	Varies: 5–25 mg/L increase from background is considered detrimental	200–400 mg/L	100–350 mg/L
BOD	1–5 mg/L	10–20 mg/L	110–400 mg/L
Total nitrogen (TN)	1 mg/L	2–6 mg/L	20–85 mg/L
Ammonia	<1 mg/L	0.5–1.0 mg/L	12–50 mg/L
Nitrate	<1 mg/L	0.5–1.0 mg/L	1–30 mg/L
Total phosphorus (TP)	<0.03 mg/L	0.3–2 mg/L	4–15 mg/L
Reactive phosphorus	<0.01 mg/L	0.1 mg/L	3–10 mg/L
Total coliforms	100 #/100 mL	10^3–10^4 #/100 mL	10^6–10^9 #/100 mL

Source: Based on Alberta Government, 1999, 2018a; CCME, 2003; Tchobanoglous et al., 2003; Water Security Agency, 2015.

How Natural Infrastructure Helps

Natural infrastructure offers significant benefits for improving water quality across these different types of water. When it comes to improving water quality, it is important to point out the difference between concentration reduction and loading reduction. Concentration reduction refers to decreasing the amount of a contaminant per unit volume of water, which improves the water quality but does not necessarily reduce the total amount of contaminants entering a water body. Load reduction, on the other hand, involves reducing the total mass of contaminants entering the system, which is crucial for long-term environmental health. Most nature-based systems can achieve both, reducing the concentration of pollutants through filtration and chemical and biological uptake while also reducing the overall pollutant load by enhancing infiltration, evapotranspiration, and natural degradation processes.

Research increasingly shows the benefits of natural infrastructure for water quality, with natural infrastructure contributing to avoided or reduced pollutant loads downstream, which, in turn, can complement, augment, or replace services provided by grey water infrastructure, like wastewater treatment plants (Clary et al., 2020). Grey infrastructure services may be at risk or vulnerable to climate-related hazards (e.g., flooding), which may cause reduced efficiency or failure of infrastructure treatment (Swanson et al., 2021). Natural infrastructure can support specific applications related to both stormwater runoff and wastewater.

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- **Stormwater**: Natural infrastructure can capture, filter, and treat sediment and pollutants during runoff events (UNEP-DHI et al., 2018). Capturing runoff can reduce the risk of sewer overflows linked with increased contamination (UNEP et al., 2014; United Nations Water, 2018). A key focus for stormwater management is reducing total suspended solids, which are harmful to fish habitat.
- **Wastewater**: Natural infrastructure, such as natural or constructed wetlands, can filter and treat wastewater effluent through biological (vegetation and microbial) processes (UNEP-DHI et al., 2018). Wetlands are also able to treat emerging pollutants (e.g., pharmaceuticals) through biodegradation processes (United Nations Water, 2018).

Natural infrastructure can be highly effective not only at removing typical pollutants, such as those listed in Table 1, but also at addressing more complex, emerging contaminants like pharmaceuticals, microplastics, personal care products, and industrial chemicals. Natural infrastructure uses natural processes involving soil, plants, and microbial communities to break down and degrade these complex compounds, offering a sustainable and adaptive approach to water purification. In addition, nature-based systems have a high buffering capacity, enabling them to treat multiple contaminants simultaneously and making them less susceptible to sudden influxes of pollutants.

Natural infrastructure can support source water protection, which helps protect the water supply for potable water treatment, reduce downstream treatment costs, and lessen impacts on humans' and ecosystems' well-being (Islam et al., 2011; United Nations Water, 2018). Source water protection uses a multi-barrier approach to protect drinking water quality and may include upstream land conservation and restoration to reduce contaminants entering water sources. It can thus reduce the cost of water treatment downstream, as well as other practices, like road management and regulations on waste management (Islam et al., 2011).

Regulatory and Policy Context

Regulations related to wastewater treatment tend to be strong, particularly with the recent introduction of the federal Wastewater Systems Effluent Regulation in Canada. The Wastewater Systems Effluent Regulation dictates the anticipated targets for effluent discharge for multiple parameters (e.g., TSS, carbonaceous biochemical oxygen demand, and total chlorine residual). Alberta, Saskatchewan, and Manitoba also have provincial regulations that govern wastewater discharges to ground and surface waters. Comparatively, regulations related to stormwater are often in the form of guidelines, which vary by province. Municipalities may require additional permits and policy-based adherence to stormwater management plans. A detailed review of stormwater regulations and guidelines on the Prairies is outside the scope of this report.

While many aquatic contaminants are regulated, there are emerging contaminants (e.g., microplastics, harmful organics, and pharmaceuticals) that are not directly regulated or treated by existing infrastructure, depending on the treatment type. Where grey infrastructure may be lacking, insufficient, or failing, or where advanced treatment is inaccessible, natural infrastructure can offer various cost-effective treatment pathways that can support both wastewater treatment (e.g., pharmaceuticals) and surface water (e.g., pesticides) management (Talib & Randhir, 2016).

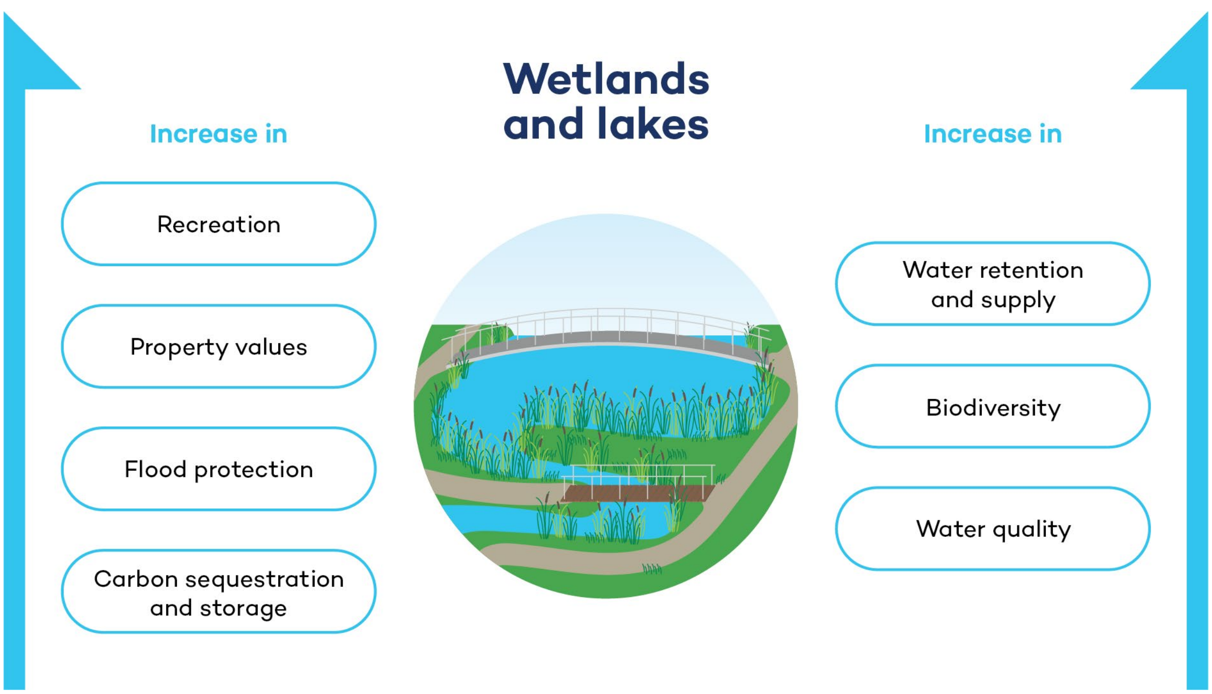
2.2 Co-Benefits

Natural infrastructure is multi-functional, with the potential to deliver a wide range of benefits to local communities (Seddon et al., 2020). While grey infrastructure is typically designed to meet a limited or specific infrastructure goal, natural infrastructure harnesses the power of nature to also provide a range of co-benefits, which are positive outcomes beyond a specified infrastructure function (CCME, 2021). For this report, water-related benefits are considered the primary benefits, while ancillary benefits are referred to as co-benefits.

Across the Prairies, issues relating to climate change mitigation and adaptation, biodiversity loss, heat exposure, and more signal the need for infrastructure solutions that can help meet core water infrastructure needs while providing co-benefits (Méthot et al., 2023). Through this lens, natural infrastructure may contribute to "multi-solving" by helping to address multiple challenges with a single intervention (Sawin, 2024).

For example, while wetlands (Figure 5) can protect against flooding and support water supply, studies indicate they can also sequester carbon, support biodiversity, increase recreation, and increase property values (Bechauf et al., 2022). Similarly, green roofs (Figure 6) can reduce stormwater runoff, improve air quality, reduce exposure to heat by providing cooling, and reduce energy use.

Figure 5. Examples of benefits and co-benefits that may be provided by wetlands



Source: Bechauf et al., 2022.

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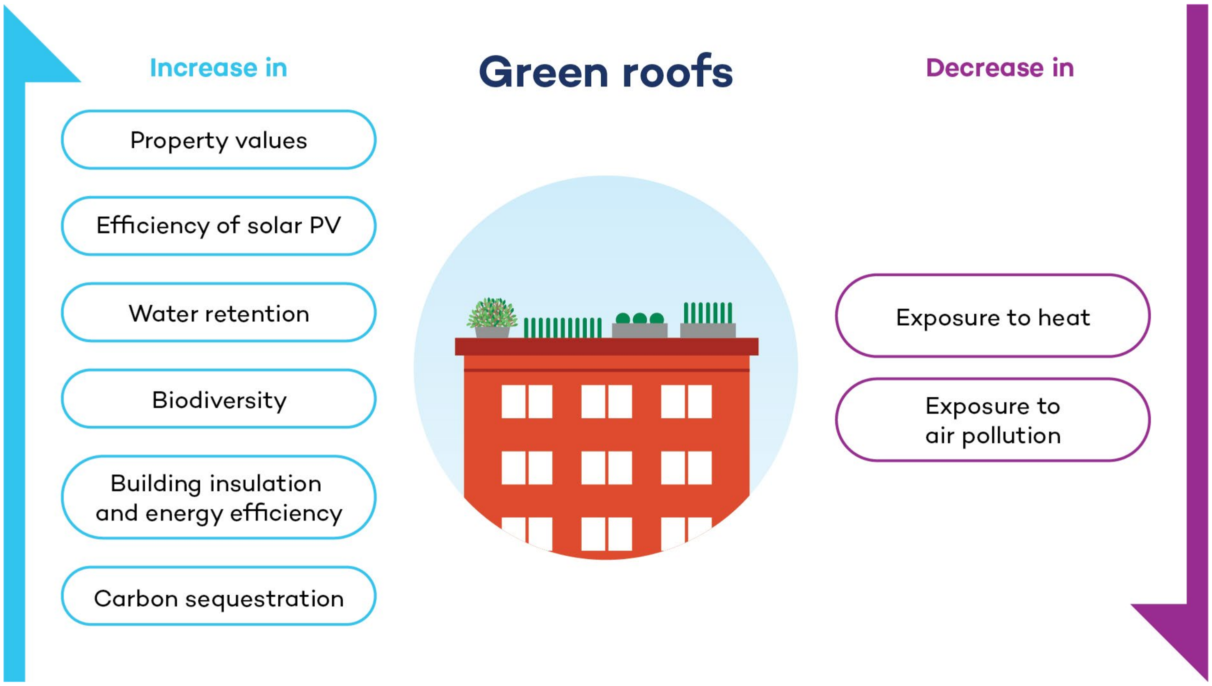
Figure 6. Examples of benefits and co-benefits that may be provided by green roofs



Source: Bechauf et al., 2022.

A broad range of benefits linked to natural infrastructure and NbS have been identified and reported in the literature.[7] While classified in different ways, co-benefits typically span environmental, economic, and social/cultural considerations. In the face of climate change, there is also a growing focus on how natural infrastructure and NbS can increase community resilience to climate hazards. Natural infrastructure can simultaneously reduce community exposure to harm (e.g., from severe heat) and increase opportunities to thrive (e.g., through recreational access or physical and mental health) (Crouse et al., 2017). Community and resilience co-benefits are essential to achieving widespread support of natural infrastructure initiatives and ensuring that natural infrastructure is not only functional but also equitable (Tozer et al., 2022). However, systematically understanding these co-benefits of natural infrastructure can be challenging due to differences in access, impacts, and the perceived value of natural infrastructure services across different service areas and social groups (Fitzgibbons, 2020; Irvine et al., 2013).

A systematic assessment of the co-benefits provided by various natural infrastructure types is outside of the scope of this report. However, recognizing the importance of understanding the potential for natural infrastructure to deliver multiple stacked benefits, we highlight examples of co-benefits (Table 2) linked to natural assets and constructed assets in Section 3.

[7] See European Commission (2021), Horizon Advisors (2019), Ommer et al. (2022), and Raymond et al. (2017) for useful examples.

Table 2. Examples of natural infrastructure co-benefits and indicators

Co-benefit category	Example benefit indicator	Unit
Biodiversity	Diversity and number of species supported	#
Habitat	Availability of species' functional habitat	Ha
Air quality	Annual mean levels of fine particulate matter (e.g., $PM_{2.5}$ and PM_{10})	µg/m³
Carbon sequestration	Sequestration of carbon dioxide	tonnes
Urban heat island/acute heat	Reduced average air temperature	degrees
Amenity and wellness	% satisfied with urban parks and open space, distance to recreation	%, metres

Source: Author.

While this report focuses on the water-related benefits and performance of natural infrastructure, the multiple benefits of natural infrastructure may be a key driver for implementation. We highlight examples of co-benefits relevant to the Canadian Prairies throughout Section 3.

3.0 Benefits and Performance of Natural Infrastructure for Prairie Water Management

3.1 Overview

3.1.1 What Qualifies as a Natural Infrastructure Asset?

According to the Miistakis Institute (2020), a system of natural infrastructure can be thought of as having assets, functions, and benefits (Table 3). Natural infrastructure requires a physical asset—something tangible that, through its ecological and hydrological functions, provides benefits in support of infrastructure service delivery alongside co-benefits.

Table 3. Distinguishing assets, functions, services, and benefits within a system of natural infrastructure

Assets	Functions	Services and benefits
Assets are the "things"—physical and tangible features of a landscape. They can be counted, mapped, and easily quantified using physical metrics. They may be "natural" or "constructed."	Functions are the activities that assets naturally perform (or what the "things" do). They happen regardless of whether humans derive value from them or not—for example, nutrient cycling or erosion control.	Functions underpin the delivery of ecosystem services (e.g., water purification), which can become benefits. Benefits (including co-benefits) are the advantages that humans derive from an asset's natural function. In many cases, these benefits are analogous to conventional infrastructure services—for example, cleaning water, reducing flood risk, or reducing heat exposure.

Source: Adapted from La Notte et al., 2017; Miistakis Institute, 2020.

This section of the report will look at the benefits and performance of 17 natural infrastructure types, including eight natural assets and nine constructed assets.

The Importance of Thinking Functionally

It can be helpful to think about natural infrastructure by considering its shape (morphology) and how it functions. When we do this, we can identify four main functional families that connect different types of natural infrastructure: (i) cover, (ii) basins, (iii) watercourses, and (iv) groundwater. These categories consider both the physical form of the natural infrastructure and the role they play in managing water quantity. For each of these families, there are natural assets (both conserved and restored) and constructed assets that leverage natural features and processes to support water management needs.

Figure 7. Natural infrastructure functional families, including select natural and constructed assets covered in this report

	Cover	Basins	Watercourses	Groundwater
Features	Vegetation and/or substrate	Surface depression	Sloped channel	Subsurface reservoir
Functions	Runoff generation and attenuation	Storage	Conveyance	Recharge, baseflow generation, and storage
Dominant mechanisms	Evapotranspiration and/or retention	Detention and/or retention	Surface flow	Percolation, interflow
Natural assets	• Grasslands • Forests	• Lakes and ponds • Wetlands	• Rivers and streams • Riparian areas • Streambank bioengineering	• Aquifers
Highlighted constructed assets	• Soil cells • Green roofs • Permeable pavements	• Constructed wetlands • Rain gardens • Rainwater harvesting • Bioretention	• Bioswales	• Infiltration trenches

Source: Authors.

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Within each family, the conserved natural assets are considered the "exemplars," with natural functions contributing to ecosystem service provision and benefits to people. If degraded, natural assets may be restored or enhanced to support service delivery. Constructed assets are alternatives, recognizing that the natural asset may not be available, physically fit in the space, or have the capacity to support a specific infrastructure need. For example, at first glance, wetlands and rain gardens, from the Basins type, might not seem related, but we can think of rain gardens as playing a similar role in urban areas that wetlands do in natural settings. While they are not direct substitutes, they share some of the same functions, such as retaining water on the landscape and reducing sediment loading. While providing different types of wildlife habitat and other benefits, they can be considered part of the same functional family from a water management perspective.

Grouping natural infrastructure into four functional families (Figure 7) is not a straightforward task; there can be overlap between the mechanisms that result in benefits. This reflects the complexity of ecosystems and the fact that natural infrastructure can influence multiple hydrological processes at once. For example, to the degree that vegetation and soil are present in any type of natural infrastructure, evapotranspiration will play a greater or lesser role, and infiltration characteristics will be altered. Nevertheless, thinking functionally across these families helps to identify commonalities along a spectrum of options linking conserved, restored, and constructed assets.[8]

3.1.2 Methodology

Sections 3.2 to 3.5 provide an overview of the benefits and performance of 17 natural infrastructure types in relation to the three primary water management objectives identified in Section 2.1: (i) flood mitigation, (ii) water supply and drought mitigation, and (iii) water quality.

Information was compiled from a range of sources, including academic literature, technical reports, policy documents, and guidelines for natural infrastructure design and implementation. Where possible, data from empirical evidence specific to the Canadian Prairies was preferred, although this was not always available. Some performance data on constructed assets in Alberta was available to the authors but has not been published.

Section 3 is organized into the four functional families described in Section 3.1.1 For each functional family, the natural assets are introduced first, followed by functionally analogous examples of constructed assets. The natural, intact assets are the exemplars. Overall, the benefits and performance for eight natural assets and nine constructed assets are presented within these families. As there are sometimes multiple names used for the same type of natural infrastructure or many variations with different names, prominent variants are identified and described at the end of some of the natural and constructed asset types, including forests, soil cells, green roofs, permeable pavement, rivers and streams, and riparian areas.

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[8] See The Nature Conservancy (2023) for a more fulsome description of how different NbS and associated hydrological processes shape water management outcomes.

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Based on the authors' opinion, the nine constructed assets include a qualitative, relative ranking of the magnitude of benefits (described in Table 4) using the following scale. Where a range is given, it often relates to the subsoil percolation rate, which is a function of the underlying soil and subsoil type and condition.

- 0 = no benefit
- 1 = minimal benefit
- 2 = small benefit
- 3 = moderate benefit
- 4 = significant benefit
- U = unknown benefit
- N/A = benefit not applicable

The primary benefit rankings are provided in a figure at the beginning of each constructed asset section, and the description and ranking of co-benefits is provided at the end of the section.

Table 4. Descriptions of water-related benefits from natural infrastructure

Flood mitigation	
Fluvial flooding	Long-duration, low-intensity rainfall or snowmelt that occurs over a large area of land (contributing area), generating a large amount of runoff and resulting in riverine flooding.
Pluvial flooding	Short-duration, high-intensity summer thunderstorms or snowmelt that generate runoff over small, localized overland areas.
Small creek/stream flooding	When the imperviousness of the contributing area increases, dramatically higher peak runoff is generated than smaller creeks and streams can handle. Along with the rate, the overall volume of water that enters the water body must be managed to avoid flooding adjacent lands.
Hydromodification reduction	When the imperviousness of the contributing area increases, over time, cumulative impacts from frequent smaller, non-flooding unnatural flows lead to accelerated erosion and a tendency for channels to move to match their new flow regime. Along with the rate, the overall volume of water that enters the water body must be managed to avoid downcutting and subsequent disconnection from the floodplain.

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Water supply and drought mitigation	
Fit-for-purpose use	Ability of the asset to treat source water of a given quality up to the quality requirements of the end use, such as drinking water standards, agricultural guidelines, industrial processes, or environmental purposes.
Recharge	Water that percolates deeply into the ground to replenish underground aquifers, facilitated by assets that either have permeable surfaces or give surface water more time to infiltrate (e.g., through open-bottomed storage or reduced water velocity).
Drought resilience	The ability for assets to support ecosystem structure and function in the face of prolonged dry periods, ensuring the provision of ecosystem services and sustainable infrastructure service delivery.
Water quality	
Sediment reduction	A decrease in dissolved and suspended sediment entering drainage systems, waterways, and aquatic ecosystems through reductions to erosion or sediment capture.
Nutrient reduction	A decrease in nutrients, such as phosphorus and nitrogen, entering drainage systems, waterways, and aquatic ecosystems through reductions in nutrient export or water treatment.
Pathogen reduction	A decrease in disease-causing bacteria, viruses, and parasites to reduce the risk of waterborne illnesses in water supplies and aquatic ecosystems through reductions to biological contaminant export or through water treatment.
Metal reduction	A decrease in metal and other trace elements, such as arsenic, mercury, and selenium, in water supplies and aquatic ecosystems through reductions to contaminant export or through water treatment.
Hydrocarbon and organic reduction	A decrease in persistent organic pollutants, such as pesticides and hydrocarbons entering drainage systems, waterways, and aquatic ecosystems, through reductions in contaminant export or water treatment.
Temperature regulation	The maintenance of water temperature between natural seasonal ranges and at depth (thermal stratification) to maintain ecosystem health.

Complex/novel contaminant reduction	A decrease in complex or novel contaminants, such as plastics and pharmaceuticals entering drainage systems, waterways, and aquatic ecosystems through contaminant capture or water treatment.

Source: Authors.

Performance Rating Tables

Water quantity performance includes volume control, rate control, and storage/supply where applicable. These parameters are expressed as a percentage of the capability of the practice to reduce water volume, reduce the flow rate, and store water supply compared to expected performance without the practice. Storage/supply is often a narrative statement as it depends on multiple variables. Water quality performance is expressed as treatment efficiency, also known as removal efficiency, which is a function of the influent concentration. Table 1 in Section 2.1.3 identifies influent characteristics of surface water, stormwater, and wastewater. Performance can be calculated by multiplying influent concentration by the removal efficiency to determine an expected reduction in concentration. Overall, the given performance ratings reflect values found in the literature that most closely resemble Prairie conditions and designs. Wide ranges are to be expected in the literature, depending on the variability of design parameters and the implementation context, including storm size.

Overall Performance Considerations

Physical Influences

Performance will vary based on many physical factors—for example, time since construction/installation, maturity of vegetation, season, temperature, light, elevation, influent concentration, hydraulic loading and head, whether the underlying subsoil percolates well or not, and more. Some examples include the following:

- During spring snowmelt events, soils can be frozen, limiting infiltration and causing water to run off in amounts similar to hard or paved (impervious) surfaces.
- Natural infrastructure that relies on the establishment of vegetation may take several years to achieve the benefits shown by published performance data or, more likely, performance data reflects the early establishment period and not mature performance.
- Vegetation exposed to direct sun can have significantly higher evapotranspiration than vegetation in shade.
- Extent and intactness (Box 2) are key considerations for understanding the performance of natural assets at scale.

Except where otherwise indicated, this report provides performance for mature natural and constructed assets in unfrozen conditions.

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On the Prairies, intense summer thunderstorms and spring melt conditions are particularly important weather characteristics that govern flood performance and nutrient transport. To address these challenges, basin-type source control practices should always be a priority across the landscape because of their retentive capacity in both spring thaw and summer conditions, regardless of storm intensity.

Assimilative Capacity

All infrastructure has a finite capacity to deal with loadings, both in terms of quantity and quality. Urban loadings can be orders of magnitude greater and different in composition to natural loadings. This can result in, for example, natural channels that erode from the force of added runoff and the assimilative treatment capacity of natural systems being exceeded. Constructed vegetated practices can leach during establishment, and all vegetated practices can leach over time as their capacity is used up. Be aware of the capacity of the chosen infrastructure.

Position on the Landscape

The location of natural infrastructure assets impacts their ability to deliver benefits. For example, consider the role of wetlands in urban versus rural settings. Wetlands can contribute to storing runoff and attenuating flows, providing recharge and maintaining water quality in urban and rural areas. However, in urban conditions, even if these features are retained, they are unlikely to be in a location or at an elevation to intercept overland flows.

Heat in urban areas is another example. Urban areas benefit from the cooling and shading that trees provide (Kumar et al., 2024), but this depends on how close and in what position trees are relative to where heat is generated and shade is needed. For example, tree canopy along sidewalks provides summer shade to pedestrians.

Constructed assets are generally designed to bridge the provision–demand gap that natural assets cannot achieve due to, for example, position on the landscape, high degree of contaminant loadings, and/or available footprint (Box 2).

Design Variables

The design of natural infrastructure can be adjusted to meet different performance objectives, such as protecting small streams from erosion, reducing nutrient loading into lakes, and combatting urban heat island impacts. Sample design customizations are provided for various constructed assets in Section 3. In general, these include design variations in soil depth and type, vegetation size and type, ponding depth (if applicable), and loading characteristics that govern performance.

Box 2. Natural assets and ecosystem services: A deeper dive

The United Nations System for Environmental-Economic Accounting (SEEA) provides a helpful frame for thinking about the relationship between natural assets, their condition, and the benefits they provide to humans. Adopted by Statistics Canada, SEEA provides a standardized approach to analyze the following:

- **Ecosystem extent**: Using maps and satellite images, SEEA shows where different types of ecosystems (or natural assets) are located, like forests, wetlands, or grasslands. Statistics Canada is actively working on multiple ecosystem extent accounts.
- **Ecosystem condition**: Ecosystem condition influences an ecosystem's ability to function and provide ecosystem services and is affected by multiple variables. For example, the condition of agroecosystems is shaped by physical (e.g., % bare ground), chemical (e.g., soil pH), compositional (e.g., proportion of non-native species), structural (e.g., presence and density of trees or shrubs), functional (e.g., dry matter productivity), and landscape (e.g., patch size) characteristics.
- **Ecosystem services**: SEEA helps analyze the things ecosystems do for people, like providing clean water, regulating climate, or supporting recreation. Each ecosystem provides a stream of ecosystem services, which can be measured in physical or monetary units. Understanding areas in Canada and across the Prairies that provide key ecosystem services helps inform decision making about the environment and the economy.

Taken together, this helps to illuminate a crucial point: the "performance" of natural assets is shaped by ecosystem extent, multiple condition variables, and ecosystem service delivery. It is difficult to generalize the performance of natural assets like grasslands and forests vis-à-vis water management due to the variability of so many factors. Advances in the field of ecosystem service modelling, through models like InVEST and ARIES,[9] help researchers analyze ecosystem services across landscape scales (Neugarten et al., 2018). New standards in Canada—like *CSA W218: Specifications for natural asset inventories*—also provide useful guidance.

Recent research also highlights that ecosystem service provision depends on, first, the *capacity* of ecosystems to supply a service and, second, a *demand* for that service by people (Mitchell et al., 2021). This human-centric lens argues that provision occurs when ecosystem services from areas with capacity flow to areas with demand. Mitchell et al. (2021) describe that "equating ecosystem service capacity to provision does not accurately capture where and how people receive benefits from nature" (p. 5).

[9] InVEST is the "Integrated Valuation of Ecosystem Services and Tradeoffs": https://naturalcapitalproject.stanford.edu/software/invest; ARIES is "Artificial Intelligence for Ecosystem Services": https://aries.integratedmodelling.org/

Operation and Maintenance

Management practices will influence performance. For example, if some natural infrastructure sites are mowed, they can become compacted and inhibit infiltration (e.g., bioswale), while cutting and removing vegetation can be deliberately used to reduce nutrient levels in a variety of treatment-oriented types of natural infrastructure (e.g., constructed wetland). Inlets and overflows need to be periodically cleaned to remove accumulated sediment and ensure flow paths are maintained. In some situations, access or use may need to be restricted to ensure full functionality of the natural infrastructure.

3.2 Cover

Cover is natural infrastructure that primarily achieves water-quantity benefits by reducing runoff through vegetation (if present) and its underlying substrate.

Terrestrial land cover plays a central role in regulating both water quality and quantity. Different combinations of soil and vegetation influence how water moves through the landscape, how much is absorbed or retained, and how much is lost as runoff or is evapotranspired (Bonsal et al., 2019). While land cover often refers strictly to what is seen on the surface, for the purposes of water benefits and performance, it is necessary to consider both what is on the surface and what is underneath it, along with how the cover is managed. For the purposes of this report, land cover refers to these features and characteristics taken together.

Natural land covers, such as grasslands and forests, have long been recognized for their significance in the Prairies, providing a range of essential services (TD Economics & Nature Conservancy of Canada, 2017). In areas where natural land covers have been altered or lost, tree planting, naturalization, and afforestation efforts can restore functionality. In denser urban contexts, more highly engineered analogues are used. Even natural, non-vegetated surfaces, such as a gravel outcropping, can be mimicked in a developed setting by using hard surfaces that can infiltrate (e.g., permeable pavement).

Vegetation

Vegetation, including both live and dead plant material, plays an important role in the hydrological function of different land covers (Adams et al., 2016). Trees, shrubs, grasses, and forbs act like an umbrella, intercepting, capturing, and storing precipitation, as well as contributing to evapotranspiration, where water is released from plants and soil into the atmosphere through transpiration and evaporation. Vegetation protects the soil surface from raindrops and erosion, slows the flow of surface runoff, and maintains infiltration and soil permeability (Adams et al., 2016). When vegetation senesces, dropping leaves and stems on the soil surface, it continues to perform an important function, acting as a physical barrier to heat and water movement on the soil surface and reducing evaporative loss. Dead plant material is called "litter," and litter is also important to slow runoff, promote infiltration, reduce evaporation, and provide cover to prevent erosion (Neufeld, 2008).

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Grasslands and forests have diverse plant communities, with plants of different heights, rooting depths, and architectures. This variability is critical to function, as different plants have unique needs for sunlight, water, and nutrients. Greater biodiversity leads to more resilient grasslands and forests (Isbell et al., 2015).

Soils

Soils play a critical role in modulating the benefits of land cover. Soil characteristics such as texture, structure, permeability, moisture state, and holding capacity influence rainfall–runoff relationships (Dingman, 2015) and the erosion potential of the landscape (Wall et al., 2002).

The Chernozemic soils located across the southern region of the Canadian Prairies were formed under native prairie grassland vegetation in various degrees of moisture deficit. These soils are characterized by high levels of organic matter and clay (Pennock, 2021). Soil groups grade from brown to black as rainfall increases across the Prairies, both from west to east and south to north. Since more rainfall supports more biomass and associated decomposition, soils get deeper, colour darkens, and humus content increases across this gradient from brown to black (Brown et al., 2021). More humus content relates to increased carbon sequestration potential and moisture-retention capacity (Heckman et al., 2023).

Clay soils develop a well-aggregated structure with a balance of macropores (diameter > 0.08 mm), supporting aeration and drainage, and micropores (diameter < 0.08 mm), supporting water retention, helping to absorb rainfall during wet periods and hold onto moisture during dry periods. Since drought is a common occurrence and is projected to increase in both frequency and severity (Bailey et al., 2010), the ability of soil to hold water during dry periods is essential.

Infiltration or drainage can be compromised by over-compaction, over-tillage, and naturally unstable aggregates, resulting in closed pores, surface crusting, and roots' diminished ability to penetrate and form macropores (McKenzie, 2010). Clay-rich soil is fertile and contributes to agricultural land use across the region; however, high clay under agricultural tillage can also lead to poor drainage and compaction, affecting water infiltration and runoff, especially during heavy rain and flood events, as seen in Manitoba's Red River Valley (Brooks, 2019).

Water Quantity

The question of whether runoff will be generated and the potential volume of runoff by a surface for a given rainfall event depends on many factors. For general comparison purposes, these factors can be reduced to the soil type, vegetation species and health, subsoil infiltration characteristics, and site management. The Soil Conservation Service (SCS) Curve Number method, developed by the Natural Resources Conservation Service (United States Department of Agriculture [USDA], 1986), combines these factors and can be used to estimate the depth of runoff from different rainfall events. The Curve Number method identifies four hydrologic soil groups, which combine soil and subsoil infiltration and percolation characteristics, ranging from high infiltration sandy "A" soils to the slowest clayey "D" soils. On the Canadian Prairies, most soils fall into the C and D classes, with only glacial or alluvial sand or gravel lenses fitting into the A or B categories.

For a detailed explanation of the origin and meaning of the Curve Number method and the values associated with different land cover and soil types, see Appendix A.

To illustrate how much runoff is generated by a small and large rainfall event using a Curve Number approach, we compare seven cover types:

- **pavement and roofs** that are highly impervious (could include parking lots, driveways, and sidewalks)
- **72% impervious** (could include urban centers and commercial zones, with extensive building footprints and paved surfaces)
- **fallow with residue** (could include agricultural land with crop residue that covers at least 20% of the surface)
- **lawn and grazed pasture**[10] (in urban areas, could include lawns, parks, golf courses, and cemeteries with more than 75% grass cover; in agricultural land could include rural grazed pasture, grassland, or rangeland)
- **straight row crop** (could include cereal crop in straight rows with no crop residue)
- **hayed meadow** with grass and no grazing (typically on agricultural land, but could also apply to urban areas with grass that is mowed once a year)
- **woods with litter** that is ungrazed and has leaf litter that covers the soil

In our example, all values used are for cover types in healthy conditions. Cover types that are in poor or fair condition are those with less plant coverage, less residue, or less litter. Note that agricultural management practices, such as contouring and terracing, do improve performance and have separate Curve Numbers that are not explored in our example. The rainfall events in our example are 25-mm and 100-mm events with these characteristics (Figure 8):

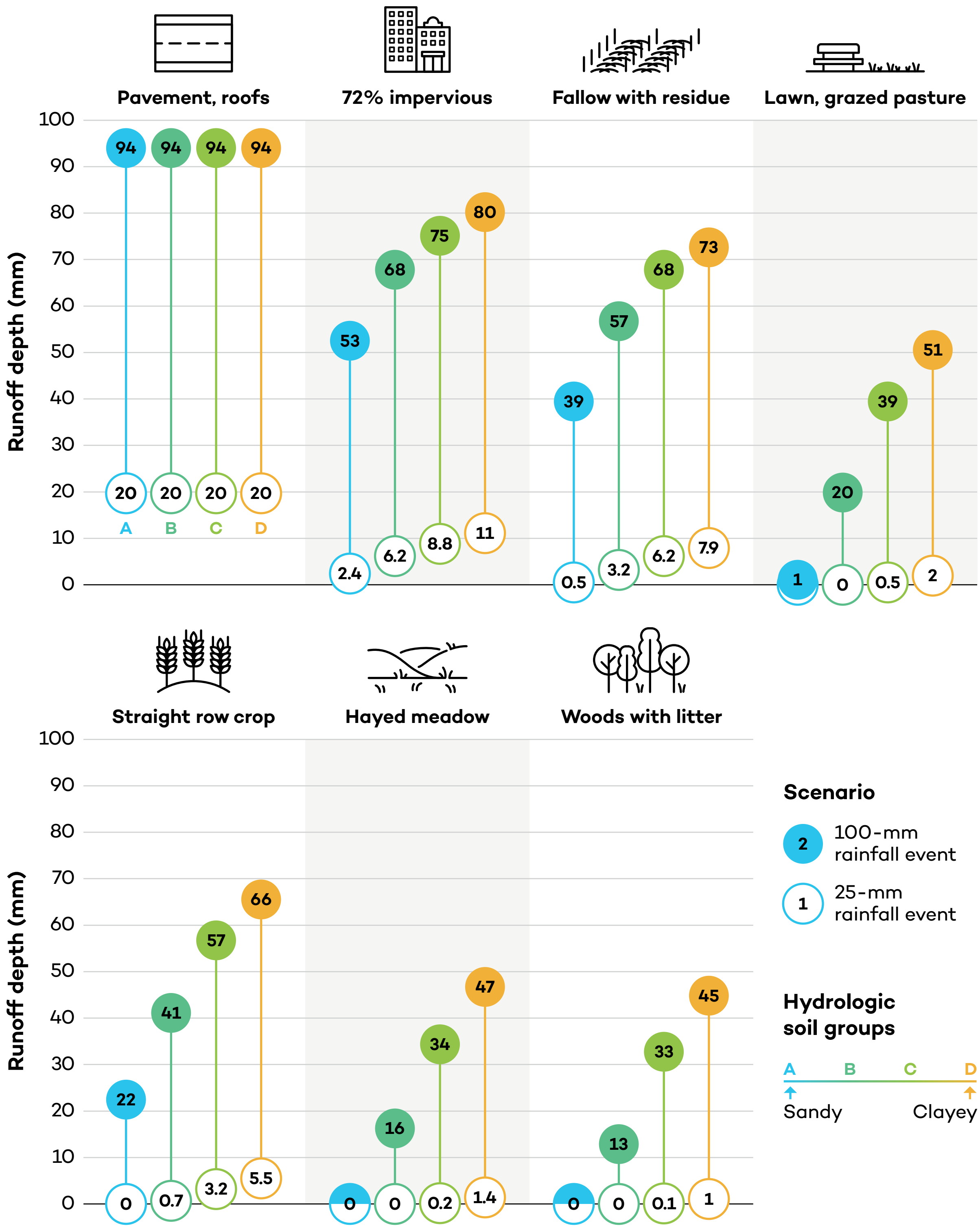
- Runoff scenario 1 is a 25-mm rainfall event, considered a small event that could happen multiple times throughout the year in wetter parts of the Canadian Prairies. Under natural cover conditions, these summer thunderstorms would generate little or no runoff anywhere on the Prairies.
- Runoff scenario 2 is a 100-mm rainfall event, considered an extreme or heavy rainfall event today (representative of a 1-in-100-year 24-hour rainfall event in some Prairie regions). This magnitude of event will happen more frequently with climate change.[11]

As described in Table 5, these different scenarios highlight how the different land covers influence the depth of runoff that is generated.

[10] Grazed agricultural land and mown turf can have similar hydrologic soil types, as shown in Table A1.

[11] According to the IDF_CC Tool 7.5 (Simonovic et al., 2015; updated June 2024), 1-in-100-year 24-hour rainfall events are estimated to be 95.40, 126.27, and 96.72 mm across Calgary, Regina, and Winnipeg, respectively, and based on historical data. Under the Shared Socioeconomic Pathway 3.70 scenario, considered likely, the magnitude of these events will increase to 109.63, 140.38, and 107.23 mm across Calgary, Regina, and Winnipeg, respectively, by the year 2100. Put another way, the 1-in-100-year rainfall of today is likely to be somewhere between the 1-in-25- and 1-in-50-year rainfall of the future, based on current predictions.

Figure 8. Comparing runoff depths by cover type for two scenarios (Scenario 1: 25-mm rainfall event and Scenario 2: 100-mm rainfall event)



Source: Author figure adapted from USDA, 1986.

Table 5. Runoff comparison between scenario 1 (25-mm rainfall event) and scenario 2 (100-mm rainfall event)

	The 25-mm rainfall event	The 100-mm rainfall event
Pavement and roofs	Generates significant runoff, nearly 20 mm (majority of the rainfall)	Generates massive runoff, nearly 94 mm (majority of the rainfall)
72% impervious	Generates significant runoff, although less than the pavement and roofs cover that is more impervious	Generates more runoff in larger events across all soil groups
Fallow with residue and straight row crop	Generates more runoff than natural cover, and only somewhat less than 72% impervious cover for type C&D soil groups Runoff varies depending on crop type, tillage practices, and soil conditions	Initially absorbs runoff, but soil becomes saturated, resulting in more runoff Lack of residue reduces infiltration and increases runoff
Lawn and grazed pasture Hayed meadow Woods with litter	Absorbs much of the rainfall, with only about <2 mm potentially becoming runoff Soil acts like a sponge, with capacity to capture and clean rainfall and prevent runoff	Generates more runoff in larger events Initially absorbs water, but soil becomes saturated, resulting in runoff Still performs much better than altered covers
Key messages	Permeable soils with healthy vegetative cover can handle routine rainfall events more effectively than cultivated agricultural covers and hardened surfaces that are common to urban areas.	Permeable soils with healthy vegetative cover reduce runoff even under extreme rainfall. Hardened covers and cultivated agricultural lands generate significantly more runoff, especially for the type C and D soils common on the Prairies.

Source: Authors.

The amount of runoff generated from a small storm on altered cover types may not seem to be significant. However, these small events occur frequently. This high frequency of runoff from altered covers—where there would have been little to none naturally—is particularly impactful on small creeks and streams that have a regime matched to the runoff characteristics of natural conditions. The constellation of impacts has come to be known as Urban Stream Syndrome, although similar impacts apply in rural areas.

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Heavy rainfall events occur less frequently, although they are expected to become more frequent with climate change. Both agriculture and developed land generate more runoff than natural conditions, particularly for type C and D hydrologic soil groups. Natural infrastructure can mitigate the impacts of all types of altered land covers by increasing the absorptive capacity of the landscape.

Note that while we are using curve numbers to illustrate the relationship between factors, we are not discussing the use of a Curve Number *modelling* approach, which has limited applicability on the Prairies for reasons ranging from seasonality and time-varying soil moisture conditions (which effectively changes the curve numbers for identical land cover and soil combinations) to the prevalence of Prairie pothole topography (which can reduce runoff due to capture within surface storage).

Water Quality

Water quality can be degraded by multiple processes, including soil erosion or deposition (both suspended solids and nutrients), nutrient export, and retention of dissolved matter. In general, most cover types produce a net export of nutrients and sediments. However, under typical conditions, these exports do not result in degraded water quality. This is because ecosystems require nutrients to function properly. Water quality issues arise when the runoff of sediments and/or nutrients is higher than normal due to changes in land management practices, such as the conversion of forests to agriculture.

The physical characteristics of soils define their susceptibility to erosion, which can influence water quality-related outcomes beyond the rainfall–runoff relationships that drive erosion processes. Non-cohesive soils with smaller particle sizes and lower resistance to shear stress, like very fine sands, are more susceptible to erosion than heavy clays (Wall et al., 2002). Soil erosion can increase total suspended and dissolved sediment in waterbodies, alongside nutrients like phosphorus and nitrogen and contaminants like metals, among others, depending on their composition. It is also important to consider the impact of seasonality on soils and its influences on water quality—for example, with more nutrient export during the spring runoff period, known as freshet. Freeze-thaw cycles also act to weaken soil structures (Wall et al., 2002) and rupture embedded soil organic matter like plant tissue (Elliot, 2013), increasing the susceptibility of soils to erosion and the availability of soluble nutrients introduced to waterways, worsening potential water quality outcomes.

The export of various waterborne contaminants can be estimated from different cover types using export coefficients.[12] Table 6 shows a range of TN, TP, and TSS export values for grasslands, forests, agricultural cover, and urban cover. It is important to note that there is a large range of values for export coefficients based on data from various sources and regions that can be

[12] Export coefficients are used to define the amount of water quality constituents exported from an area over a specified period. For example, export coefficients can be representative of the export during a specific year and hydrologic event or the average from a range of years and hydrologic events.

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used, and the data presented in this report are just select examples and not representative of a comprehensive meta-analysis. For example, Jeje (2006) notes that nutrient export coefficients may vary in high and low runoff seasons/years within the same region and are based on precipitation, soil, land use, and management. Field measurements are thus critical for understanding the composition of contaminants in soils that may be directed to waterbodies.

Table 6. Ranges of TN, TP, and TSS export from various cover types

	TN (kg/ha/year)		TP (kg/ha/year)		TSS (kg/ha/year)	
Cover type	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Grassland	0.05	2.34	0.04	0.75	24.02	100.99
Forest	0.23	3.93	0.01	0.38	250	253
Agriculture	0.1	14.9	0.002	9.4	1000	4900
Urban	0.35	9.72	0.03	3	208.6	2000

Source: Based on Bourne et al., 2002; Jeje, 2006; LimnoTech, 2007.

Table 6 demonstrates, generally, how nutrient and sediment export is an order of magnitude higher for urban and agricultural cover types relative to grassland and forest covers. To look at it another way, the export of sediments and nutrients from natural cover types, like grasslands and forests, can be viewed as the baseline required to maintain the equilibrium of ecosystems. More details about TN, TP, and TSS export from various land covers are provided in Section 3.2.1 on grasslands and Section 3.2.2 on forests.

This section reviews benefits and performance for select natural and constructed assets within this family, including grasslands (Section 3.2.1), forests (Section 3.2.2), soil cells (Section 3.2.3), green roofs (Section 3.2.4), and permeable pavement (Section 3.2.5).

Aquatic covers, such as streams and wetlands, are covered under Basins in Section 3.3 and Watercourses in Section 3.4.

3.2.1 Grasslands

Grasslands once dominated the Prairies. They evolved under the influence of a continental, arid climate, with cold winters and warm summers (Bailey et al., 2010; McGinn, 2010). Bailey et al. (2010) list five native Prairie ecoregions: dry mixed grass, mixed grass, foothills fescue, parkland northern fescue, and tallgrass prairie, based on climate, vegetation, and soils. Annual precipitation varies across the Prairie ecoregions (McGinn, 2010), shaping diverse ecosystems, with the dry mixed prairie being the driest and the tallgrass prairie receiving the most moisture. Native grasslands have adapted to be cold-hardy and drought resistant. Native grasslands have high biological diversity, with native grasses, forbs, sedges, shrubs, and trees, providing habitat for wildlife—including rare, endangered species like the burrowing owl, piping plover, and swift fox—and forage for livestock (Bailey et al., 2010).

There are also tame and restored grasslands, which can include areas seeded to tame forage species for haying and grazing or degraded areas that are re-vegetated with native or tame species (Kulshreshtha et al., 2015). Approximately 80% of prairie grasslands have been lost, largely due to annual cropland and urban expansion (Bailey et al., 2010).

Benefits and Performance

Primary Benefits

Flood Mitigation
The vegetative cover of grasslands slows the flow of surface water moving across the landscape (Chow, 1959, as cited by Government of Canada, 2019), intercepting and storing rainfall before

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it reaches the soil surface and promoting greater infiltration capacity, all of which help reduce flood risk. For example, Zou et al. (2015) reported that the aboveground water storage capacity (e.g., the amount of rainfall interception) of tallgrass prairie in Oklahoma ranged from 0.27 mm in the early growing season to 3.86 mm at senescence.

Table 7 shows the difference in rainfall–runoff between grasslands and other prominent land-cover types, demonstrating that when grasslands are converted to urban or agricultural cover, runoff increases.

Table 7. Increase in rainfall–runoff from land-cover conversion (based on 25- and 100-mm rainfall events and average of available hydrologic soil groups using the SCS Curve Number method)

Land-cover change	25-mm rainfall–runoff (mm)	100-mm rainfall–runoff (mm)
Grassland to urban (~100%) impervious	18.51 to 19.70	63.66 to 89.43
Grassland to agriculture	0.39 to 5.63	19.68 to 36.12
Grassland to forest	-0.88 to 0.00	-7.80 to -2.57

Source: Based on USDA, 1986.

Water Supply and Drought Mitigation

Grasslands support water infiltration and aquifer recharge (United States Army Corps of Engineers, 2023) and play a significant role in shaping baseline drought conditions across watersheds. Grass species with deeper rooting depths, such as little bluestem, are more resilient to drought, increasing survivability and the reliable provision of benefits. Though grasslands contribute significantly to evapotranspiration, which affects the water balance across the Prairies (Fang et al., 2007), this drives the natural water cycle that supports future precipitation.

Water Quality

Grasslands provide water quality benefits by slowing runoff; filtering sediment, nutrients, and other contaminants; and reducing runoff to downstream environments (Bailey et al., 2010). Export coefficients from different land-use conversions provide a simple approach to estimating water quality benefits from the conservation or restoration of grasslands (Bourne et al., 2002; Jeje, 2006; LimnoTech, 2007). If grasslands were converted to agricultural or urban environments, exports of nitrogen, phosphorus, and TSS would generally increase, depending on management (Table 8).

Table 8. Range in change of nutrient exports based on land-use conversion from grassland

Land-cover change	TN (kg/ha/year)	TP (kg/ha/year)	TSS (kg/ha/year)
Grassland to urban	0.3 to 7.38	-0.01 to 2.25	184.6 to 1899
Grassland to agriculture	0.05 to 12.56	-0.038 to 8.65	-1024 to 4499
Grassland to forest	0.18 to 1.59	-0.37 to -0.03	152.01 to 225.98

Source: Based on Bourne et al., 2002; Jeje, 2006; LimnoTech, 2007.

To illustrate how grassland loss impacts water quality, Limnotech (as cited by Houston Engineering, 2017) estimates that the average annual TP export from grassland, cropland, and low-intensity urban land are 0.17, 0.38, and 0.91 kg/ha/yr, respectively. Using these specific and relative values, it is estimated that for every km^2 of grassland converted to cropland, an additional 21 kg of TP, or 2 times as much, would be exported to downstream receiving water bodies. Similarly, for every km^2 of grassland converted to low-intensity urban land, it is estimated that an additional 74 kg of TP, or 5 times as much, would be exported.

Grassland Example With Co-Benefits

Kainai Nation, in Southern Alberta (Figure 9), is weaving together Blackfoot and Western scientific knowledge to restore native grasslands and traditional plants, like sage, sweetgrass, mint, and turnips, with community involvement that includes workshops and events, seed collection, a traditional plant inventory, and skill building for invasive species control (Derworiz, 2022). The grassland restoration effort includes the reintroduction of bison, which helps balance grassland health, and will provide another way for community members to connect to their culture and history. Alongside other projects on the Kainai Nation, which include stream restoration via willow planting and beaver dam analogues to support water security, these efforts highlight the multiple benefits of natural infrastructure—sequestering carbon, supporting biodiversity, improving resilience to flood and drought, restoring traditional connections, and providing engagement and job opportunities for local youth.

Figure 9. Volunteers at Kainai Nation planting 3,000 traditional plants

Credit: Oldman Watershed Council (reprinted with permission).

3.2.2 Forests

Forests are regions of land with a high density of trees and can be best described as complex ecosystems with a maximum number of vertical layers, including trees, shrubs, herbaceous plants, vines, and roots. In the Canadian Prairie ecozone, approximately 4% of all land cover is forested (Figure 2), which is much sparser than in neighbouring ecozones (Government of Canada, 2016, 2023a). In the Aspen Parkland, large grasslands are interspersed with small aspen stands or dense aspen woodlands, with only 10% of Aspen Parkland forests estimated remaining (The Nature Conservancy of Canada, n.d.). Trees fall under both deciduous and coniferous classifications, and common species include poplar and spruce, respectively.

Forests in the headwaters of the Lake Winnipeg basin, along the eastern slopes of the Rocky Mountains, are an important source water region for the Prairies (Alberta Government, 2018b). While they are outside the Prairie ecozone, forests in the boreal foothills contribute significantly to water quantity and quality dynamics across the Prairies.

Benefits and Performance

Primary Benefits

Flood Mitigation
The vegetative cover of forests slows the flow of surface water moving across the landscape (Chow, 1959, as cited by Government of Canada, 2019), intercepting and storing rainfall before it reaches the soil surface and enabling infiltration, all of which help reduce flood risk. The loss of

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forest cover can amplify flooding by increasing peak discharge, flood volumes, and flood extent (Bradshaw et al., 2007; Lallemant et al., 2021).

Increasing forest cover can be an effective method for mitigating flood risk in watersheds by reducing annual runoff volume (Pham & Alila, 2024). Small stream impacts from a loss of forest cover were observed to be correlated for watersheds up to an area of 1,000 km^2 (Zhang et al., 2017). On the Canadian Prairies, natural forest cover is generally scattered, and extents are limited; thus, the flood-mitigation benefits of future afforestation activities are likely to be most impactful in smaller Prairie watersheds.

Forests in the headwaters of Canadian Prairie watersheds are estimated to have an aboveground groundwater storage capacity (e.g., the amount of rainfall interception) in the range of 0.6 mm to 3.8 mm (Hadiwijaya et al., 2021). This storage contributes to overall reductions in runoff volume from precipitation events in a watershed. However, overall flood peak timing, volume reduction, and groundwater recharge are also dependent on underlying soil characteristics and topography, including slopes, in addition to vegetation type and its associated surface roughness. Table 9 demonstrates the difference in rainfall–runoff between forests and other common land-cover types in the Prairie region.

Table 9. Change in rainfall–runoff from land-cover conversion from forest (based on 25-mm and 100-mm rainfall events and the average of available hydrologic soil groups using the SCS Curve Number method)

Land-cover change	25-mm rainfall–runoff (mm)	100-mm rainfall–runoff (mm)
Forest to urban (~100%) Impervious	19.40 to 19.70	71.46 to 92.00
Forest to agriculture	0.39 to 6.51	22.25 to 43.92
Forest to grassland	0.00 to 0.88	2.57 to 7.80

Source: Based on USDA, 1986.

In urban watersheds, trees are sometimes considered “the first line of defence” to help restore more natural hydrological regimes, as they intercept rainfall, delay runoff, increase infiltration into soils, and transpire captured stormwater (Kuehler et al., 2017). Integrating trees into urban areas can reduce the volume of urban stormwater runoff, especially when coupled with other runoff reduction strategies (Kuehler et al., 2017). However, it is also important to consider the drought resiliency of planting new trees.

Water Supply and Drought Mitigation

Forests shade snow accumulations from the sun (Varhola et al., 2010), slowing both the melting and release of water volume to reduce flood risk and providing water security for downstream water supply (Newton et al., 2021). In addition, forested land can provide enhanced aquifer recharge (Government of Canada, 2021b), which is supported by the slowed flow of water on

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forest floors with a high stand density. For example, forests upstream of the Prairie ecozone in the headwaters of Alberta watersheds slowly release snowmelt water, which maintains flow for longer periods during dry years (Alberta Government, 2018b). As a drought-prone region, on the other hand, an important consideration in the Prairies is whether afforestation can exacerbate water scarcity over the short term for downstream users, as they contribute to higher evapotranspiration (Zhang et al., 2017).

Water Quality

Forested regions can stabilize soil and reduce erosion and sediment runoff downstream (UNEP et al., 2014). In addition, forests can filter, uptake, and/or transform contaminants and nutrients, reducing loads downstream (UNEP et al., 2014; UNEP-DHI et al., 2018). The water quality benefits of conserving and restoring forests are highlighted by comparing export coefficients between common land-cover types (Bourne et al., 2002; Jeje, 2006; LimnoTech, 2007). If forests were converted to agricultural or urban environments, exports of nitrogen, phosphorus, and TSS would generally increase depending on practices (Table 10).

Table 10. Range in change of export based on land-use conversion from forests

Land-cover change	TN (kg/ha/year)	TP (kg/ha/year)	TSS (kg/ha/year)
Forest to urban	0.12 to 5.79	0.02 to 2.62	-41.4 to 1747
Forest to agriculture	-0.13 to 10.97	-0.008 to 9.02	750 to 4647
Forest to grassland	-1.59 to -0.18	0.03 to 0.37	-225.98 to -152.01

Source: Based on Bourne et al., 2002; Jeje, 2006; LimnoTech, 2007.

For example, to illustrate the impact of forest conversion on water quality, Limnotech (as cited by Houston Engineering, 2017) estimates that the average annual TP export from forest, cropland, and low-intensity urban land are 0.075, 0.38, and 0.91 kg/ha/yr, respectively. Using these specific and relative values, it could be estimated that for every km^2 of natural forest converted to cropland, an additional 30.5 kg of TP, or 5 times as much, is exported to downstream receiving bodies of water. Similarly, forested land lost to (low-intensity) urban land would result in 83.5 kg, or 12 times as much TP, export for every km^2 of natural forest converted. Impacts on the condition of forests can also influence water quality downstream. For example, forest fires and post-fire salvage logging may result in more variable water quality, with the potential to cause challenges and increase the cost of drinking water treatment, depending on existing infrastructure (Emelko et al., 2011).

Forest Example With Co-Benefits

The City of Calgary has mapped, inventoried, and assessed the value of its 7 million trees located on both public and private lands across parks, natural areas, and green spaces (Figure 10). On public land, the urban forest has a collective value of CAD 1.3 billion (City of Calgary, n.d.). This understanding of the value of urban forests helps build the case for the benefit of managing and investing in natural assets, as is regularly done for grey infrastructure. Trees provide shade and heat reduction, with an estimated avoidance of 18 heat-related deaths per year (City of Calgary, 2021), and improve air quality, contributing CAD 227 million in health co-benefits. Additionally, urban trees contribute CAD 721 million toward land-based recreation, like biking, bird and wildlife watching, and enjoying parks (City of Calgary, 2021).

Figure 10. Urban forest along the Bow River in Calgary, Alberta

Credit: iStock.

Variants

Street Trees

Typically widely spaced, linear, planted specimen trees along road right-of-ways. Historically, they are planted in an insufficient volume of overly compacted soil, leading to poor vigour and very early mortality, with a survivability half-life of 13 to 20 years (Roman & Scatena, 2011). Street trees can thrive and live longer if supported by favourable growing conditions, possibly with the use of soil cells, as described in Section 3.2.3.

Food Forests

A layered approach to food production that allows more plants per unit area to thrive. Seven layers are generally recognized: overstory, understory, shrubs, herbaceous plants, roots, groundcovers, and vines.

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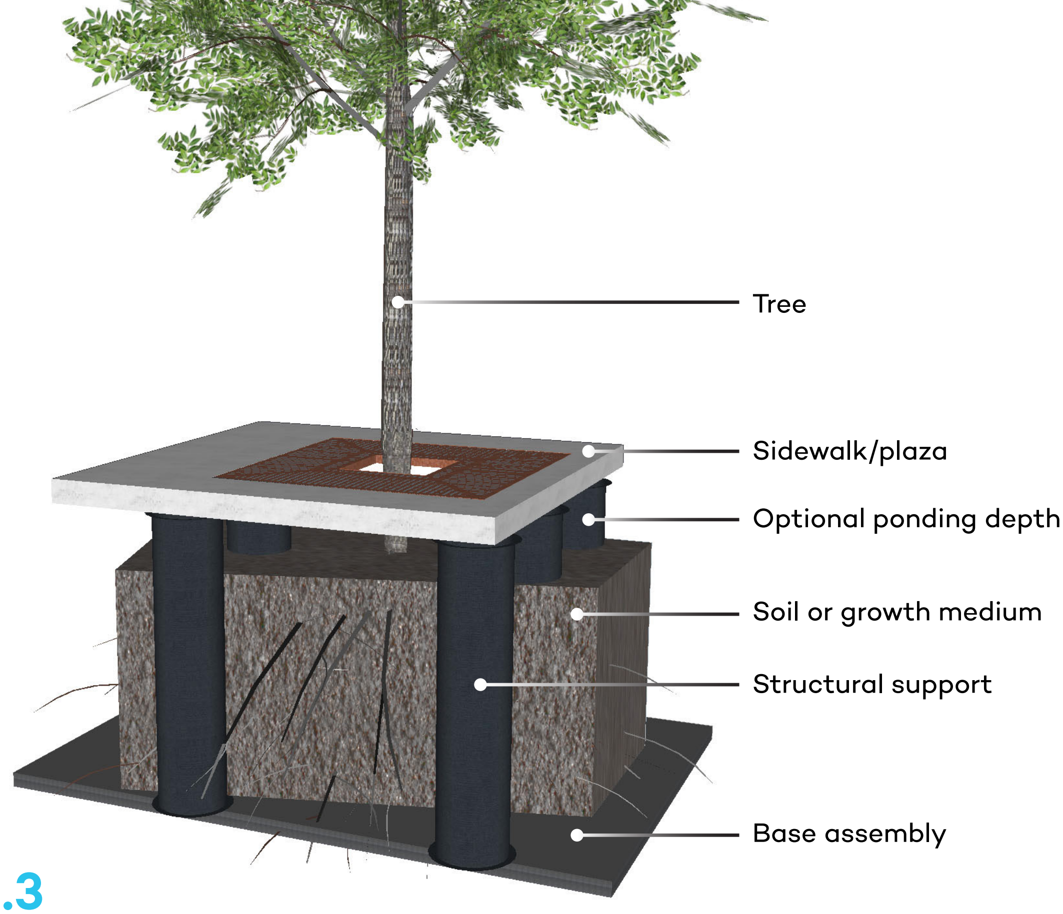
Miyawaki Forests

A technique introduced in Japan that seeks to accelerate afforestation through dense plantings that rapidly advance to a climax forest state. Native species are used, and multiple layers of vegetation are included (e.g., trees, shrubs, groundcovers). It is applicable primarily in parks and open spaces.

Shelterbelts

Rows of trees that are intentionally planted to provide shelter or a windbreak for livestock, fields, and yards. A variety of species can be used, from shrubs to tall trees. Eco-buffers are becoming popular: they are designed to mimic a forest by planting multiple rows with a variety of species, like spruce, poplars, aspens, rose bushes, saskatoons, or raspberries (as opposed to traditional methods that include fewer rows with a single species). The Shelterbelt DSS app[13] helps users design a shelterbelt with information on the carbon sequestration potential of different species and an associated dollar value.

[13] See more on the Shelterbelt DSS app here: https://iss.madlabsk.ca/wordpress/



Credit: Alberta Low Impact Development Partnership (ALIDP) (reprinted with permission).

3.2.3 Soil Cells

Soil cells are modular, plastic structural support systems that provide a space with uncompacted soil. Soil cells are installed near and under concrete areas, like sidewalks, parking lots, plazas, and roadways, supporting the survival and health of the planted trees. Soil cells facilitate healthy tree planting in urban areas, where they otherwise would lack sufficient uncompacted soil volumes to thrive, resulting in high mortality, reduced vigour, and shortened lifespans.

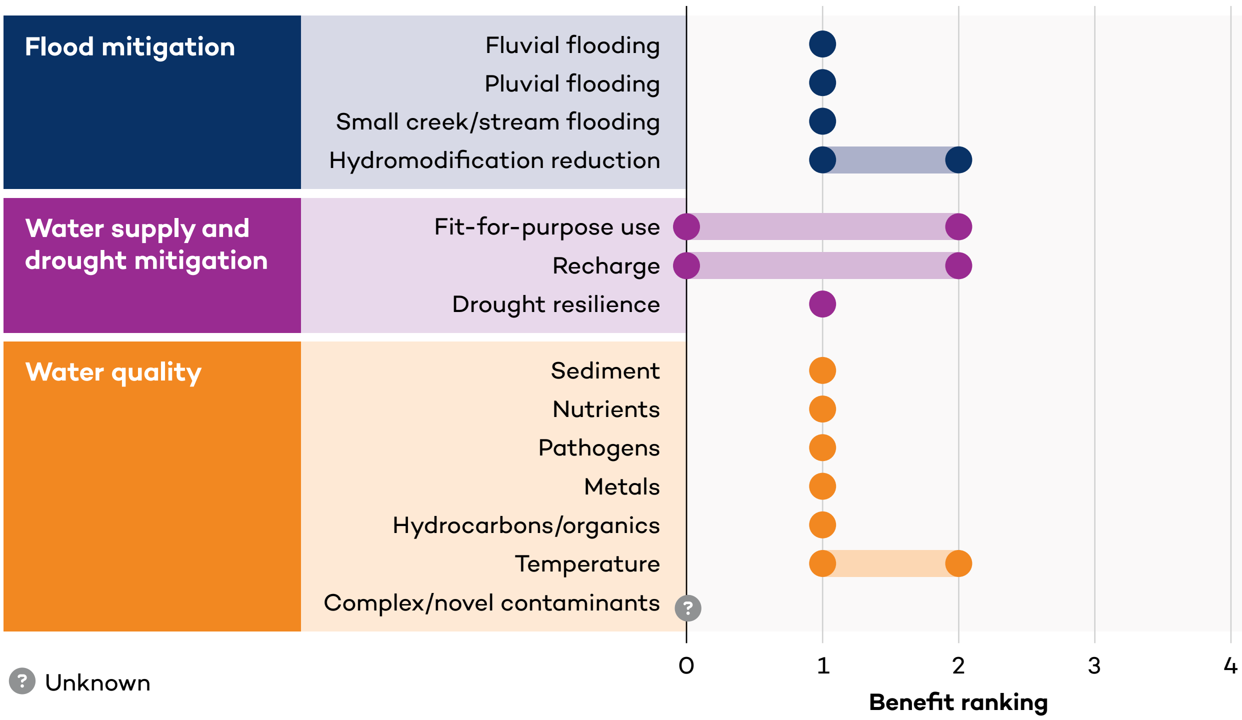
On the Canadian Prairies, where vegetation may be subject to long periods of drought, soil cells are most often installed so that stormwater from nearby surfaces is directed into them, providing passive irrigation (Citygreen, personal communication, November 17, 2021), making them a popular variant of bioretention (Section 3.3.6). Soil cells designed to incorporate stormwater runoff offer significant water-related benefits in urban areas (Ordóñez-Barona et al., 2018).

In this section, benefits and performance are considered only when soil cells receive direct rainfall, not when stormwater runoff is directed into soil cells. This would be an equivalent performance case to a healthy street tree implemented with adequate soil volume (but without a soil cell). For a discussion of soil cell performance when receiving concentrated flows of stormwater runoff, see Section 3.3.6, Bioretention.

Benefits and Performance

A useful tool for evaluating combined, measurable benefits of trees is the i-Tree group of models developed by the USDA Forest Service (i-Tree, 2019). Among various tree attributes are water and ecosystem benefits that can be quantitatively assessed by the software.

Figure 11. Primary benefit ranking for soil cells



Source: Authors.

Primary Benefits

Flood Mitigation

Limited flood-mitigation benefits are offered without deliberate routing of stormwater runoff into soil cells, as these systems do not offer ponding depth or active storage, which limits their detention and retention functionalities. The primary benefit of soil cells without directed runoff is to create favourable conditions for trees to survive to maturity, which maximizes their associated interception and evapotranspiration benefits, compared to a typical street tree without the recommended soil volume and space.

To contextualize, temperate coniferous forests intercept and evaporate 20%–40% of annual rainfall, while deciduous forests intercept 10%–20%. These values would be lower for urban or open canopy contexts (Kuehler et al., 2017). Key to the soil cell benefit is the enhancement of soil structure to increase soil volume and reduce compaction, which has been shown to facilitate tree growth (Graborsky et al., 2001; Layman et al., 2016).

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A runoff–reduction benefit may still be achieved with routine active watering from a rainwater or stormwater storage source, such as a nearby stormwater pond or parkade rainwater harvesting system. These systems are typically more feasible at the site level or in park settings than in conjunction with street trees, particularly in a retrofit context. The application of stored runoff shifts the storage benefit from mere detention to retention. This is represented in the upper range of the hydromodification benefit in the rankings. Flood mitigation does not change, as irrigation occurs separately from rainfall events.

Water Supply and Drought Mitigation

While trees in soil cells on the Prairies are often designed to receive passive watering from rainwater or stormwater sources, this section considers performance without this enhancement (Table 11). Greater soil volumes are more resilient to drought stress but not as resilient as when additional rainwater or stormwater is directed to them. Without this passive watering, active watering is required for several years after planting and in times of drought, particularly in the drier western part of the Prairies. Active watering (e.g., a truck with a water tank) from a non-potable water source will conserve treated water. Watering with rainwater or stormwater from a storage source will add a runoff reduction benefit. It is not known to what extent additional uncompacted soil volume on its own contributes to drought resilience.

Aquifer recharge potential is limited by the amount of precipitation minus evapotranspiration and the suitability of subsurface conditions for deep percolation.

Table 11. Soil cell: Water quantity performance

	Volume control	Rate control	Storage/supply
Mechanism	Interception (canopy) Evapotranspiration Subsoil percolation (if unlined)	Controlled by media infiltration rate	N/A
Capacity	~10% for deciduous ~20% for coniferous	N/A	N/A

Source: Based on Kuehler et al., 2017.

Water Quality

For the bioretention version of soil cells, the system can be configured for filtration, where stormwater is routed to stormwater sewers through underdrains. For such systems, media filtration and associated processes can offer a variety of benefits, including reducing suspended solids, nutrients, and metals (Table 12) (Silva Cell, 2018). On their own, without stormwater, trees do not provide a filtration-driven water-quality benefit but are considered highly beneficial for phytoremediation due to their substantial biomass and extensive root systems (Garg et al., 2018). Urban forestry studies suggest that trees play a role in reducing nutrient and heavy

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metal pollution in waterways (Livesley et al., 2016). However, if not coupled with stormwater or rainwater sources, the opportunity for treatment is limited to contaminants delivered by direct precipitation.

Leaf litter in a street context tends to fall onto hard surfaces, which are often directly connected to sewers and may result in added nutrient loadings and lower dissolved oxygen in receiving water bodies. On the Prairies, leaf sizes are relatively small and seem to be less consequential than in milder regions; however, the net impact of this phenomenon requires further investigation.

Table 12. Soil cell: Water quality performance

	Mechanism	Treatment efficiency	Media	Vegetation
BOD	Organics in media vs. biofilm consumption	71%	Low organics	May release
TSS	Straining	85%–90%	N/A	Preferential flow
P	Straining and sorption	70%–75%	Low P and amendments	Uptake opportunities
N	Nitrification and denitrification	65%–80%	Low N	Uptake opportunities
Pathogens	Straining	N/A	N/A	N/A
Metals	Sorption	90%–95%	N/A	Uptake opportunities

Source: Based on Silva Cell, 2018.

Soil Cell Examples of Co-Benefits

Biodiversity and Habitat (Rank: 2–3)

Street trees are subject to numerous stresses in an urban environment. Species selection is influenced by safety needs like height clearances for pedestrians and setbacks from roadways and buildings; fruit, leaf, or branch drop on sidewalks; longevity; and susceptibility to disease and infestation. Elm and ash are the primary species for street tree plantings on the Prairies. Urban forestry departments do use other species for biodiversity enhancement, but it remains the case that tree species richness potential is low relative to shrub and herbaceous species richness potential. Street trees enhance travel corridors for wildlife. Space may not be available for anything but trees in some highly dense urban contexts, and trees do provide ecological benefits distinct from other flora.

Air Quality (Rank: 0–4) and Carbon Sequestration (Rank 2–4)

While street trees intercept pollutants, they can also impede the escape of emissions from street level when they are implemented near tall buildings (Grylls & van Reeuwijk, 2022). Near-road air quality improvement is achievable through specific design methods, which may require a shrubby layer to direct airflow (Bauldauf, 2017).

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The i-Tree calculator can be used to evaluate the carbon sequestration potential of particular tree species in different settings. Street trees need to survive 20–30 years in order to achieve net-zero carbon emissions (Smith et al., 2019), which emphasizes the importance of creating favourable growing conditions so they can reach these ages. Materials used for soil cells have high embodied carbon, but recycled content can be as high as 100%. Carbon sequestration is therefore ranked lower than the maximum.

Urban Heat Island and Acute Heat Mitigation (Rank: 4)
Street and plaza trees in urban areas are uniquely able to provide shade and cooling at the street level when carefully sited (Horizon Advisors, 2019).

Amenity and Wellness (Rank: 4)
Plazas can provide significant amenity value, and street trees improve walkability. Tree canopy contributes to wellness, although line-of-sight "viewshed" greenness may contribute more (Ordóñez-Barona et al., 2023). Even though their footprint and functionality for water management may not be as high as for other practices, street trees are highly visible and can be distributed throughout communities. For these reasons, they have a high rating for wellness.

Applicability

Trees without adequate soil volume succumb to stresses in a very short period of time, anecdotally reported to be in the range of about 8 years (Paul Atkinson, City of Calgary, personal communication, n.d.). Soil cells may be the only means to provide street trees with the soil volume they require in highly urbanized areas. Urban trees are often the only vegetated natural infrastructure practice that is implemented in higher-density contexts.

With only direct precipitation, water quantity, quality, and recharge benefits are limited.

Because the footprint where soil cells and street trees can be implemented is quite limited compared to other practices, the overall benefit potential is constrained, notably for greenhouse gas emissions and air pollution compared to the magnitude of emissions (Pataki et al., 2021).

Sample Design Customizations

Sample design customizations are provided for soil cells in Table 13.

Table 13. Soil cell sample design customizations

Goal	Adjustment
Enhance runoff reduction	• Select larger species • Increase soil volume • Select species with greater leaf area • Combine with understory (e.g., shrubs) • Add rainwater/stormwater (convert to bioretention) • Provide non-potable irrigation

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Goal	Adjustment
Capture particulates and vehicle emissions at walking level on streets	• Provide leafy cover at the street level with appropriate airflow (e.g., shrubby layer)
Mitigate urban heat island	• Select coniferous species (needles absorb more heat)
Mitigate acute heat	• Select deciduous trees with larger canopies (more shade, more evapotranspirative cooling), direct air currents
Shelter from winter wind – reduce building heating costs	• Select coniferous species placed on the windward side of the building

Source: Based on Silva Cell, 2018.

Natural Infrastructure in Action

The Quarters redevelopment/revitalization project on the east side of downtown Edmonton installed more than 4,000 soil cells to support the rapid growth of 90 new trees (Figure 12). 96th Street is now a pedestrian-friendly green street known as The Armature. In this project, stormwater is directed into the soil cells. A monitored event in 2016 achieved peak flow and volume reductions of 72% and 35%, respectively. Catch basins provide sediment pretreatment. This example also demonstrates the incorporation of an understory layer of ornamental grasses.

Figure 12. Quarters redevelopment/revitalization project in Edmonton, Alberta

Credit: DeepRoot, 2025 (reprinted with permission).

Columbia Avenue is another revitalization project in Edmonton using soil cells to improve stormwater performance, increase drought resiliency, provide shade and cooling, and increase wellness related to goals such as walkability and livability. The industrial area is being transformed into a medium-density, mixed-use shopping district complete with bike lanes. Trees planted in soil cells grow rapidly, as shown in Figure 13.

Figure 13. 105th Avenue in the Unity Square area, Edmonton, Alberta, elm trees planted in soil cells (2017) show continuing rapid growth after 5 years (2022)

Credit: City Green, n.d. (https://citygreen.com/case-studies/105th-street-edmonton-canada/).

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Variants

Structural Soil

An engineered product comprised of a load-bearing rock component mixed with a sandy or soil-based medium that achieves an uncompacted soil volume integrated with a load-bearing paving base to support healthy, long-lived trees in ultra-urban areas under paved surfaces. It is not intended to handle stormwater collected and concentrated from surrounding land areas (Denig, 2015).

Through large volumes of growing media, soil cells offer a better growing environment for plants than structural soils (Ow & Ghosh, 2017). Structural soils are associated with poor water-retention capacity, which poses a risk for resilient applications in more arid climatic settings.

Tree Trenches

A non-proprietary alternative to soil cells providing a connected soil volume that can be installed with sides and top surfaces that are structurally self-supporting. These are typically used in sidewalk applications where structural spans are relatively short.

Related Practices

Soil cells and variants with stormwater directed into them—Bioretention (see Section 3.3.6).

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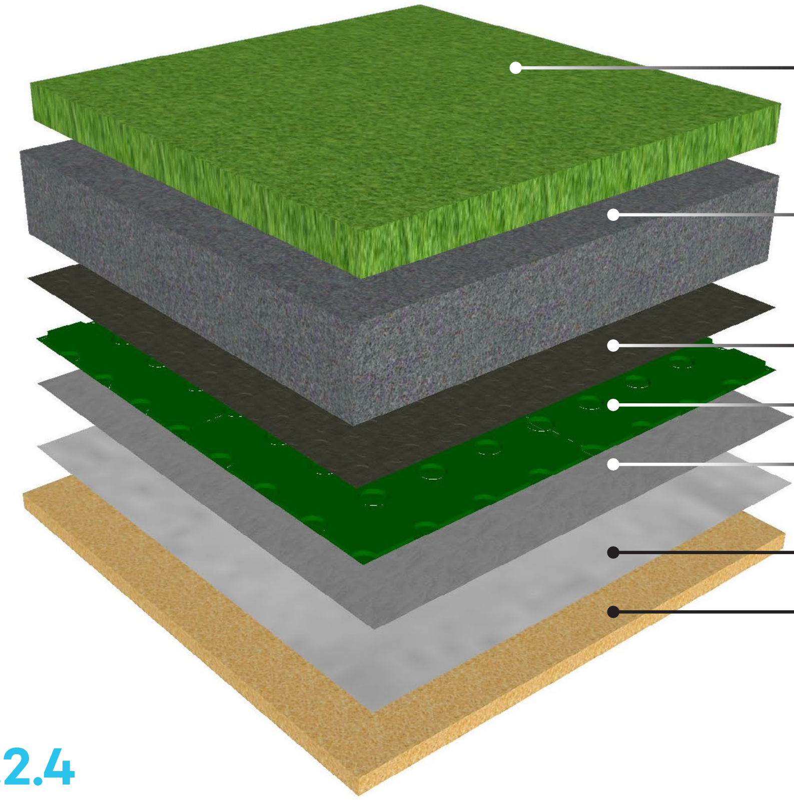

Credit: ALIDP (reprinted with permission).

3.2.4 Green Roofs

A green roof is a vegetated system that is functionally integrated with a roof area. Vegetation may range from low-growing succulent plants, flowering perennials, and native grasses to shrubs and trees. The type of vegetation has implications for a building's structural loading requirements, media characteristics and thickness, maintenance, and performance. Systems with shallow soil (up to approximately 150 mm) are referred to as extensive, while those with deeper soil (sometimes 600 mm or even more) and bigger plants are referred to as intensive. Semi-intensive systems are in between. Water storage layers, capillary mats, and other strategies to increase stormwater performance are often included.

The City of Calgary stormwater design guidelines recommend a minimum media depth of 150 mm for resistance to wind uplift, flood mitigation, and drought tolerance (Struck et al., 2014). This depth can support a biodiverse, often native, plant palette.

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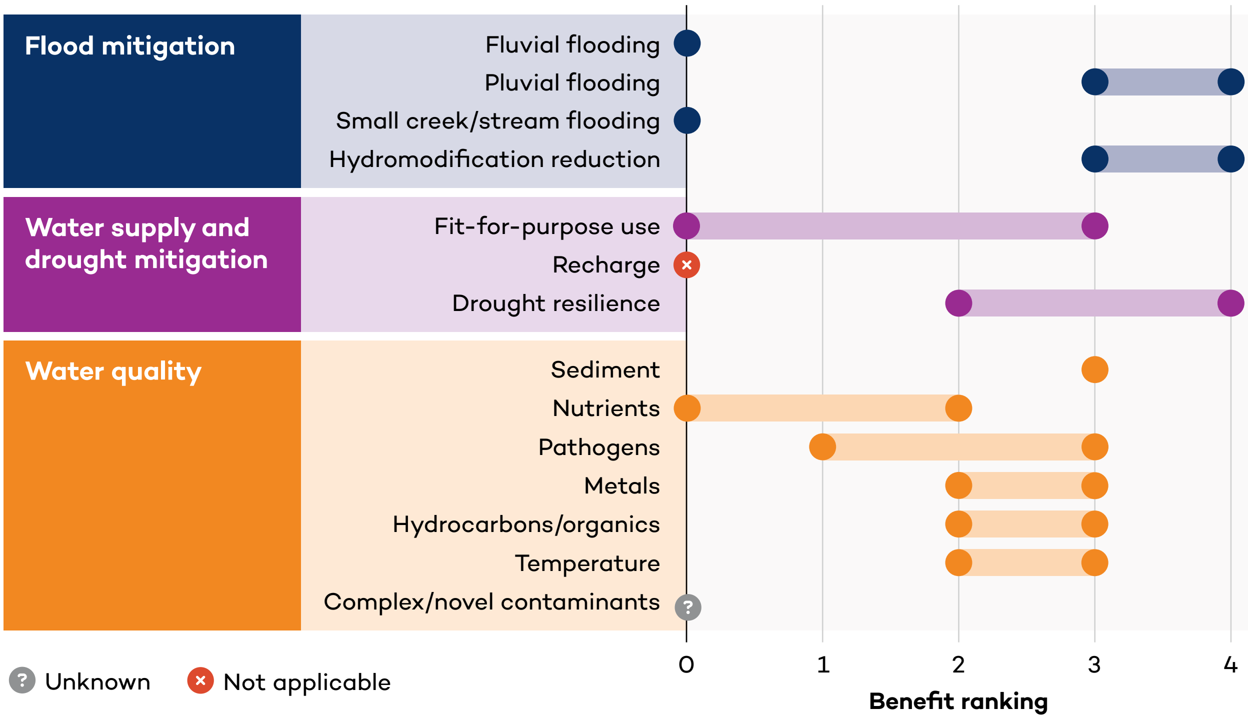
Benefits and Performance

Figure 14. Primary benefit ranking for green roofs



Source: Authors.

Primary Benefits

Flood Mitigation

Green roofs reduce runoff compared to conventional roofs. Of the multiple factors governing quantity performance, media depth has the greatest influence on the extent of retention benefits (Fassman & Simcock, 2012). To further enhance the benefit, green roofs can be watered with stored rainwater or stormwater (usually stored elsewhere on-site). This can accomplish both luxuriant irrigation and enhanced runoff reduction.

A conservative estimate of runoff reduction is around 50% (CVC & Toronto and Region Conservation Authority [TRCA], 2010). Green roofs with deeper media (300 mm) can achieve as high as 97% of runoff reduction in a prairie setting (Struck et al., 2014). Key parameters that dictate the effectiveness of runoff reduction are depth and water holding capacity of the media, plant coverage and type, antecedent moisture conditions, rainfall intensity, and/or precipitation depth (Getter et al., 2007; Mentens et al., 2006; Villarreal & Berndtsson, 2005).

Water Supply and Drought Mitigation

When a non-potable irrigation source is used, enhanced runoff reduction will be achieved, although green roofs should not be designed to require irrigation from a potable source (Table 15). In terms of drought mitigation, green roofs can aid in maintaining cooler, more humid microclimates in urban areas. Additionally, they can be designed to store water and support drought-tolerant vegetation, enhancing urban resilience in times of water scarcity.

Table 14. Green roofs: Water quantity performance

	Volume control	Rate control	Storage/supply
Mechanism	Interception (canopy) Evapotranspiration	Controlled by media infiltration rate and thickness	N/A unless combined with storage tanks or irrigation/re-use
Capacity	39%–72%	50%–88%	N/A

Source: Based on TRCA (2006), with recommended 150 mm media depth.

Water Quality

Green roofs offer benefits with respect to capturing pollutants deposited with direct precipitation and dustfall, such as suspended solids, metals, and pathogens (Toronto and Region Conservation Authority, 2006). However, green roofs may also act as a source of dissolved nutrients, especially phosphorus (Akther et al., 2021; Karczmarczyk et al., 2018). Downstream impacts of nutrient release need to be considered or mitigated through design (e.g., deeper media that retains more runoff). Load reduction is achieved through substantial runoff volume reduction, which counterbalances pollutant concentration effects. The form and percentage of organic matter used in green roof media tend to dictate the severity of nutrient leaching.

Given that direct precipitation is comparatively low in contaminants, the water quality benefits of green roofs are somewhat limited, yet are significant when compared to traditional roof materials (Table 15).

Table 15. Green roofs: Water quality performance

	Mechanism	Treatment efficiency	Media	Vegetation
BOD	Organics in media vs biofilm consumption	74%	Low organics	May release
TSS	Straining	88%	N/A	Preferential flow
P	Straining and sorption	0%	Low P and amendments	Uptake opportunities
N	Nitrification and denitrification	92%–96%	Low N	Uptake opportunities
Pathogens	Straining	N/A	N/A	N/A
Metals	Sorption	51%	N/A	Uptake opportunities

Source: Based on Toronto and Region Conservation Authority, 2006.

Green Roof Examples of Co-Benefits

Biodiversity and Habitat (Rank: 3–4)

Green roofs offer habitats for a variety of plants, insects, birds, and other urban wildlife. This increase in vegetation diversity can attract and sustain a wide range of species, contributing to urban biodiversity. Green roofs can play host to numerous species, providing refugia, stepping stones, and island habitat (Bergeron et al., 2018; Struck et al., 2014).

Air Quality (Rank: 2–3)

A modelling study of ozone and particulate matter (PM10) annual removal in Washington, D.C., found that 2 million m^2 of green roof would provide comparable pollutant removal to 25,000 to 33,000 street trees (US EPA, 2008).

Ecoroofs help reduce ambient air temperatures and insulate buildings, increasing energy efficiency and reducing the need for cooling systems, thus reducing emissions. With the reduction in ambient air temperatures and the mitigation of the urban heat island effect, the production of ozone decreases and ultimately creates better air quality (Learned & Kinas, 2019).

Urban Heat Island and Acute Heat Mitigation (Rank: 4)

Green roofs and walls reflect between 20% and 30% of solar radiation and absorb up to 60% through photosynthesis, which reduces urban temperatures (Berardi et al., 2014). Green roofs offer the biggest surface area for the mitigation of heat associated with buildings and are therefore ranked more highly than street trees for this purpose, although the two practices should be pursued in tandem.

Amenity and Wellness (Rank: 3–4)

Green roofs can be designed to provide amenity space, often on podium roofs associated with high-rise construction. In this rating system, they are ranked lower than street-level trees for their social benefits, as they are not seen from the street level and are often in private spaces. This does not diminish their benefit to those with access to viewing or visiting them.

Applicability

In highly urbanized areas, green roofs offer the possibility to provide the functionality of a landscape where little or no ground-level landscape is available. They can and should be more widely implemented to clean air, combat urban heat impacts, and improve the thermal performance of buildings.

Sample Design Customizations

Sample design customizations are provided for green roofs in Table 16.

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Table 16. Green roofs: Sample design customizations

Goal	Adjustment
Enhance runoff reduction	• Select plants with more biomass • Increase media thickness and/or storage capacity • Provide irrigation from rainwater or stormwater sources
Enhance treatment	• Provide irrigation from rainwater or stormwater sources • Ensure adequate carbon sources for metal sequestration • Ensure adequate cation exchange capacity to support nutrient cycling • Refrain from fertilizer usage

Source: Authors.

Natural Infrastructure in Action

The Fidek Office Building is a Gold LEED-certified building with a green roof in Red Deer, Alberta. Home to Berry Architecture + Associates and Downey Roth Hrywkiw Fidek LLP, the building's green roof features a stream, vegetable gardens, native plantings, and bird, bee, and butterfly habitats (Figure 15). Monarch butterflies and their caterpillars were seen there in 2023.

Figure 15. Fidek Office Building green roof in Red Deer, Alberta

Credit: Living Lands Landscape and Design.

Variants

Ecoroof

The terms green roof, ecoroof, living roof, and blue–green roof are used interchangeably by some. However, ecoroofs can be understood to encompass all roof enhancements that result in superior ecological outcomes compared to conventional roofs. For example, the City of Toronto Ecoroof Incentive Program identifies green roofs and cool roofs both as ecoroofs.[14]

Living Roof

Interchangeable with the term "green roof."

Rooftop Garden

Interchangeable term with green roof, often indicating an intensive green roof with an accessible amenity space.

Blue-Green Roof

A green roof strategy that considers both storage and release aspects of collected water.[15]

Blue Roof

A non-vegetated roof that stores and releases rainwater. It should be part of the basin family but is included here to keep green roof variants together.

White Roof, Cool Roof

A high albedo (high reflectance) roof, also known as a cool roof.

Biosolar Roof

A green roof combined with solar panels.[16]

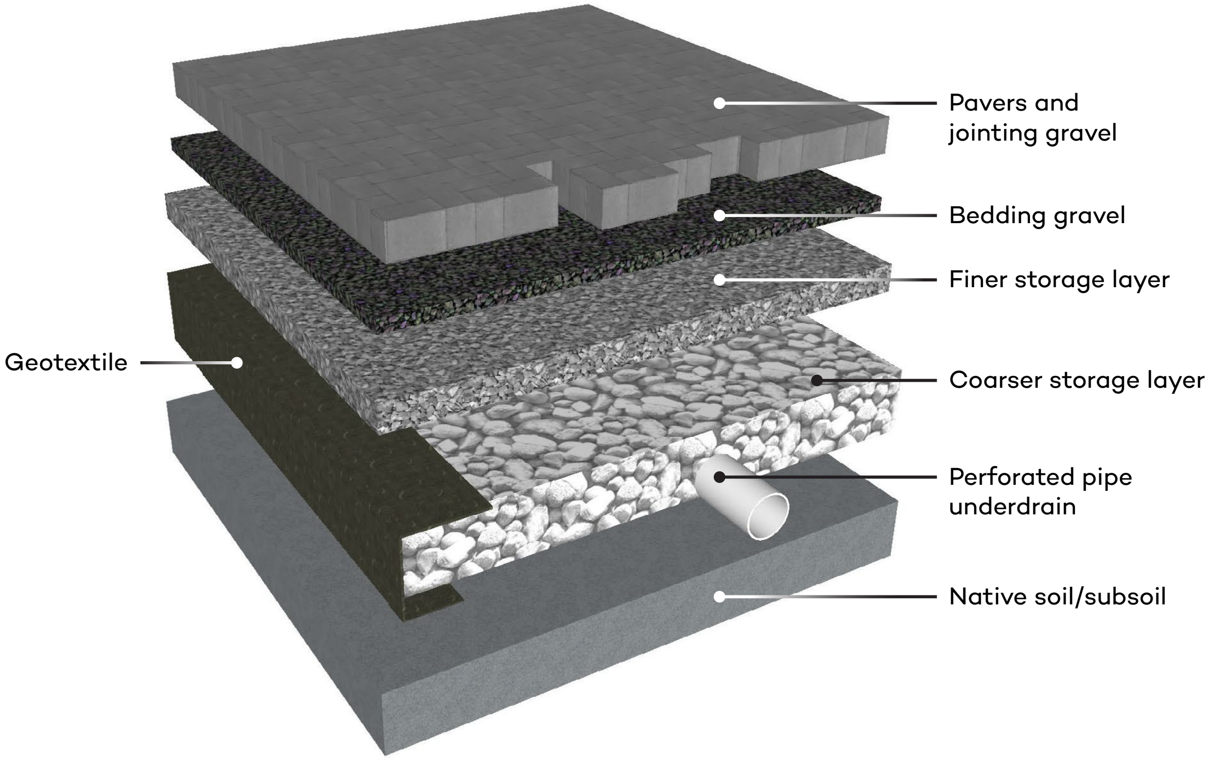
Related Practices

Green walls are not covered in this document. In particular, vertical forests, in the style of Milan's Bosco Verticale, should be explored for their potential co-benefits, especially if they can be maintained with irrigation from non-potable sources.

[14] Read more about the City of Toronto program here: https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives/green-your-roof/

[15] Read more about blue-green roofs here: https://livingroofs.org/introduction-types-green-roof/blue-green-roof-cities-stormwater/

[16] Read more about biosolar roofs here: https://livingroofs.org/introduction-types-green-roof/biosolar-green-roofs-solar-green-roofs/



Credit: ALIDP (reprinted with permission).

3.2.5 Permeable Pavement

Permeable pavement is a catch-all term for an entire range of alternative pavement structures that allow the infiltration of direct rainfall and runoff from hard surfaces while supporting loads for roads, pathways, plazas, parking lots, and other impervious surfaces in urban areas. Options include interlocking permeable pavers (as illustrated above), grid systems, and pervious concrete and asphalt. Designs and terminology vary widely.

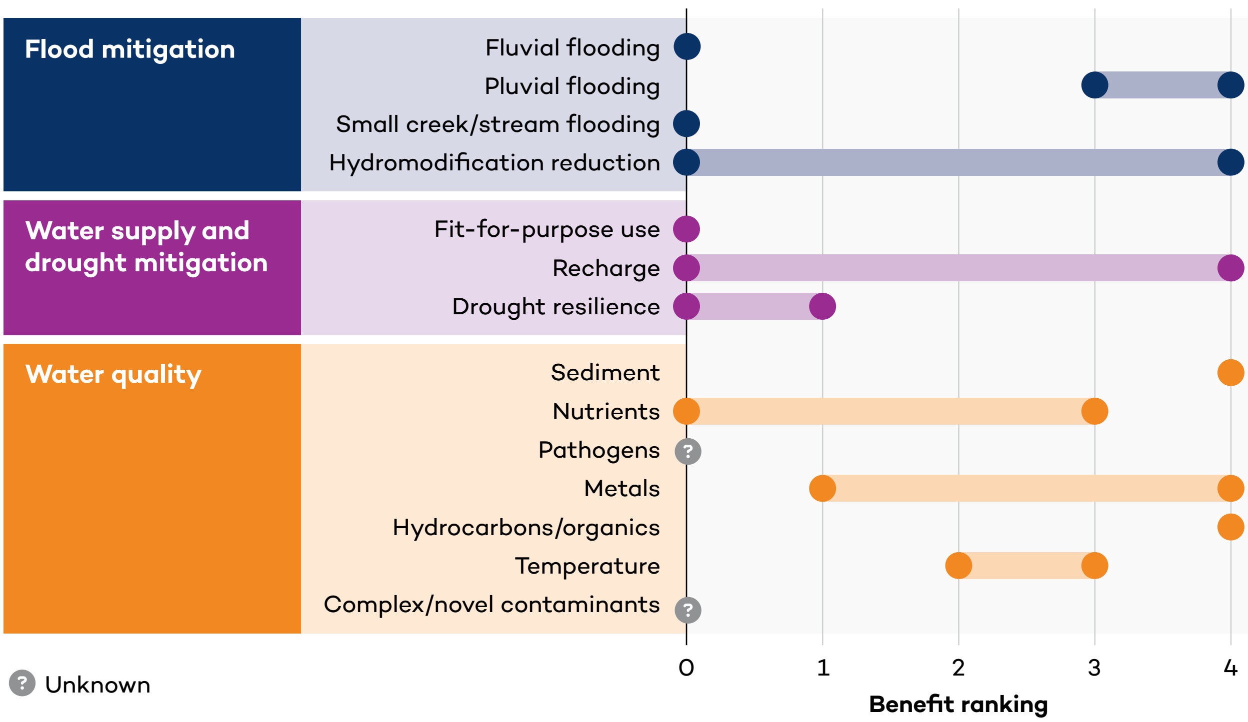
The illustration above shows a typical permeable paver implementation. The pavers themselves are the same composition as regular impermeable pavers but are laid with gaps between them. Water infiltrates through a coarse jointing material between the pavers. Restorative maintenance is typically required to maintain the long-term hydraulic capacity of permeable pavement (Sansalone et al., 2008). Newer paver systems have entered the market with polymer-stabilized jointing material or no jointing material, which reduces and simplifies maintenance. Gap (open) grading of the storage layer(s) provides expansion space for water when it freezes (CVC & TRCA, 2010).

Pervious concrete and asphalt rely on gap-graded aggregates in their mixes that, when placed, provide numerous paths for water to infiltrate. Pervious pavers with gap-graded aggregates as part of their mix also exist but are much less common than permeable pavers. Pervious options may be less favourable because of the fear of clogging the small passages in the aggregate, particularly related to winter sanding. Porous pavers (grid systems), which are typically made of concrete or plastic, stabilize vegetated or aggregate surfaces to increase their load-bearing capacity.

Aggregate-filled grid systems are excellent for walkways and secondary parking areas. Grassed grid systems typically use sandy media that is not conducive to healthy grass growth in the Prairie climate. Aggressive colonizing weeds establish themselves readily. Turf aesthetics are difficult to maintain in the Prairie climate without fertilizer, herbicide, and irrigation and are therefore not recommended.

Benefits and Performance

Figure 16. Primary benefit ranking for permeable pavement



Source: Authors.

Primary Benefits

Flood mitigation

A typical asphalt surface results in runoff mirroring rainfall quite closely, whereas permeable pavement of all types can rapidly infiltrate precipitation with little to no runoff (Brattebo & Booth, 2003). Quantity benefits vary widely as a function of the pore or gap size coupled with the presence of underground storage and infiltration characteristics. The degree of benefit depends on the amount of storage within the subbase and the properties of the underlying soils (Abbott & Comino-Mateos, 2003).

The typical installation is permeable pavers with an underdrain. A low I/P ratio is assumed for the flood-mitigation ratings. If installed without an underdrain in a high-percolation setting, creek flooding attenuation would also be realized.

Annual volume reductions can range between 50% and 100% (Roseen et al., 2012). As with other infiltrative practices, water quantity benefits depend on whether permeable pavements have underlying underdrains. The expectation would be that about half of the runoff (direct precipitation-induced) may be retained with underdrains and over 80% without underdrains (Bean et al., 2007). Peak flow reductions have also been documented (Scholz & Grabowiecki, 2007). The hydrologic response from permeable pavement is comparable to that of shallow-depth groundwater drainage with a peak flow reduction of 90%, which can be considered a wider metric for percolation-driven source control practices (Roseen et al., 2012).

Water Supply and Drought Mitigation

Where the runoff source is clean enough or properly treated, underground storage may be used for landscape irrigation, contributing to drought mitigation (Table 17). Permeable pavers can be used in conjunction with soil cells to deliver runoff to street and plaza trees. Salt content is a limiting factor when runoff is applied to vegetation. The practice can be designed to percolate if subsoil conditions allow. In urban areas, the fate of percolated water should be carefully considered. Chloride is highly mobile and can contaminate groundwater without adequate separation.

Table 17. Permeable pavement: Water quantity performance

	Volume control	Rate control	Storage/supply
Mechanism	Infiltration	Controlled by infiltration rate	N/A, unless combined with storage
Capacity	47%–93%	47%–94%	N/A

Source: Based on CVC, 2022.

Water Quality

As influent may be rainwater, stormwater, or both, water quality benefits vary accordingly (Table 18). For practices that are not vegetated, phytoremediation benefits are not present. Treatment processes are rather dominated by filtration, volatilization, and biofilms, resulting in hydrocarbons, metals, and particulate-bound contaminants as the targeted pollutants for removal (Scholz & Grabowiecki, 2007). Filtration of particulate-bound pollutants is enhanced by increased depth of the subsurface gravel layers, as well as finer gradation of the granular materials (Huang et al., 2016a). Nitrogen removal is understood to not be effective in a lined pavement system, unless specific design modifications are applied (Huang et al., 2016b).

Experiments in Calgary, Alberta, have shown that greater than 75% removal of TSS can be expected, whereas TP removal ranges between 40% and 85% (sometimes as low as 0%); TN removal is generally below 40%; and heavy metals (Cu, Pb, and Zn) are between 30% and 90% (Huang et al., 2016b). Highlights of this practice include the removal and breakdown of hydrocarbons, including a 99% reduction of motor oil, diesel, and other automotive-associated contaminants. Zinc, copper, and lead can be removed effectively as well.

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Permeable pavement can reduce the need for de-icing chemicals (Minnesota Pollution Control Agency, n.d.), which is a relatively unique benefit.

Table 18. Permeable pavement: Water quality performance

	Mechanism	Treatment efficiency
BOD	Biofilm consumption	N/A
TSS	Straining	71%
P	Straining and sorption	41%–98%
N	Nitrification and denitrification	N/A
Pathogens	Straining	N/A
Metals	Sorption	68%–91%

Source: Based on Clary et al., 2020; CVC, 2022.

Permeable Pavement Examples of Co-Benefits

Air Quality (Rank: 1–2) and Carbon Sequestration (Rank: U)
"In areas adjacent to permeable pavements, reduced use of de-icers decreases salt dispersion via air pathways. Permeable pavements may result in lower air emissions associated with traffic and snow clearing equipment" (Minnesota Pollution Control Agency, n.d.).

Urban Heat Island/Acute Heat Mitigation (Rank: 1–3)
Some products are formulated in lighter colours with higher albedo to better reflect heat, which reduces heat island impacts and decreases cooling requirements.

Amenity and Wellness (Rank: 1–2)
Pavers can be used creatively to assist with wayfinding and decoding streetscapes. They can contribute to walkability by providing a more certain grip surface and by having reduced pooling and better intrinsic de-icing capability than conventional paving choices.

Applicability

Permeable pavement may be an attractive solution for retrofits in existing communities with limited downstream pipe capacity and land options for other solutions. It is one of the most effective source control practices when it comes to land-use efficiency, as it does not require an additional footprint (Huang, 2015). It is not typically implemented on higher-speed roads, limiting the potential scope of its implementation. To varying degrees, depending on the product, clogging due to winter sanding contributes to the need for more maintenance than in non-sanding environments. Where space and grades support routing runoff to a landscaped area or vegetated practice from paved areas, it is cheaper and more beneficial to do so for drought-resilience purposes.

At the lot level, grid pavers are an attractive, cost-effective solution for secondary parking where a paved surface might otherwise be chosen. If subsurface storage is not required, cost will be reduced, which may increase the attractiveness of the practice. Ratings assume no additional storage reservoir.

Sample Design Customizations

Sample design customizations are provided for permeable pavement in Table 19.

Table 19. Permeable pavement: Sample design customizations

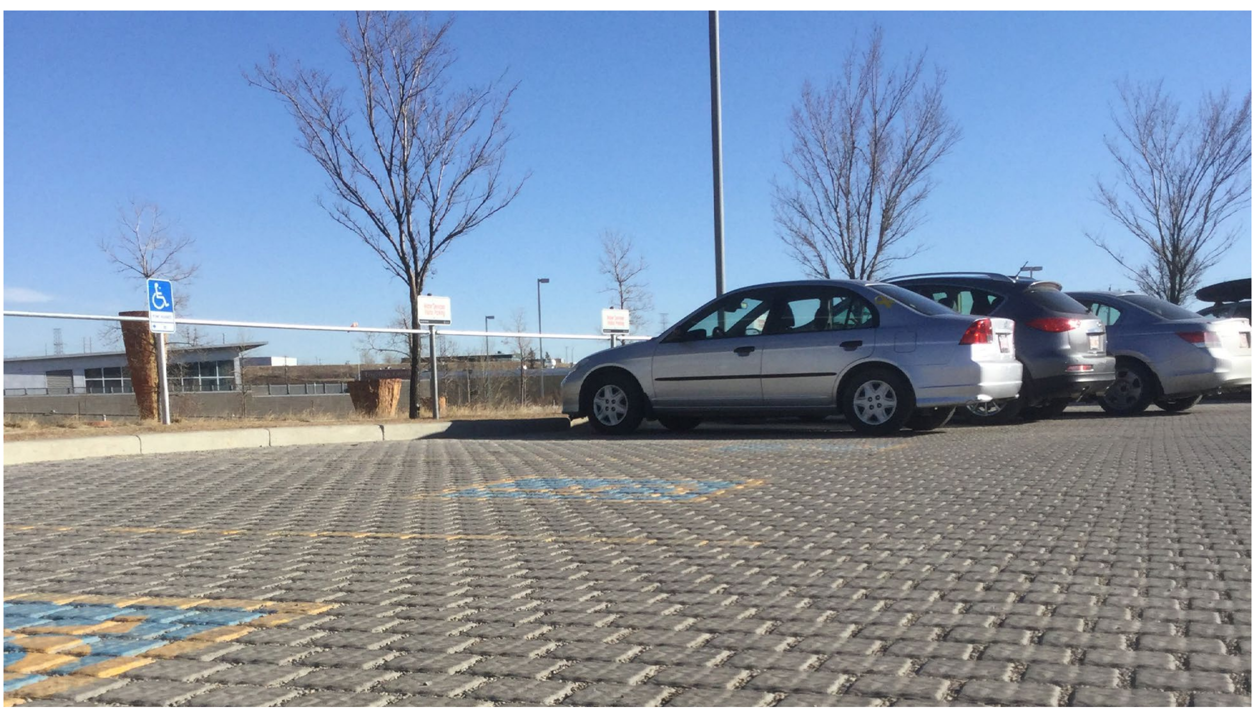
Goal	Adjustment
Enhance runoff reduction	• Wider gaps between pavers • More underground storage (in tight subsoils) • Add an underdrain (in tight subsoils)
Enhance particulate capture	• Use deeper gravel layers and finer granular materials
Mitigate the urban heat island effect and acute heat	• Choose high-albedo pavers

Source: Authors.

Natural Infrastructure in Action

This Calgary, Alberta site with permeable pavement has hosted a number of performance-monitoring and maintenance-feasibility investigations, including a prior configuration with pervious concrete and asphalt (Figure 17). Research by Huang et al. (2016b) includes findings from this site.

Figure 17. Permeable pavement site in Calgary, Alberta



Credit: ALIDP (reprinted with permission).

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Variants

Pervious Alternatives

Pervious rubber or even wood chips are sometimes used in playground installations, often in a poured-in-place application with an epoxy resin binder.

Related Practices

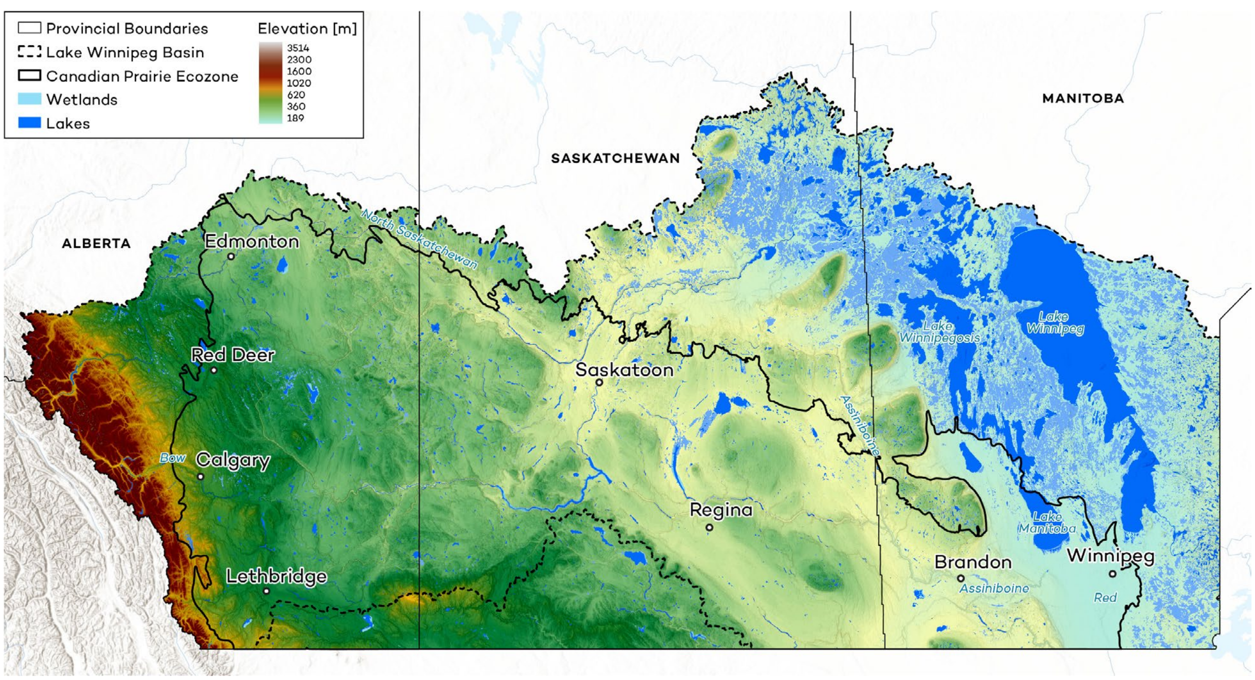
Rainwater harvesting (see Section 3.3.5).

3.3 Basins

Basins are natural infrastructure that primarily achieve water-quantity benefits by detaining and/or retaining runoff in surface depressions.

Basins, in the context of this report, refer to depressions that collect, store, and treat surface water. These can be natural assets, like wetlands, or constructed assets, like rain gardens. Basins can fully store runoff (retention) or be designed to temporarily store and then slowly discharge runoff (detention)—or, most likely, a combination of both. They can be permanently or intermittently wet. They occur across all scales, from the site level to large, regional features. When considering the influence of basins on water quality, both the capture and treatment of water can play an important role (Box 3).

Figure 18. Lake Winnipeg basin and Canadian Prairie topography



Source: Author map based on AAFC, 2013, 2024a; Government of Canada, 2015, 2016, 2017, 2023a.

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The Canadian Prairies are known for their "knob and kettle" topography—a landscape dotted with wetlands, also known as "prairie potholes"—which formed when blocks of ice in glacial till melted and then slumped to form depressions. Wetlands, together with lakes of varying sizes, are key natural assets in the Basin family, providing natural storage and treatment on the landscape (Figure 18).

Recognizing the significant loss of wetlands across the Prairies—estimated between 40% to 70% due to agricultural drainage and urban expansion (Davidson, 2014, as cited in Baulch et al., 2021)—there is keen interest in restoring this type of natural asset in both urban and rural areas. In urban areas, this is challenging for many reasons, so different types of constructed assets may be preferable or be used in tandem with efforts to restore natural features, each with varying abilities to mimic their natural counterparts.

Box 3. Balancing pollutant treatment and water capture

When selecting infrastructure that stores water for the purpose of improving water quality, it is important to consider the various roles and functions that reduce runoff and pollutant loads downstream. For example, some natural infrastructure may not treat the target pollutant directly; instead, it reduces runoff downstream through volume capture, which ultimately reduces the pollutant load (Gonzalez-Meler et al., 2013). However, contaminants lost through recharge (Section 3.5) can degrade groundwater quality and re-emerge later as surface water. Therefore, any infrastructure that targets both pollutant treatment (e.g., uptake/degradation) and volume capture should be considered to reduce negative consequences to groundwater quality.

The capacity and threshold of natural infrastructure to treat or store contaminants are also influenced by pollutant load and type (UNEP-DHI et al., 2018; United Nations Water, 2018). Notably, "a wetland can only treat so much wastewater before it becomes overloaded" (UNEP-DHI et al., 2018, p. 9), meaning that for any natural ecosystem, there are limitations in their capacity to treat high pollutant concentrations from some sources, like industrial or mining effluent (United Nations Water, 2018). It is also important to consider the retention time of some natural infrastructure (e.g., wetlands) to effectively remove/treat specific pollutants and the area required to meet the same rate of treatment as grey infrastructure (United Nations Water, 2018). In addition, some natural infrastructure can initially be a source of pollutants. For example, restored wetlands that rely on biological and chemical processes may initially contribute to nutrient and greenhouse gas emissions (Altor & Mitsch, 2008; Petrescu et al., 2015). Furthermore, where surface water retention-based natural infrastructure types are considered, soil testing should be practiced to ensure that sites are a sink rather than a source of nutrients like phosphorus.

Non-contributing areas make up a significant part of the Prairies (see Figure 33), influencing how water is distributed across the landscape. These are areas where water does not flow into major rivers or streams under average conditions. They can be critical for water retention, groundwater

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recharge, water filtration, and more. The impact and complexity of these areas cannot be adequately represented through evaluations of simple rainfall–runoff relationships, like those described with the Curve Number method in Section 3.2 alone, but within these areas, the cover types are paramount.

The role of natural infrastructure for storing water depends on the environmental constraints of different Prairie regions as well as the needs of each community and local stakeholders. At a local level, water infrastructure may be designed to meet various demands, including drinking water supply, agricultural uses for irrigation and livestock, and recreational purposes. Considerations for water supply requirements may also include temporal variability, location, and volume for distribution (United Nations Water, 2018). Water supply timing may also be influenced by practice (e.g., agriculture) and season. For example, water for irrigation is needed during the late summer months when surface water flows are typically low in the Prairie region (WaterSMART Solutions Ltd, 2020) and will vary by crop type (United Nations Water, 2018). At a watershed scale, infrastructure designed to provide flood mitigation or supply water benefits must ensure that the volume and rate of incoming water are well understood.

This section reviews the benefits and performance of lakes and ponds (3.3.1) and wetlands (3.3.2), alongside analogous constructed assets, including constructed wetlands (3.3.3), rain gardens (3.3.4), rainwater harvesting (3.3.5), and bioretention (3.3.6).

3.3.1 Lakes and Ponds

Lakes and ponds are natural water bodies and in-land aquatic ecosystems formed from depressions in land, often described as lentic (slow-moving water) compared to lotic river systems (flowing water) (Eramma et al., 2023). The characteristics of lakes and ponds vary by depth, stratification/circulation, nutrients, productivity, light penetration, dissolved oxygen, and season (Eramma et al., 2023). Lakes and ponds are often described as closed systems (Eramma et al., 2023). However, they can be both connected or disconnected via the surface from larger basins. For example, a lake may exist within the headwaters of a watershed (e.g., Lake Louise in Alberta), be part of a longer river system (e.g., Lake Diefenbaker in Saskatchewan), or be the termination point for surface water in a closed sub-basin, connected to a larger overall basin only through the subsurface (e.g., Whitewater Lake in Manitoba).

Benefits and Performance

Primary Benefits

Flood Mitigation

Lakes and ponds store excess volumes of water following large rainfall and snowmelt events and often serve as the termination point for rivers and streams (Section 3.4). Outflows from lake and pond outlets are generally more controlled than their inflows, which can enable them to act as buffers that gradually release stored water and reduce downstream flood risk (Leach & Laudon, 2019). The flood-mitigation function of lakes and ponds is particularly important for regions like

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the Canadian Prairies, which are prone to significant seasonal flooding from regular snowmelt events (Huziy & Shusama, 2017) and require large storage areas to reduce their impacts.

Water Supply and Drought Mitigation

Lakes and ponds are critical sources of water supply on the Canadian Prairies. For example, Shoal Lake (City of Winnipeg, 2022), which straddles the eastern boundary of Manitoba, has provided access to clean drinking water to the City of Winnipeg for over 100 years.[17] However, it is important that lakes be managed such that water withdrawals are sustainable when used for water supply and to support existing healthy aquatic ecosystems.

Smaller localized ponds can also provide significant water supply benefits to landowners and agricultural producers, providing access to water for irrigation and livestock and reducing the need to purchase and haul water on-site (Puzyreva et al., 2022). Additionally, when water tables are low, lakes and ponds provide drought mitigation benefits through groundwater recharge to local aquifers (Haque et al., 2021), which provide their own significant water supply benefits (Section 3.5.1).

Water Quality

The water quality of lakes and ponds is highly influenced by upstream conditions, land-use change and management, population growth, and climate change, among others (Bhateria & Jain, 2016). Lakes and ponds are very important natural assets that offer many ecological goods and services that benefit society. Implementing natural infrastructure and management practices that protect and conserve these regions can have significant water quality benefits that protect these services and improve resiliency (CCME, 2021).

Lakes have very well-defined and linked ecosystem (biological, chemical, physical) processes that provide many important services to biota and humans (e.g., fisheries, drinking water, industries, etc.). They contain defined regions that house various organisms with important roles in ecosystem functioning, like vegetation in the littoral zone, phytoplankton in the limnetic zone, and decomposers in the benthic zone (Bhateria & Jain, 2016). Piña-Ochoa and Álvarez-Cobelas (2006) conducted a meta-analysis on the denitrification potential in aquatic ecosystems and found that lakes had high variability that is influenced by the seasons (highest in summer), as well as controlled by low concentrations of phosphorus and oxygen and high concentrations of nitrate and dissolved organic carbon. During the warmest month, denitrification is influenced by low oxygen and high organic carbon and nitrate.

[17] This report acknowledges that the provision of clean drinking water for the City of Winnipeg caused devastating impacts for the residents of Shoal Lake 40 First Nation, who where isolated and without road access to the mainland for over 100 years. This isolation made it challenging for residents to access basic services, resulting in a 24-year boil water advisory that was finally resolved in 2021 when the Freedom Road, built in 2019, allowed access to upgrade the water treatment facility (Thompson & Hashmani, 2023).

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Cedar Lake Example With Co-Benefits

Manitoba is home to over 100,000 lakes. Critical to fresh water supply and teeming with biodiversity, lakes also play an important role in the provincial economy for tourism, angling, and commercial fisheries and in the traditional livelihoods of many First Nation and Métis communities. Manitoba's commercial fishing industry employs more than 2,300 people and generates more than CAD 100 million in the local economy annually, with Indigenous fishers accounting for 85% of licensed commercial net fishers (Rutgers, 2022). In 2022, the province launched an initiative called Fish Forward,[18] which works with local fisheries, retailers, and consumers to promote and support sustainable practices and, eventually, eco-certification. Indigenous fishers are leading the way: Skownan First Nation fishers and Cedar Lake Fisheries were the first two fisheries to be awarded the Marine Stewardship Council certification, ensuring that fish populations and the industry remain healthy for future generations (Figure 19).

Figure 19. Cedar Lake Fisheries near Easterville, Manitoba

Credit: IISD.

Lake Winnipeg Example With Co-Benefits

In Manitoba, the Rural Municipality (RM) of Gimli recently changed the designation of a rare riparian zone along the shores of Lake Winnipeg, known as Moonlight Bay (Figure 20). The change from "Agriculture Rural – Limited Area and Urban Residential Area" to "Parks,

[18] See more on the program here: https://fishforward.ca/.

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Recreation and Open Space Area" will prevent residential development in a region popular for cottage development. This designation will ensure that the natural sand beach and lush treeline remain, which will protect the shoreline from erosion, improve water quality, and promote enjoyment for residents today and in the future. On the other side of the riparian area lies a 144-acre parcel of land that includes a decommissioned wastewater treatment lagoon that will be restored to a coastal wetland.

Figure 20. Moonlight Bay riparian area along Lake Winnipeg in Manitoba

Credit: Will Jacobson.

3.3.2 Wetlands

Wetlands are shallow surface depressions that are saturated with freshwater for enough time that unique aquatic processes are promoted, thanks to the poorly drained soil, wetland vegetation, and biological activity that is adapted to a wet environment (UNEP-DHI et al., 2018). The Prairie Pothole Region is a ~715,000 km^2 region with abundant wetlands across southern Alberta, southern Saskatchewan, southwestern Manitoba, northeastern Montana, northern and east central North Dakota, eastern South Dakota, western Minnesota, and northwestern Iowa (Euliss et al., 1999). Prairie wetlands are recharged annually by snowmelt and precipitation events, and spring flood events occur naturally and are part of their hydrological cycle (Buttle et al., 2016). Basin volume, soil type (e.g., clay soils tend to hold water and reduce infiltration as compared to sandy soils), position on the landscape, and surrounding land use can all influence the water-related benefits of wetlands.

The Stewart & Kantrud (1971) Classification System is commonly used to classify undrained wetlands. Five classes out of seven are relevant to the Prairie Pothole Region and are based on the permanence of water, both the depth and the period of time that water is present, and the resulting wetland vegetation communities (Box 4). The benefits of wetlands—which include providing surface water storage, groundwater recharge, water purification, wildlife habitat, and carbon sequestration—are well understood, yet wetlands are highly threatened. It is estimated that 40%–70% of wetlands across the Prairies have been drained for agricultural and urban development (Davidson, 2014, as cited in Baulch et al., 2021), with drainage and loss ongoing and estimated at 10,800 hectares per year (Watmough et al., 2017).

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Box 4. Classifying wetlands

The permanence of water influences the soil characteristics and promotes the growth of plants that are adapted to wet conditions. The classes of wetlands and some characteristics include the following (Ducks Unlimited Canada, 2019):

- Class 1 ephemeral wetlands have porous soils, such as sand and silt, that allow water to drain quickly. Ephemeral wetlands often have surface water for 1 to 3 weeks in early spring. In years that are dry or have normal moisture conditions, ephemeral wetlands dry once the ice seal in the soil has melted, and they are often cultivated or seeded in annual cropland. Their soils do not have hydric indicators for prolonged soil moisture.
- Class 2 temporary wetlands hold water for 2 to 6 weeks in the spring and early summer in years with normal snowmelt but can also store water for multiple days after heavy rainfall. In years that are dry or have normal moisture conditions, temporary wetlands are often cultivated and seeded or may be seeded later, once conditions are dry enough. Their soils do not have hydric indicators for prolonged soil moisture.
- Class 3 seasonal wetlands hold water for longer periods in the spring and mid-summer in years with normal moisture, often becoming dry late summer. Seasonal wetlands may be cut for hay once they dry in late summer. Their soils have hydric indicators, like mottling, that show a long presence of flooded soil conditions.
- Class 4 semi-permanent wetlands hold surface water throughout the spring, summer, and fall in most years. In years with normal moisture, the semi-permanent wetland may become dry by late summer. These wetlands often develop on open-water area that is too deep for emergent vegetation. In some areas of the semi-permanent wetland, the soils have hydric indicators, like mottling and gleying, that show a long presence of flooded soil conditions.
- Class 5 semi-permanent wetlands hold surface water year-round in most years. There is an area of permanent open water at the deepest point (or lowest elevation) within the wetland. They may go dry in extreme droughts, leaving an area of bare soil where the open water was previously. In some areas of the permanent wetland, the soils have hydric indicators, like mottling and gleying, that show a long presence of flooded soil conditions.

Benefits and Performance

Primary Benefits

Flood Mitigation

Prairie pothole wetlands contribute to natural flood control, providing water storage on the landscape and slowing surface water runoff, which can minimize flood damage (Dumanski et al., 2015; Pattison-Williams et al., 2018; Spence et al., 2022), with large-scale models demonstrating

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reduced flood risk in Prairie river basins (Simonovic & Juliano, 2001). However, many considerations influence a wetland's ability to provide flood-mitigation benefits, such as (Acreman & Holden, 2013)

- the size and type of rainfall or runoff event,
- the position and configuration on the landscape,
- soil characteristics,
- topography,
- existing soil moisture conditions, and
- surrounding land management.

For example, Costa et al. (2020) demonstrated that wetland flood-mitigation potential is influenced by their distribution, its existing condition (e.g., current water level or remaining storage capacity) prior to the rainfall or snowmelt event, and the size of the rainfall or snowmelt event. Wetland storage is influenced by soil drainage characteristics, and wetlands with greater soil drainage (e.g., sand or silt) are more likely to have additional capacity prior to flooding, thanks to more infiltration.

Water Supply and Drought Mitigation
In addition to providing flood mitigation, the storage and soil characteristics of a wetland influence drought mitigation and water supply benefits. Wetlands capture and store water, losing water to groundwater recharge and evaporation. While not all wetlands contribute to groundwater recharge, ephemeral or class 1 wetlands are shown to be a primary source of groundwater infiltration, with the majority of recharge during spring (Bam et al., 2020). There are also discharge ponds, which have a water level below the surface of the confined groundwater aquifer, and actually receive and store water from the aquifer (Lissey, 1971 and Sloan, 1972, as cited in Bam et al., 2020). The supply of surface water in wetlands is critical to agricultural producers and wildlife during periods of drought.

Whether flood mitigation, water supply, or drought mitigation is of concern, the volume of wetland storage is a key parameter influencing performance, which can be difficult to assess based on the surface area of the wetland alone. Soil characteristics are also key. However, the limited availability of soil information only provides practitioners with a rough estimate. The storage volume for natural wetlands is related to landscape topography, which has been estimated using surveys and simple regression analysis for some regions of the Prairies (Wiens, 2001). More recent studies use modelling approaches (using both remote sensing and survey data) to determine finer spatial distributions of wetland storage per unit area, which has the potential for replication in other prairie regions (Cui et al., 2021). These estimates of wetland storage can be used to infer simplified local flood mitigation, drought mitigation, and water supply benefits in wetland assessments or be used to inform model inputs at larger scales to evaluate more complex benefits, such as drought mitigation over multiple decades.

Wetland drainage, estimated at 90% in the City of Calgary (Alberta Government, 2011b), provides an example of lost storage capacity, where an estimated 133,000 ha have been drained over the past 40 to 60 years, with a subsequent loss of 379,000,000 m^3 of storage capacity (Canadian Climate Institute & Smart Prosperity Institute, 2021). This is equal to about 21 times the volume of water that is stored in the Glenmore Reservoir (a drinking water reservoir) in Calgary.

Water Quality

Wetlands are well known for their ability to filter and store contaminants due to their biological, physical, and chemical processes (Aziz & Van Cappellen, 2021; UNEP-DHI et al., 2018; World Bank, 2021). For example, the microorganisms and vegetation within a wetland can metabolize, uptake, and breakdown pollutants in the water (UNEP-DHI et al., 2018), before they infiltrate the groundwater aquifer or move downstream into receiving waterbodies. Water quality improvements vary and some notable points include:

- Smaller wetlands have greater removal rate constants, thanks to greater sediment surface area to volume ratios, which are inversely correlated to site residence time, surface area, and water depth. Cheng and Basu (2017) also noted that if smaller wetlands were lost in equal areas to large wetlands, there would be a greater loss of nutrient removal potential on the landscape.
- Aziz and Van Cappellen (2021) note that the ability to remove sediment and nutrients varies by wetland type. They estimated that the phosphorus retention rate (mean ± standard deviation) was 23.9 ± 19 kg/ha/year, 34.6 ± 21 kg/ha/year, 44.7 ± 35 kg/ha/year, and 57.9 ± 42 kg/ha/year for fens, swamps, bogs, and marshes, respectively, in southern Ontario's Mixedwood Plains ecozone, a region characterized by intensive agriculture. Sediment retention rates were 14 ± 10 m^3/ha/year, 22 ± 10 m^3/ha/year, 23 ± 10 m^3/ha/year, and 36 ± 20 m^3/ha/year for fens, swamps, bogs, and marshes, respectively.
- Cheng et al. (2023) found that in semi-arid regions like North Dakota, ephemeral wetlands are highly efficient at filtering excess nitrogen, with retention rates of up to 1.8 times compared to systems with limited transiency. Their conservation is important to improving water quality downstream.

Table 20 lists some water quality performance characteristics of wetlands (Cheng & Basu, 2017; Clary et al., 2020). Cheng and Basu (2017) include the natural wetland subset from a data series compiled from 600 lakes, reservoirs, and wetlands across the world, with the highest concentration of sites in North America and Europe and in the temperate latitudes. Clary et al. (2020) include data for wetland basins from the International Stormwater BMP Database, which is useful for characterizing the stormwater treatment performance of different types of BMPs (referred to as "natural infrastructure" in this report). For more specific information, it is important to review datasets from wetland basins that are similar to the local site conditions, regions, and influent characteristics.

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Table 20. Summary of water quality performance for wetlands

	Mean[a]	Median[b]	Number of studies included*
TSS	N/A	60.6%	30 (influent) and 31 (effluent)
TDS	N/A	-17.3%	5 (influent and effluent)
TP	27.9 ± 26.1%	28.2%	27 (influent and effluent)
Phosphate	26.3 ± 19.2%	0.3% (orthophosphate)	13 (influent) and 14 (effluent)
DP	N/A	16.4%	8 (influent) and 9 (effluent)
TN	17.5 ± 14.4%	4.2%	14 (influent and effluent)
TKN	N/A	8.1%	15 (influent) and 17 (effluent)
Nitrates/ nitrites	58.7 ± 26.1% nitrate	36.7% nitrate+ nitrite	22 (influent and effluent)
Ammonia	N/A	22.1%	16 (influent and effluent)

Notes:
* There are limitations to these values, as they are calculated based on the median inflow and median outflow for a suite of studies and not the median of the percent removal of each individual study. The values presented here are calculated as the % reduction between concentrations in the influent compared to the effluent.
TDS – total dissolved solids
TKN – total Kjeldahl nitrogen
DP – dissolved phosphorus
[a] Source: Cheng & Basu, 2017.
[b] Source: Based on Clary et al., 2020.

While wetlands play an important role in improving water quality, there are limitations to the storage and treatment capacity of wetlands (Aziz & Van Cappellen, 2021; UNEP-DHI et al., 2018), as well as variability in capacity under different climate regimes and at different times of the year (e.g., spring runoff, plant growing season and senescence, microbial activity, etc.). Cheng et al. (2020) also point out the importance of conserving and restoring wetlands of different sizes or classes, as they each provide unique benefits to the landscape, as opposed to the more common focus of maximizing the total wetland area of basins of a larger size or higher class.

Wetland Example With Co-Benefits

Wetlands provide a multitude of benefits, like water storage and filtration, carbon sequestration, and wildlife habitat, but they also play an important role in improved health and well-being (Figure 21). The Canadian Psychological Association (2021) reported that natural landscapes increase positive emotions, promote pro-social behaviours like helpfulness and generosity, and

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improve attention, working memory, and self-control. Proximity to natural landscapes is also important, with reduced risk of depression, stress, and anxiety for those who live closer, as well as better psychological resilience for children who live near nature. Wetlands are especially important in urban centres, ensuring equal access to all residents. In Brandon, Manitoba, the East Area Interpretive Wetlands project was restored, and an accessible boardwalk was installed, making it easier for all residents to benefit from time in nature.

Figure 21. East Area Interpretive Wetlands in Brandon, Manitoba

Credit: Sandy Black.

Credit: Bryana Nicolas (permission to use)

3.3.3 Constructed Wetlands

Constructed (or artificial) wetlands aim to mimic the hydrological processes of natural wetlands, often functioning as biological treatment systems. They are extensively used around the globe for their versatility in treating different types of water. Though their application is widespread, their efficacy in cold climates remains a subject of ongoing discussion, with a particular focus on performance concerns during colder weather. Constructed wetlands are used for both stormwater and wastewater treatment, each with specific design characteristics and functionalities:

- **Stormwater wetlands**: Designed for stormwater management, these wetlands typically perform a flood-mitigation/rate-control function, as well as remove pollutants such as sediments, nutrients, and heavy metals. They typically have a shallow basin (less than a 1-m deep wet pool) with emergent vegetation designed similarly to other end-of-pipe practices. Conventional end-of-pipe practices, such as dry or wet ponds, are designed for rate control (detention) benefits without the natural infrastructure benefits described in this section.
- **Wastewater wetlands**: In the context of wastewater, constructed wetlands serve as an alternative or complement to conventional treatment facilities and can replace/supplement chemical additives. They leverage natural processes with wetland vegetation, soils, and microbial life to effectively reduce organic matter, nutrients, and pathogens. The more common applications involve surface flow wetlands that are similar to stormwater designs. Subsurface designs are gaining popularity as well.

Overall, constructed wetlands offer efficient treatment of urban stormwater runoff and municipal or industrial wastewater. They are adaptable, fit various scales and environmental conditions, and contribute positively to ecological conservation and landscape aesthetics.

Floating Treatment Wetlands

A floating treatment wetland is an innovative water treatment technology designed to improve water quality in ponds, lakes, and reservoirs (Lewtas et al., 2015). It consists of a buoyant mat that supports wetland plants, which float on the water surface while their roots dangle, submerged, creating a unique aquatic habitat (Zhang et al., 2024). These roots, along with attached biofilms, act as a natural filtration system, absorbing nutrients, pollutants, and sediments from the water.

As the mat is a manufactured product, implementation is subject to associated costs and carbon footprint. Periodic maintenance to manage plant overgrowth and ensure the buoyancy and integrity of the floating mats is needed, which can be especially challenging in large-scale applications or inaccessible locations.

Floating treatment wetlands harness the purifying power of wetland ecosystems in a compact and adaptable format, making them a unique solution to treat a variety of waters, including runoff from urban and agricultural landscapes, domestic and municipal wastewater, landfill leachate, and more. They can enhance the performance of existing water bodies that were not designed for the growth of wetland plants or work with reduced footprints where ground space for traditional wetlands may not be adequate (Arslan et al., 2022). Urban stormwater facilities may incorporate floating treatment wetlands where perimeter vegetation is difficult to establish due to highly fluctuating water levels, steep banks, or saline conditions. They also provide habitats for aquatic and semi-aquatic species, enhancing biodiversity and ecosystem resilience. Floating treatment wetlands can be scaled to fit the size and treatment needs of a variety of water bodies.

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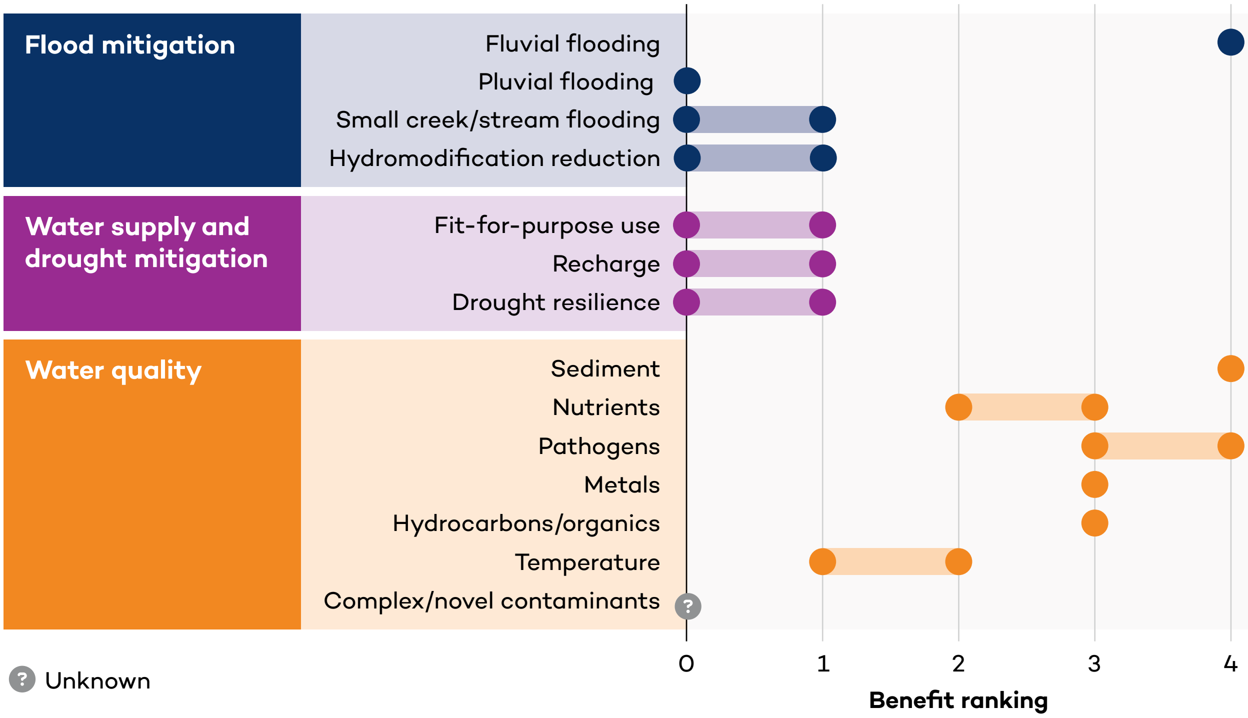
Benefits and Performance

Figure 22. Primary benefit ranking for constructed wetlands



Source: Authors.

Primary Benefits

Flood Mitigation

Constructed wetlands play a role in stormwater management by moderating water flow rates, which is key in reducing peak runoff rates during heavy rainfall events and lessening flood risks (Scholz, 2006). These systems may also function as natural sponges, retaining and storing water after heavy rains, thereby mitigating downstream flooding, particularly in urban areas with extensive impervious surfaces that cause rapid runoff (Konyha et al., 1995). Their ability to hold water and allow slow percolation through the subsoils enhances groundwater aquifer replenishment if the system is not lined and groundwater contamination is not a concern. Additionally, evapotranspiration from wetland plants may serve as an ancillary mechanism for managing water levels and downstream impacts (Harne et al., 2023).

Stormwater constructed wetlands are primarily designed for fluvial flood mitigation. They can be made to address small stream impacts when combined with reuse for irrigation. Their role in pluvial flooding is minimal as they are usually end-of-pipe facilities in urban neighbourhoods. They cannot normally be made large enough to provide runoff volume reduction aspects of hydromodification reduction benefits.

Water Supply and Drought Mitigation

Constructed wetlands regulate water flow throughout a watershed, releasing water gradually over time and thereby maintaining more consistent stream and river flows during dry spells.

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Constructed wetlands also aid in potable water conservation, especially where treated water is used for irrigation or industrial purposes (Kadlec & Wallace, 2009).

Vegetation in constructed wetlands does not tolerate the wide water-level fluctuations necessary for reuse for volume-reduction purposes, which is the normal application of the reuse practice.

Table 21. Constructed wetlands: Water quantity performance

	Volume control	Rate control	Storage/supply
Mechanism	Evapotranspiration Subsoil percolation (if unlined)	Controlled by discharge control structure or natural outlet geometry	Varies, depending on freeboard and water permanence
Capacity	Varies	Varies	Varies

Source: Based on Davis et al., 2022.

Water Quality

Constructed wetlands are a multifaceted solution for water treatment, offering various benefits, including nutrient removal, sediment and suspended solids reduction, organic matter breakdown, pathogen removal, detoxification of pollutants, and phytoremediation. Acting as natural filters, these wetlands facilitate the settling of sediments and suspended solids essential for maintaining water clarity and supporting aquatic life (Vymazal, 2011). They may reduce nitrogen and phosphorus levels, especially from high concentrations found in agricultural runoff and sewage, thus reducing eutrophication and algal blooms (Kadlec & Wallace, 2009). Constructed wetlands can also be prone to nutrient leaching when the substrate and/or decomposing biomass are acting as a nutrient source (Fisher & Acreman, 2004). Leaching may be mitigated by using substrate amendments that sequester the nutrients. The microbial processes within wetlands are instrumental in breaking down organic matter, significantly reducing BOD and consequently decreasing the risk of oxygen depletion in water bodies (United States Environmental Protection Agency [EPA], 2021).

Constructed wetlands contribute to pathogen reduction, as the synergistic interaction among wetland plants, sunlight, and microbes effectively neutralizes harmful bacteria and viruses (Nivala et al., 2017). They are also capable of detoxifying pollutants, including heavy metals and various industrial wastes, through accumulation, absorption, and transformation by wetland plants and microbes (Langergraber et al., 2020). As with all constructed practices, consideration should be given to the true breakdown or mitigation of pollutants, as compared to accumulation, which may require ongoing management for removal. Temperature gains are minimized in constructed wetlands, where vegetation cover is dense and distributed over the facility footprint, compared to open-water stormwater ponds (including naturalized-edge stormwater ponds).

Despite being one of the most-studied practices, some aspects of constructed wetlands require further consideration. For example, their performance may change over time, there is evidence of nutrient release with plant senescence, and pollutants being remobilized under ice conditions.

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The values in Table 22 provide a comprehensive overview of the typical performance metrics of constructed wetlands in various treatment scenarios.

Table 22. Constructed wetlands: Water quality performance

	Mechanism	Treatment efficiency	Media	Vegetation
BOD	Biofilm consumption and settling	70%–90%	Low organics	May release
TSS	Settling and straining	50%–90%	N/A	Preferential flow
P	Straining and sorption	30%–60%	Low P and amendments	Uptake opportunities
N	Nitrification and denitrification	40%–80%	Low N	Uptake opportunities
Pathogens	Straining	90%–99.9%	N/A	N/A
Metals	Sorption	50%–80%	N/A	Uptake opportunities

Source: Based on Kadlec & Wallace, 2009.

Constructed Wetland Examples of Co-Benefits

Habitat and Biodiversity (Rank: 4)

Constructed wetlands create habitat for diverse wildlife, such as birds, amphibians, insects, and aquatic organisms, thereby enhancing local biodiversity, which is especially crucial in urban or agricultural areas where natural habitats are scarce (Zedler & Kercher, 2005). They can contribute to wildlife corridors to support the protection and movement of fauna.

Air Quality and Carbon Sequestration (Rank: 2–4)

Vegetation in constructed wetlands improves air quality by filtering pollutants and producing oxygen, depending on stature, type, coverage, and density. As significant carbon sinks, the vegetation in these wetlands captures carbon dioxide, aiding in climate change mitigation, and the accumulated organic matter in wetland soils contributes to long-term carbon storage (de Klein & Van der Werf, 2014).

Urban Heat Island/Acute Heat Mitigation (Rank: 2–4)

Constructed wetlands introduce water and vegetation into urban landscapes, which naturally cool the surrounding air through evapotranspiration. This process, where plants release water vapour, helps lower ambient temperatures, countering the heat absorbed and re-emitted by urban infrastructure like concrete and asphalt. Additionally, the presence of wetlands in urban areas creates microclimates that are cooler and more humid, providing a refreshing contrast to the typically warmer urban surroundings. They are not typically implemented in the densest urban contexts where heat mitigation is most needed.

Amenity and Wellness (Rank: 2–4)
Constructed wetlands provide recreational and educational opportunities, including walking, interpretive signage, and bird watching, which enhance community awareness about ecosystems (Braskerud, 2002). However, unlike street trees and site-level vegetation, they are only easily visible to community members who live or work within the neighbourhood where they are built, while others must travel in order to enjoy them. Regardless, their aesthetic value positively impacts mental health and property values (Maund et al., 2019).

Applicability

Stormwater constructed wetlands are widely implemented in newer communities but have limited ability to be retrofitted into existing communities as land and/or funding may not be available. In a wastewater context, treatment wetlands are used to replace or supplement conventional treatment options, such as lagoons and/or mechanical treatment plants, during expansion or infrastructure upgrades.

Sample Design Customizations

Sample design customizations are provided for constructed wetlands in Table 23.

Table 23. Constructed wetlands: Sample design customizations

Goal/benefits	Design optimizations
Flood mitigation	The basin needs to allow for temporary ponding and control structures to provide rate control. Volume control may be achieved through infiltration and/or evapotranspiration. The extent of benefits will depend on the functional area.
Water supply and drought resilience	Incorporate a reservoir/basin (surficial or underground) designed to hold water for extended periods of time of sufficient volume.
Water treatment	The removal efficiency depends on the type of wetland, hydraulic loading rates, and the specific pollutants in question. Various optimizations can be implemented with the wetland type, media selection, and specialized amendments.

Source: Authors.

Natural Infrastructure in Action

This naturalized water retention site in the RM of De Salaberry, Manitoba, was built primarily to provide flood relief and to reduce downstream erosion (Figure 23). However, given its multi-week hydraulic retention time during high flow periods and the existence of permanent pools of water within its reservoir during low flow periods, the site provides water quality improvements like phosphorus reduction through the deposition of suspended sediment from upstream erosion of agricultural land and uptake of nutrients by emergent vegetation (Simoes et al., 2022).

Figure 23. Water retention project in the RM of De Salaberry, Manitoba

Credit: Author.

Figure 24. Floating treatment wetland deployment in the RM of East St. Paul, Manitoba

Credit: Author.

This stormwater pond in the RM of East St. Paul, Manitoba, has suffered from water quality issues (Figure 24). Excess nutrients in the pond have resulted in significant algal bloom growth, which floating treatment wetlands are now being used to address. Improved water quality is facilitated through competition for the same nutrients needed for algae growth by the floating treatment wetland vegetation. This deployment of floating treatment wetlands demonstrates how existing stormwater ponds can be environmentally remediated without the need for expensive re-design or conventional treatment while providing additional co-benefits like improved air quality.

Variants

Surface Flow Constructed Wetlands
Designed to allow water to flow horizontally across the surface of the wetland vegetation. Surface flow constructed wetlands are typically used for wastewater treatment and are characterized by shallow water depths and a variety of wetland plants that help remove pollutants through physical, chemical, and biological processes.

Subsurface Flow Constructed Wetlands
Consist of water directed through a porous medium (such as gravel or sand) beneath the surface, where it comes into contact with the roots of wetland plants. These wetlands are effective at removing pollutants and are often used for municipal and industrial wastewater treatment.

Hybrid Constructed Wetlands
Combine elements of both surface flow and subsurface flow systems to achieve enhanced treatment capabilities. These systems are versatile and can be adapted to specific treatment goals and site conditions.

Free Water Surface Constructed Wetlands
Constructed wetlands characterized by open-water surfaces with emergent vegetation. They are commonly used for treating domestic wastewater and stormwater and can provide habitat for wildlife.

Floating Treatment Wetlands
Floating mats or rafts planted with wetland vegetation. They are sometimes used in stormwater management and can improve water quality by capturing pollutants and promoting biological processes.

Vertical Flow Constructed Wetlands
Vertical flow constructed wetlands use a vertical flow of wastewater through layers of media, often gravel or synthetic substrates, to treat pollutants. These systems are effective for small-scale wastewater treatment and can be implemented in areas with limited space.

Integrated Constructed Wetlands
Integrated wetlands combine different types of wetland cells or treatment stages to optimize treatment efficiency. They may include a combination of surface flow, subsurface flow, and other wetland components.

Constructed Wetland Ponds
These are large, open-water systems that incorporate wetland vegetation around the edges and are often used for stormwater management and enhancing water quality in retention or detention ponds.

Naturalized-Edge Stormwater Ponds
These are constructed basins with emergent vegetation on the perimeter of the open water.

Naturalized-Edge Stormwater Ponds

A naturalized-edge stormwater pond is an engineered stormwater management feature designed to control runoff and improve water quality by mimicking natural processes (Ross et al., 2018). Unlike conventional stormwater ponds, naturalized ponds feature gently sloping banks that are deliberately vegetated with native plants and grasses. These ponds are characterized by large open-water areas, which sets them apart from constructed wetlands. The vegetation on the edges acts as a buffer zone, reducing erosion and contributing to removing nutrients and sediments through natural processes. The vegetated perimeter offers habitat for wildlife, enhancing biodiversity. These ponds may be strategically implemented within urban and suburban landscapes to manage stormwater effectively, mitigating flood risks while supporting local ecosystems and offering aesthetic benefits (City of Moncton, 2015). However, establishing and maintaining naturalized edges requires deliberate planning and occasional maintenance to prevent erosion and ensure the health of the vegetative buffer, which might entail additional costs and resources. With vegetation only around the perimeter of the pond, phytoremediation potential is significantly lower than with other types of constructed wetlands where emergent vegetation has greater coverage.

Related Practices

Beaver dam analogues (see Box 4 in Section 3.4), rain gardens (see Section 3.3.3), and bioretention (see Section 3.3.6).

Credit: ALIDP (reprinted with permission).

3.3.4 Rain Gardens

Rain gardens[19] are garden beds built with a shallow depression (10–15 cm) and soil designed to collect, infiltrate, percolate, and evapotranspire runoff, typically collected from a portion of a roof. They are designed with drought-resistant and moisture-tolerant plants for a regime that is dry most of the time and occasionally wet. They can be considered analogues of seasonal wetlands, except that they continue to vastly fluctuate in moisture conditions throughout the growing season, receiving runoff every time it is generated from the hard surface or roof they collect from.

[19] The term "rain garden" is often used interchangeably with the term bioretention, which is not typically the same practice on the Prairies. Most of the literature that uses the term rain garden is actually describing bioretention. Literature on the performance of rain gardens as the term used in this report is scant.

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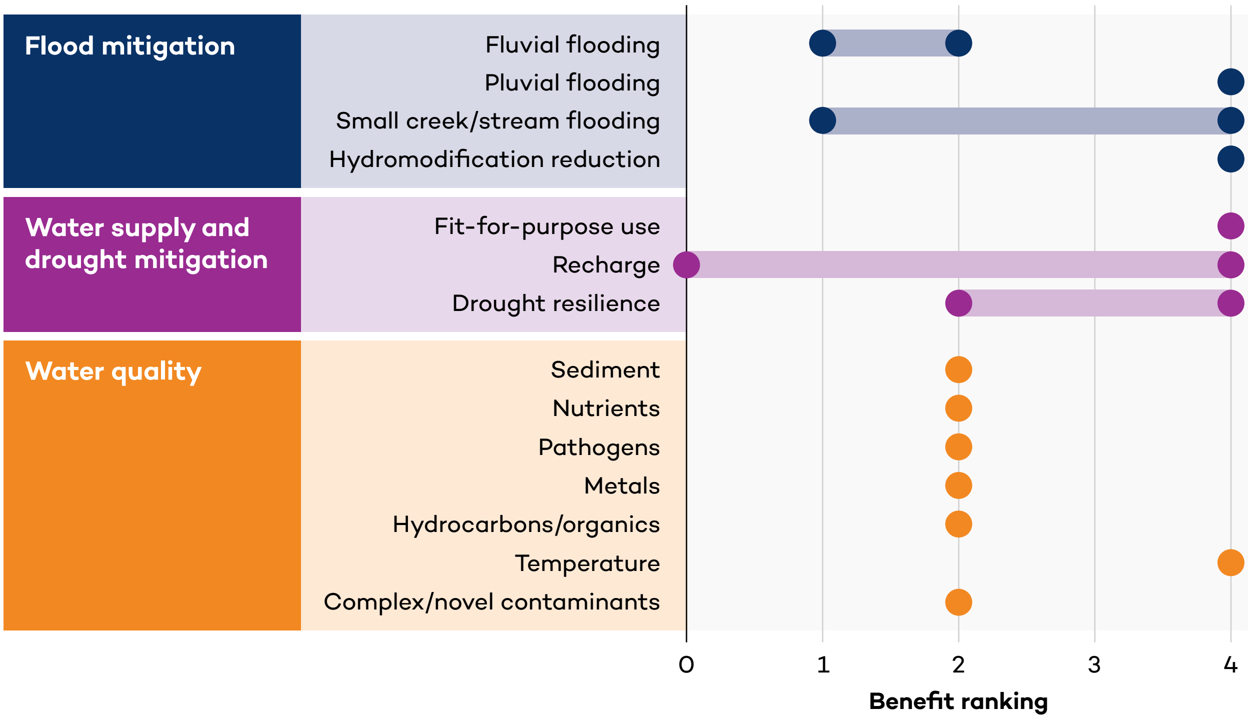
Benefits and Performance

Figure 25. Primary benefit ranking for rain gardens



Source: Authors.

Primary Benefits

Flood Mitigation

Rain gardens are typically sized in terms of retention, with a large footprint, ideally with an I/P ratio of 3 for maximized performance. But when peak flow reduction is the primary goal, rain gardens can be designed for both detention and retention, using a deeper ponding depth combined with a leaky outflow for the upper portion of the depth. When working over tight subsoils, as is typically the case across the Prairies, the need for an underdrain is avoided by carefully relating the ponding depth to the soil depth, I/P ratio, and permeability, such that excessive ponding duration is avoided regardless of subsoil conditions. The basin that a rain garden provides is key to its superior performance for runoff management, as it is not hindered during the most intense storms by the infiltration rate of the soil. To summarize, rain gardens can reduce the annual runoff volume and peak runoff rate to various extents through the combined action of basin storage, infiltration, and evapotranspiration, depending on design characteristics (Table 24).

Distinguishing Rain Garden and Bioretention Assets

A lot of guidance considers the term rain garden to be synonymous with the term bioretention. However, it is beneficial to distinguish these practices in northern climates for several reasons. First, street loadings are laden with salt and sediment, whereas roof runoff is not, requiring different plant selection. Second, rain gardens are usually sized for flood mitigation or to address hydromodification, whereas bioretention is typically sized for treatment. Rain gardens have a lower ratio of contributing I/P ratio than bioretention does to retain as much runoff as possible rather than just act primarily as a filter. This ratio may be ideally in the order of three to four for rain gardens up to a suggested maximum of five under typical design conditions (van Duin, 2023), whereas bioretention is commonly around 20 but may go as high as 50 or below 10 in high salt- or sediment-loading contexts (CSA Group, 2018, p. 32). Third, rain gardens can be designed with native, unengineered soil and sized to not need an underdrain, even on tight clay subsoils. In contrast, bioretention is normally designed with engineered media and sized for concentrated flows, such that an underdrain is typically required (unless subsoils are naturally free draining).

Distinguishing the practices prevents misunderstandings in performance by professionals and in communicating to, for example, homeowners who would not choose to implement a rain garden because they think they need the complexity of engineered media, multiple layers of different granular materials, an underdrain, etc. Homeowners have also been known to balk because, for example, they have heard that bioretention treats metals and hydrocarbons, and they wonder why a person would want to keep those things on their property without perceiving the difference in the contaminant characteristics (for details about the characteristics of roof runoff vs. street runoff, see Footnote 4 in Section 2.1.2).

Flood-mitigation ratings provided are for low I/P ratios (3–4) and retention depths of 100 mm to 150 mm. If percolation rates are high, small creek/stream flooding and recharge ratings will be high and fluvial flood mitigation will be moderate.

Rain gardens are infiltrative practices that are inserted into landscaped areas. As a result, they are typically in contact with adjacent soil. When they are, lateral influences are significant, improving observed performance over water–balance–modelling results that do not include this parameter (ALIDP, personal communication, January 17, 2024). Rainwater planters and wicking beds (variants) are not in contact with lateral adjacent soil, so they only have an evapotranspirative mechanism (up) plus the storage capacity of the soil and percolation (down), reducing their capacity and performance in back-to-back events. Performance of fully lined systems is even lower, since there is only an evapotraspirative mechanism (up).

Water Supply and Drought Mitigation

Rain gardens are passively watered by rainwater, extending the plant palette beyond what would normally be possible in a purely xeric garden. For unlined rain gardens, soil moisture is readily recharged, and interflow is supported.

Percolation for aquifer recharge is a function of the tightness of the subsoil and is assumed to be low in typical cases. Deep percolation is assumed to be very low (0.5 mm/hour) unless tested and proven otherwise (Table 24).

Table 24. Rain gardens: Water quantity performance

	Volume control	Rate control	Storage/supply
Mechanism	Interception (canopy) Evapotranspiration	Controlled by media infiltration rate	N/A unless combined with storage or irrigation/re-use
Capacity	Up to 90%	Up to 90%	N/A

Source: Based on Metcalf, 2022.

Water Quality

Roof runoff is the usual source of influent. See the Rainwater Harvesting section for characterization of this type of source water (Table 28 in Section 3.3.5). Low ratings for water-quality improvement are a function of low influent concentrations, not the mitigative capability of the practice (Table 25).

Leaching is not considered to be a concern, as there is no underdrain present, loadings are low as a function of both the influent concentration and the I/P ratio, and there is a surrounding vegetated area to assist with sequestration and uptake mechanisms or the system is lined. Adequate separation to groundwater needs to be maintained.

Table 25. Rain gardens: Water quality performance

	Mechanism	Treatment efficiency	Media	Vegetation
BOD	Organics in media vs. biofilm consumption	N/A	Low organics	May release
TSS	Straining	>90%	N/A	Preferential flow
P	Straining and sorption	80%	Low P and amendments	Uptake opportunities
N	Nitrification and denitrification	65%–75%	Low N	Uptake opportunities
Pathogens	Straining	N/A	N/A	N/A
Metals	Sorption	92%	N/A	Uptake opportunities

Source: Based on Sharma & Malaviya, 2021.

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Rain Garden Examples of Co-Benefits

Biodiversity and Habitat (Rank: 4)

Rain gardens are typically planted with diverse flowering perennials and grasses, providing much-needed pollinator habitat. Increasingly, native species or nativars are being used. Shrubs and trees can be incorporated. There is a high potential for habitat connectivity, especially within suburban areas.

Urban Heat Island/Acute Heat Mitigation (Rank: 2–3)

Rain gardens can reduce the urban heat island effect, as the evapotranspiration from the vegetation provides a cooling effect and also absorbs less heat compared to paved areas (UNEP, 2014).

Amenity and Wellness (Rank: 4)

Rain gardens can be designed to create welcoming amenity spaces. Generally a feature of front yards, they increase wellness benefits from seeing green at eye level, which is also appreciated and beneficial for those passing by (Ordóñez-Barona et al., 2023). Installations at community spaces and schools can be combined with learning. Benches, amphitheatres, and walking paths are often associated with these features.

Applicability

Rain gardens have the potential to be widely implemented throughout the landscape in all but the highest development densities. Because of the basin-type storage capacity that they provide, they are particularly important to add in existing communities, where conventional infrastructure is often undersized or non-existent.

Sample Design Customizations

Sample design customizations are provided for rain gardens in Table 26.

Table 26. Rain gardens: Sample design customizations

Goal	Adjustment
Enhance runoff reduction	• Select larger plants for increased evapotranspiration • Increase ponding depth and soil volume
Target peak flow reduction	• Provide detention storage that will rapidly drain, in addition to retention storage

Source: Authors.

Natural Infrastructure in Action

The Langford residential rain garden was the first demonstration project built in Edmonton by ALIDP as part of Alberta Environment and Protected Areas' Watershed Resiliency and Restoration Program (Figure 26). In this case, runoff from the entire roof area was able to be routed into the garden. Existing soil was deep and well structured and was therefore kept in situ. With a basin depth of merely 100 mm, typical summer thunderstorms are fully retained, and hydromodification damage to the small receiving creek is reduced or eliminated.

A hot, dry, exposed expanse of turf was converted to alternative groundcovers with a rain garden on one side of the main entry and a mini-wetland on the other in front of the County of Wetaskiwin office in Wetaskiwin, Alberta (Figure 27). Both were built with the same basin sizes, but the wetland has a slightly bigger contributing area, so it does not have the opportunity to dry out as much between events. The wetland intercepts flows that were previously causing nuisance flooding in the adjacent parking lot. Threaded with pathways that incorporate benches, the areas were quickly adopted by staff as amenity spaces for breaks and lunches.

Figure 26. Langford residential rain garden in Edmonton, Alberta, with interpretive signage

Credit: Mat Langford.

Figure 27. Rain garden in front of the County of Wetaskiwin administrative office in Wetaskiwin, Alberta

Credit: County of Wetaskiwin.

Variants

Absorbent Landscaping

A heterogeneous term that may mean a shallow landscaping depression (approximate maximum 50 mm) without concentrated inflow (as opposed to the concentrated flow that is present in a rain garden) or deeper topsoil (typically 300 mm) with roof runoff distributed over it (roof runoff distributed over the landscape without deeper topsoil is known as downspout dispersion).

Mini-Wetland

Small-scale wetlands that act as source control, similar to rain gardens but with a permanently wet pool. They are usually constructed rather than retained.

Rainwater Planter

A rain garden in a raised planting bed that allows runoff to flow over the surface of the garden, infiltrating into the soil. It may be equipped with an underground storage layer that can overflow.

Stormwater Planter

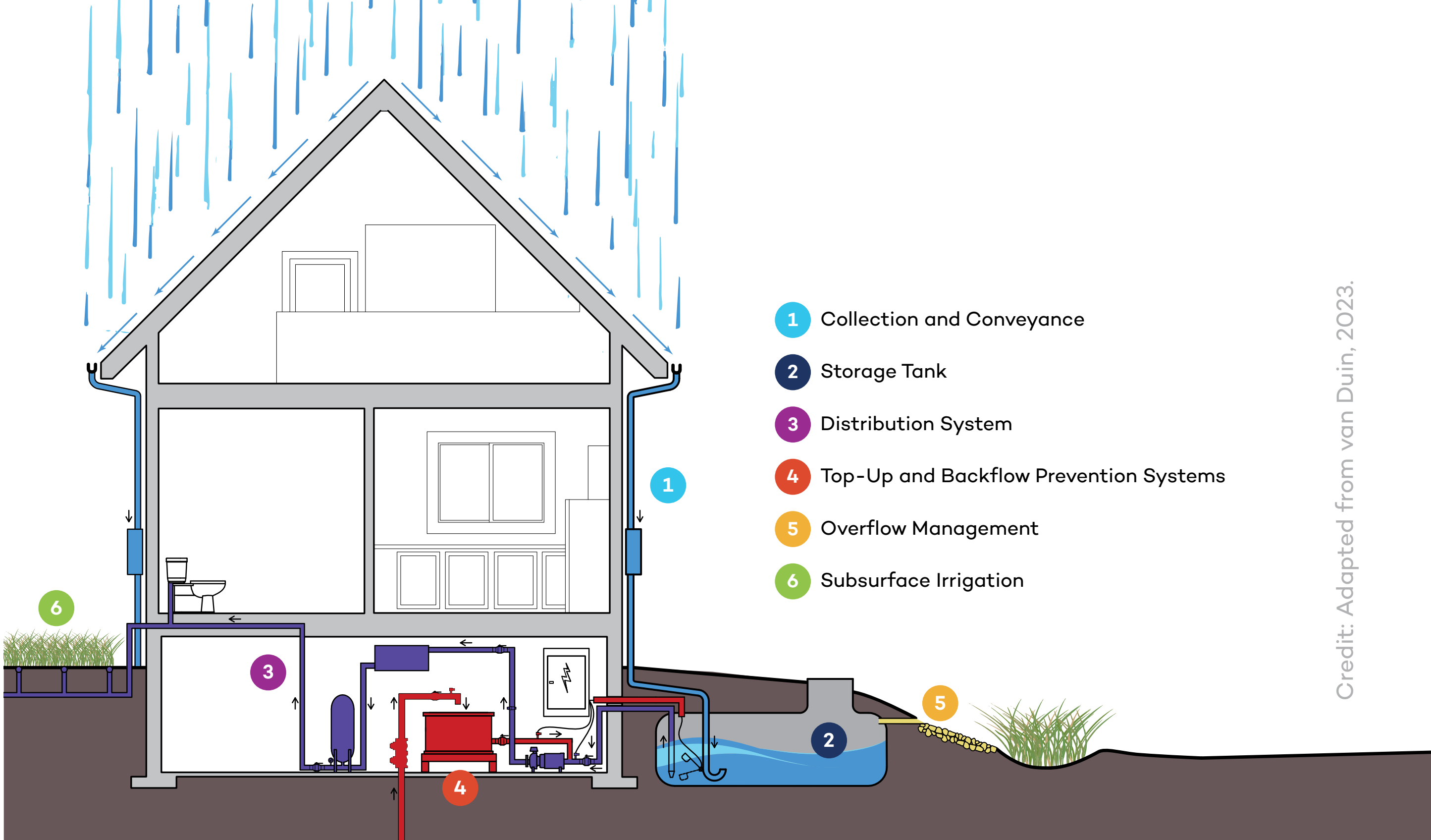
An in-ground or partially in-ground feature with vertical sides (usually made of concrete) receives stormwater rather than rainwater, functionally similar to bioretention.

Wicking Bed

A rain garden in a raised planting bed that allows runoff to travel directly to a storage layer and be wicked back into the soil volume through capillary action. It is capable of overflowing.

Related Practices

Bioretention (see Section 3.3.6) and constructed wetlands (see Section 3.3.3).



Credit: Adapted from van Duin, 2023.

3.3.5 Rainwater Harvesting

Rainwater harvesting is one of the oldest practices used worldwide to meet or supplement water supply needs. Rainwater harvesting traditionally refers to conveying and storing rainwater into a reservoir for later use. Systems range from individual rain barrels for spot watering to larger systems for gardening or landscape irrigation. Toilet flushing, often in a condominium setting, represents a "fit-for-purpose use," where the source water (rainwater) is matched to the end use, such that minimal treatment is required to meet requirements such as public health guidelines.

Using rainwater harvesting to meet stormwater management objectives is a much newer idea. Storage vessels act as micro-retention features (when water is later used for landscape irrigation) or detention features (when water slowly discharges through a tap or other small opening).

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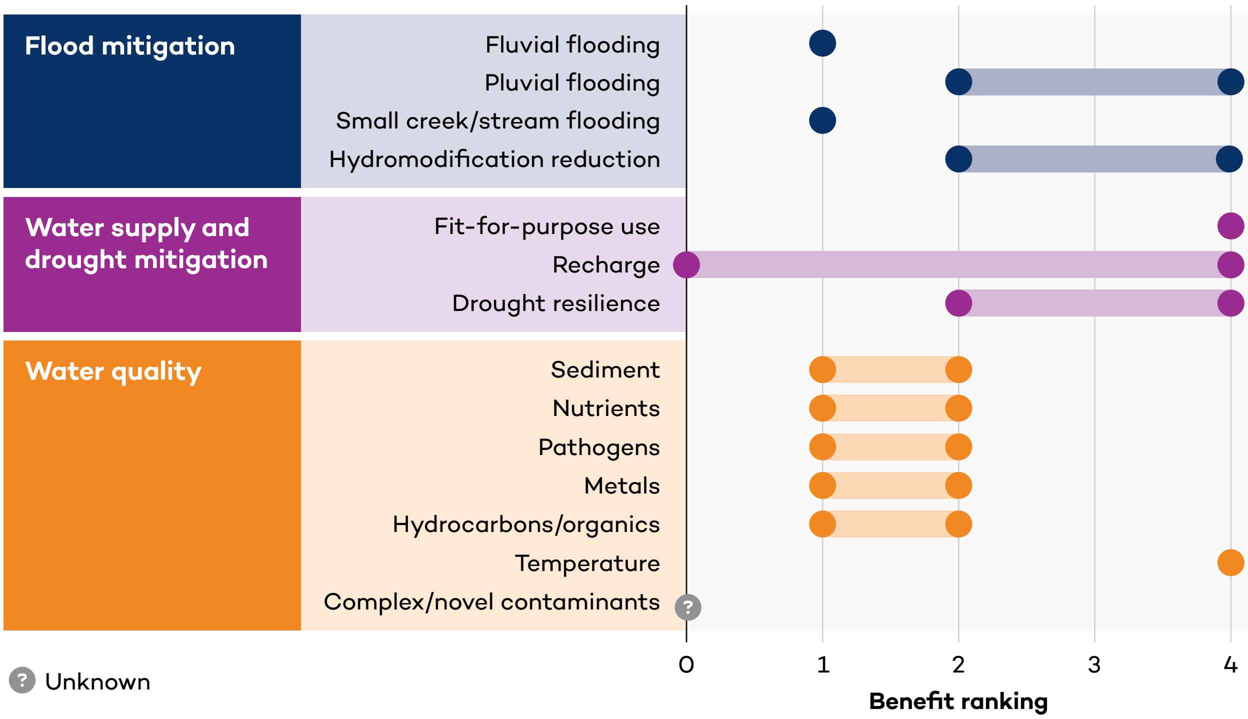
Benefits and Performance

Figure 28. Primary benefit ranking for rainwater harvesting



Source: Authors.

Primary Benefits

Flood Mitigation

Rainwater harvesting systems provide peak flow reduction (detention) when coupled with an orifice that allows runoff to slowly discharge rather than be retained for use and volume reduction (retention) when water is applied to the landscape or routed out of the stormwater management system into the wastewater management system through an application such as toilet flushing.

Water-balance benefits (retention) are a function of tank capacity, duration between storm events, and demand for rainwater use (CVC & TRCA, 2010). Runoff reduction and water-saving efficiency were found to be a function of storage capacity and climatic patterns, with reductions of up to 20% to be expected in semiarid regions with a single rain barrel applied in residences (Steffen et al., 2013).

Water Supply and Drought Mitigation

Rainwater harvesting provides a fit-for-purpose water source that reduces potable water demand for various purposes, primarily landscape irrigation (Table 27). However, in times of drought, potable water for landscape irrigation is one of the first types of use to be restricted. Resilient landscapes are designed such that little to no irrigation is required. Landscaping should not be designed to be reliant on irrigation. Rainwater may also be used for other purposes, such as toilet flushing.

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Table 27. Rainwater harvesting: Water quantity performance

	Volume control	Rate control	Storage/supply
Mechanism	Storage and re-use	Controlled by use dynamics	Directly dependent on the volume
Capacity	18%–42%	N/A	N/A

Note: Performance is provided without consideration of the fate of the harvested water.
Source: Based on CVC & TRCA, 2010.

Water Quality

Water quality performance is directly tied to the system's ability to capture runoff and prevent contaminants from moving through the system. Rainwater harvesting systems are often designed with a landscape irrigation component, which disperses runoff back to the landscape for treatment. Rainwater can also be collected and used for toilet flushing or other domestic purposes (where permitted). It then is routed through the more rigorous wastewater treatment process, resulting in higher-quality discharges to receiving water bodies. Ratings for quality are modest due to the relatively clean water source.

The contributing catchment and its properties impact the quality of the water collected. Even with roof runoff (in contrast to street runoff), water quality is affected by the roofing material and potential pathogenic effects associated with fecal matter deposited by animals (de Kwaadsteniet et al., 2013). For example, green roofs contribute to higher dissolved organic carbon content whereas shingle roofs produce higher bacterial loads (de Kwaadsteniet et al., 2013). Tree cover over the roof and who is allowed access to the roof can also affect roof runoff quality. Typical rainwater concentrations are presented in Table 28 for Minneapolis, Minnesota.

Table 28. Typical rainwater pollutant concentrations

Constituent	Minneapolis
Copper	0.0075 mg/L
E. coli	764 bacteria/100 mL
Lead	0.0032 mg/L
Nitrate-N	0.586 mg/L
TN	0.421 mg/L
TP	0.104 mg/L
TSS	10 mg/L
Zinc	0.101 mg/L

Source: Based on Minneapolis Public Works, 2008, as cited by Minnesota Pollution Control Agency (n.d.).

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Proper downspout management (i.e., discharging runoff onto adequate landscaped areas rather than hard surfaces, especially those that are directly connected to the street) may provide similar quality attenuation as rainwater harvesting. The opportunity to directly couple runoff with a landscaped area is not always available. Rainwater harvesting provides a way to store and route runoff to an appropriate landscaped area when it has the capacity to receive and treat it.

Contaminants and their concentrations in rainwater are relatively low compared to those in stormwater, so, for example, a source water protection plan may rather focus investments primarily on direct treatment measures for street runoff using bioretention. However, when used as part of a treatment train approach, the quantity attenuation that rainwater harvesting provides will both reduce and enhance the performance of downslope quality measures, such as bioretention (Table 29).

Rainwater Harvesting Examples of Co-Benefits

Biodiversity and Habitat (Rank: 0–4)
Rainwater harvesting can provide supplemental irrigation, which can support biodiversity, particularly when native plants are selected. With the rise of global habitat loss, gardens and green spaces in urban centres can provide a critical haven for biodiversity (Soanes & Lentini, 2019).

Applicability

Compared to other water sources, rainwater can be viewed as sustainable and circular in most contexts, offering long-term resilience for reuse initiatives (Sauvé et al., 2021). Because they can be implemented in a distributed fashion and as part of the densest of land development contexts, rainwater harvesting systems may provide the greatest water-quantity watershed-wide benefits of all structural BMPs (Young et al., 2009). Benefits for stormwater management rely on the capacity of the storage vessel to be available when it rains; therefore, the water must be used for some purpose.

Rainwater harvesting is more likely to be implemented in lower-density residential settings off garages with primarily detention storage discharged to a lane (no vegetation) or where water is used for productive landscapes (e.g., vegetable gardens). These applications have little value for many of the functions associated with vegetated cover (e.g., evapotranspiration, habitat) and therefore have lower ratings.

It is unclear whether watering restrictions during future droughts will change societal behaviour around landscaping and watering. Recharge depends to some extent on whether the practice is detention (rank: 0–2) or retention (rank: 2–3) and if it is over high-percolation subsoils. Rain gardens are rated more highly for recharge and drought resilience because they are more passive to operate and maintain and, thus, more likely to operate to design assumptions.

Sample Design Customizations

Sample design customizations are provided for rainwater harvest in Table 30.

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Table 29. Rainwater harvesting: Sample design customizations

Goal	Adjustment
Enhance retention capacity	• Increase storage capacity
Enhance detention capacity	• Increase storage capacity and ensure emptying time is fast enough to allow for capacity for back-to-back storm events
Target water quality	• Improve treatment or pre-treatment • Apply to landscaping for volume reduction-based improvement and phytoremediation

Source: Authors.

Natural Infrastructure in Action

This residence at Currie Barracks is part of the inner-city redevelopment of the former CFB Calgary lands by Canada Lands Corporation. This site includes an 8,000 L buried cistern that receives and stores runoff from the roof (furthest downspout with the partially buried lid). This system is linked to an automated irrigation system (Figure 29), part of a lot-level residential program to reduce runoff in this medium-density community in Calgary, Alberta, where there is limited downstream pipe capacity.

Figure 29. Rainwater harvesting and irrigation system in Calgary, Alberta

Credit: ALIDP (reprinted with permission).

Variants

Stormwater Capture and Reuse

An end-of-pipe runoff–volume–reduction practice. Runoff in a stormwater pond is used to water adjacent landscapes. Enhanced tree planting to increase evapotranspiration is typically employed. The City of Calgary has developed a tool to calculate and maximize how much irrigation can be applied to various turf, tree, and shrub species for stormwater management purposes (Dillon Consulting Limited, 2019). Other uses are also possible.

Storage and application of captured stormwater can be coupled with constructed wetlands, bioretention, and even permeable pavement or any practice that acts as a collection and possibly a treatment step for runoff. However, constructed wetlands on their own are not typically suitable for use as direct storage for landscape irrigation due to the drastic fluctuations in water levels that accompany this practice and the deleterious impacts that these fluctuations have on perimeter vegetation.

Any landscape irrigation from a stormwater source is to be considered luxuriant irrigation, in that it is not intrinsic to the survivability of the landscape in times of drought, only supplemental. Landscapes should be intrinsically drought tolerant and not reliant on stormwater irrigation.

Credit: ALIDP (reprinted with permission).

3.3.6 Bioretention

Bioretention areas (also known as bioretention systems) are constructed, shallow vegetated depressions designed primarily to treat high volumes of stormwater runoff. They are typically implemented in public right-of-ways and open spaces, providing direct treatment for both sediment-bound and dissolved contaminants. The shape, size, media, underdrain, and/or vegetation can all vary depending on the objectives of the asset.

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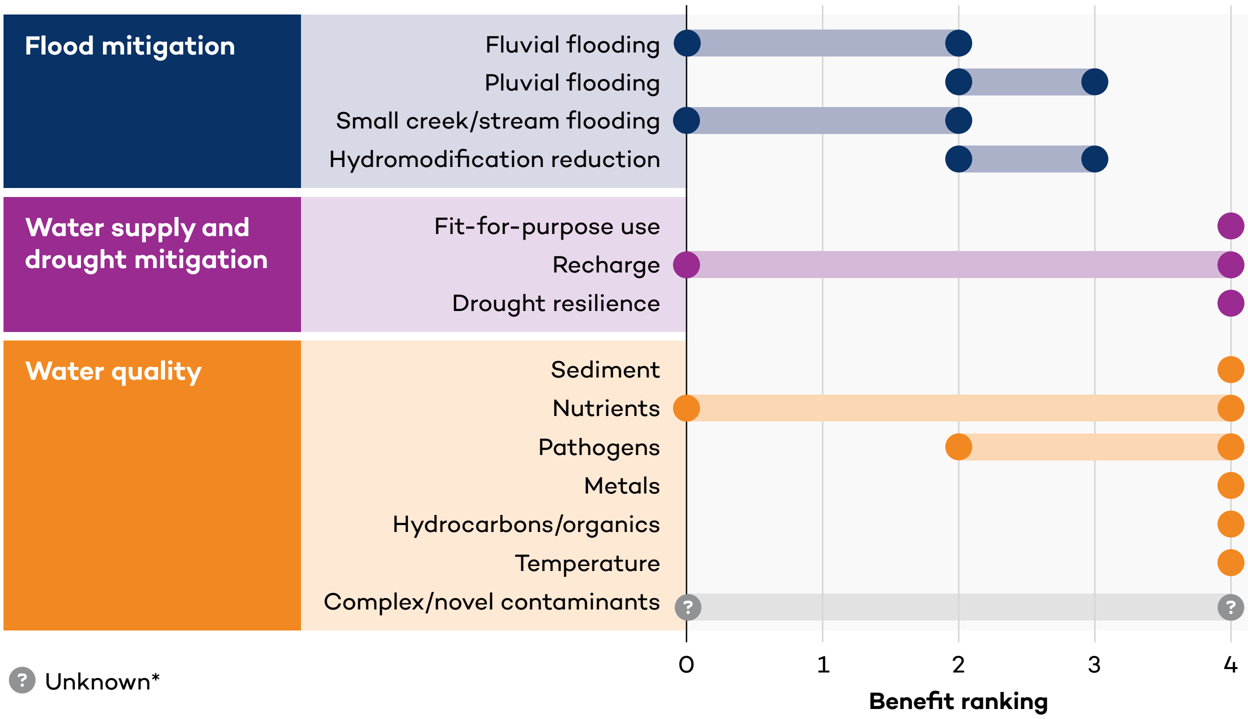
Benefits and Performance

Figure 30. Primary benefit ranking for bioretention



* Note: A range from unknown up to 4.

Source: Authors.

Primary Benefits

Flood Mitigation

Though they are designed primarily for their treatment benefits, bioretention systems do reduce runoff volumes and peak flows. Variability in the hydrological performance of bioretention systems can be shaped by many contributing factors, such as I/P ratio, presence of an underdrain, depth of ponding, subsoil conditions and subsoil infiltration rate, as well as growing media composition (Li et al., 2019; Zhang & Chui, 2018). Studies report water retention ranging from 27% to 86% (Davis, 2008; Hathaway et al., 2014; Hunt et al., 2006). Studies with lined systems show lower water retention (i.e., 19%–33%) and point out the physical limitations to cumulative runoff capture associated with available media storage and evapotranspiration (Hatt et al., 2009; Li et al., 2009).

Rate control (reduction) comes from the hydraulic limitation of the growing media, where desired hydraulic conductivity is a balance of throughput and treatment. Volumetric runoff reduction varies widely depending on system size, media type, vegetation type, underdrain configuration, and underlying soils (Hathaway et al., 2014; Houdeshel et al., 2015; Liu & Fassman-Beck, 2016). When there are high percolation rates, bioretention systems are capable of significantly reducing overall runoff volume and effectively capturing most of the runoff generated by small storm events (U.S. EPA, 2000).

Bioretention systems on the Prairies are most often located over tight subsoils with low percolation rates, so they typically incorporate an underdrain. When they are located in streetscapes (their usual application), they have a limited footprint, and high I/P ratios are the norm. This combination of factors means that bioretention for water quantity purposes on the Prairies is low to moderately beneficial for pluvial and hydromodification purposes but not useful for fluvial or small stream/creek flooding. If the percolation rate is high, a modest benefit for these factors can be expected.

Water Supply and Drought Mitigation

Bioretention systems are self-watering and can be highly drought tolerant with proper media and vegetation selection. Because they are typically designed with underdrains and are even sometimes lined (e.g., over hotspots, where infiltration is undesirable), they do not typically contribute to recharge. However, they can contribute to recharge wherever infiltration rates are high enough that underdrains are unnecessary and infiltration is permissible (Table 31). Canada's national bioretention design standard, *CSA W200: Design of Bioretention Systems*, includes information about high-risk sites and site activities that preclude the use of infiltration-based bioretention systems (CSA Group, 2018, Table 2).

Table 30. Bioretention: Water quantity performance

	Volume control	Rate control	Storage/supply
Mechanism	Evapotranspiration Subsoil percolation (if unlined)	Controlled by media infiltration rate	N/A unless combined with storage tanks
Capacity	30%–97%*	50%–96%	N/A

* Note: Highly dependent on the contributing area.
Source: Based on CVC, 2022.

Water Quality

Pollutants targeted by bioretention systems vary but typically include sediment, nutrients, organics, metals, pathogens, and novel/emerging contaminants (Table 32). Sediment and particulate matter removal has been shown to be effective and consistent due to the straining effect of the media (LeFevre et al., 2015). Metal removal has been effective as well, with removal efficiencies of over 80% frequently reported (Lange et al., 2020).

Nutrient removal has been highly variable for both phosphorus and nitrogen (Li & Davis, 2014). As bioretention media is a growth medium for vegetation, a certain amount of nutrient mobility is to be expected, especially in spring and fall when evapotranspiration and nutrient cycling are low. Adsorptive amendments to increase the cation exchange capacity of the growth medium, such

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as alum-containing water treatment residuals, are a promising remedy for phosphorus export. Denitrification can be enhanced through the incorporation of an internal water storage layer. A certain amount of initial leaching is to be expected (typically six months), but persistent nutrient leaching may take place and requires mitigation with media amendments (Zhang et al., 2023). It is unclear whether dissolved phosphorus removal can be in the same unit operation as media designed to support plant growth, given the relatively weak influent concentrations of stormwater (Chad Penn, USDA, personal communication, n.d.). Bioretention holds promise for filtering and breaking down or sequestering novel contaminants of concern, such as tire-derived chemicals, before they reach aquatic ecosystems (Rodgers et al., 2023). Because it treats stormwater, which tends to be the dirtiest runoff, and can treat dissolved constituents that other tools do not address, it receives the highest ratings for treatment.

Table 31. Biorentention: Water quality performance

	Mechanism	Treatment Efficiency	Media	Vegetation
BOD	Organics in media vs. biofilm consumption	N/A	Low organics	May release
TSS	Straining	77%	N/A	Preferential flow
P	Straining and sorption	0%–85%	Low P and amendments	Uptake opportunities
N	Nitrification and denitrification	24%	Low N	Uptake opportunities
Pathogens	Straining	43%–99%	N/A	N/A
Metals	Sorption	84%	N/A	Uptake opportunities

Source: Based on Clary et al., 2020; CVC, 2022.

Bioretention Examples of Co-Benefits

Biodiversity and Habitat (Rank: 2–4)

Bioretention is typically vegetated with sedges, grasses, and shrubs. Trees and flowering perennials can also be incorporated. Vegetation is limited to salt-tolerant species. Trees need to be spaced so they do not create undue amounts of litter that can smother and clog the narrow spaces common in streetside implementation. Many common native species are adapted to bioretention conditions, including milkweed, which provides critical habitat for the endangered monarch butterfly. An Australian study found that the number of species, species richness, and diversity were higher in roadside bioretention than in garden beds and lawn-type green spaces (Kazemi et al., 2011). Opportunities for many small patches of habitat spaced fairly close together are high.

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In such cases, basins facilitate functional connectivity for pollinating insects, providing stepping-stone habitat patches (Bjørn & Howe, 2023).

Urban Heat Island/Acute Heat (Rank: 3–4)
As a vegetated basin receiving stormwater, bioretention will contribute to heat mitigation. Where trees are incorporated, shade will also be provided, although, based on proximity to buildings, accompanying benefits will vary.

Amenity and Wellness (Rank: 4)
Bioretention areas can be readily incorporated into public amenity spaces and along boulevards, greatly enhancing these highly visible spaces. They often feature understory species that are absent in other upland plantings.

Applicability

Bioretention can be widely adopted across a range of densities in new communities and in retrofit and redevelopment applications. It can be designed to meet a range of quantity and quality objectives where conditions allow. Its potential footprint on the landscape is low to moderate.

Sample Design Customizations

Sample design customizations are provided for bioretention in Table 33.

Table 32. Bioretention: Sample design customizations

Goal	Adjustment
Increase retention capacity	• Increase ponding depth • Increase soil depth • Decrease I/P ratio
Increase detention capacity	• Add ponding depth with leaky overflow • Decrease I/P ratio
Modify for pervious subsoil	• Omit drain rock, underdrain, and stormwater tie-in
Increase N treatment	• Add upturned elbow or elevated subdrain in drain-rock layer
Increase metal sequestration	• Increase carbon components, e.g., mulch, organic amendments
Prevent P leaching	• Add P-sorbing amendment
Enhance drought mitigation	• Oversize the drain-rock layer and/or combine it with additional storage

Source: Authors.

Natural Infrastructure in Action

A bioretention area in Okotoks, Alberta receives runoff from the surrounding parking lot (Figure 31). It is coupled with an underground cistern that buffers moisture in the bioretention area itself and provides irrigation for the adjacent green space. Runoff from the parking lot is filtered as it makes its way through the bioretention media. Any lingering nutrients that are applied to the green space naturally support its growth. The system can provide ample irrigation for the adjacent landscape beds without a potable supply.

Performance monitoring showed that the bioretention bed captures over 90% of total runoff (Skorobogatov, 2023). For water quality, while initial nutrient leaching was observed, it stabilized within one season. A unique advantage of using bioretention effluent for irrigation is its dual benefit: mitigating the risk of excess nutrient leaching while addressing stormwater management through rate control and volume reduction.

Figure 31. Drought-resilient bioretention area in Okotoks, Alberta

Credit: Author.

Variants

Soil Cell or Tree Trench Receiving Stormwater

Urban hardscapes, like sidewalks or plazas, that can sit on top of uncompacted media volumes for trees (Ordóñez-Barona et al., 2018). Overall, soil cell performance is similar to that of bioretention (Page et al., 2015). Soil cells and tree trenches often include distribution pipes near the surface rather than a ponding depth on top. Tree trenches are a variant that provide a shared soil volume for multiple trees without the use of a proprietary structural support system.

Tree Box
A form of bioretention with very high flow-through rates, often located in parking lots. Most of the treatment performance comes from the filtration of sediment rather than treating dissolved contaminants.

Stormwater Planter
Usually denotes bioretention with impermeable sides and bottom intended to treat stormwater, with little quantity attenuation. Useful where infiltration is undesirable, like in areas with a high groundwater table. If the water source is rainwater and the I/P is less than approximately 8, the practice should be seen as a downspout dispersion, rain garden or rainwater harvesting technique and not as bioretention, as the water source is already relatively clean.

Biobed
An impermeable cell that promotes the formation of white rot fungi in its specialized media that typically is designed to break down pesticide residues.

Bioreactor
Typically targets a particular contaminant, which is often nitrogen. This tool may have different flow regimes where pumped flow and surface distribution are present. Vegetation may or may not be present. It is often used in agricultural settings.

Sand Filter
Targets particulates and pollutants attached to particulates. It does not reduce quantity. Enhancements, such as iron, can be added to target dissolved phosphorus. It does not support plants. Media is subject to crusting and clogging. A chamber system can be used where appearance is not important.

Blind Inlet
Graded aggregates prefilter agricultural runoff at a low point within a field. Sediment and sediment-bound pollutants are captured.

Related Practices

Rain gardens (see Section 3.3.4), bioswales (see Section 3.4.4), and infiltration trenches (see Section 3.5.2).

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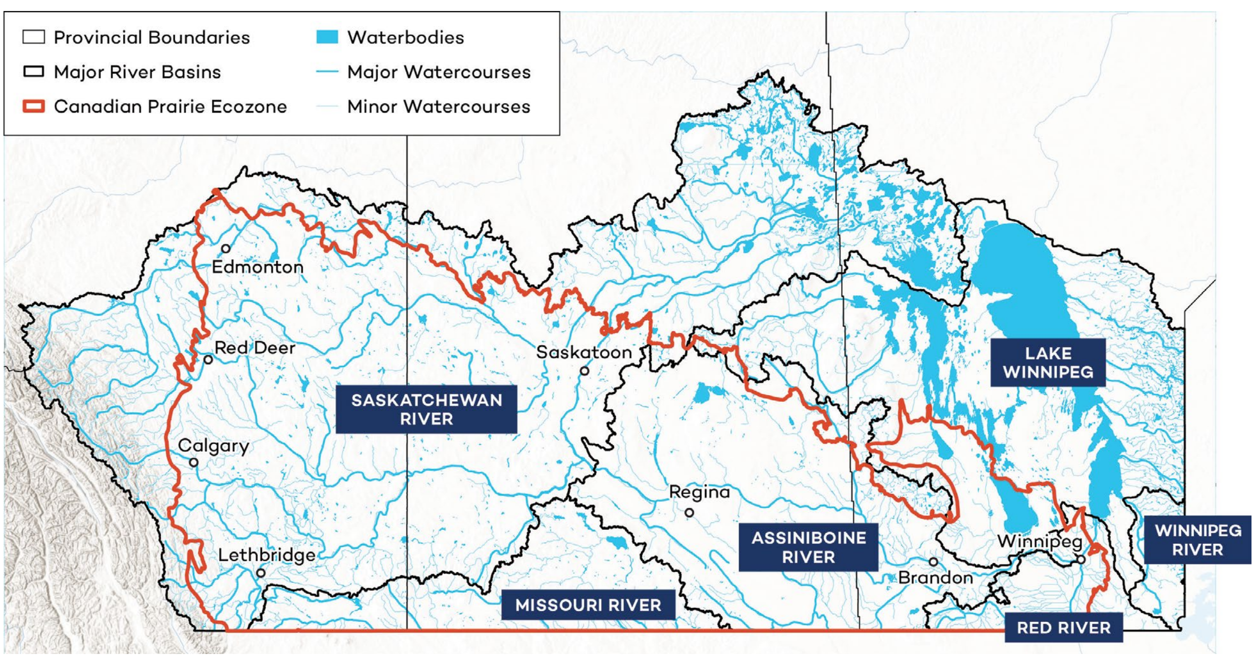
3.4 Watercourses

Watercourses are natural infrastructures that primarily achieves benefits via water transportation through sloped channels.

Watercourses—including rivers and streams—alongside their associated riparian areas and floodplains, are vital elements of watersheds affecting upstream and downstream and aboveground and belowground water flows. They provide an array of critical ecosystem services. Viewed through the lens of natural infrastructure, these natural assets can affect the timing, distribution, volume, and quality of water flows, with important implications for watershed health and infrastructure service delivery.

The Canadian Prairies region includes five major drainage basins: the Saskatchewan River, Missouri River, Assiniboine River, Lake Winnipeg, and Red River (Figure 32). The Saskatchewan, Assiniboine, and Red rivers form part of the larger Lake Winnipeg basin, which conveys water from the Rocky Mountains in Alberta and terminates in Manitoba, requiring coordination and cooperation between communities across Canada and the United States to ensure long-term sustainability and equity (PPWB, 2021). The Missouri basin flows southeast through the United States to the Mississippi.

Figure 32. River basins and watercourses across the Canadian Prairies



Source: Author map based on AAFC 2013; Government of Canada, 2017.

Natural watercourses across the Prairies have often been heavily modified by human intervention, like altering the path of the watercourse, altering the channel cross-section, installing riprap along the banks, and constructing things like dams and weirs within the channel, impacting their natural processes and functions. Water quality in rivers and streams is influenced by factors like discharge, channel slope, and the shear resistance of the channel. When the force of water is great enough to mobilize the material that makes up a conveyance feature, erosion occurs and can degrade water quality. Conversely, when water is flowing slowly and without significant turbulence, deposition occurs and clarifies water. The modification of stream channels and banks alters these dynamics, influencing both water quality and quantity.

This section starts by reviewing rivers and streams (Section 3.4.1), with a specific focus on natural channel protection and rehabilitation techniques that support river functions. We also review the benefits provided by riparian areas (Section 3.4.2) and constructed analogues like streambank bioengineering (Section 3.4.3) and bioswales (Section 3.4.4).

3.4.1 Rivers and Streams

Rivers and streams are natural watercourses that flow across the surface of land in channels, connecting natural resources, supporting aquatic ecosystems (Hauer et al., 2016), and supplying water for uses like drinking and irrigation (Alberta WaterSMART, 2016). Floodplains are the land next to the river and stream channels that provide temporary storage when water levels rise more than what the channel can hold. They support a diverse array of ecosystem functions (Fitch & Ambrose, 2003).

Natural watercourses have often been heavily modified by human activities, like straightening or realigning the watercourse, widening or deepening the channel, hardening the bank and bed with concrete or rip rap, and adding in-channel structures like dams and weirs. Some land uses around rivers and streams can also have a negative impact, such as uncontrolled livestock access or removal of streambank vegetation, increasing erosion. Ephemeral channels can be removed from the landscape, increasing flood risk and altering surface drainage. The development of infrastructure like roads, houses, and dams within floodplains is common across the Prairies, affecting fluvial processes, biodiversity, and more (Hauer et al., 2016). Due to the past degradation of rivers and streams, many natural functions have been lost (Skidmore & Wheaton, 2022).

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There are different approaches to restoring the natural function of rivers and streams. For example, the Room for the River Program, first developed in the Netherlands, provides flood protection by reconnecting rivers to natural floodplains and moving residents and infrastructure out of low-lying areas, which is particularly urgent as more frequent and heavier rainfall is anticipated (Dutch Water Sector, 2019). A growing family of techniques can help restore natural processes and features within rivers and floodplains and support their many benefits for the environment and people (Burgess-Gamble et al., 2018; The River Restoration Centre, 2021). As summarized by Burgess-Gamble et al. (2018), these can be grouped into:

- **river restoration**: involves reestablishing natural features and physical processes in river systems.
- **floodplain restoration**: focuses on reconnecting rivers to their floodplains to restore hydrological connectivity
- **leaky/wood barriers**: installing wood or leaky barriers in channels or floodplains to manage water. Box 5 describes one approach with beaver dam analogues.

Box 5. Beaver dam analogues

While beavers and their dams have a history of issues among rural landowners and municipalities, there is growing recognition that they play an important role in watershed resiliency and restoration. Beaver dams hold back water and slow the flow, helping water to infiltrate the ground during spring runoff and rainfall events and releasing water during hot, dry weather or drought conditions in the summer. Beavers contribute to both flood and drought mitigation tools (Hood, 2011). Beaver dams can increase the width of flood plains, reduce erosion, increase sediment deposition, lower water temperatures, and improve stream complexity and wildlife habitat (Fitch, 2016). Beaver ponds can act as fire breaks and a refuge for wildlife and livestock, experience less burning during wildfires, and aid in recovery (Fairfax et al., 2020).

Beaver dam analogues can be installed in line with watercourses to mimic a natural beaver dam, acting as a type of basin (Section 3.3). It involves installing upright posts within a stream channel, weaving woody vegetation like willow or spruce through the posts, and packing some mud or gravel around the base (Figure 33). These analogues are often multiple smaller structures installed along the length of a stream. Depending on the project, the intention may be for the beaver dam analogue alone to contribute to restoration by trapping sediment and debris and slowing water flow or to attract beavers to recolonize the location and provide long-term benefits.[20]

[20] Visit the website Working with Beavers for Watershed Resiliency and Restoration for more information and techniques to co-exist with beavers: https://www.workingwithbeavers.ca/index.php

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Figure 33. A beaver dam analogue on King Bolt Creek at installation (top) and the following spring (bottom).

Credit: Freshwater Conservation Canada

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Benefits and Performance

Primary Benefits

Flood Mitigation

Flooding and erosion are dynamic natural processes that are an integral part of a stable river system. A natural channel adjusts depending on the water and sediment it receives and the characteristics of the land that it flows across. The size of a channel is naturally adjusted to reflect the volume and speed of the flows that it receives. During flood flows, water, sediment, and energy are spread onto the floodplain. River channels migrate across their floodplains over time through erosion and deposition. Flood and erosion risks often arise along natural and modified channels where buildings and other infrastructure have been constructed in river floodplains where flooding and erosion naturally occur.

Water from rainfall and snowmelt events drains into rivers and streams, which ultimately provide an outlet or relief for surface flood waters in upland areas (Institute for Catastrophic Loss Reduction, 2021). In addition, the channels themselves provide some volume of online flood storage (Ackers et al., 2010), which is greater when the river overflows into the floodplains. While floodplains can provide the same flow resistance benefits as riparian areas when vegetated (Section 3.4.2), they can also provide significant temporary online storage, especially when connected with other surface storage landscapes like wetlands, which can further reduce flood and erosion risk downstream where available (FEMA, 2022a).

The role of natural and modified channels in regulating flood risk is often degraded by human activities. Channel restoration and rehabilitation measures may help to improve flood risk management performance. For example, the United Kingdom's Working with Natural Processes – Evidence Directory (Burgess-Gamble et al., 2018) provides evidence that

- restoring natural features and processes in river channels may attenuate high flows, working to reduce flood peaks and flow velocities;
- river restoration can slow flood flows by reintroducing sinuous river features such as meanders, which also help to reconnect rivers with their floodplains and enable storage of floodwaters on floodplains; and
- in-channel features that increase hydraulic roughness can temporarily store and slow the flow of water.

The performance of these measures in reducing flood risk is dependent on the local situation, existing river processes, and historical interventions. The Evidence Directory acknowledges that it can be difficult to establish the standard of flood protection provided by river restoration techniques (Burgess-Gamble et al., 2018).

Water Supply and Drought Mitigation

Rivers and streams are vital sources of fresh water for people, industry, agriculture, and ecosystem health. Intact river systems, including their floodplains, can act as natural water storage areas,

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slowly releasing stored water during drier periods and helping to maintain baseflows. Rivers can meander long distances and across borders, often requiring more complicated sustainable management practices and regulations to ensure the availability of water supply between upstream and downstream users (PPWB, 2021). For example, the South Saskatchewan River provides the primary drinking water supply for the City of Saskatoon (n.d.), which is fed and influenced by upstream activities on the Bow and Oldman rivers in Alberta. Additionally, rivers and streams are better known for gaining water from sources of groundwater, but when water tables are low, rivers and streams can instead lose water to soils. This loss of water contributes to recharging groundwater in local aquifers (Water Science School, 2018), which ultimately provide their own water supply benefits (Section 3.5.1).

Climate change is affecting stream flows across seasons, making it crucial to support in-stream flow needs that are a cornerstone for both ecosystem health and human activities that depend on rivers for water supply. Low flows pose a risk to drinking water intakes and other critical infrastructure that depend on reliable streamflow (Associated Engineering, 2020).

Water Quality

River and stream water quality conditions are highly influenced by their structure, integrity, and adjacent/upstream land practices. Protecting and rehabilitating rivers and streams can improve water quality by reducing erosion, sediment, and nutrient levels. Studies have shown that features such as meanders and gravel bars can reduce phosphorus and nitrogen levels through sediment deposition, retention, and purification (Burgess-Gamble et al., 2018; Hoffmann et al., 2011). Practices that slow the flow of a river encourage the development of in-channel vegetation communities, enhance floodplain areas, help to trap and stabilize fine sediment (Grabowski & Gurnell, 2016), and can improve nutrient cycling, with the potential to reduce downstream pollution (World Bank, 2021). For example, encouraging the re-establishment of river connections to wetlands or riparian areas can enhance nutrient and sediment capture and filtration, providing cost-effective services to drinking water treatment downstream (Skidmore & Wheaton, 2022).

Floodplain restoration can reduce flood intensity and, in doing so, decrease streambed and bank erosion during floods. It can also reduce nutrient loads in rivers through sediment deposition, as substances adsorbed by sediment particles are removed from streamflow (The Nature Conservancy, 2023). A review of field studies in North America and Europe found that floodplain restoration resulted in a mean removal rate of 200 kg/ha/year of nitrate and 21 kg/ha/year of total or particulate phosphorous (Gordon et al., 2020).

The denitrification potential of water within rivers and streams varies, but the highest rates may be found during warmer months (Piña-Ochoa & Álvarez-Cobelas, 2006). Conversely, large-scale water-quality assessments, like the bi-national application of the SPARROW model for the Assiniboine River basin, have shown that in-stream decay of phosphorus is not statistically significant (Benoy et al., 2016). This suggests that reductions to excess phosphorus are generally necessary before runoff is received by rivers, even at a great distance from downstream lakes that are at risk for eutrophication.

River Example With Co-Benefits

Meewasin, a non-profit organization, is dedicated to conserving the natural and cultural resources of the Meewasin Valley, which surrounds a section of the South Saskatchewan River (Meewasin Valley Authority, 2019) (Figure 34). Their programs and projects take a landscape approach, including the river, creeks, and surrounding riparian areas, as well as swales, native grasslands, and wetlands. By restoring the ecological health of these areas, the Meewasin Valley helps to improve water quality and provides regions with floodplain access during spring runoff. Meewasin Valley is centred in the City of Saskatoon and stretches outward to the adjacent Corman Park. This urban greenspace provides residents and visitors with recreation opportunities, including walking trails, skating, and unique tours like adventure camps, birding breakfasts, dark sky events, and education programs for local schools (Meewasin Valley Authority, 2024). Meewasin Valley is currently being considered for an urban national park (Government of Canada, 2025).

Figure 34. South Saskatchewan River in the City of Saskatoon

Credit: Author.

Variants

There are multiple types of rivers and streams—for example, they can be confined valleys, unconfined valleys, and ephemeral channels. Rather than list examples of types of rivers and streams, we consider the following techniques for river and floodplain restoration.

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Channel Realignment
Reconstructing or modifying the course of a river to restore the form and function of a stream corridor and aquatic habitat.

Floodplain Reconnection
Restoring the hydrological connection between rivers and floodplains so that floodwaters inundate the floodplains and store water during high flows.

Channel Daylighting/Re-Creation
Uncovering or restoring a buried or altered stream to restore its natural course, flow, and ecological functions.

In-Channel Features and Vegetation
Installing physical structures (like logs or boulders) and planting native vegetation within a river channel to improve habitat, stabilize banks, and enhance water quality.

3.4.2 Riparian Areas

Riparian areas are vegetated regions adjacent to streams, rivers, lakes, wetlands, or other waterways that separate upland habitat from aquatic habitat (CCME, 2021; Enanga et al., 2010; Fitch et al., 2003; UNEP-DHI et al., 2018). This section focuses on riparian areas along watercourses. Riparian areas are influenced by both upland and aquatic processes, although the presence of water and saturated soils is the primary driver of the ecological functions in riparian areas. This results in vegetation and wildlife communities that are unique to riparian habitats (Alberta Environment and Sustainable Resource Development, 2012). Riparian areas are natural features but have been historically degraded and altered due to agricultural use (e.g., livestock grazing), resource extraction (e.g., logging), and infrastructure development (e.g., bridges and buildings). Different approaches are available to conserve existing riparian areas or to restore degraded areas in targeted locations along streams to replant native vegetation (e.g., trees, shrubs, grasses, and forbs) and decrease bare soil that is prone to erosion.

Riparian areas have eight key ecological functions that offer benefits and improve performance when they are healthy (e.g., diversity of vegetation, little bare ground and human disturbances like roads/structures, few invasive species, and water can leave the channel). These eight functions are (Fitch & Ambrose, 2003):

- trapping and storing sediment, which improves water quality and builds riparian soil;
- building and maintaining the streambank, which stabilizes it to balance out the natural erosion process along outer banks and maintains the stream channel;

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- storing water and slowing flows, which allows the stream to overflow its channel into the riparian area during floods to slow its velocity and prevent erosion;
- recharging aquifers, which helps to promote infiltration and maintain surface flows;
- filtering water, which allows riparian plants to uptake contaminants and nutrients and trap sediment;
- reducing energy, which slows the velocity of flowing water to reduce erosion and sediment transport;
- maintaining biodiversity, which provides habitat and connects habitat corridors; and
- creating productivity, which contributes to more diverse vegetation and different age classes (e.g., seedlings to mature) and enhances the soil.

Benefits and Performance

Primary Benefits

Flood Mitigation
Flooding is a natural part of riparian processes, and riparian areas provide flood-mitigation benefits by slowing the flow of water (Fitch & Ambrose, 2003). This mitigation is achieved when water rises above the stream channel and accesses the floodplain, which is the riparian area that exists outside of the channel. Floodplains provide a temporary storage area for excess water, where the velocity of the flowing water is slowed, sediment is deposited, and groundwater infiltration occurs (Fitch & Ambrose, 2003).

The type and age of vegetation influence flow resistance. Cole et al. (2020) reported that riparian areas with vegetation that is taller, less flexible, and denser provide rougher borders along the channel and greater flow resistance, but seasonality and flood event context are also important considerations in evaluating performance. During spring runoff on the Canadian Prairies, riparian soils can remain frozen, and vegetation has limited regrowth (Sheppard et al., 2012), reducing the flood-mitigation benefits of riparian areas in this season.

Water Supply and Drought Mitigation
As riparian areas help to slow the velocity of water and temporarily store flood water in the floodplain, they help maintain water supply and productivity during drought. Often, there is a connection between the channels of streams and rivers and the groundwater aquifer via riparian areas, which supports greater aquifer recharge and provides baseflow for rivers and streams when groundwater tables are low or high, respectively (Zhang et al., 2022). Riparian areas can provide much-needed forage and water for livestock producers during drought, as the linkage to the groundwater aquifer and water storage ensures water in the channel and higher moisture keeps vegetation green and growing (Fitch et al., 2003).

Water Quality
Riparian areas contribute to water quality maintenance and improvements through sediment filtration and uptake/transformation of pollutants (e.g., nutrients and other contaminants)

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by plant, microbial, and physical processes (Alberta Environment and Sustainable Resource Development, 2012; Enanga et al., 2010; UNEP-DHI et al., 2018). The roots of riparian vegetation stabilize slopes and shorelines, reducing erosion and sediment runoff (Alberta Environment and Sustainable Resource Development, 2012; UNEP-DHI et al., 2014) while protecting ecosystem integrity and habitat.

The recognized water quality benefits of riparian areas led to the creation of USDA Natural Resources Conservation Service design standards for grass filters (or strips) and riparian forest buffers (Lee et al., 2003). Daniels and Gilliam (1996) found a similar performance for riparian buffers as grass strip BMPs in more recent studies (Clary et al., 2020) but note that sheet flow provides the best-case scenario for this type of asset to provide water filtration. Critically, these assets may only provide effective filtration when flow is evenly distributed as water travels from field to stream, rather than when it is concentrated as in-channel streamflow that overflows the banks that riparian areas occupy. Results indicate that this type of asset can effectively remove total suspended solids and most nutrients; however, dissolved fractions may bypass physical filtration, uptake, or settling. For example, in a meta-analysis of grass strip BMPs, Clary et al. (2020) found a 52.1% median removal of TSS but an increase of 46.4% TDS (Table 34).

Similar to solids, dissolved phosphorus and orthophosphates can pass through riparian areas and vegetated buffers (Alberta Environment and Sustainable Resource Development, 2012; Clary et al., 2020; Daniels & Gilliam, 1996) causing TP yields to generally increase. These results indicate that riparian areas may be effective at reducing sediment-bound phosphorus under specific conditions but that this alone is insufficient when phosphorus reduction is a priority. Tackling phosphorus at the source with volume-reduction strategies and direct treatment in upland areas, along with management practices, is critical to reducing phosphorus loading, such as fertilizer management, harvesting of riparian vegetation, and strategic placement of riparian management (Alberta Environment and Sustainable Resource Development, 2012).

Mayer et al. (2007) reported that riparian buffers could remove 67.5 ± 4.0% (mean ± standard error, N=88) of nitrogen, with the effectiveness varying by relationships between vegetation type (forested vs. herbaceous), buffer width, flow patterns, and other important site factors (e.g., soil type, subsurface hydrology, and biogeochemistry). This reinforces how important site conditions are to ultimately understanding the potential improvements to water quality.

While water quality improvements are possible, it is important to note that performance may vary with seasonal freeze-thaw cycles in the Canadian Prairies and by location, considering the size, topography, and geography of the watershed, as well as site characteristics like the slope, soils, and substrate (Alberta Environment and Sustainable Resource Development, 2012). For example, Sheppard et al. (2012) note that riparian areas and buffers are less effective during snow melt, as vegetation has not yet recovered from overwintering. Vanrobaeys (2018) also notes similarities in seasonal performance with vegetated filter strips.

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Table 33. Summary of water quality performance meta-analysis of grass strip BMPs

Results	Median	N (studies)
TSS	-52.1%	52
TDS	+46.4%	33 to 34
TP	+24.3%	50
Orthophosphate	+138.6%	40
DP	+225.0%	5 to 6
TN	-11.3%	10 to 11
TKN	-14.3%	45 to 47
Nitrate/nitrites	-23.5% nitrate + nitrite	48 to 49
Ammonia	-27.1%	36

Note: There are limitations to these values, as they are calculated based on the median inflow and median outflow for a suite of studies and not the median of the percent removal of each individual study. The values presented here are calculated as the % reduction between concentrations in the influent compared to the effluent.
Source: Based on Clary et al., 2020.

The width of the riparian buffer or the setback distance from permanent development, like residential/commercial development or roads, also influences riparian function and the ability to improve water quality. While it is difficult to settle on a prescriptive setback distance, studies generally agree that wider, forested riparian areas are more effective for water quality. Alberta Environment and Sustainable Resource Development (2012) provides a methodology for determining appropriate widths, and while specific site conditions must be considered, the report suggests a 20 m buffer width for lakes, rivers, streams, seeps, and springs on glacial till when the average slope is <5%.

Riparian Area Example With Co-Benefits

A ranching family in central Alberta hoped to conserve the riparian area along Washout Creek that runs through their property and partnered with the Modeste Natural Infrastructure Project[21] to improve the health of that creek (Figure 35). They installed fencing to manage livestock access to the creek and riparian area on 21 ha. They also use two solar-powered remote watering units that allow the landowner to draw water from the creek without giving the cattle direct access to the waterway and riparian area. By controlling livestock access, there is less soil erosion and more vegetation to protect the soil and shade the creek. There are also benefits for livestock health when

[21] See more on the project here: https://alus.ca/wp-content/uploads/2022/04/Modeste-Natural-Infrastructure-Project_ALUS_2022.pdf

drinking clean water as opposed to drinking from the creek, and there is an option to occasionally graze in the riparian area during drought or when pasture is limited.

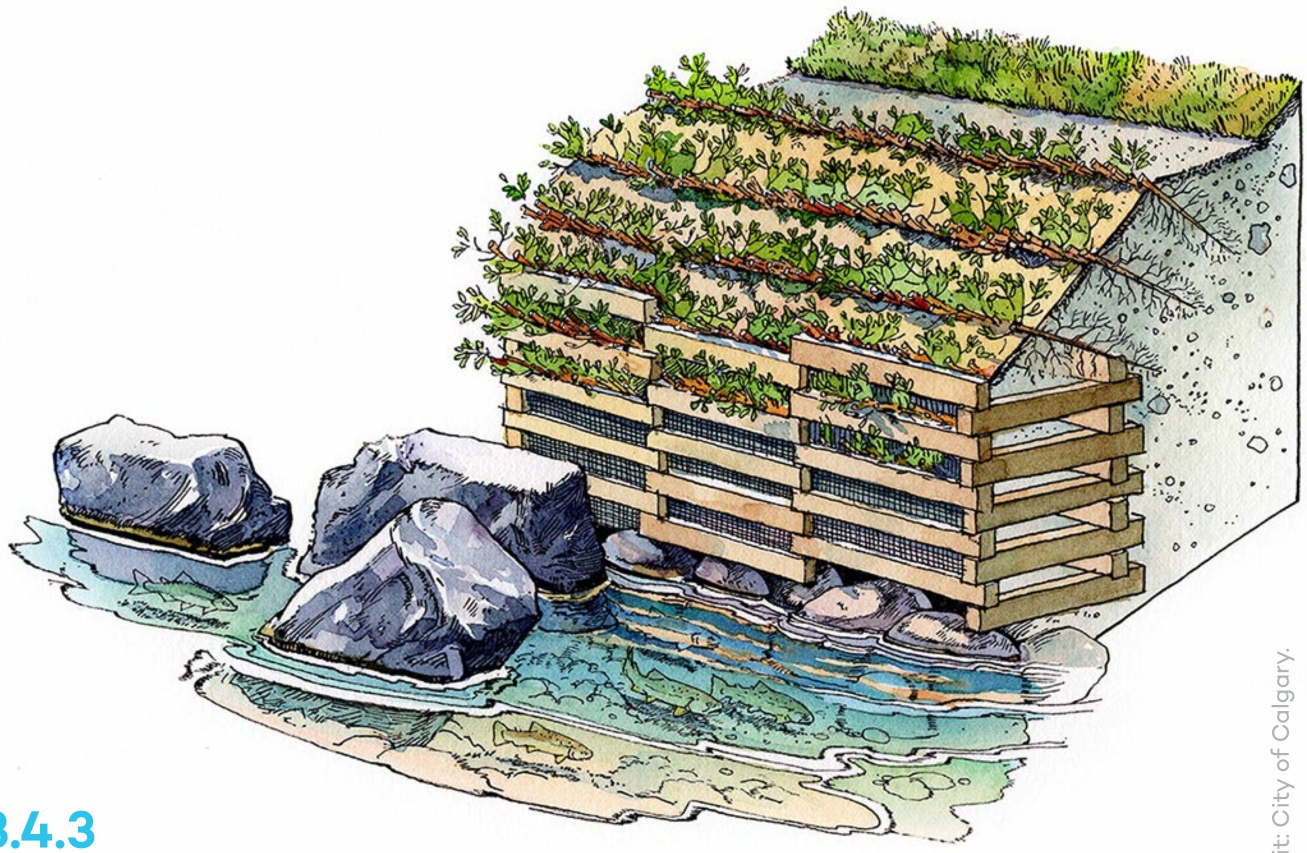
Figure 35. Washout Creek riparian area in central Alberta

Credit: County of Wetaskiwin.

Variants

Vegetated Buffer or Filter Strip

An area of land between annual cropland and surface water that is planted with dense, perennial vegetation—typically grass—to protect water quality. Vegetated buffers or filter strips can be strategically placed to intercept the runoff from cropland, slowing it down and filtering sediment and nutrients before they enter the body of water. The vegetation also helps to protect the soil and prevent erosion.



Credit: City of Calgary.

3.4.3 Streambank Bioengineering

Streambank bioengineering involves various practices that enhance streambanks and restore riparian areas (City of Calgary, 2012; Evette et al., 2009; Goldsmith et al., 2014). It is "an approach incorporating living and non-living plant materials, in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetation establishment" (USDA, 2007). Bioengineering techniques fall into two general categories: 1) plant-based/soil bioengineering (e.g., live staking, wattle fences, and brush mattresses), or 2) living structures/biotechnical (e.g., vegetated riprap and vegetated timber crib walls). The selected streambank bioengineering technique should consider the specific objectives and site conditions.

Bioengineering can be used as an alternative or complement to the conventional use of riprap for streambank stabilization. Riprap consists of large, loose rocks that can be added to slopes, streambanks, channels, or other areas subject to erosion. Riprap is often installed at the toe of slopes to provide instant protection to stream banks, with an expectation that vegetation that is co-planted with the riprap will fill in over time and enhance long-term performance. While generally viewed as better than lining a channel with concrete, riprap does not provide the benefits of vegetated practices and is not a streambank bioengineering approach. Once established, vegetation provides better erosion control than riprap through root-associated soil enmeshment, dissipation of wave energy, and interception (Allen & Leech, 1997). Literature shows that soil with deep, binding roots is more resistant to shear stress than bare soil, and the effect is amplified by increasing root diameter (Khanal & Fox, 2017).

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Changes in impervious cover in urban environments have deleterious effects on urban streams, with as little as 10% imperviousness having significant impacts (Simon & Steinemann, 2000). Bioengineering can mitigate the negative impacts of urbanization and lend resilience to streams and drainageways. Unlike other preferred natural infrastructure that is applied to prevent stream impacts, bioengineering hardens streambanks to resist the consequences of increased imperviousness. Bioengineering can also be used to discourage natural meandering, for example, to protect infrastructure or buildings built too close to waterways. As with other living technologies, establishment and seasonality are important factors in performance (Bischetti et al., 2021).

Benefits and Performance

Primary Benefits

Flood Mitigation

Stream bioengineering aids in flood mitigation by stabilizing streambanks, which helps to absorb and slow down floodwaters (Krymer & Robert, 2014) compared to fully channelized waterways, and by reducing land and property damage from erosion during flooding. Stream bioengineering is recognized for its sustainability and cost-effectiveness compared to conventional riparian flood-management methods, such as lining the channel with concrete, making it an environmentally and economically beneficial choice. A multi-year stream bioengineering effectiveness study in the City of Calgary found a similar level of erosion protection between stream bioengineering techniques and conventional riprap, based on an estimate of shear stress resistance using literature values (Kerr Wood Leidal, 2023).

Although bioengineering installations are not usually explicitly designed to impact the water balance, the benefits would include retention through evapotranspiration, as well as potentially enhancing the surface–subsurface connectivity of water movement, similar to riparian areas (Kabenge & Irmak, 2012). The key benefits of bioengineering installations are reductions in flow velocity and associated scour. Bioengineering may provide greater benefits in a sinuous channel (Krymer & Robert, 2014). One of the benefits of vegetation is associated with increases in soil matric suction through evapotranspirative losses, which can be beneficial in slope stability (Boldrin et al., 2019).

Water Supply and Drought Mitigation

Stream bioengineering enhances drought resilience and water supply by promoting the natural retention and slow release of water in the environment. This process can aid in replenishing groundwater levels and ensure a more consistent water supply. Additionally, the roots of plants and other natural structures used in bioengineering create microenvironments that can store water, leading to improved water availability in streams and surrounding areas during droughts, similar to that of riparian forests (Haase, 2017).

Water Quality

Stream bioengineering can reduce the need for more invasive mechanical or chemical water

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treatment methods and is being considered in municipal source water protection plans. Natural vegetation and materials filter out sediments and particulate contaminants. Plant roots are particularly effective at stabilizing soil along water bodies, which prevents erosion and the re-suspension of sediment. This stabilization is key to reducing the re-release of contaminants, contributing to clearer and cleaner waterways. Quantitative assessment of bioengineering and its performance is still emerging (Kerr Wood Leidal, 2023; Rey et al., 2019). The greater impacts on water quality typically come through runoff entering water bodies from outfalls. As such, riparian areas are mainly accessed during more severe events, typically the 2-year event and higher.

While people and property may be protected, the application of these techniques does not necessarily translate into a net ecological improvement. This is because erosion is a natural process, and hardening channels, even with a bioengineering approach, hinder natural erosion and the natural succession that follows, indicating that a life-cycle assessment is needed to understand the net impact of the practice to ecology (Rauch et al., 2022).

Bioengineering techniques promote sediment and organic matter deposition, which offers downstream benefits (Kettenhuber et al., 2023). Denitrification and phosphorus retention, as well as carbon sequestration, were estimated to be 20 to 30 times greater when bioengineering was applied (Symmank et al., 2020).

Streambank Bioengineering Example with Co-Benefits

West Nose Creek near Calgary, Alberta, is a small stream that was eroded by upstream land development. It was rehabilitated by adding several levels of wattle fencing to the outside bank of the stream (Figure 36). These plantings will provide essential habitat for a wide range of aquatic and terrestrial species by improving the quality of aquatic habitat, including more shade, lower water temperature, and increased organic matter (Janssen et al., 2021). Ideally, plantings are implemented below the normal water level to maximize the benefits (Schmitt et al., 2018). Streambank restoration can also provide heat mitigation with lab, field, and meta-analysis studies demonstrating an average of 1°C cooling effect (Boldrin et al., 2019).

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Figure 36. Wattle fencing for stream rehabilitation led by volunteers in West Nose Creek near Calgary, Alberta

Credit: Bert van Duin.

Variants

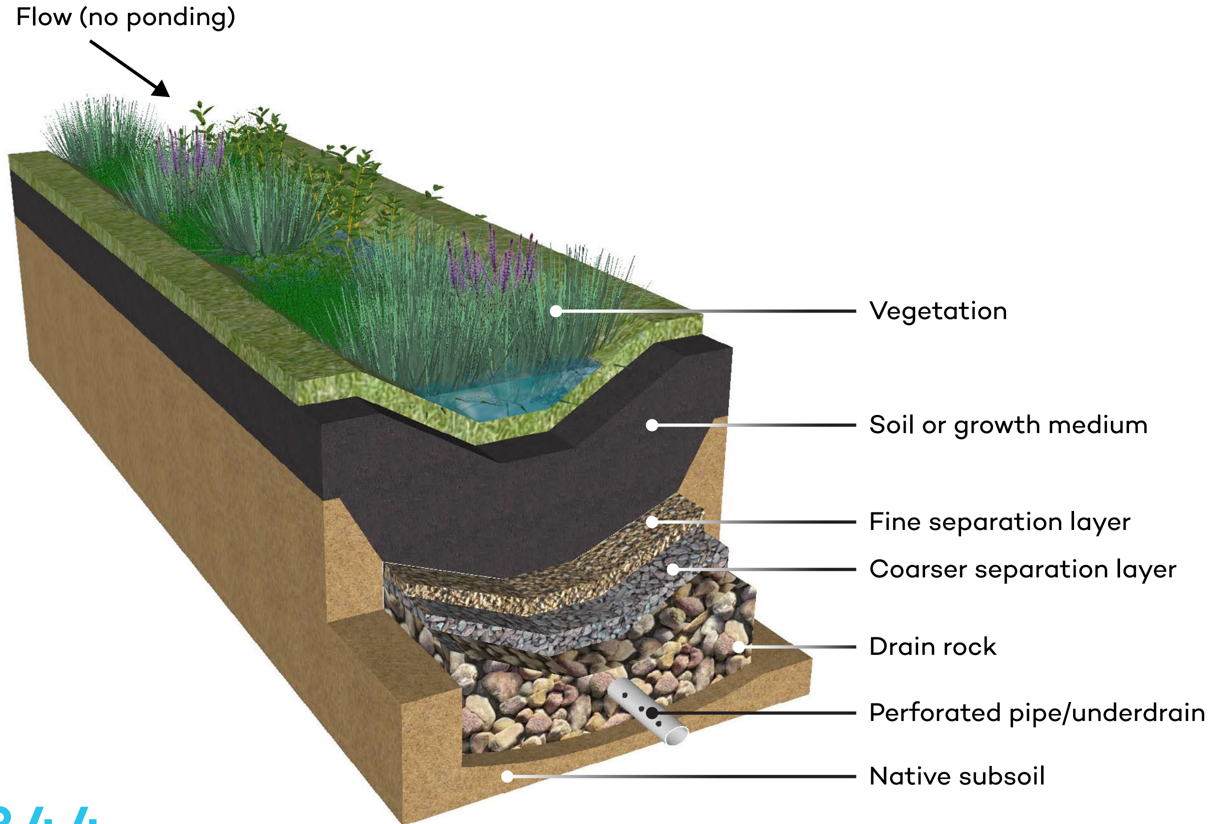
There are multiple streambank bioengineering practices—see Ministry of Agriculture, Food, and Fisheries (2004), North (2022), and Kerr Wood Leidal (2023) for examples.

Live Stakes
Living woody stakes can be placed in a variety of configurations to stabilize slopes. Willow species are a common choice.

Wattles
Living fences that act as short retaining walls in heavy soils, typically placed following the curve of the outside bank of the channel, with enough soil moisture available to sprout the face of the fence.

Brush Mattress or Brush Mat
A thick layer (15 to 30 cm) of branches laid perpendicular to the direction of flow pinned with live stakes and a toe protection measure. Soil is mixed in with the branches to the surface grade.

Live Crib Wall
A retaining wall built of timber and backfilled with soil and live stakes or live-rooted cuttings that can immediately resist substantial erosion while the stakes grow. Timbers eventually decompose as the live stakes mature.



Credit: ALIDP (reprinted with permission).

3.4.4 Bioswales

Bioswales[22] are dry, vegetated open channels that are designed to attenuate and treat rainwater or stormwater flows while providing a conveyance function. Compared to standard ditches and vegetated swales, bioswales have minimized slopes (2% or less) and include deeper, less compacted soil to promote infiltration. Except for on-lot or site settings where velocities are low, bioswales on the Prairies are typically vegetated with mat-forming grasses to resist scour. To reduce compaction and maximize the benefits associated with the presence of vegetation, mowing is discouraged. Like bioretention, bioswales may include an underdrain in a drain-rock layer. Check dams may be included to provide additional storage capacity and enhance infiltration and treatment. In rural areas, bioswales are sometimes employed continuously around an area, such as a quarter section of land.

[22] As bioswales, bioretention, and rain gardens are emerging practices, it is necessary be cautious in the interpretation of literature. The performance of bioswales is often presented for designs that include check dams and a ponding depth, which is more akin to bioretention, or, at the other end of the spectrum, is considering vegetated swales without the infiltrative enhancements of a bioswale. Information about the performance of bioswales that do not provide significant storage is therefore difficult to identify with confidence in the literature.

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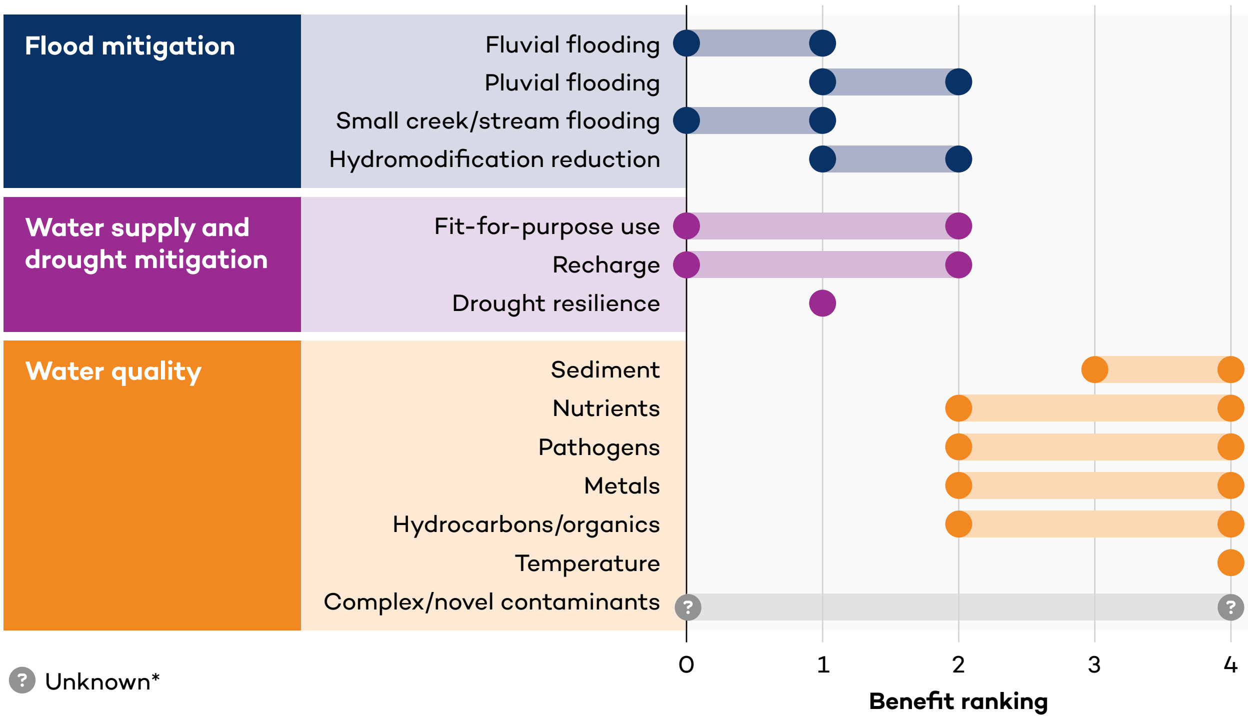
Benefits and Performance

Figure 37. Primary benefit ranking for bioswales



* Note: A range from unknown up to 4.

Source: Authors.

Primary Benefits

Flood Mitigation

Runoff rate reduction is generally very low compared to bioretention, as bioswales do not provide storage for ponding in their basic form. However, when the starting moisture condition is drier, very small storms will be retained, providing some pluvial flooding and hydromodification reduction benefits. Deeper soils and unmown vegetation with reduced compaction compared to mown ditches, along with underdrains and a trapezoidal shape, contribute to infiltration and maximized water quantity performance. Flows that might otherwise cause localized flooding can be efficiently conveyed away from problem spots. If bioswales are implemented with check dams or flow restrictions such that ponding occurs, their performance will be like bioretention.

Water Supply and Drought Mitigation

Bioswales are self-watering and drought-tolerant compared to conventional landscaping. Because they are often designed with underdrains and are even sometimes lined (e.g., over hotspots, where infiltration is undesirable), they do not typically contribute much to recharge. However, they can contribute to recharge wherever percolation rates are high enough that underdrains are unnecessary and infiltration is permissible (Table 36).

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Table 34. Bioswales: Water quantity performance

	Volume control	Rate control	Storage/supply
Mechanism	Evapotranspiration and infiltration	Controlled by check dams and infiltration	N/A
Capacity	10%–20%*	N/A	N/A

* Note: 10% on hydrologic soil group C or D; 20% on hydrologic soil group A or B.
Source: Based on CVC & TRCA, 2010.

Water Quality

Bioswales may remove sediment, nutrients, metals, and hydrocarbons (Jurries, 2003). As shown in Table 37, water quality improvements depend on velocity and flow within the channel and the associated ability of the channel to slow down the flow and facilitate sedimentation and infiltration.

For stormwater influent, reported pollutant mass removal rates are over 70% for TSS and over 50% for TP and TN (Deletic & Fletcher, 2006). The primary pollutant removal mechanism is filtration, which leads to the effective removal of particulate material (Purvis et al., 2018). Factors that may influence pollutant removal effectiveness include slope (<1 %), subsoil infiltration rate (15 mm/hr or greater), flow velocity (less than 0.5 m/s for a design event), and side slopes (3:1 or shallower) (CVC & TRCA, 2010).

Table 35. Bioswales: Water quality performance

	Mechanism	Treatment efficiency	Media	Vegetation
BOD	-	N/A	Low organics	May release
TSS	Sedimentation	47%–75%	N/A	Preferential flow
P	Sedimentation and sorption	0%–41%	Low P and amendments	Uptake opportunities
N	Nitrification and denitrification	11%	Low N	Uptake opportunities
Pathogens	Sedimentation	0%	N/A	N/A
Metals	Sorption	50%	N/A	Uptake opportunities

Source: Based on Clary et al., 2020; Schueler, 1987; Schueler et al., 1992; and Winer, 2000 as cited by Gulliver & Anderson, 2008.

Bioswales Examples of Co-Benefits

Biodiversity and Habitat (Rank: 2–3)

Bioswales are typically vegetated with stiffer-stemmed sedges and grasses. Trees and flowering perennials can also be incorporated, though trees are often kept out of the flowpath and placed higher on the sideslope or immediately adjacent. Vegetation is limited to salt-tolerant species. Many common native species are adapted to bioswale conditions, including habitat for the endangered Monarch butterfly. Bioswales can create linear ribbons of habitat. Snow accumulation or drift hazards next to roads may limit the inclusion of woody species.

Urban Heat Island/Acute Heat (Rank: 2–4)

As a vegetated practice receiving stormwater, bioswales will contribute to heat mitigation (CCME, 2021). Where trees are incorporated, shade will also be provided, although proximity to buildings and associated benefits will therefore vary. Since bioswales can have a significant footprint relative to land value, they are not usually implemented in the highest-density contexts, where they would have the highest benefit for urban heat mitigation.

Amenity and Wellness (Rank: 3–4)

Bioswales can be readily incorporated into public amenity spaces and along boulevards, enhancing these highly visible spaces, although bioretention provides more functionality and is the preferred option along the streetscape, when possible. Bioswales are more often implemented along walking trails where they can intercept back-of-lot flows that might otherwise saturate and shorten the lifespan of the trail surfacing. They often feature understory species that are absent in other upland plantings.

Applicability

Bioswales can be widely adopted across a range of densities, particularly in new communities. They can be more challenging or infeasible to add to retrofit and redevelopment applications in existing communities. They can be used to enhance the performance of ditches that need to be built or already exist. Robust or woody vegetation may create snow accumulation or drift hazards next to roadways. The potential footprint on the landscape is low.

Sample Design Customizations

Sample design customizations are provided for bioswales in Table 38.

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Table 36. Bioswales: Sample design customizations

Goal	Adjustment
Enhance runoff reduction	• Increase soil volume • Select larger vegetation • Include check dams • Reduce slope • Reduce design velocity
Enhance treatment	• Same as for runoff reduction • Harvest vegetation • Provide pretreatment

Source: Authors.

Natural Infrastructure in Action

A bioswale in the Starling subdivision in Edmonton, Alberta, attenuates and cleans urban stormwater destined for Big Lake in Lois Hole Centennial Provincial Park. These flows would otherwise enter the lake largely untreated. The park is home to more than 235 bird species, including at-risk species like trumpeter swans, Sprague's pipits, peregrine falcons, short-eared owls, and bald eagles (City of St. Albert, 2024).

The primary reason for the bioswale was to improve wildlife habitat in Big Lake, but residents in the Starling subdivision also benefit from the privacy created by the planting. Fast-growing native plant species took a few years to fill in, as seen in the difference in the vegetation growth in the photos between 2014 and 2022 (Figure 38 and Figure 39). Another benefit is that the bioswale intercepts flows from the backyards, protecting the walking path from saturation and premature degradation from freeze-thaw heave.

Figure 38. Bioswale in the Starling subdivision in Edmonton, Alberta, shortly after planting in 2014

Credit: ALIDP (reprinted with permission).

Figure 39. The well-established bioswale in the Starling subdivision in Edmonton, Alberta, in 2022

Credit: Alberta Lake Management Society.

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Variants

Dry Riverbed
A bioswale with a gravel or rock bottom, frequently incorporated as an ornamental feature at the site level to convey rainwater. Damming the lower end creates a rain garden hybrid.

Vegetated Swale
Similar to a ditch or grassed waterway but usually denoting a smaller scale and often mown. It has limited soil depth and absorptive capability.

Wet Swale
A cross between a swale and a wetland that is either designed as such with stepped, flat-bottomed pools that support wetland vegetation or that is naturally wet due to high groundwater levels.

Grassed Waterway
A natural, modified, or constructed channel that is lined with grass to attenuate flow, reduce soil erosion, and filter water. Flows are intermittent or ephemeral in nature to ensure that grass can thrive.

Enhanced/Multi-Stage Ditch
Ditches enhanced with intermittent permanent pools for treatment purposes, to check dams to provide retention or check leaky overflows to provide detention, or in other ways to increase their performance.

Stream Daylighting
Historically, streams have been routinely buried to accommodate urban growth. Where space is available, when velocities are low enough to protect public safety, and when water quality is adequate, daylit streams can restore lost functionality and provide amenity and wellness benefits. The capacity of a daylit stream is normally significantly greater than the pipe it replaces.

Related Practices

Bioretention (see Section 3.3.6) and infiltration trenches (see Section 3.5.2).

3.5 Groundwater

Natural infrastructure in the Groundwater family is part of groundwater systems or primarily achieves benefits by recharging subsurface reservoirs.

Not all natural infrastructure is visible on the surface. Aquifers store water underground and can be integral to achieving benefits for flood mitigation, water supply and drought mitigation, and water quality. Other natural infrastructure, such as infiltration trenches, basins, and chambers, focus on percolating water deep below the ground to recharge groundwater in these aquifers.

Grouped within the Groundwater family, this section reviews the benefits of aquifers (Section 3.5.1) and infiltration trenches (Section 3.5.2). While other types of natural infrastructure also

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influence groundwater quantity and quality, assets within the groundwater family focus primarily on percolation to subsurface storage.

Groundwater and surface water can be connected in complex ways. Groundwater contributes to surface water, and vice versa, although the degree of connectivity can vary based on factors including geology and groundwater depth. Interflow occurs within the unsaturated zone of soils when water is exfiltrated from the water table or percolated surface water reaches a confining (low-permeability) layer and moves laterally toward receiving water bodies, enhancing surface water levels and baseflow (Dingman, 2015).

Figure 40 presents five of Canada's nine main hydrogeological regions (Sharpe et al., 2008), which differ in water storage, transmission, and recharge/discharge capabilities overlayed on the Canadian Prairie ecozone and its characteristic non-contributing areas (AAFC, 2013).

Figure 40. Hydrogeological regions of Canada and non-contributing areas within the AAFC Watershed Project

Source: Author map based on AAFC, 2013; Government of Canada, 2016; Sharpe et al., 2008.

The Western Plains hydrogeological region underlies the Prairie ecozone. It is low relief and composed of both bedrock and sediment-dominated terrains (Sharpe et al., 2008). Thin layers of glacial deposits mean that shallow aquifers are typically found only in the hummocky areas of western Alberta, while near-surface bedrock aquifers are composed mainly of marine and fluvial sandstone elsewhere. Moreover, non-contributing landscapes, which have traditionally been viewed as less significant in hydrological studies, possess great potential to capture snowmelt and enhance groundwater recharge (Hayashi et al. 2003). Understanding the dynamics of these

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areas is essential for effective water resource management, particularly in regions where aquifer recharge is critical for maintaining water supply and where existing development and drainage have taken place.

As water demand grows across the Prairies, there is increasing focus on the potential for groundwater to meet the needs of different sectors. The Government of Canada (2013b) highlights data from Statistics Canada 1996, indicating that 30.2%, 42.8%, and 23.1% of Manitoba's, Saskatchewan's, and Alberta's respective populations already rely on groundwater sources, mostly in rural areas, noting the largest users are within the agricultural industry for livestock watering. For smaller municipalities, groundwater is often the most accessible source of water supply, especially when these communities are positioned away from lakes and rivers.

The quality of groundwater in the Prairies is variable, influenced by the characteristics of the hydrogeological region and anthropogenic activities like oil extraction and mining. For instance, local geological factors such as the depth and characteristics of layered rock formations can play a role in whether water is saline or non-saline (Sharpe et al., 2008). Growing demand for clean water supply from multiple sectors highlights the importance of groundwater recharge and protection to ensure that adequate water supply can be ensured for future generations.

3.5.1 Aquifers

An aquifer is a belowground region of permeable/porous materials, like sand, gravel, silt, or fractured rocks, that is recharged by rain and snowmelt, forming a source of groundwater (Government of Canada, 2013b; PPWB, 2019a). Aquifers can be confined by a relatively impermeable layer of rock or clay-rich sediment, while others are unconfined with the water table defining the upper surface (Government of Canada, 2013b). Wells typically need to be installed to access groundwater, except when water can be collected from springs. Groundwater can be an important water source for various uses and can be essential during periods of drought by naturally supplying water to waterways (Government of Canada, 2013b).

Aquifers differ from other types of natural infrastructure because their boundaries are not always clearly defined or discernible, and their influence can extend over large layered and interconnected areas (Groundwater Information Network, 2015). Managing aquifers as physical assets is complex, recognizing that groundwater recharge and flow pathways can be both local and continental. The Paskapoo, Judith River Formation, and Carbonate Rock aquifers are all examples of just one key aquifer in each Prairie province, which are critical for supplying water for residential and commercial uses (Grasby et al., 2014, as cited by Spence et al., 2019). Intertill sands and gravels and buried valley aquifers are also highly distributed across the Canadian Prairies and provide access to water.

Benefits and Performance

Primary Benefits

Flood Mitigation

Aquifers act as natural underground reservoirs that can absorb and store excess water during flood events and lower peak flood levels, depending on if there are permeable land surfaces above that allow floodwater to infiltrate and percolate into aquifers. The infiltration rates of different land covers and their associated subsoils will influence whether aquifers belowground can support flood-mitigation benefits. The potential for aquifers to support flood mitigation is also influenced by the saturation of soils, the depth of the water table, geology, and aquifer capacity. Much of the water that percolates below the root zone will be stored in these underground reservoirs.

When a water table is low, an aquifer will have more room to store water, and generally, the rate of infiltration and percolation will decrease until the soil is fully saturated with water (Todd & Mays, 2005). In many parts of the Prairies, the water table is several metres below the surface, indicating that aquifers might support flood mitigation depending on land cover, soil characteristics, and multiple aquifer characteristics (e.g., location, type). However, in the lower Lake Winnipeg basin, where the water table can often be higher, there may be a limit on potential contributions to flood mitigation (Government of Canada, 2011).

In California, for example, a strategy called Flood-Managed Aquifer Recharge (Flood-MAR) is gaining attention as a way to divert floodwaters to recharge aquifers and can be implemented at various scales, from individual farms to entire watersheds. This approach can mitigate flood and drought risks simultaneously (California Department of Water Resources, 2022). It is unclear if this approach would be effective in the Canadian Prairies based on geology and recharge efficiencies, so future studies are warranted.

Water Supply and Drought Mitigation

Aquifers serve as a vital source of water for many Prairie communities and sectors. For example, about 23.1% to 42.8% of the population in Alberta, Saskatchewan, and Manitoba relies on groundwater. While some Prairie aquifers are small and may only supply water locally, larger bedrock aquifers may provide more substantive supplies, although groundwater quality and salinity vary widely. The ability of aquifers to supply water depends on how much water is in the aquifer, the rate of movement of groundwater discharge from the aquifer, and the ability of the aquifer to be recharged with other water sources (PPWB, n.d.).

Aquifers' water supply is accessed using wells, which are critical infrastructure for communities that do not have direct access to rivers or lakes for surface water withdrawals. For example, the City of Steinbach (2012) in Manitoba obtains water from three wells that draw from a limestone aquifer. Like any water supply, it is crucial that withdrawals of water from aquifers be managed appropriately to ensure their use remains sustainable, including protecting recharge zones (PPWB, 2021).

When water tables are high, aquifers provide groundwater discharge that keeps wetlands, lakes and ponds, or rivers and streams from drying out (USGS, 2018), providing an accessible water supply for both human activities and aquatic ecosystems. For example, a study of the Elbow River in Alberta found that aquifers may contribute 40% to 60% of streamflow from May to October, although this varies seasonally (Campbell et al., 2021).

A modelling study by Negm et al. (2021) predicted that annual groundwater recharge in topographic depressions on the Canadian Prairies may decline with climate change. Despite increased precipitation overall, a combination of less snowmelt and warmer summers with higher evaporation would counter the effects of higher precipitation. According to Huang et al. (2024), hydrological modelling scenarios suggest a shift toward more severe groundwater droughts on the Prairies, referring to a period where decreased groundwater levels result in insufficient water supply in groundwater-dependent regions, lower base flows and water well yields, and potentially a dry-up of wells or rivers (Huang et al., 2024).

To increase the amount of water that reaches and is stored in aquifers, it is critical that upland depressions that form non-contributing areas are left undrained (e.g., wetlands) so that water can be stored and given adequate time to recharge groundwater (Hayashi et al., 2016). Without longer-term water storage, potential evapotranspiration can often exceed any surface water inputs from rainfall and snowmelt events, limiting effective recharge. Management approaches can also be applied to enhance water yield in aquifers while reducing the need for the construction of grey infrastructure storage—for example, aquifer storage and recovery and managed aquifer recharge (Alberta Government, 2011a). However, there is a need for feasibility analyses of these practices across the Prairies, because, to the best of our knowledge, they have not been implemented regionally to date.

Water Quality

Water is naturally filtered when it is recharging an aquifer, often making aquifers suitable sources for drinking water. However, aquifer water quality may vary depending on conditions, such as recharge water, passing through different materials (e.g., rock or soil) and its residence time. For example, faster-flowing groundwater will have less time to dissolve materials (Government of Canada, 2013b). Conversely, groundwater from aquifers is often free of microorganisms that cause disease if nearby sources are not contaminated and can have lower concentrations of suspended solids than surface water (Government of Canada, 2013b).

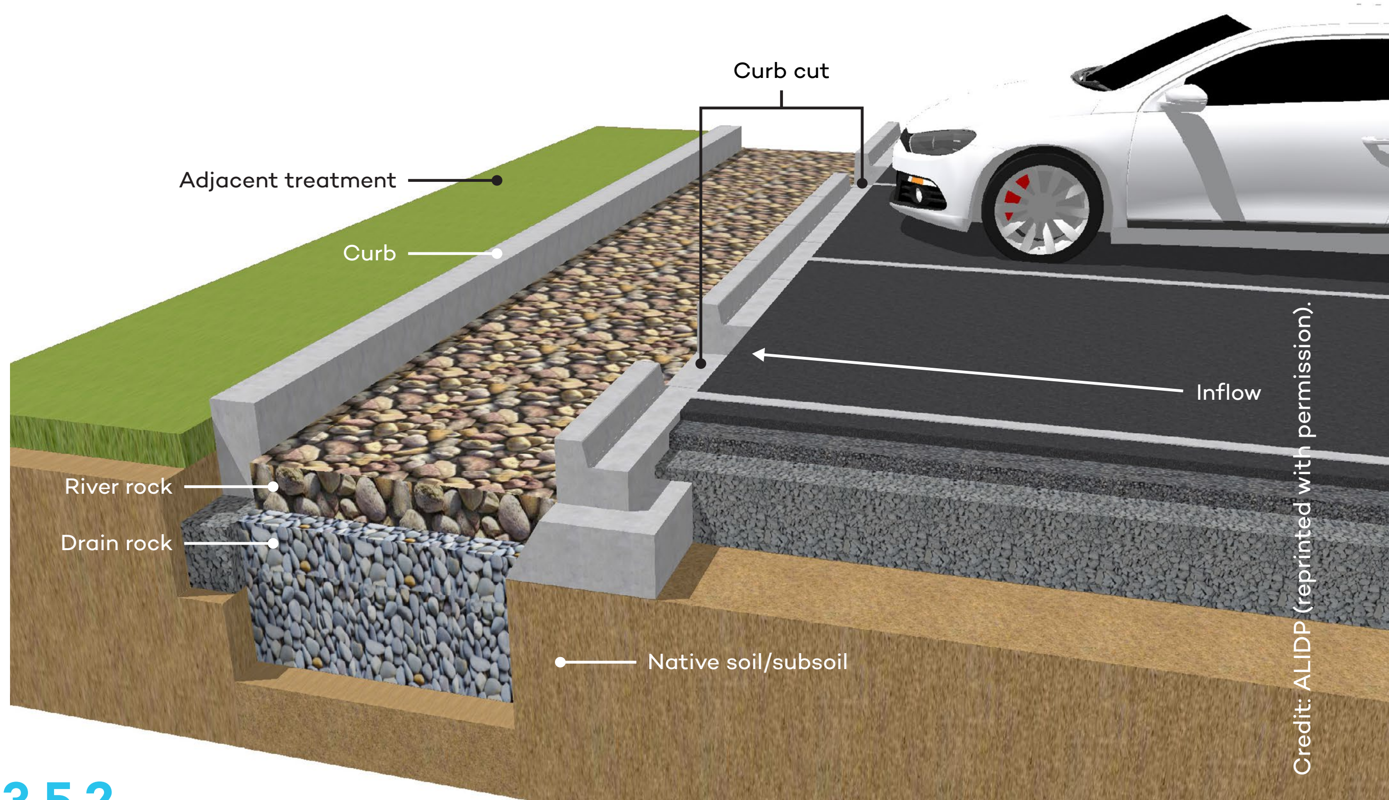
Great care must be taken when withdrawing water from aquifers, as groundwater can be contaminated both naturally and due to human activities like mining. For example, arsenic is one of several highly toxic chemicals found naturally within rocks and soil that needs to be removed before it can be used in municipal drinking water supplies (Government of Manitoba, 2019). Water in aquifers may also be contaminated from recharge sources (e.g., industry and agricultural activities) (Government of Canada, 2013b; PPWB, 2019a) or when drilling wells are not properly sealed during decommissioning (PPWB, 2019b). Aquifer depth, type, and recharge rate will influence how sensitive it is to source contamination—for example, shallow aquifers are more likely to be contaminated by recharge sources. Groundwater is difficult to remediate if contaminated, and as such, the protection of groundwater needs to be prioritized (PPWB, 2019b).

Aquifer Example

In Gibsons, British Columbia—a town of 4,400 people with limited resources for infrastructure maintenance and replacement—the local aquifer provides water storage and delivers drinking water that meets health standards without chemical treatment, saving money on the construction, operation, and maintenance of a water treatment facility (Figure 41). In 2014, the town council called nature its most valuable asset and has since been an early leader in natural asset management in Canada (Municipal Natural Assets Initiative, 2022). The town has made a commitment to understand, measure, value, and protect its natural assets to ensure the reliable flow of infrastructure services, including safe and reliable drinking water.

Figure 41. Gibsons, British Columbia, recognizes nature as its most valuable asset, including its local aquifer

Credit: Town of Gibsons.



3.5.2 Infiltration Trenches

Infiltration trenches are linear excavations filled with granular material chosen to maximize storage capacity, such as drain rock. Trenches are designed to rapidly infiltrate runoff and then percolate it into surrounding soils and/or subsoils. Additional chamber-type storage may be incorporated. If subsoils are tight or if percolation is not desired, capacity is limited to the void space of the granular material. In such cases, an overflow or other escape method is provided. As with all infiltration and exfiltration practices, if the source of runoff is stormwater, pretreatment is necessary to manage sediment, trash, and debris to preserve the lifespan of the practice and rigorous maintenance schedules must be adhered to (Sustainable Technologies Evaluation Program, n.d.).

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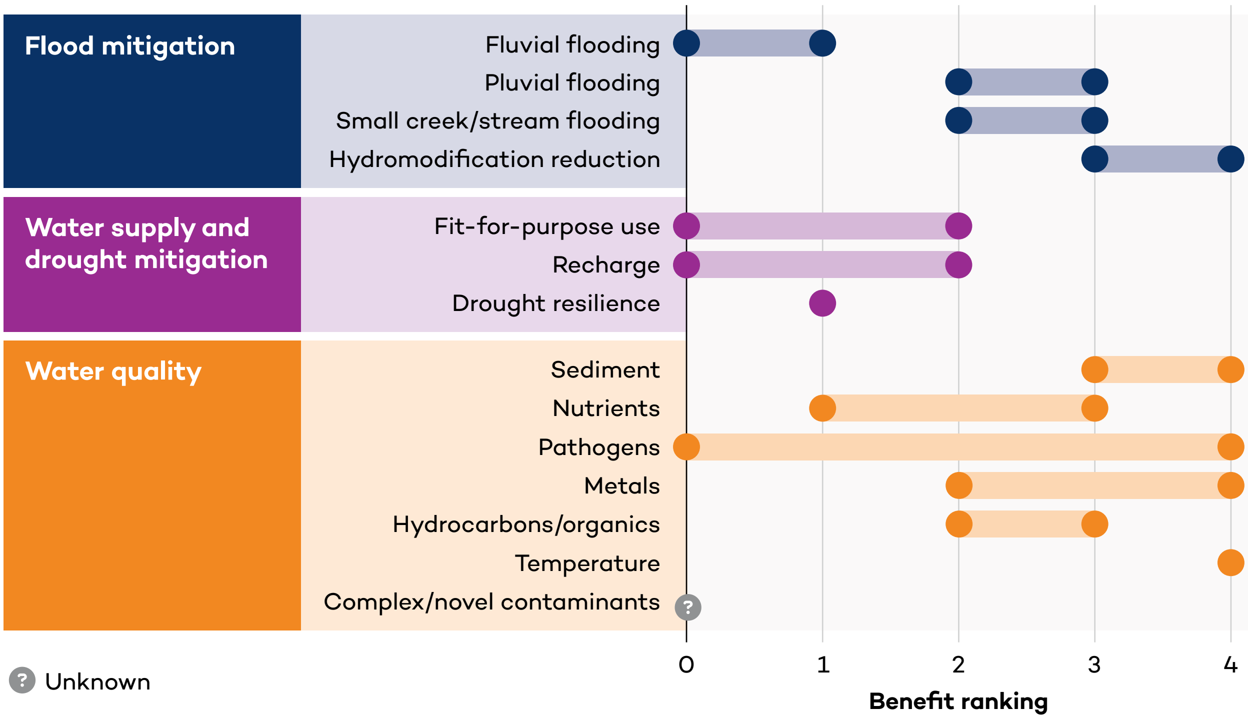
Benefits and Performance

Figure 42. Primary benefit ranking for infiltration trenches



Source: Authors.

Primary Benefits

Flood Mitigation

Performance data are limited and depend on the geometry/storage capacity of the system and the permeability of the subsoils (Table 39). In the typical case of low subsoil permeability, infiltration trenches and chambers on the Prairies are designed as detention features that discharge into the piped stormwater system, similar to other storage chamber practices. Soakaways are a variant that, due to their small scale and likely contact with surrounding soil (with higher permeability than subsoil), may achieve some retention.

Water Supply and Drought Mitigation

Where percolation rates are high enough to meet drawdown times of 24–48 hours, infiltration practices provide an opportunity to support recharging aquifers. However, on most of the Prairies, subsoils are not sufficiently permeable to achieve this.

Facilities cannot be sited over karst topography to avoid the formation of sinkholes. Interflow to support stream baseflow is a possibility in certain localized conditions.

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Table 37. Infiltration trenches: Water quantity perfomance

	Volume control	Rate control	Storage/supply
Mechanism	Infiltration	Controlled by infiltration rate and surface area	N/A
Capacity	N/A	N/A	N/A

Source: Authors.

Water Quality

Treatment is a function of the source water (Table 40). While rainwater is relatively clean, stormwater must be aggressively pretreated to prevent clogging. Its quality will be improved by this pretreatment rather than the infiltration practice itself. The surrounding soil and/or subsoil will provide additional treatment of dissolved pollutants. The subsurface flow pathway will improve water temperature. When stormwater is the source water, the risk of groundwater contamination from salts and other constituents must be considered, as it is in bioretention.

Table 38. Infiltration trenches: Water quality performance

	Mechanism	Treatment efficiency	Media	Vegetation
BOD	Biofilm	70%–90%	Low organics	May release
TSS	Straining	90%–99%	N/A	Preferential flow
P	Straining and sorption	60%–75%	Low P and amendments	Uptake opportunities
N	Nitrification and denitrification	50%–70%	Low N	Uptake opportunities
Pathogens	Straining	94%	N/A	N/A
Metals	Sorption	90%–99%	N/A	Uptake opportunities

Source: Based on Schueler, 1987; Schueler et al., 1992; Winer, 2000, as cited by Gulliver & Anderson, 2008.

Infiltration Trenches Examples of Co-Benefits

Urban Heat Island/Acute Heat Mitigation (Rank: 0–1)

The siting of infiltration trenches varies widely. The increased surface area associated with rocks may provide minor evaporative cooling following a rain event; however, materials would need to be of a high albedo (light colour) to offer any gain at all.

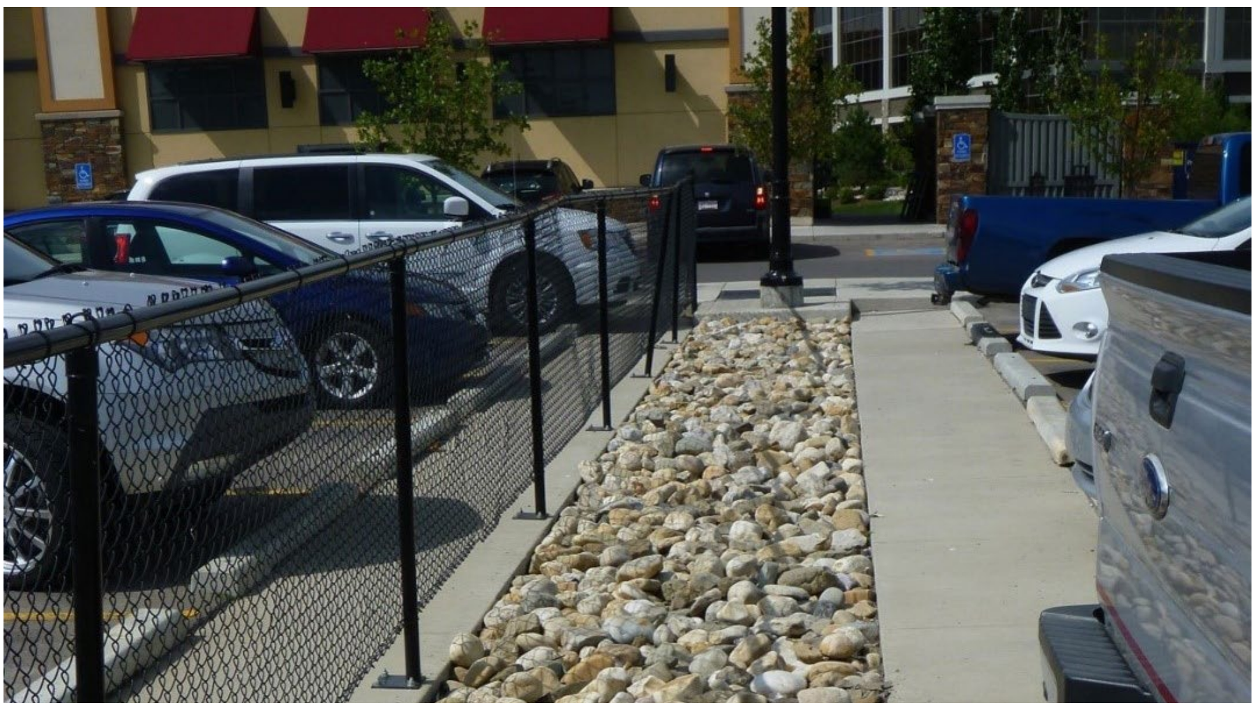
Applicability

Due to the limited area of subsoils with adequate permeability on the Prairies, deep infiltration practices are seldom applicable. River valleys and areas with coarse soils and subsoils may be suitable. Bioretention, rain gardens, and other vegetated practices are preferred for their evapotranspirative capacity, co-benefits, and intrinsic ability to resist clogging. Small-scale soakaways for rainwater are a more common application, but rain gardens and dry riverbeds are preferred if surface space is available. Overall, due to their limited applicability, little benefit can be achieved.

Natural Infrastructure in Action

The infiltration trench in Figure 43 collects parking lot runoff in a community with granular subsoils in a river valley in Calgary, Alberta, allowing for percolation.

Figure 43. Infiltration trench in Calgary, Alberta



Credit: ALIDP (reprinted with permission).

Variants

Infiltration Chamber

Similar to an infiltration trench, except the storage feature is not linear and is buried with an inlet directly tied to it. It may be used to denote that the storage is provided using a load-bearing system without the use of granular materials (e.g., plastic crate or arch system).

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Soakaway or Dry Well
Typically used in reference to a smaller-scale or site-level infiltration chamber that is generally either an area filled with drain rock, rubble wrapped in geotextile, or a structural, perforated shell often made of concrete.

Exfiltration Trench
A trench installed in conjunction with or in place of conventional storm sewer pipes incorporating perforated pipe on a gentle slope in a rock trench and plugged at the downslope end at regular intervals to facilitate percolation (exfiltration). Runoff enters through catch basins, and the system typically includes maintenance holes. Exfiltration trenches can accomplish both exfiltration and conveyance (Sustainable Technologies Evaluation Program, n.d.).

Infiltration Basin
A larger-scale vegetated basin sited over permeable soils that has drawdown requirements similar to bioretention and is usually sited in open spaces. It employs a very sandy substrate that is not drought resilient in the Prairie climate and offers little benefit for water quality improvement related to cation exchange capacity (i.e., dissolved nutrients).

Related Practices

Bioretention (see Section 3.3.6), rain gardens (see Section 3.3.4), and bioswales and dry riverbeds (see Section 3.4.4).

4.0 Putting Natural Infrastructure to Work

How can natural infrastructure assets work together across the Canadian Prairies to support water infrastructure needs while also supporting the overall health and resilience of the region? This section reviews key considerations to guide the protection, planning, and deployment of natural infrastructure.

4.1 Key Considerations

4.1.1 Scale and Systems Thinking

Natural infrastructure projects can be implemented at different scales—for example, parcel, neighbourhood, community, and watershed scales (Action on Climate Team, 2023). The spatial coverage of natural infrastructure projects affects their ability to deliver desired outcomes. For example, installing small-scale source control measures like rain gardens and rainwater harvesting in private yards can be key to addressing pluvial street flooding due to summer thunderstorms, especially in older neighbourhoods. However, neighbourhood-level detention storage, like constructed wetlands, is still necessary to protect neighbourhoods further downstream from pluvial flooding impacts as flows accumulate. Similar spatial thinking can be applied across agricultural and rural landscapes, where agricultural water retention practices, like wetland restoration, can provide localized benefits to individual landowners but need to be scaled up significantly across watersheds at an appropriate density for benefits at the river basin scale to be sensitive to this change (Simoes et al., 2023a).

To optimize benefits and rationalize investments, a multi-scale, multi-benefit approach should be applied to meet water management needs linked to flood mitigation, water supply and drought mitigation, and water quality. It is important to continue work across all scales to support the ecological processes and services that underpin watershed health and resilience. Numerous case studies around the world show examples where NbS, including natural infrastructure, can be used to support holistic risk management and resilience across landscapes, often combining ecosystem-based approaches with grey infrastructure to achieve desired outcomes (Peñailillo et al., 2022; Somarakis et al., 2019). For example, in the case of drought risk reduction, it is critical to consider a mix of natural and grey infrastructure solutions across a watershed or even larger landscape scale (Peñailillo et al., 2022).

4.1.2 Treatment Train

When assets are sequenced in steps to optimize the achievement of performance objectives, it is known as a treatment train. The treatment train approach is used in multiple infrastructure settings:

- **Wastewater**: The treatment train concept originated in the wastewater sector and has primary, secondary, and tertiary treatment steps. Some wastewater only receives primary treatment or primary and secondary treatment.
- **Drinking water**: A common treatment train for drinking water would include a settling operation, filtration, and disinfection. The disinfection step occurs last in the sequence and cannot be moved earlier, as it would be ineffective.
- **Stormwater**: A complete treatment train would aim to prevent runoff, reduce the amount of runoff, and treat runoff as close to the source as possible. Conventional stormwater management, using dry and wet ponds, is limited in what it can achieve but does provide rudimentary rate control, settling, and filtration. An expanded treatment train approach mobilizes the existing landscape to supplement, enhance, or replace conventional stormwater management.

Natural infrastructure is a building block to achieve different goals for different contexts. For flood mitigation, key measures include preserving existing landscapes and implementing storage close to where runoff is generated. To protect source water for drinking where urbanization has occurred, road runoff can be treated with bioretention to remove hard-to-treat contaminants before they reach end-of-pipe facilities. Bioretention performance will be enhanced if volumes are reduced first. In fact, all stormwater and combined sewer treatment trains ideally begin with volume reduction because it enhances all further steps in the train. A natural infrastructure approach is, in some ways, synonymous with a treatment train approach, as both look to optimize cost and benefit in a sequence of asset acquisition and deployment. Table 41 shows a treatment train approach for stormwater management along a sequence from left to right of preservation, source control, and end-of-pipe intervention.

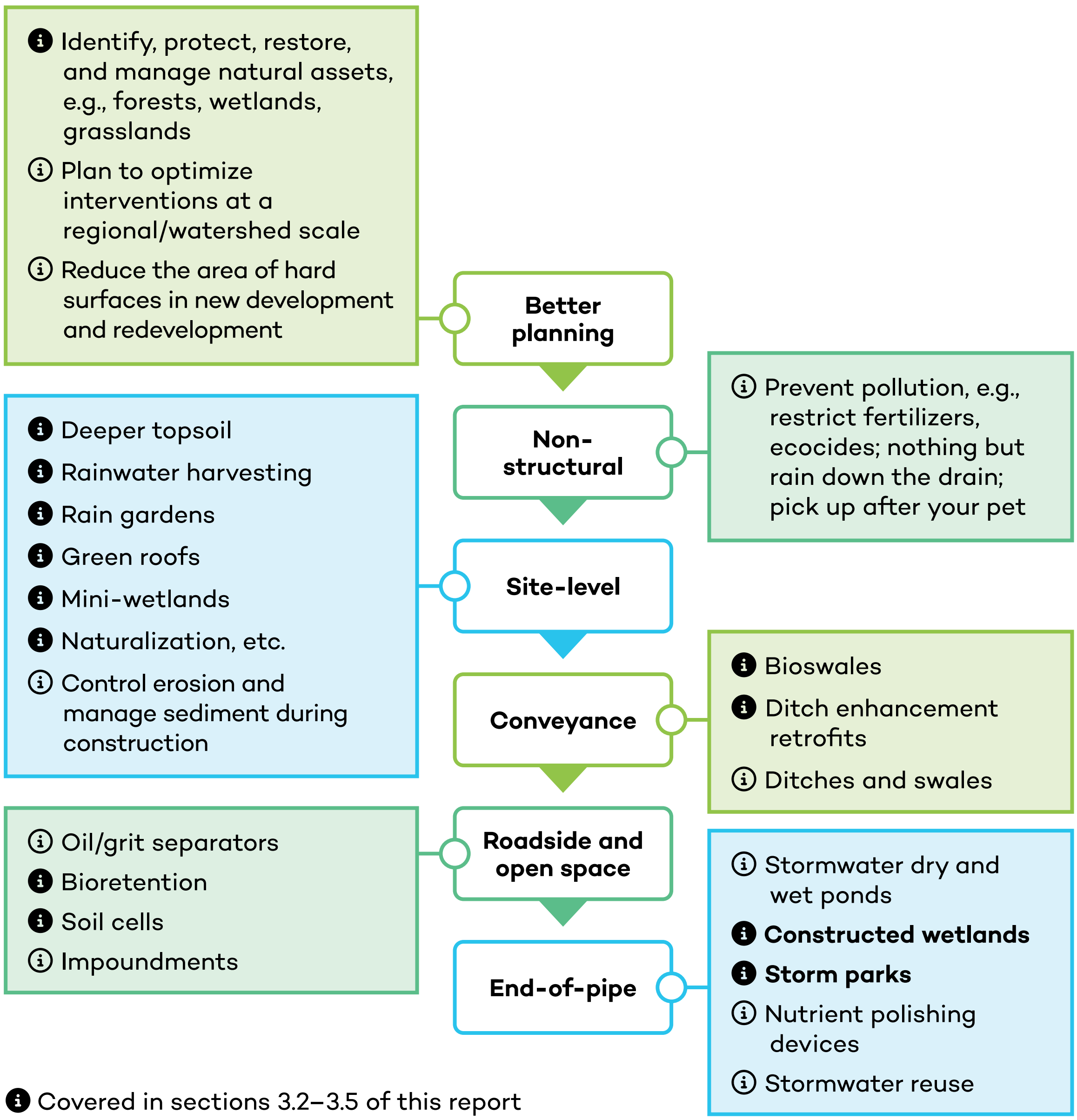
Table 39. Stormwater treatment train for stormwater management

Natural assets (preservation)	Constructed assets (source control)	End-of-pipe enhancements
Preserving and restoring natural areas and natural features (down to individual trees and native soils at the site level) wherever feasible.	Mimicking natural *features* and natural *processes* to restore predevelopment water balance and water quality conditions. Note: *literal* greenness does not make something natural infrastructure—it is the *function* that restores natural conditions that is important, not the *form*.	Stormwater wet and dry ponds are part of the conventional toolbox, having been in use since the 1980s to reduce peak flows. For these practices, the natural infrastructure component would apply to enhancements over and above standard practice—for example, naturalized vegetation around the perimeter of a stormwater wet pond. All treatment ponds and constructed wetlands should include a naturalized perimeter as standard practice.

Source: Authors.

Figure 44 expands the concepts identified in Table 41 to show how natural infrastructure fits into a stormwater treatment train that also includes non-structural planning and policy elements, such as bylaws that prevent pollution, and conventional treatment elements, such as oil-grit separators for sediment management.

Figure 44. A treatment train approach for urban stormwater that includes natural infrastructure



Source: ALIDP.

4.1.3 Local Priorities and Equity

Building a better business case for natural infrastructure must also integrate and respond to the needs and priorities of local communities. According to the *Stakeholder Engagement Guide for Nature-Based Solutions* (Brill et al., 2022), projects related to NbS are "more likely to achieve positive and lasting results when they are co-designed with Indigenous Peoples and local

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communities." It is critical to ground projects in the local context—e.g., for understanding regulatory drivers, hydrology, drivers for action, implementation capacity, etc.—and to engage early and often with multiple stakeholders and rights holders. In 2020, the International Union for the Conservation of Nature issued its *Global Standard for Nature-Based Solutions*, including criteria for inclusive, transparent, and empowering governance processes (International Union for the Conservation of Nature, 2020).

This is particularly important when considering the needs of Indigenous, rural, and underserved communities across the Prairies. For example, Indigenous cultures and knowledge systems can significantly influence perceptions of value, as well as the benefits and co-benefits of interest. This has important implications for how the benefits and co-benefits of natural infrastructure are conceptualized, including the framing of "a business case" for natural infrastructure and the interplay between Western scientific perspectives and Indigenous Knowledge. While this report centres a mechanistic approach to understanding natural infrastructure based on Western science, Indigenous Knowledge is shaping numerous natural infrastructure projects on the ground, weaving together ways of knowing (Bear et al., 2023; North, 2022).

> "The opportunity to collaborate and integrate the long lineage of Indigenous Knowledge alongside Western natural infrastructure (increasingly used by landscape architects), provides this great opportunity to corroborate our shared ideals toward environmental restoration" (North, 2022).

Equity—defined as the just distribution of benefits and trade-offs among stakeholders—is also an essential lens for the design and implementation of natural infrastructure projects to ensure costs and benefits are distributed fairly (Diringer et al., 2019). There are Indigenous communities and underserved rural communities across the Prairies where water infrastructure challenges are acute and where access to funding or other support falls short. If projects do not include equity considerations, they risk making existing inequalities worse. Natural infrastructure projects can be inclusive or exclusive (Moore, 2021), potentially placing costs or negative impacts on those who do not benefit (Saguin, 2017) and can contribute to gentrification (Sbicca, 2019). There are many equity-based approaches that can help better understand local contexts, needs, priorities, and values (Brill et al., 2021; Tozer et al., 2022).

4.1.4 Building a Better Business Case

In recent years, there have been growing calls to build a better business case for natural infrastructure to inform decision making. An essential first step to building a better business case for natural infrastructure is benefit *identification*. Many decision-makers may not consider or be aware of the full suite of benefits that can accrue from the implementation of natural

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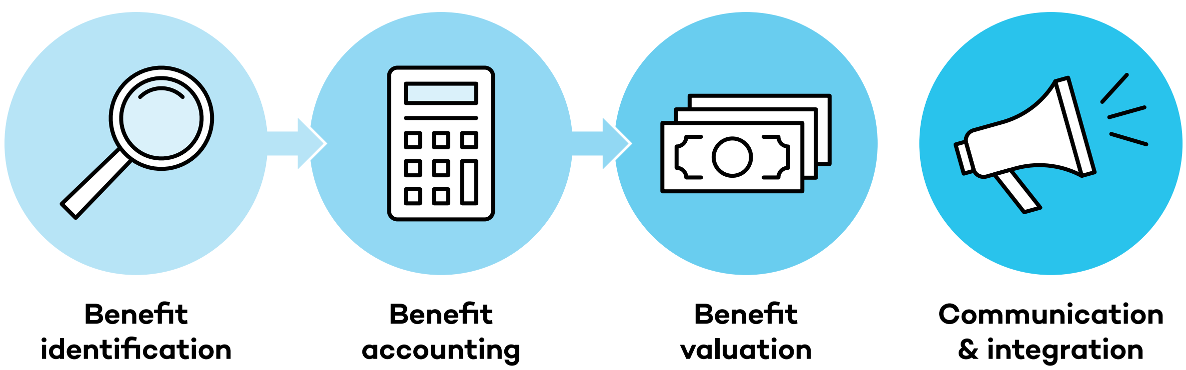
infrastructure. After identification comes benefit *accounting*—the qualitative or quantitative estimation or measurement of benefits and performance. The third step after benefit accounting is *benefit valuation*, which typically assigns a monetary value to benefits or co-benefits; however, there are also non-monetary approaches to valuation (Brill et al., 2021).

Valuing benefits can help compare natural infrastructure to grey infrastructure options, recognizing that in traditional economic assessments, grey infrastructure may appear as the more attractive option upfront and on paper, despite the broad and longer-term value proposition of natural infrastructure (Bassi et al., 2021). While most infrastructure and planning decisions are considered in economic terms, they often focus narrowly on market benefits and exclude many of the non-market benefits provided by natural infrastructure. This effectively gives nonmarket benefits a value of zero and puts natural infrastructure at a disadvantage relative to grey infrastructure (FEMA, 2022b).

A recent review of the effectiveness of NbS to mitigate hazards, including over 20,000 global studies, concluded that many NbS are cost effective at mitigating hazards (Vicarelli et al., 2024).

Figure 45. Key elements of building a better business case for natural infrastructure



Source: Author, adapted from Brill et al., 2021.

Taken together, benefit identification, accounting, and valuation can help support the business case for natural infrastructure (Brill et al., 2021). Appendix B includes examples of frameworks and methodologies to support benefit identification, accounting, and valuation from various sources. Figure 45 depicts key elements of building a business case for NbS according to Brill et al. (2021), and this report adds "*Communication and Integration*," in recognition of the need to work with key decision-makers, rights holders, and the public to ensure the business case—or holistic case—is well understood while also grounded in the needs, priorities, and perspectives of local communities.

These key elements for building a better business case for natural infrastructure are pieces of an even larger puzzle. In reality, a constellation of factors shapes infrastructure decision making—for example, approval timelines for infrastructure development, the availability of personnel and expertise, maintenance costs, mindsets that favour grey infrastructure, institutional protocols, and more.

4.2 Next Steps

The 2022 IISD Forum on Natural Infrastructure brought together over 50 leading experts and practitioners to discuss priorities for building a better business case for natural infrastructure on the Canadian Prairies (Simoes et al., 2023b). A report on the proceedings of the forum identified eight key themes to guide future work on the business case for natural infrastructure (Box 6). Clearly, strengthening the case for natural infrastructure is multifaceted, spanning a range of topics from monitoring to metrics to economics to worldviews, and more.

Box 6. Building the business case

A summary of the 2022 IISD Forum on Natural Infrastructure Performance and Metrics documents the most significant themes and actions suggested by participants from across Canada and the Prairies to strengthen the business case for natural infrastructure (Simoes et al., 2023b). The eight top themes include the following:

1. Focus on metrics that matter to decision-makers (“Tell the story”).
2. Invest in data and shared platforms (“Leverage data”).
3. Work at regional and watershed scales (“Scale matters”).
4. Embed within practice (“Set standards and targets”).
5. Strengthen the use of economic valuation of natural infrastructure (“Economics is king”).
6. Equip funders with tools to understand the return on investment of natural infrastructure (“Inform funding and evaluation”).
7. Build capacity by investing in people and involving local networks (“Support people and networks”).
8. Bridge worldviews and address equity (“Two-Eyed Seeing”).

Foundational to this work, there is a significant need to advance work in areas related to the design, assessment, and evaluation of natural infrastructure on the Prairies. Table 42, developed for this report, outlines some of the specific needs linked to data and decision making for natural infrastructure projects. There is a clear demand for more tools and guidance—particularly for the economic valuation of natural infrastructure and to better include co-benefits as a key multi-solving strategy. For additional context, see van Zanten et al. (2023) and Twigg et al. (2024).

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Table 40. Key needs for strengthening the business case for natural infrastructure on the Canadian Prairies, grouped by category

Category	Need	Outcome
Natural infrastructure's primary performance	Monitoring data and analysis of real-world performance	Quantification of performance; design, analysis, and management optimization
	Design standards and guidance	Tying data, tools, and design together to achieve expected performance
Life-cycle costs	Quantifying cost components of projects—including capital expenditures (CapEx), operating expenditures (OpEx), and other costs	Assessment of costs over the whole life of the asset; rationalization of natural vs. grey infrastructure investments
Holistic consideration of co-benefits	Understanding, quantifying, and valuing co-benefits, with clear guidance on best practices and development of economic benchmarks	More accurate and trusted guidance on how to include co-benefits within project scoping and valuation; clear, locally applicable costing
Markets and investment	Metrics and tools to support the valuation of benefits for the purpose of making the case for investment (e.g., performance metrics and valuation); may include making the case for public or private sector investment (see Vajjhala & Roy, 2020; Puzyreva et al., 2024) and/or the establishment of new markets and instruments to fund and finance natural infrastructure across sectors	Mobilizing capital from public and private sources—e.g., via payments for ecosystem services, insurance models, or cross-sector investment
Integrated/ systems-level analysis	Evaluation, creation, and refinement of decision-support frameworks and tools—e.g., spatial prioritization, multicriteria analysis, cost-benefit analysis	Landscape-level planning, investment, and complex strategic decision support

Source: Authors.

Different decision-support frameworks—for example, cost-benefit analysis, cost-effectiveness analysis, spatial analysis, and multicriteria analysis—can be used to compare infrastructure options, each with its own pros and cons (van Zanten et al., 2023). For example, in the United States, the federal government during the Biden administration recognized that high discount rates in federal cost-benefit analyses often favour grey infrastructure projects with greater short-

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term benefits (White House Council on Environmental Quality, 2022) and committed to review their overarching guidance on cost-benefit analyses to better account for nature.

However, the multitude of options introduces complexity to users and decision-makers seeking clear guidance on infrastructure options specific to the Prairies. As shown in Table 42, finding avenues to support a systems-level approach at a landscape scale to rationalize infrastructure investments—one that considers capital costs alongside life-cycle costs and co-benefits—is ideal. Currently, such integrated approaches are not the standard practice, but they are essential to rationalizing long-term, effective decision making. At the same time, the growing urgency of water-related risks underscores the importance of balancing analysis with timely, informed action. Focusing analyses on what is required to support decision making can help advance solutions without becoming stalled in prolonged assessment.

Conducting economic valuation for potential natural infrastructure projects on the Prairies is a practical way forward, leveraging approaches like IISD's Sustainable Asset Valuation (SAVi), the Sustainable Technologies Evaluation Program's Low Impact Development Life Cycle Costing Tool, or the Climate Risk Institute's Risk Return on Investment tool, among others.

> "For the valuation of ecosystem services to become common practice in environmental policy and infrastructure investment decisions, three shifts need to happen: the realization that ecosystem services have a value, understanding and knowledge of how to monetize ecosystem service value, and a requirement to undertake valuation exercises to decide future land use" (Coalition for Disaster Resilient Infrastructure, 2023, p. 147).

5.0 Conclusion

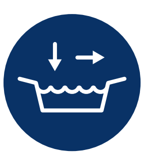
This report explored the benefits and performance of 17 key types of natural infrastructure relevant to the Canadian Prairies. It described how both natural and constructed assets support water-related outcomes and resilience in the Prairie region, a region that has been heavily altered by land development, including agriculture, industry, and urbanization.

Natural infrastructure is not a one-size-fits-all solution. While the protection and restoration of critical Prairie landscapes are essential to supporting ecological function and service provision, urban areas and highly developed regions often lack the space or suitable conditions to rely on natural assets alone. In these contexts, there is a need to turn to constructed assets that can also harness the power of nature to provide infrastructure services and other benefits.

The key takeaway is that we must work across the full spectrum of natural to constructed to grey infrastructure. Each approach plays a role, depending on the specific context and challenges at hand. The integration of these types of infrastructure, when done thoughtfully, can offer an effective approach to delivering resilient, sustainable water infrastructure.

This report presented four functional families of natural infrastructure based on their physical forms and the roles they play in managing water quantity: (i) cover, (ii) basins, (iii) watercourses, and (iv) groundwater. How we put natural infrastructure to work across the Prairies will vary by family:

Cover
Given the significant loss of natural covers across the Prairies, opportunities for the conservation and restoration of remaining forests and grasslands should be prioritized. Attention in developed areas should be directed to minimizing turf and hard surfaces, restoring topsoil depth, adding healthy tree canopy, selecting plants to increase biodiversity and habitat value, and naturalization.



Basins
Basins are the preferred type of natural infrastructure to deploy in both rural and urban contexts because of the intensity and magnitude of summer thunderstorms on the Prairies and because of the need for water supply and drought mitigation. Shallow wetlands once dominated the Prairies. Prairie potholes' "fill and spill" characteristics attenuate both snowmelt and rainfall, mitigating flooding, and sustaining flow within watercourses and basins in times of drought. Therefore, conserving and restoring wetlands should be a key water security strategy for the Canadian Prairies.

Rain gardens and bioretention are constructed wetland analogues that can be distributed throughout developed areas, even where space is limited. Constructed wetlands incorporate vegetation that delivers superior performance compared to conventional stormwater ponds. Constructed wetlands for wastewater are used to supplement or replace conventional treatment facilities.

Watercourses

The conservation and restoration of rivers and their floodplains are critical for healthy watersheds across the Prairies, providing multiple benefits to people and ecosystems. Making room for rivers and reconnecting rivers with their floodplains can support flood mitigation, drought resiliency, and water quality. Small streams are particularly sensitive to alterations in the natural cover of their catchments, resulting in a cascade of negative impacts. These impacts are difficult to overcome, particularly in drier parts of the region where natural runoff is minimal and artificial loadings are therefore most significant. Retaining ephemeral and intermittent streams is desirable for their substantial absorptive and treatment capability, but it is critical to ensure loadings do not exceed their capacity. Bioswales are a constructed analogue that can maximize absorptive capacity and treatment compared to conventional ditches and swales.

Groundwater

Many Prairie communities rely on groundwater for drinking water, and groundwater is a growing water supply consideration in the context of climate change. Much of the Prairies is underlain by slow-percolating subsoils, making the protection of more porous groundwater recharge zones crucial to protect water quantity and quality within aquifers. In developed areas, infiltration trenches, basins, and chambers are options to recharge aquifers where subsoils have higher infiltration rates. However, because non-vegetated practices lack habitat value and cannot assimilate sediment (making them more vulnerable to clogging), they are less favoured than vegetated options such as bioretention. Managed aquifer recharge and aquifer storage and recovery are potential practices to replenish aquifers and store groundwater; however, feasibility analyses specific to the Canadian Prairies are needed.

While there is growing evidence that natural infrastructure can support water infrastructure needs while providing an array of co-benefits, there remains a critical need to better monitor and assess benefits and performance specific to the Canadian Prairies. Systems-level approaches for rationalizing investments that consider capital costs, life-cycle requirements, and co-benefits are essential to ensure long-term, effective decision making. Framing the multi-solving potential for natural infrastructure is also important—beyond water benefits, natural infrastructure is well positioned to support interlinked societal challenges, including climate mitigation, biodiversity protection, and health and well-being, among others. Ultimately, equipping community members, decision-makers, and analysts with the necessary tools and guidance to navigate these complexities is key to shaping a sustainable path forward.

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Appendix A. The Curve Number method for runoff estimation

The United States Department of Agriculture (1986) Natural Resources Conservation Service developed the Curve Number method in the 1950s to evaluate runoff generated on unfrozen soils by various cover types. Originally developed to size culverts in rural settings, it remains the most common approach for single-event analysis, typically used in urban contexts for sizing basins for flood control where release rates can provide quick drawdown following storm events. A lower Curve Number means less runoff is generated for a given land-cover type and soil type.

The Curve Number method assigns values from a combination of the hydrologic soil group (ranging from A to D) and the cover type, with modifiers for condition (poor, fair, good) and management practice (e.g., terracing, mowing, grazing). The hydrologic soil group is a classification of runoff potential when thoroughly wet, governed by the saturated hydraulic conductivity of the least transmissive layer, the depth to a more or less impermeable layer or to groundwater, texture, structure, and degree of swelling clays, if present. Class A has the lowest runoff potential, and Class D has the highest. The Canadian Prairies are predominately made up of clayey soils underlain by clayey subsoils, which have the lowest ability to infiltrate and percolate, putting them primarily into the C or D hydrologic soil group. In the Prairies, type A or B hydrologic soil groups are rare and are only encountered in river valleys and other sandy or silty areas associated with glacio-fluvial features.

In this report, the curve number for select land-cover types and soil groups A to D have been used to estimate runoff depth for 25 mm and 100 mm storms. The hydrologic soil groups are listed in Table A1.

Table A1. Hydrologic soil groups for selected cover types

	Hydrologic soil group			
Cover type	**A**	**B**	**C**	**D**
Pavement, roofs	98	98	98	98
72% impervious	81	88	91	93
Fallow with residue	74	83	88	90
Lawn, grazed pasture	39	61	74	80
Straight row crop	63	75	83	87
Hayed meadow	30	58	71	78
Woods with litter	30	55	70	77

Source: Adapted from USDA, 1986.

Appendix B. Natural Infrastructure Benefit Frameworks

Table B1 describes several complementary frameworks and resources in support of natural infrastructure implementation. We have categorized these frameworks according to whether they support benefit identification, accounting, or valuation, as well as by their geographic scope.

Table B1. Frameworks and resources in support of natural infrastructure implementation

Existing approaches	Category (identification, accounting, valuation)	Approach description	Geographic scope
Pacific Institute & CEO Water Mandate's Benefit Accounting of Nature-Based Solutions for Watersheds, Multiple Benefits for Water Projects & NBS Benefits Explorer	Benefit identification	The Multi-Benefit Framework for Decision-Making is a step-based guide to incorporating co-benefits into water infrastructure planning. The approach emphasizes opportunities for public–private partnerships. The NBS Benefits Explorer is a web-based tool designed to quickly identify the potential benefits to be derived from natural infrastructure.	Global/ unspecified
SFU ACT: Accounting for Natural Assets	Benefit identification	This guide explores the co-benefits of different types of natural assets (e.g., aquifers), with a focus on low-carbon development and climate resilience.	British Columbia
GI-Val	Benefit identification	This open-source tool provides a step-based process to identify and value the benefits and co-benefits of green infrastructure. The user guide provides methods for monetary, quantitative, and qualitative benefit identification.	United Kingdom

Existing approaches	Category (identification, accounting, valuation)	Approach description	Geographic scope
Expert Panel on Climate Change Adaptation and Resilience Results	Accounting	This report provides a framework for monitoring progress toward key climate change adaptation outcomes. The report outlines 54 outcome indicators to consider and provides regional stakeholders with guidance for implementing monitoring and evaluation programs.	Canada
Volumetric Water Benefit Accounting	Accounting	A standard approach to evaluating the benefits of corporate water stewardship activities. This approach frames corporate volumetric water objectives in relation to local projected water challenges and policy priorities.	Global/ unspecified
Landscape Architecture Foundation's Landscape Performance System	Accounting	This guide outlines a systematic approach to evaluating the performance of designed landscapes incorporating nature-based elements. The guide also explores 33 benefits categories, each with its own methods for assessing performance.	Global/ unspecified
IISD Sustainable Asset Valuation (SAVi) tool	Valuation	SAVi is a customizable tool that combines financial forecasting with systems modelling to develop a comprehensive evaluation of the costs, benefits, and risks associated with a planned infrastructure project.	Global/ unspecified
Risk and Return On Investment Tool (RROIT)	Valuation	This tool allows asset managers to evaluate the financial risks and investment value of their assets in relation to forecasted climatic changes (such as changes in flood risks).	Canada

Existing approaches	Category (identification, accounting, valuation)	Approach description	Geographic scope
EPA Green Values Strategy Guide and National Stormwater Management Calculator	Valuation	A toolset allowing asset managers to identify and estimate the value of stormwater natural infrastructure in relation to climate, health, and economic benefit categories.	United States
Green Infrastructure Benefits Valuation Tool	Valuation	A quick reference guide to estimating the economic value of various benefits derived from nature-based water management solutions.	United States

Source: Authors.

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