Sustainable Technologies
EVALUATION PROGRAM

Making Green Infrastructure Mainstream:

Improving the business case for green stormwater infrastructure

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Report contributors from CVC:

Kyle Menken	Alexandra Veglio	Asif Bhatti	Rohan Hakimi
Kyle Vander Linden	Amanda Slaght	Shannon Malloy	Phil James

Documents prepared by STEP are available at www.sustainabletechnologies.ca. For more information about this or other STEP publications, please contact:

Kyle Menken
Technician, CVC and STEP
Credit Valley Conservation
1255 Old Derry Road
Mississauga, Ontario
E-mail: kyle.menken@cvc.ca

Kyle Vander Linden
Program Manager, CVC and STEP
Credit Valley Conservation
1255 Old Derry Road
Mississauga, Ontario
E-mail: kyle.vanderlinden@cvc.ca

THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The water component of the STEP is a partnership between Toronto and Region Conservation Authority, CVC, and Lake Simcoe Region Conservation Authority. STEP supports broader implementation of sustainable technologies and practices within a Canadian context by:

- carrying out research, monitoring, and evaluating clean water and low carbon technologies;
- assessing technology implementation barriers and opportunities;
- developing supporting tools, guidelines, and policies;
- delivering education and training programs;
- advocating for effective sustainable technologies; and
- collaborating with academic and industry partners through our Living Labs and other initiatives.

Technologies evaluated under STEP are not limited to physical devices or products; they may also include preventive measures, implementation protocols, alternative urban site designs, and other innovative practices that help create more sustainable and livable communities.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

Much of the stormwater infrastructure in Canada's urban municipalities provides inadequate flood protection and water quality controls. This leaves many of our homes and businesses vulnerable to flooding and degrades our infrastructure, rivers, lakes, and coastal waters. Between 2003 and 2012, **urban flooding** likely caused about $20 billion in damage nation-wide (Kovacs and Sandink, 2013). Insufficient investment in stormwater infrastructure renewal and the predicted effects of climate change are a serious concern for municipalities.

Recognizing the need to improve stormwater management, recent reports have stressed the need to invest in **green stormwater infrastructure (GSI)**,[1] a suite of engineered, at-source stormwater management practices.[2]

GSI (also known as low impact development, or LID) can control **peak flows**, remove sediment and other pollutants from **runoff**, reduce **nutrient pollution**, provide erosion control, and help to restore the natural **water balance**. Stormwater management benefits aside, GSI's potential **co-benefits** include air pollution removal, **urban heat island** reduction, habitat creation, energy savings, and greenhouse gas reduction. GSI facilities can also double as recreational greenspace and raise property values. Practices include **bioretention** in its various forms, **green roofs**, **infiltration chambers**, **exfiltration systems**, **enhanced grass swales**, **rainwater harvesting**, and more.

Many Canadian municipalities have begun building GSI programs. This document describes the efforts of four such organizations through individual case studies. Each organization has financial, environmental, and social reasons for using GSI to address stormwater management in **legacy developments**, urban areas built before flooding or water quality controls became requirements for new development. Each case study presents the GSI solutions developed to address their stormwater management problems—problems that are common to most Canadian municipalities.

1.1 The Case Studies

The Edmonton case study describes the efforts of Edmonton's stormwater utility provider, EPCOR, to combat urban flooding in the city's older neighbourhoods. EPCOR uses GSI as a low-cost method to reduce flood risk. GSI lowers flood risk by keeping stormwater from reaching the piped stormwater system during intense rainstorms, increasing the system's capacity. Edmonton's previous plan to reduce flood risk relied on **grey infrastructure** upgrades and would have cost between $2.2 billion and $4.6 billion over 80 years. EPCOR's plan, in which

[1] See the glossary for definitions of bolded terms.
[2] For example, Insurance Bureau of Canada, 2018; Environmental Commissioner of Ontario, 2016; Institute on Municipal Finance and Governance, 2016; National Oceanic and Atmospheric Administration, 2015; Kovacs and Sandink, 2013.

GSI plays a key role, will cost $1.6 billion over 30 years while reducing risk of floods more effectively.

The Kitchener case study describes Kitchener's systematic plan to steadily and cost-effectively retrofit the city's legacy developments with GSI. This plan sets a target of 12.5 millimetres as the minimum amount of rainfall prevented from entering the stormwater sewer network after a rainfall event. The city set this target for all development and redevelopment projects. Packaging road reconstruction projects with GSI increases total project costs by only four per cent on average.

The Vancouver case study describes Vancouver's Rain City Strategy, which aims to retrofit over 40 per cent of the city's impervious surfaces with **green rainwater infrastructure** by 2050. Meeting this ambitious target would reduce Vancouver's **combined sewer overflows (CSOs)**, reduce potable water use, lower flood risk, and prepare the city for climate change.

The Southdown case study presents the results of a technical and financial feasibility study conducted by Credit Valley Conservation (CVC) in Mississauga's Southdown district. This study examines whether incentivized GSI retrofits on private industrial and commercial properties are a financially feasible alternative to traditional stormwater measures on public property. The results show that GSI retrofits on private property would cost about $208,300 per hectare over a 50-year period, while traditional stormwater management ponds on public property would cost $378,400 over the same time frame. In addition to the cost savings, the GSI retrofits on private property would provide a higher standard of stormwater management and a host of co-benefits.

1.2 Recommendations

Based on our assessment of the four case studies, CVC recommends the following:

- Develop and implement a stormwater master plan supported by a municipal **stormwater charge** and **runoff volume control target (RVCT)**. Developing and implementing a stormwater master plan that is supported by a municipal stormwater charge and RVCT secures annual funding and streamlines the design and construction process. See the **City of Kitchener Case Study** for details.
- Incentivize communal GSI retrofits on private property. Incentivizing communal GSI retrofits on private property is a technically and financially feasible approach for municipalities to improve stormwater management in legacy developments. Building a proof of concept in Mississauga's Southdown neighbourhood is the next step. See the **Southdown Case Study** for details.
- Use GSI on private and public property to augment or replace existing grey infrastructure systems. Municipalities without adequate stormwater management in legacy developments should investigate using GSI on private and public property as a less costly way to improve water quality and reduce flood risk and CSOs. See the
- **City of Vancouver Case** Study for details.

- Combat urban flooding. Municipalities should investigate augmenting their existing stormwater infrastructure with GSI to lower urban flood risk. See the **City Of Edmonton Case Study** for details.

2.0 PURPOSE OF THIS DOCUMENT

The purpose of this guidance document is to:

- improve the **business case** for **green stormwater infrastructure (GSI)**; and
- provide an overview of best practices and innovative thinking from four Canadian municipalities.

This guidance document is meant for municipal decision-makers as well as stormwater design professionals, project managers, contractors, and operations personnel. While each municipality is unique, all municipalities' stormwater issues stem from a set of common problems. This suggests that the challenges can be addressed through a set of common, transferable solutions. The case studies contribute to these solutions. The themes are as follows:

- Systematic approaches to securing annual funding, to streamlining the design and construction process, and to assessing urban flood risk show that GSI can cost-effectively combat **urban flooding**.
- The distributed nature and the design flexibility of GSI's component practices make it a cost-effective solution for retrofitting dense urban environments.
- Bundling multiple GSI projects together or with other infrastructure projects leads to economies of scale.
- Cooperation between municipalities and non-residential landowners leads to better stormwater management outcomes at a lower cost.
- Counting **co-benefits** and working across municipal departments can achieve multiple municipal objectives.

2.1 Structure of this Document

The Introduction provides a brief overview of:

- the risk of urban flooding in Canada's **legacy developments**;
- how stormwater sewer designs affect water quality;
- the benefits and co-benefits of GSI; and
- how private land—and not public lands alone—can be used for GSI retrofits. (**Section 3.0**)

The Common Themes section outlines:

- stormwater management challenges common across Canada;
- how the case study subjects use GSI to address stormwater management challenges; and
- how Edmonton, Kitchener, Vancouver, and Credit Valley Conservation (CVC) are improving the business case for widespread GSI implementation. (**Section 0**)

Each case study has the same structure (see **Figure 1**):

1. It characterizes the stormwater challenges faced by each organization.

2. It shows how each organization:
   - has set objectives to address the stormwater challenges;
   - has devised a cost-effective strategy using GSI to realize these objectives; and
   - is using its strategy.

Figure 1: Common structure for each case study.

This structure follows the decision-making and program-building processes that each organization used to develop their innovative approach to GSI implementation and stormwater management generally.

The Kitchener and Vancouver case studies demonstrate how these municipalities are building effective programs for widespread GSI implementation to meet stormwater management objectives. (**Section 5.0** and **Section 0**)

The Edmonton case study describes the efforts of its stormwater utility provider, EPCOR, to combat urban flooding in the city's older neighbourhoods. (**Section 6.6.0**)

The Southdown case study describes the results of an exploratory technical and financial feasibility study of communal GSI retrofits on aggregating private industrial and commercial properties. This case study primarily examines whether private-property retrofits are less costly than stormwater management on public properties in legacy developments while providing greater or equal levels of service (**Section 8.0**).

The terminology in this report is common to stormwater management and urban design. For non-experts, these terms are bolded the first time they appear in each section of this report. These definitions are also found in teal textboxes in each section. A **Glossary** (**Section 9.0**) at the end of this report defines these terms.

We shorten some longer terms to make them easier to use. Any abbreviation used more than once is listed in the **Abbreviations** section (**Section 10.0**).

The **Citations** section lists all the references used in this report (**Section 11.0**).

3.0 INTRODUCTION

Many of Canada's urban areas were built before stormwater quantity, quality, and **water balance** controls were put in place. As a result, susceptibility to **urban flooding** is widespread and our water resources continue to degrade.

Municipalities face a rising deficit in stormwater infrastructure spending as our stormwater infrastructure ages and reinvestment fails to keep pace (Canadian Infrastructure Report Card, 2016 and 2019; Environmental Commissioner of Ontario, 2016). What's more, daily extreme precipitation is becoming more frequent under all climate change scenarios (Government of Canada, 2019, pg. 155).

Recent years have seen many reports, studies, and guidance documents on **green stormwater infrastructure (GSI)** and stormwater management charges. These describe how communities can use some combination of GSI and stormwater management charges to reduce flood risk, improve water quality, provide **co-benefits** for climate change adaptation, and tackle the deficit in stormwater infrastructure spending (e.g. Insurance Bureau of Canada, 2018; ECO, 2016; Henstra and Thistlethwaite, 2017, National Oceanic and Atmospheric Administration, 2015; and Kovacs and Sandink, 2013).

Water balance accounts for inflow and outflow of water in a system according to the components of the **hydrologic cycle** (precipitation, **runoff**, **infiltration**, groundwater flow, and **evapotranspiration**). Precipitation over natural areas generates low amounts of runoff and high amounts of infiltration and evapotranspiration, while precipitation over urban areas generates high amounts of runoff and low amounts of infiltration and evapotranspiration.

GSI facilities lower runoff by increasing infiltration and evapotranspiration.

Urban flooding, or "pluvial flooding," includes **surface flooding** and **sanitary sewer surcharging**. Urban flooding results from intense or prolonged rainfall in urban areas overwhelming the capacity of the sewer system, causing flooding in low-lying areas.

Green stormwater infrastructure (GSI): a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution. GSI practices manage runoff as close as possible to the source in order to preserve or restore pre-development hydrologic and ecological functions. To preserve pre-development functions, GSI uses site design to minimize runoff and to protect natural drainage patterns. To restore pre-development functions, GSI uses distributed structural practices that filter, **detain**, **retain**, **infiltrate**, **evapotranspire**, and **harvest stormwater**. GSI practices can effectively remove sediment, nutrients, pathogens, and metals from runoff, and they reduce the volume and intensity of stormwater flows. Also known as low impact development (LID).

Co-benefits: positive effects of **GSI** that are not directly related to traditional stormwater management goals. Co-benefits include air pollution removal, **urban heat island** reduction, habitat creation, energy savings, and greenhouse gas reduction.

This document takes a slightly different approach: we examine how municipalities are improving the **business case** for GSI by building effective programs for widespread GSI implementation. In this context, improving a business case means providing financial, economic, or scientific justification for public investment in a project to realize "specific outcomes in support of a public policy objective" (Government of Canada, 2020). The Kitchener, Vancouver, and Edmonton case studies follow this format.

In the public sector, a **business case** is a financial, economic, or scientific justification for public investment in a project to realize "specific outcomes in support of a public policy objective" (Government of Canada, 2020).

The Southdown case study, on the other hand, examines whether retrofits on private industrial and commercial properties cost less than providing equal or greater stormwater management service levels on public properties in **legacy developments**. Led by Credit Valley Conservation (CVC), this technical and financial feasibility study suggests that the economic, environmental, and social benefits of public investment in private property GSI retrofits should proceed to a proof-of-concept implementation study.[3]

Legacy developments are urban areas that were built before quantity or quality controls became requirements for new development in Canada. Typically, legacy developments only have infrastructure to convey stormwater from built-up areas to receiving water bodies.

3.1 Legacy Developments and the Infrastructure Deficit

The type and condition of stormwater infrastructure in urban municipalities in Canada depend on when it was constructed. Urban areas built before the 1940s typically have **combined sewer systems**. These convey both wastewater and stormwater to wastewater treatment plants (ECO, 2016, pg. 7).

By the 1970s, most municipalities had begun building separate stormwater and sanitary sewers, with the stormwater sewers designed to quickly convey rainwater away from roads, homes, and businesses and into receiving waterways, without quality treatment. Also beginning in the 1970s, **peak flow control** for flood

Combined sewer systems collect and convey both stormwater and wastewater. Though **separate sewer systems** use different piped systems for stormwater and wastewater, these two systems can interact through **inflow**

Peak flow control is the reduction of the maximum flow of **runoff** from a drainage area during a storm using stormwater management technologies (e.g. wet ponds, **dry ponds**, GSI). Dry ponds are an open area that can be used to detain stormwater during intense storm events. Dry ponds can have dual purposes; for example, they can be outdoor facilities such as soccer fields, baseball diamonds, public parks, urban forests, and outdoor cultural spaces.

[3] Given that the City of Mississauga would not invest in private infrastructure without a legislative, regulatory, or legal driver, funding for this study will have to come from federal or provincial sources.

mitigation—**dry ponds** and increased pipe capacity—were adopted by some municipalities.

These legacy developments—those constructed without stormwater quality control, quantity control, or both—are the focus for the projects discussed in the case studies.

By the 1990s, most municipalities required that new developments provide quantity control measures to reduce peak flow and erosion as well as quality control measures. The most common measures have been wet stormwater management ponds and **oil and grit separators** (OGSs). More recently, water balance has been added to quality and quantity control requirements, and some municipalities are beginning to put in place distributed, at-source stormwater management, that is, GSI, to re-establish a natural **hydrologic cycle**.

Oil and grit separator: a type of stormwater management technology that treats stormwater primarily by using gravity to remove settleable particles and phase separation to remove buoyant materials (free oils and grease) from water

Hydrologic cycle: the circulation of water from the atmosphere to the earth and back, through precipitation, **runoff**, **infiltration**, groundwater flow and **evapotranspiration**. See **water balance**.

The stormwater infrastructure in much of Canada's urban areas does not meet current regulatory standards. For example, most of the urban area in the Greater Toronto Area (GTA) was built before 1981 (see **Figure 2**). Only 20 per cent of the urban area in the City of Mississauga has both quality and quantity controls, and 59 per cent has no stormwater management controls (Region of Peel, 2017, pg. 79).

In the Toronto and Region Conservation Authority's jurisdiction, 65 per cent of the total developed area lacks stormwater management (TRCA, 2013). In the Lake Simcoe Region Conservation Authority's jurisdiction, 62 per cent of the developed area lacks stormwater management (LSRCA, 2007, pg. 11).

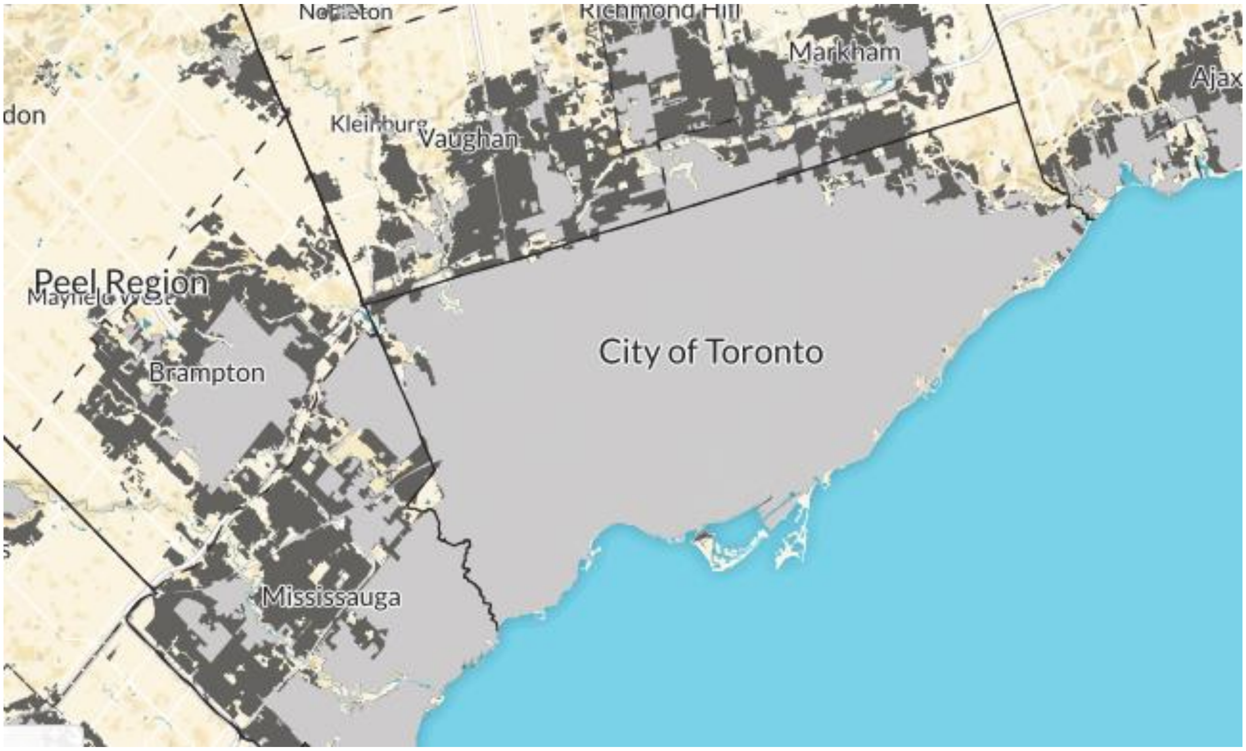


Figure 2: Age of development in the Greater Toronto Area (GTA), Ontario.
Areas shown in light grey were originally built before 1981. Areas shown in dark grey were built between 1981 and 2011. Redevelopment with the urban cores of the GTA has occurred since, with improvements to stormwater management.
Source: Neptis Geoweb, 2020

Municipalities across the country are not investing in renewing infrastructure at a rate that keeps pace with its degradation. Estimates of the Canada-wide "infrastructure deficit" vary between $110 billion and $270 billion (CanInfra Challenge, 2017, pg. 9). The Province of Ontario's *Infrastructure for Jobs and Prosperity Act* and Regulation 588/17 are meant to help Ontario's municipalities begin addressing this deficit. The 2016 Canadian Infrastructure Report Card surveyed Canadian municipalities about the condition of their stormwater infrastructure and reinvestment rates. While the target annual reinvestment rate for stormwater pipes is 1 to 1.3 per cent of the total value of those assets, responding municipalities were only spending, on average, 0.2 to 0.3 per cent. The rate for non-linear assets (e.g. stormwater ponds) was better, with stormwater management facilities seeing average annual reinvestment at 1.4 per cent. But this was still below the 1.7 to 2 per cent recommended (Canadian Infrastructure Report Card, 2016, pg. 89).

Much of the infrastructure that will soon need to be replaced dates from the 1970s and earlier. Achieving the target reinvestment rate to maintain this stormwater infrastructure would only maintain the status quo. Renewing this infrastructure to provide sorely needed improvements in water quantity, quality, and balance is daunting.

The case studies in this report describe how communities across Canada are building wide-scale GSI programs to tackle this infrastructure deficit and to solve environmental problems caused by legacy stormwater infrastructure.

3.2 What GSI Can Do

Wide-scale GSI implementation can mitigate urban flood risk, improve water quality, and prepare Canada's urban areas for climate change by providing multiple co-benefits. In each of the case studies described in this report, GSI forms part of a holistic plan to augment or replace existing **grey stormwater infrastructure** assets.

Grey stormwater infrastructure uses centralized facilities—typically stormwater ponds as well as curbs, catchbasins, and pipes—and does little to re-establish the natural **hydrologic cycle**. In **legacy developments**, grey stormwater systems typically discharge collected stormwater directly into waterways, without quality treatment or quantity control.

3.2.1 Urban Flooding

Flooding due to intense rainfall and inadequate stormwater infrastructure is the most common extreme weather risk confronting Canadian municipalities (IBC, 2018, pg. 10). It has overtaken fire and theft as the leading cause of property and casualty claims (Canadian Institute of Actuaries, 2014, pg. 1). Damage claims from extreme weather events have been rising steadily for decades, according to the Insurance Bureau of Canada (IBC, 2018, pg. 8).

Many people will remember the most catastrophic flooding events—southern Alberta's flooding in the spring of 2013 (about $1.7 billion in insured losses) and the GTA's summer rainstorm that same year (about $1 billion in insured losses). Many other flooding events fly under the national news media's radar. Between 2003 and 2012, urban flooding likely caused $20 billion in damage nationwide. In most years, damage from urban flooding is 10 times that from **riverine flooding** (Kovacs and Sandink, 2013, pg. 3).

Also known as "fluvial flooding," **riverine flooding** occurs when a river overflows its banks, causing water to flow across its flood plain.

Figure 3: Heavy rainfall caused urban flooding in Orangeville on February 20, 2018.
Photo source: James Matthews

Although GSI can't provide the primary means of flood mitigation for all types of flood risk—water volumes associated with riverine or waterfront flooding are often beyond its **retention** and **detention** capabilities—it can help combat urban flooding caused by short-duration, high-intensity storms. In smaller urbanized watersheds, it can also mitigate riverine flood risk.

Retention is the capture of stormwater for filtration, **infiltration**, and **evapotranspiration**. Retained stormwater does not become streamflow or **runoff**. Retaining stormwater helps to restore the natural **water balance**.

Detention is the temporary storage of stormwater to control discharge rates and to allow sedimentation. Detained stormwater eventually becomes runoff or streamflow. Detaining stormwater does not help re-establish the natural water balance. (See definitions for **hydrologic cycle** and **water balance**.)

The Edmonton and Southdown case studies show how GSI can be used to combat urban flooding.

3.2.2 Water Quality: Combined Sewer Overflows and Urban Stream Syndrome

Combined sewer overflows (CSOs) occur when combined sewer systems overflow or when wastewater treatment plants bypass incoming flows. This results in the release of untreated sewage into receiving water bodies. Wastewater plants do this to prevent damage to the plant itself and to prevent sanitary sewer backups and basement flooding.

Between 2013 and 2017, Canada's combined sewers released approximately 786 million cubic metres of untreated sewage into our waterways, averaging 157 million cubic metres annually (Statistics Canada, 2018).

Figure 4: Untreated sewage entering the Red River in Winnipeg, Manitoba.
Photo credit: Marcel Cretain

Simply separating sanitary and stormwater sewers does not solve the problem. Urban streams in municipalities with **separate sewer systems** can still have "urban stream syndrome." Symptoms of urban stream syndrome include "a flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology, and reduced biotic richness, with increased dominance of tolerant species" (Walsh et al., 2005). Poor stormwater management is the primary contributor to these symptoms.

Separate sewer system: areas with a sewer system for wastewater and a separate sewer system for stormwater.

The Vancouver case study showcases an innovative approach to reducing CSOs and improving water quality in urban watersheds through the systematic implementation of GSI. While

Mississauga does not have combined sewers, the Southdown case study shows how GSI retrofits on private property can be a cost-effective tool for decreasing the frequency and extent of CSOs in other jurisdictions.

3.2.3 Counting Co-benefits

GSI, especially vegetated GSI practices, can provide a host of co-benefits: improved air quality, reduced **urban heat island effect**, expanded urban greenspace**, inflow and infiltration** reduction, energy savings, carbon sequestration, and water conservation. Grey stormwater infrastructure does not have these co-benefits.

While all the case studies discuss the co-benefits of GSI, the Southdown case study pays particular attention to quantifying them.

The **urban heat island effect** occurs because urban areas are covered with surfaces that retain heat—concrete, brick, and asphalt. These areas are frequently hotter than surrounding rural or natural areas. Also, because they often have little vegetation, these areas do not benefit from the cooling effects of **evapotranspiration**.

Inflow and infiltration occur when stormwater enters the sanitary sewer system, either through maintenance access holes (inflow) or by entering cracked pipes underground (infiltration).

3.2.4 Bridging the Public–Private Divide

Attempting to improve stormwater management in a legacy development often runs immediately into a barrier: there simply is not enough room on municipally or publicly owned land to manage all the **runoff** that a heavily urbanized area produces. In any given legacy development, up to 85 per cent will be privately owned (CVC, 2021). Working in crowded rights-of-way or publicly owned parks, schools, and municipal facilities may not be possible in a densely developed urban area. Considering private lands as opportunities for GSI retrofits, however, opens a significant portion of the urban land fabric.

Runoff is precipitation that falls on and flows over hard surfaces such as roofs and roads, instead of infiltrating into the ground. Urban runoff carries heavy metals, nutrients, bacteria, and other pollutants into local streams, adversely affecting human, animal, and plant life.

Municipalities would not likely consider funding infrastructure on private property without a legislative, regulatory, or legal driver. However, where such drivers are present, examples from the USA suggest that this is a workable strategy that can result in significant cost savings compared with working on public lands alone (see **Sections 4.2.2** and **8.4.5**). Incentivizing landowners to engage in GSI retrofits also opens the possibility for cost sharing with the private sector and other public agencies, further reducing costs.

The Southdown case study explores the potential of infrastructure on private property in detail, and the Kitchener and Vancouver case studies discuss redevelopment requirements.

3.3 Conclusion

Stormwater management is a young and rapidly evolving field. The detrimental effects of stormwater on water quality were only first recognized in the 1960s and 1970s, after the worst effects of poor wastewater treatment practices were addressed. Stormwater management emerged as its own field in the 1970s. Since then, it has—in infrastructure terms—sped through several distinct phases. The most recent phase, which emphasizes distributed GSI to re-establish natural hydrologic processes, has the potential to be transformative if widely and judiciously applied.

Stormwater management often comes as an afterthought. If the status quo continues, Canadian municipalities run the risk of "sinking billions of dollars into grey infrastructure, instead of green infrastructure; and into disaster clean-ups instead of prevention. For the environment, this means a higher risk of flooding, decreased water quality and degraded habitats" (ECO, 2016, pg. 3).

By looking at how municipalities are building the business case for wide-scale GSI implementation, this document aims to show the potential for improved stormwater management across Canada.

4.0 COMMON THEMES: HOW CANADIAN MUNICIPALITIES ARE IMPROVING THE BUSINESS CASE FOR GSI

Each case study summarizes the economic, environmental, social, and scientific reasoning that each organization followed to determine that investing in wide-scale **green stormwater infrastructure (GSI)** implementation is warranted. Three of the case study subjects—Kitchener, Edmonton, and Vancouver—have adopted innovative policies that rely on wide-scale GSI implementation to achieve their stormwater management objectives. The Southdown case study describes the results of a technical and financial feasibility study on the cost-effectiveness of aggregating private industrial and commercial properties for GSI retrofits.

Green stormwater infrastructure is a stormwater management strategy that seeks to mitigate the impacts of increased **runoff** and stormwater pollution. GSI practices manage runoff as close as possible to the source in order to preserve or restore pre-development **hydrologic** and ecological functions. To preserve pre-development functions, GSI uses design to minimize runoff and to protect natural drainage patterns. To restore pre-development functions, GSI uses distributed structural practices that filter, **detain**, **retain**, **infiltrate**, **evapotranspire**, and **harvest stormwater**. GSI practices can effectively remove sediment, nutrients, pathogens, and metals from runoff, and they reduce the volume and intensity of stormwater flows. Also known as low impact development (LID).

We have grouped the key findings from the case studies under five themes:

Systematic approaches: Securing regular funding and engaging in the master-planning process are two prerequisites for effective, wide-scale implementation of GSI. With funding and a master plan in place, Kitchener has developed methods to compare the cost-effectiveness of GSI types and to streamline its design process. In Edmonton, EPCOR's consequence-based approach to evaluating urban flood risk across the city has led to the development of a cost-effective plan to mitigate flood risk. GSI plays an important role in this plan.

Working in dense urban environments: Attempting to raise stormwater service levels in established urban areas built without water quantity or quality controls runs into an immediate problem: lack of space for end-of-pipe controls. GSI's distributed, flexible, dual-use nature means that it can complement existing land uses. In Southdown, GSI retrofits on private property optimize developable space and achieve better stormwater management outcomes while costing much less than end-of-pipe measures on public property. In Vancouver, the Rain City Strategy aims to augment its existing grey infrastructure with **green rainwater infrastructure (GRI)** to extend the lifespan and increase the capacity of the city's grey infrastructure.

Green rainwater infrastructure (GRI) is a suite of rainwater management tools that use both engineered and nature-based solutions to protect, restore, and mimic the natural **water cycle**. This is the term the City of Vancouver uses for GSI.

Building economies of scale: Bundling GSI with other infrastructure projects, particularly road reconstruction projects, reduces GSI project costs. Since adopting a **runoff volume control target (RVCT)** of 12.5 millimetres, Kitchener has completed several road reconstruction projects that included GSI. Adding GSI to these projects increased costs, on average, by only four per cent. Vancouver is strategically retrofitting the Cambie Corridor neighbourhood, which presents an excellent opportunity to package multiple GRI projects with other infrastructure renewal initiatives.

Bridging the public–private divide: Retrofitting **legacy developments** to bring sorely needed quantity and quality controls will require the private and public sectors to work together. The Southdown case study shows that GSI retrofits on private industrial and commercial properties are more cost-effective than building new stormwater ponds. This suggests that offering adequate incentives for private-property retrofits should be further investigated through a proof-of-concept implementation study.

Co-benefits and shared objectives: GSI provides multiple benefits aside from meeting stormwater objectives. Planning, building, and operating GSI to optimize these benefits requires input from and participation across municipal departments, as seen in the Kitchener, Edmonton, and Vancouver case studies. The Southdown case study explores the **co-benefits** of renaturalization and tree plantings in **enhanced grass swales**.

The stormwater objectives and strategies to achieve them differ between case study subjects. See **Table 1** for summaries of the main challenges, strategies, and costs and benefits of each case study's GSI plans.

A **runoff volume control target (RVCT)** requires that stormwater systems capture and retain the first portion of precipitation from a rainfall event (e.g. 12.5 millimetres). This keeps the rainwater from entering the piped storm sewer network as runoff.

Legacy developments are urban areas that were built before quantity or quality controls became requirements for new development in Canada. Typically, legacy developments only have infrastructure to convey stormwater from built-up areas to receiving water bodies.

Co-benefits: positive effects of **GSI** that are not directly related to traditional stormwater management goals. Co-benefits include air pollution removal, **urban heat island** reduction, habitat creation, energy savings, and greenhouse gas reduction.

Enhanced grass swales are vegetated open channels designed to convey, treat, and attenuate stormwater **runoff**.

Table 1: Summary of the main challenges, strategies, and costs and benefits of each case study

Site	Main challenges	Strategies	Costs and benefits
Kitchener	• Addressing a 75% stormwater infrastructure gap across the city • Improving municipality-wide stormwater infrastructure level of service • Reducing impacts of stormwater on receiving streams to benefit ecological and human health	• Using a stormwater charge and credit program • Developing an Integrated Stormwater Management Master Plan (ISWM-MP) and coupling this with an implementation plan • Implementing a city-wide RVCT of 12.5 millimetres for new and redevelopment projects • Applying stormwater fees to redevelopment if RVCT is not met or only partially met • Allocating budget for GSI to road reconstruction and resurfacing projects • Coupling GSI with road reconstruction projects • Developing design standards for GSI and systematic implementation processes • Including GSI in road standards and development manuals	• Bundling GSI with road reconstruction projects adds only 3–6% to the total project cost • Meeting the RVCT through redevelopment is often less costly than paying a stormwater fee • Sharing cost of improving stormwater management level of service city-wide by municipality and private development by using RVCT and stormwater fees • Providing co-benefits of GSI
Edmonton	• Reducing flood damages from short-duration, high-intensity storms	• Focusing on risk reduction rather than meeting design standards • Systematically evaluating flood vulnerability across the city • Engaging residents through surveys to rank priorities	• Using GSI and dry ponds for flood-risk mitigation is less costly than upgrading the city's grey infrastructure system • Providing co-benefits of GSI

Site	Main challenges	Strategies	Costs and benefits
Vancouver	• Combatting aging and undersized infrastructure and older drainage systems that result in combined sewer overflows • Managing large quantities of rainwater runoff in a dense urban area • Capturing and cleaning 90% of rainwater to improve water quality and reach the goal of becoming greenest city in the world	• Developing Rain City Strategy—this has the support of the Vancouver City Council and has goals for all land uses • Developing budget strategy where developers contribute funds when infrastructure upgrades are required	• Combining grey and green infrastructure upgrades to meet common goals and save on costs • Sharing cost and responsibilities for wide-scale implementation of GRI among city staff and private developers • Providing co-benefits of GRI
Southdown	• Sharing the cost of retrofitting legacy development between the public sector and private property owners • Incentivizing GSI retrofits on private property to lower payback periods for commercial and industrial landowners • Dedicating space in a dense urban environment for centralized stormwater management facilities	• Aggregating private commercial and industrial properties for communal GSI retrofits • Cost sharing among benefiting stakeholders	• Saving money through communal systems on private property, which are more cost-effective than centralized stormwater management • Providing significant co-benefits and improved stormwater management outcomes resulting from communal implementation of GSI on private property

Abbreviations: GRI, green rainwater infrastructure; GSI, green stormwater infrastructure; ISWM-MP, Integrated Stormwater Management Master Plan; RVCT, runoff volume control target.

4.1 Systematic Approaches

There are several prerequisites to building an effective program for wide-scale GSI implementation. Without dedicated, long-term funding, GSI projects will only occur sporadically, when funds become available. The master-planning process is equivalent, in part, to developing a business plan for stormwater infrastructure renewal generally and GSI implementation more particularly. Without a master-planning process, GSI projects will be opportunistic rather than strategic stormwater interventions.

4.1.1 Dedicated Funding

Financing for stormwater management capital projects and operations typically comes from a municipality's general funds. When a cash-strapped municipality evaluates its funding priorities, stormwater management initiatives compete with education, emergency services, transportation, and social services. As a result, stormwater management often does not receive the level of funding necessary to maintain—much less raise—service levels. This shortfall in funding contributes to a stormwater infrastructure deficit (see the .

Introduction).

Stormwater charges are an annual fee charged to landowners by municipalities. The charges are for providing stormwater services. Stormwater charges are separate from general property taxes and provide a dedicated revenue source for maintaining, operating, and revitalizing stormwater infrastructure.

Before municipalities can implement any systematic approaches to raising stormwater infrastructure levels of service, they need to address this funding shortfall. In one way or another, all four case study subjects dedicate annual funding to stormwater management initiatives. Edmonton, Mississauga, and Kitchener have separated **stormwater charges** from general property taxes, and charge property owners a specific fee for stormwater services. Vancouver will secure funding from newly dedicated development charges for stormwater infrastructure in 2022.

The case studies show that a committed funding source is a prerequisite for maintaining and upgrading their stormwater systems. The City of Kitchener found that dedicated GSI funding avoided potential interdepartmental competition because the budget for municipal stormwater management is clearly outlined. This ensures GSI projects get off the ground without conflict, saving time and money.

Several recent reports and studies outline the importance of stormwater charge programs and how to design one (e.g. ECO, 2016; Sustainable Prosperity Institute, 2016). Without dedicated funding, the program development and long-term planning necessary to realize operational efficiencies are not possible. **Table 2** shows the 21 communities in Canada that had working stormwater charge programs in 2016 (Sustainable Prosperity Institute, 2016, pg. 40). Since 2016, six Ontario municipalities (**Table 3**) have developed stormwater charge programs, making a total of 13 in that province. Although this proportion is low—Ontario has 414 lower-tier and single-tier municipalities—the trend toward stormwater charges is growing.

Table 2: Canadian communities with a stormwater charge in 2016

#	Community	Province
1	Halifax	Nova Scotia
2	London	Ontario
3	Aurora	Ontario
4	Saint Thomas	Ontario
5	Kitchener	Ontario
6	Mississauga	Ontario
7	Richmond Hill	Ontario
8	City of Waterloo	Ontario
9	Regina	Saskatchewan
10	Saskatoon	Saskatchewan
11	Calgary	Alberta
12	Edmonton	Alberta
13	Saint Albert	Alberta
14	Strathcona County	Alberta
15	Langley	British Columbia
16	Pitt Meadows	British Columbia
17	Richmond	British Columbia
18	Surrey	British Columbia
19	Victoria	British Columbia
20	West Vancouver	British Columbia
21	White Rock	British Columbia

Source: Sustainable Prosperity Institute, 2016, pg. 40

Table 3: Ontario municipalities that adopted stormwater charge programs since 2016

#	Community
1	Brampton
2	Guelph
3	Markham
4	Newmarket
5	Ottawa
6	Vaughan

After developing a funding program, three of the case study subjects began and completed a stormwater master plan. These plans detail how these funds are to be spent and the systems for gaining interdepartmental support, for studying the issues, and for prioritizing stormwater infrastructure strategies and projects.

4.1.2 Benefits of Master-Planning Processes

Municipality-wide stormwater management plans underlie the initiatives discussed in the Kitchener, Edmonton, and Vancouver case studies. Enacting a master-planning process—characterizing the existing drainage system and its problems, setting objectives for maintaining and improving it, evaluating strategies to accomplish these objectives, and planning to employ that strategy—provides a decision-making framework that enables cost-effective resource allocation.

4.1.2.1 Moving Beyond Pilot Projects: Design, Construction, and Maintenance Standards

As a newer method for managing stormwater, early GSI projects in Canada served to test the technology in a northern climate, to familiarize municipal staff, to educate the public about stormwater management, and to beautify public spaces. As a result, these pilot facilities tended to be high-profile, overdesigned projects in public spaces, with high retrofit, design, project management, and communications costs. Initially unfamiliar with the technology, designers, contractors, and project managers made costly mistakes as they learned about GSI.

The Kitchener case study shows how experience gained from pilot projects can help devise a cost-effective program for widespread GSI implementation. Kitchener implemented a city-wide RVCT of 12.5 millimetres, identified road reconstruction and resurfacing projects to meet the RVCT, developed a corresponding project schedule and budget, identified appropriate GSI types for meeting the RVCT and other design objectives in a cost-effective manner, and laid out a plan to integrate and standardize designs in their development manual. These standardized designs, along with project-specific feasibility studies and conceptual design reports, streamline the design and engineering process. This lowers related costs and reduces the likelihood of expensive errors.

After adopting its RVCT, Kitchener evaluated how to meet this target in the most cost-effective manner. Road reconstruction projects can meet the target using various types of GSI, with some costing less than others. Kitchener defaults to **exfiltration trenches** over **permeable pavements** or **bioretention** for its road reconstruction projects because the cost per hectare for exfiltration trenches is $100,000 versus $1.6 million for permeable pavers or $200,000 for bioretention (see **Table 7**).

Exfiltration trenches are a type of GSI practice where surface **runoff** is collected via drainage inlets and delivered to a perforated pipe. This pipe is usually surrounded by gravel, from where the water **infiltrates** into the surrounding soil.

Permeable pavements are a type of GSI practice that allows precipitation to **infiltrate** through surface pores (permeable asphalt and concrete) or through joints between pavers.

Bioretention is a type of GSI practice that uses soil and vegetation to capture, filter, **infiltrate**, and **evapotranspire** stormwater. Bioretention practices vary in complexity based on soil types, design objectives, and available resources, from simple landscaped depressions to complex systems with impermeable liners, gravel storage layers, special soil mixtures, and underdrains.

Standardized designs help operations staff with their inspection and maintenance activities. If each facility type has the same features, staff know what to expect, what might go wrong, and how to keep the facilities operational. EPCOR, Edmonton's stormwater utility provider, is following Kitchener's lead and investigating design standards. EPCOR also plans to open a "GSI university" to familiarize operations staff with built examples of selected GSI measures and how to maintain them.

4.1.2.2 Re-thinking Flood Mitigation: Risk Reduction vs. Meeting a Specific Design Standard

When EPCOR started operating Edmonton's drainage services in 2017, it began work on its Stormwater Integrated Resource Plan (SIRP). SIRP's focus is to reduce urban flooding, which is a major problem in Edmonton's older neighbourhoods. Approved in May 2019, the capital investment plan calls for spending $1.6 billion over 30 years to lower the risk of urban flooding to acceptable levels in the city's highest-risk **subbasins**. The plan uses both GSI and traditional grey infrastructure. The previous City-Wide Flood Mitigation (CWFM) plan relied almost exclusively on grey infrastructure and would have cost between $2.2 billion and $4.6 billion and taken 80 years to implement. Adopting SIRP led to Edmonton's flood preparedness ranking increasing from a "C" in 2015 to a "B+" in the Intact Centre's 2021 ranking of Canadian cities' flood preparedness (Feltmate, B. and M. Moudrak, 2021).

Subbasins are urban areas that drain stormwater to a single trunk sewer or outlet.

The main difference between the two approaches—SIRP and the CWFM plan—lies not in the use or exclusion of GSI, but in the methodology used to arrive at objectives for their respective plans. Municipalities typically manage flooding using a hazard-based model, where a specific design standard—a 1:50-year or a 1:100-year storm—is used to direct resources to areas that do not meet that design standard. This approach does not consider the consequences of 1:10- or 1:25-year storms, for example. Susceptibility to flooding does not necessarily mean that flooding will cause damage (Henstra and Thistlethwaite, 2017, pg. 2).

What is a 1-in-100-year storm? It's a designation that says that precipitation of a certain depth (say, 90 millimetres) and over a certain duration (say, four hours) has a one per cent chance of occurring in a location in any given year. This is called a return period and is expressed as a ratio (e.g. 1:5, 1:10, 1:100). Historical data determine the return periods for storms in a given area.

Depending on the type of storm, the affected area can be relatively small. If a storm lasts a short time, it's referred to as a high-intensity convection storm. EPCOR used this type of storm to create risk rankings for SIRP—one part of a city can receive precipitation depths predicted for a 1:200-year storm, and another part of the city only kilometres away might not receive any rainfall.

When engineers design stormwater infrastructure to manage a storm with a particular return period—say a 1:100-year storm—it is called a design storm. Stormwater infrastructure in many urban areas across Canada can only handle 1:10-year storms or less (called the "minor system"). Overland flow routes to safely convey flows caused by storms with a higher return period (called the "**major system**") and stormwater ponds for quality and volume control only became standard across Canada in the 1980s and 1990s. In Edmonton, this shift occurred in 1989 (EPCOR 2018a, pg. 2).

The previous CWFM plan sought to renew stormwater infrastructure in legacy developments to meet a specific design standard. In comparison, SIRP seeks to reduce risk in Edmonton's most vulnerable subbasins to acceptable levels. To do this, EPCOR risk-ranked the 1,300 subbasins in Edmonton's legacy developments using a five-step process:

1. Determine storm scenarios and plot them on a likelihood scale using five return-period storms (1:20, 1:50, 1:75, 1:100, 1:200).
2. Gather information (modelling reports, insurance industry maps, 311 calls reporting basement flooding, etc.) to determine the likelihood of each type of flooding for each subbasin based on the current capacity of its stormwater infrastructure.
3. Evaluate the condition of existing stormwater assets and adjust risk-rankings accordingly.
4. Use capacity indicators to rank each subbasin's flood risk in four impact categories: health and safety, environmental, social, and financial.
5. Conduct public opinion research to develop weightings for each of the four impact categories.

Steps 1 and 2 determine the flooding hazard; that is, the likelihood that a storm will occur and result in flooding. Steps 3 through 5 relate this hazard risk to its potential consequences; that is, whether or not the hazard will result in negative effects for property, infrastructure, and Edmonton's residents. The resulting risk-rankings allow EPCOR to direct resources to subbasins where flood risk is highest, rather than uniformly across Edmonton's legacy developments.

EPCOR's emphasis on reducing risk rather than meeting a specified design standard allows it to augment, rather than replace, targeted portions of Edmonton's existing drainage system. GSI plays a key role in this augmentation plan. By capturing the first 25 to 35 millimetres of rain dropped by an intense storm, GSI can turn peak flows associated with a 1:20-year storm into those associated with a 1:10-year storm, a 1:50-year storm into a 1:20-year storm, and so on. GSI's retention capacity alone can significantly reduce flood risk and potential damage to the many subbasins in Edmonton that are at risk from these more frequent storms. GSI practices can also detain the smaller amounts of precipitation that fall at the edge of a storm, increasing available sewer capacity in the storm's immediate path.

Dry ponds are open areas that can be used to detain stormwater during intense storm events. Dry ponds can have dual purposes; for example, they can be outdoor facilities such as soccer fields, baseball diamonds, public parks, urban forests, and outdoor cultural spaces.

Runoff: rainwater that flows over hard surfaces such as roofs and roads as runoff instead of **infiltrating** into the ground. Urban runoff carries heavy metals, nutrients, bacteria, and other pollutants into local streams, adversely affecting human, animal, and plant life.

The 30-year plan allocates $470 million from its $1.6 billion budget to GSI measures and $470 million to **dry ponds**. Both measures will detain **runoff**, slowing it before it reaches the city's existing pipe system. While the plan allocates $300 million to pipe upgrades, EPCOR's analysis found that using GSI and dry ponds to keep water from the existing piped network is less costly than upgrading the piped network itself. For these reasons, EPCOR adopted a "move where you must, slow where you can" approach.

4.2 Working in Dense Urban Environments

Legacy developments typically lack the space for traditional end-of-pipe measures. Public and private lands in these areas are also already in use for myriad purposes.

The distributed, flexible nature of GSI practices allows for easy integration into established urban areas. To illustrate, bioretention facilities can double as amenity spaces and pleasing gardens and as stormwater management source controls (see textbox "Performance Under Pressure: Bioretention on Elm Drive in Mississauga"); subsurface **infiltration chambers** can safely underlie driveways, and parking lots provide stormwater quantity control; and **green roofs** add stormwater functionality to otherwise underused space.

Infiltration chambers: underground storage chambers that are designed to capture large volumes of stormwater. They reduce flood risk and allow precipitation, such as rainwater and snowmelt, to get under and **infiltrate** below hard surfaces, such as parking lots.

Green roofs are a thin layer of vegetation and growing medium installed on top of a conventional flat or sloped roof for capturing and treating stormwater. Also referred to as living roofs or rooftop gardens.

This dual-use flexibility augments the **business case** for GSI on three levels:

- At the lot level, GSI is often the lower-cost option for retrofits where redevelopment policies set specific stormwater targets.
- At the neighbourhood level, municipalities do not need to dedicate large parcels of valuable land to centralized end-of-pipe facilities. Instead, they can take a less costly decentralized approach that uses public and private lands (as shown in the Southdown case study).
- At the watershed or municipality level, municipalities can delay or avoid expensive sewer system upgrades through strategic GSI retrofits.

In the public sector, the term **"business case"** means giving a financial, economic, or scientific justification for public investment in a project to realize "specific outcomes in support of a public policy objective" (Government of Canada, 2020).

Performance Under Pressure: Bioretention on Elm Drive in Mississauga

CVC, working with the Peel District School Board and the City of Mississauga, implemented a bioretention facility at an adult education centre on Elm Drive in Mississauga, Ontario. Since the site became operational in May 2011, CVC has monitored it extensively.

On July 8, 2013, an intense rainstorm across the Greater Toronto Area caused nearly $1 billion in insured damages (Insurance Bureau of Canada, 2019). Although CVC designed the facility for water quality treatment, not for peak flow control, the Elm Drive bioretention facility did a good job of handling 105 millimetres of rainfall over five hours. The facility reduced peak flows by 60 per cent and attenuated peak flows by 20 minutes, providing significant relief to the downstream stormwater system (CVC, 2013).

Bioretention design in North America has gone through several phases, with earlier designs focusing on water quality treatment and runoff volume reduction. After initial practice development, bioretention practitioners have altered the design principles to provide greater peak flow reduction and attenuation by adding subsurface storage, increasing ponding depths, and increasing the volume of soil media.

4.2.1 Lot-Level Savings: Dual Uses and Grey–Green Cost Comparisons

Typically, the drainage area of a permeable pavement parking lot equals its surface area. Because a permeable pavement lot only provides stormwater control for its own surface area, it may appear to be less cost-effective than other GSI practices that have larger surface area to drainage area ratios. But the more accurate way to understand the relative cost difference is to calculate the cost difference between a permeable pavement lot and a traditional asphalt or concrete parking lot plus added facilities for equivalent stormwater functionality (see **Table 7** for a comparison of the cost-effectiveness of three GSI types in the City of Kitchener case study).

The City of Kitchener retrofitted the Huron Natural Area in 2015–2016. Replacing the existing parking lot was a key part of the revitalization plan (**Figure 20**). The cost to construct the permeable paver parking lot was $65,000. The estimated cost to construct a traditional asphalt parking lot instead was $41,000. But with a $35,000 **oil and grit separator** (OGS), the cost of the asphalt parking lot would have risen to $76,000. In other words, while the permeable paver parking lot would cost approximately $23,000 more than the traditional lot alone, building an asphalt lot and managing its stormwater with an OGS would have cost an additional $12,000.

If the stormwater management option for this parking lot was, for example, a bioretention garden, the same point would apply.

4.2.2 Neighbourhood-Level Savings: Distributed vs. Centralized Stormwater Management in Southdown

Figure 5 and **Figure 6** show two design scenarios for retrofitting a legacy development in Mississauga's Southdown district. One uses end-of-pipe wet ponds on public property **(Figure 5**) and the other uses GSI on private property (**Figure 6**).

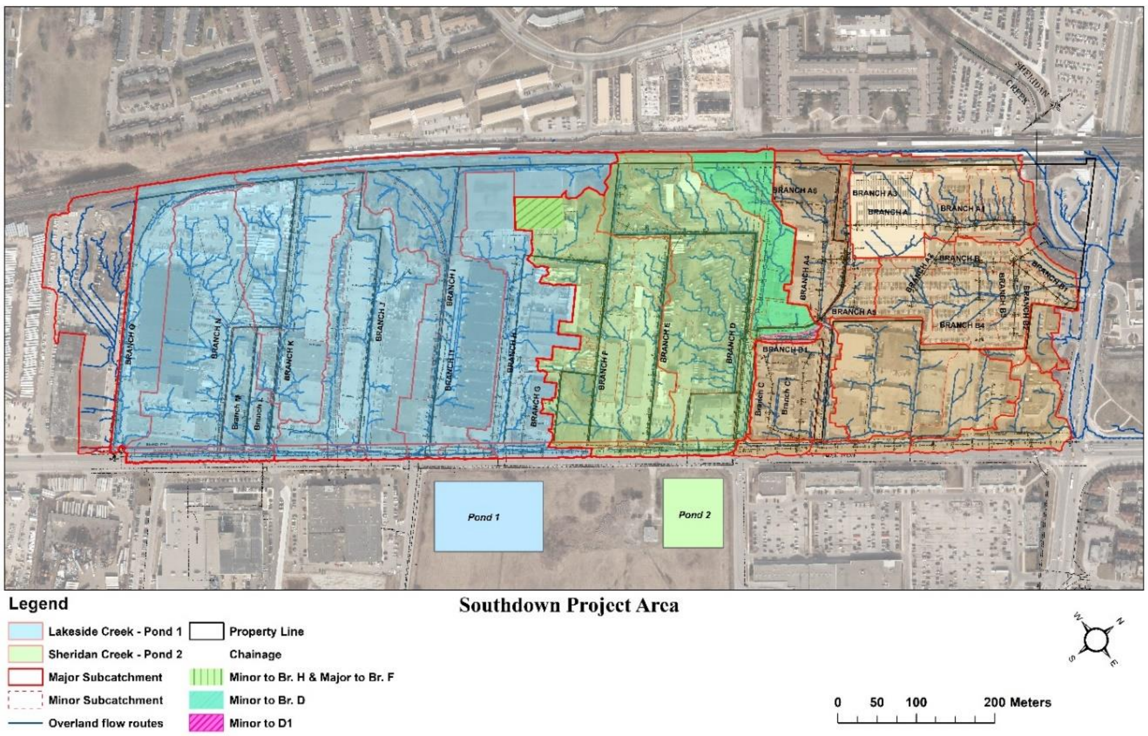


Figure 5: Plan of the public property design scenario from the Southdown case study.
The proposed location for the stormwater ponds in this design would occupy what is currently privately owned vacant land.

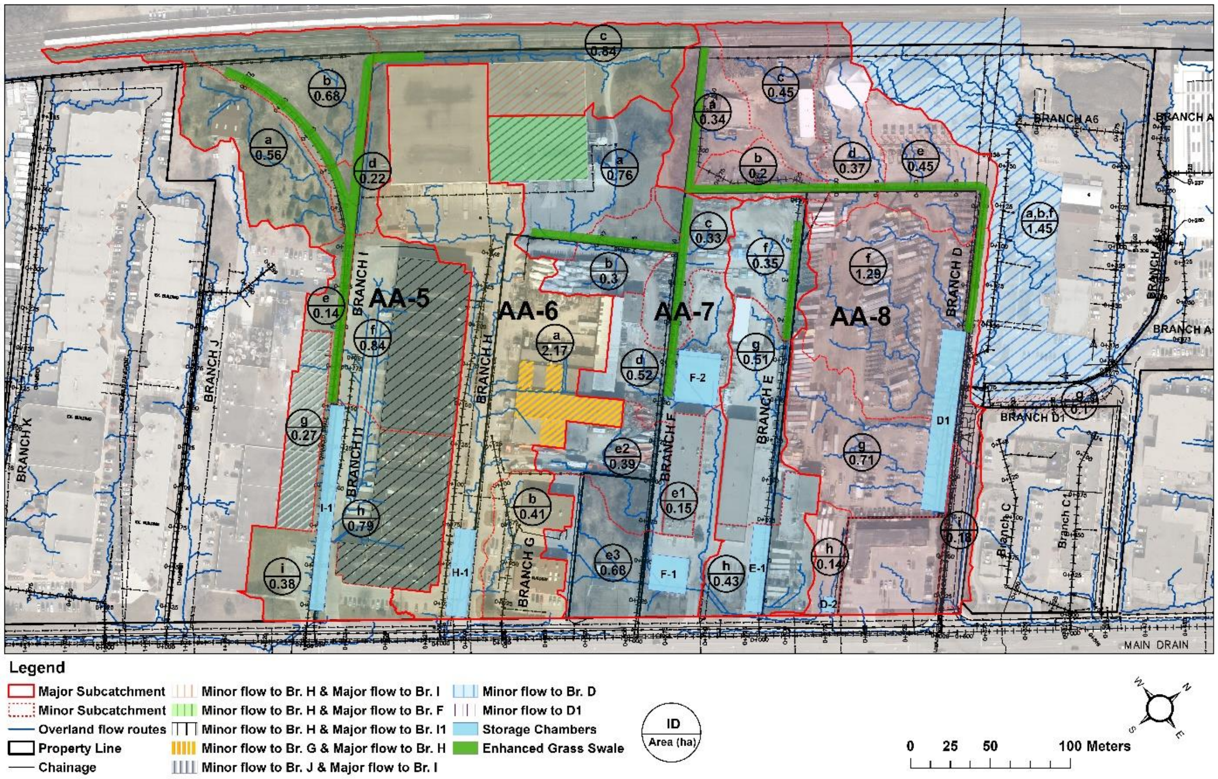


Figure 6: Plan of the private property design scenario from the Southdown case study.
The chambers (in blue) and the enhanced grass swales (in green) were carefully placed to accommodate current and future land uses.

The private property design scenario (**Figure 6**) was carefully constructed to accommodate current land uses and potential future development. The infiltration chambers can be safely positioned under existing parking lots and driveways, and the enhanced grass swales can be built along overland flow routes that already convey stormwater. Where possible, the design team straddled infiltration chambers that service multiple properties along property lines. Setback requirements preclude new building in these areas, so the design uses these otherwise non-functional spaces for stormwater management.

Opportunity costs are the foregone economic or financial gains from selecting one alternative from a set of mutually exclusive options.

The public property scenario (**Figure 5**) uses an end-of-pipe facility constructed on vacant land and is meant to provide a benchmark for comparison with the private property scenario. In this case, the land would have to be acquired for building a new pond,[4] but the same point applies given the **opportunity cost** of building new end-of-pipe stormwater management facilities on municipally owned land. From an economic standpoint, it does not matter whether the municipality owns the land or needs to buy it. The value of the land is what

[4] The City of Mississauga does not plan to acquire the lands identified in Figure 5 for the design scenarios discussed in the Southdown case study.

matters. Using land for stormwater management foregoes the opportunity to sell it or use it for another purpose.

Building new stormwater ponds in legacy developments takes up valuable land that could otherwise be used for new businesses, homes, or parks. In some cases, stormwater ponds can be integrated with existing parks or other recreational facilities. However, for the most part, stormwater ponds only serve one function.

The decentralized, flexible nature of at-source GSI measures means that it is not always necessary to dedicate larger areas to stormwater management ponds. Comparing the costing of the public and private property design scenarios in the Southdown case study puts a monetary value on this difference. While retrofitting the study area using GSI on private property would cost $274,200 per hectare in capital costs, it would cost $320,000 per hectare to provide an equivalent level of stormwater management using wet ponds on public property.

Land acquisition costs for the public property design scenario amounted to 84 per cent of its total capital costs. For the private property design scenario, we estimated land values for the GSI facilities using methods employed by drainage engineers in Ontario. This amounted to 34 per cent of the total capital cost for the private property design scenario (**Table 4**).

Table 4: Comparison of per-hectare capital cost between the private property and public property design scenarios*

Scenario	Capital costs† ($)	Land costs ($)	Land costs as a percentage of capital costs (%)
Private / communal GSI	274,200	91,900	34
Public / end-of-pipe facilities	326,000	274,600	84

Abbreviation: GSI, green stormwater infrastructure.
* Because the drainage areas for the two scenarios differ, the costs are per hectare. This table features capital costs only.
compares the scenarios for life-cycle costs.
† Construction, land, design, and administration.

Why the difference in land values? For the public property scenario, larger land areas need to be purchased (see **Figure 5**). For the private property design scenario, GSI is either implemented subsurface or as enhanced grass swales that run along the perimeter of affected properties (see **Figure 6**). In other words, the GSI facilities are compatible with existing land uses: the chambers would be positioned underneath parking lots, and the enhanced grass swales would be retrofits of existing swales that currently convey stormwater.

Also, the GSI facilities proposed in the private property design scenario were placed to allow for future development. In any event, if any of these properties redevelop, they would need to provide both peak flow reduction and water quality treatment for stormwater, according to the City of Mississauga's current development requirements.

This reasoning leads to a larger point about land uses, land values, and improving stormwater management in established urban neighbourhoods. Building new stormwater ponds in legacy developments takes up valuable space that could be used for some other purpose, while retrofitting existing properties with GSI does not, at least not to the same extent. Using design standards from Ontario's Ministry of the Environment, Conservation and Parks, providing erosion control, volume control, and enhanced water quality treatment using stormwater ponds would take up as much as 10 per cent of an urban area's total footprint, depending on the imperviousness of each pond's drainage area (see **Table 5**). When land values are at a premium in intensifying Canadian cities, the opportunity costs from building new stormwater ponds in established urban areas are enormous.

Table 5: Analysis of how much land is required to manage highly impervious drainage areas using wet ponds

Drainage area (80% impervious)	10 ha	20 ha	30 ha	40 ha
Required area for pond (ha)	0.85	1.21	1.53	1.82
Pond footprint (% of total)	8	6	5	4

Abbreviation: ha, hectare.

4.2.3 Municipal-Level Savings: Augmenting Aging Infrastructure in a Dense Urban Environment

Vancouver estimates the replacement value for its sewer and drainage infrastructure at $6.1 billion in 2018 dollars. Recent assessments show that 23 per cent of this infrastructure is in poor or very poor condition. While separating combined sewers across the city is a long-term goal, the near-term plan is to augment the existing system with green rainwater infrastructure (GRI). GRI will keep rainwater from entering the sewer system, increasing its capacity and extending its lifespan. This avoids or delays costs by avoiding or delaying expensive sewer upgrades until they can be packaged with other infrastructure renewal programs—for example, upgrades to the drinking water system or road reconstruction projects. As noted in the Cambie Corridor Plan, "[T]he extent of upgrades that will be required to the conventional sewer network will depend on the amount of stormwater that can be managed through alternative green infrastructure strategies" (City of Vancouver, 2018a, pg. 239).

4.3 Building Economies of Scale

Kitchener has shown that bundling GSI with road reconstruction projects results in an overall four per cent increase in total project costs. Vancouver's strategic retrofit program presents an opportunity to package multiple GSI projects together in the city's growth areas.

4.3.1 The Incremental Cost Increase of Bundling GSI with Road Reconstruction

Since adding GSI to its road-retrofit program to meet the 12.5-millimetre RVCT, Kitchener's total road reconstruction costs have increased by three to six per cent. The relative cost increase—the cost of meeting the RVCT minus the cost of traditional stormwater management infrastructure (catchbasins and pipes, in this case without treatment facilities)—most accurately compares the grey and green options (**Table 9**). (See comparing costs between grey and green options for the Huron Natural Area in **Section 4.2.1** and **Section 5.5**.) The cost of six road reconstruction projects in Kitchener in 2018 totalled $16.5 million. The total GSI costs amounted to $700,000.

Bundling road retrofits and GSI into single projects is cost-effective: the equipment needed to build a GSI facility is already on site, a single contractor can complete both projects, and so on. Seeing the value in bundling road reconstruction with GSI implementation, EPCOR has partnered with Edmonton's Building Great Neighbourhoods program to coordinate their respective infrastructure renewal projects.

4.3.2 Packaging Multiple GRI Projects Together

Vancouver's Rain City Strategy contains a well-thought-out plan to build the necessary capacity to scale up GRI implementation from individual, site-by-site pilot projects to district- or neighbourhood-wide projects. Cambie Corridor, one of the city's major growth areas, will be a test case for Vancouver's Strategic Retrofits Green Rainwater Infrastructure Program (City of Vancouver, 2019b, pg. 121). The city has begun an options analysis for the corridor and will conduct cost-benefit analysis of the identified options.

Given that Vancouver aims to strategically retrofit 10 per cent of the city's surfaces with GRI by 2050 (City of Vancouver, 2019b, pg. 121), growth areas like the Cambie Corridor present an opportunity to package multiple GRI projects together. This could result in significant cost savings (P3 Great Lakes, 2017). In four jurisdictions in the USA—Philadelphia, New York, Portland, and Milwaukee—savings from large-scale GRI implementation ranged from 40 to 96 per cent, with budgets ranging from US$9 million to US$3 billion.

Similarly, the Southdown case study examines aggregating multiple private properties for communal GSI retrofits. This approach lowers costs in two ways. First, a lot-by-lot approach multiplies the number of facilities needed to manage the same amount of stormwater. Using one set of infiltration chambers to service, for example, three properties is less costly than building a facility for each property. Second, packaging these retrofits into a single project realizes economies of scale.

4.4 Bridging the Public–Private Divide

In most urban areas, runoff from private properties finds its way into a municipal stormwater system, which carries it to a treatment and storage facility or directly into a receiving water body. Put another way, municipalities provide stormwater services using infrastructure on property that they own. However, as discussed in the Introduction and the Southdown case study, lack of space in legacy developments prevents this approach.

To overcome stormwater challenges in legacy developments, all the case study subjects include initiatives on private property as part of their stormwater management strategy. They do this for two reasons. First, to share the burden of improving stormwater management in legacy developments, private sector participation is needed. Second, GSI retrofits on private property are often less costly than equivalent measures on public property due to availability of space.

4.4.1 Redevelopment Policies

While each of the case study subjects requires new developments and redevelopments to include at-source stormwater controls, the Kitchener and Vancouver case studies investigate this theme in detail.

Kitchener's Integrated Stormwater Management Master Plan (ISWM-MP) Implementation Plan requires all development and redevelopment projects to meet the 12.5-millimetre RVCT. Developments that fail to meet this target must pay a one-time fee, set at $100,575 per hectare in 2019. This fee allows the city to implement compensatory measures elsewhere. If a parcel of land provides some runoff control but does not meet the target, the site's owner must pay a portion of the fee.

It's generally less costly for developers to build GSI controls than to pay the stormwater fee. In the case of the Homer Watson Boulevard redevelopment and the Seabrook Drive development projects, their savings amounted to $35,000 and $150,000, respectively. Without implementing GSI, their fees would have been $170,000 and $290,000. What's more, each of these properties now qualifies for the stormwater credit program, resulting in additional annual savings (**Table 10**).

Vancouver's Rain City Strategy aims to create rainwater management design standards for private property development and redevelopment by 2022. The Strategy's target—to control 90 per cent of all rainwater for 40 per cent of the city's impervious surfaces by 2050—will require participation from both the public and private sectors. Development and redevelopment policies for the private sector will play a key role in meeting this target.

4.4.2 Providing Incentives for GSI Retrofits on Private Property: Incentive Programs, Easements, and the Drainage Act

Some municipalities have put in place methods for financing, building, and maintaining municipal drainage systems on private property. The City of Philadelphia is leading a movement that uses financial incentives to motivate private landowners to retrofit their properties with at-source GSI stormwater controls. GSI on private property can be far less costly than providing equivalent stormwater services on public property (Valderamma and Davis, 2015). This provides a financial motivation for considering GSI retrofits on private property alongside traditional stormwater management methods.[5]

While maintenance of publicly funded infrastructure on private property is a hurdle, the Southdown case study discusses how to overcome this barrier.

In Philadelphia, landowners who receive capital grants under the Greened Acre Retrofit Program (GARP) must register these maintenance plans as an easement on their properties for 45 years or the life cycle of the facility, whichever is greater. If the property owner fails to maintain these facilities, they must pay back the total amount of the grant. This protects the capital investment made by the Philadelphia Water Department and makes sure that the maintenance agreement is in place if the property changes owners. Philadelphia's GARP gives a model for other municipalities to follow.

Finally, Ontario's ***Drainage Act*** enables public and private landowners to collaborate on mutually beneficial GSI retrofits that, once built, are protected from interference by easements gained under the statute.

The ***Drainage Act*** is an Ontario statute that enables landowners, public or private, to petition their municipality for the construction of communal drainage works, whether on public or private property. If a *Drainage Act* petition is deemed valid, the municipality fronts the costs for building the drainage works and then charges affected landowners for the works and their future maintenance based on their use of the drain and how much they benefit from it. Works constructed under the Act are, in effect, user-pay infrastructure: if you benefit from the infrastructure, you pay your fair share for it. Though typically used in an agricultural context, the *Drainage Act* has been successfully used in urban watershed areas to facilitate the construction of storm drains, drainage swales, and storm water management ponds. For more information on the *Drainage Act*, visit sustainabletechnologies.ca.

4.5 Co-benefits and Shared Objectives

While the primary goal of GSI practices is improved stormwater management—quality, quantity, and **water balance**—GSI, and especially vegetated GSI facilities, provides a host of co-benefits that grey infrastructure does not. Counting these co-benefits using quantitative or qualitative methodologies is necessary for a full cost-benefit analysis. While

Water balance is the accounting of inflow and outflow of water in a system according to the components of the **hydrologic cycle** (precipitation, **runoff**, **infiltration**, groundwater flow, and **evapotranspiration**). Precipitation over natural areas generates low amounts of runoff and high amounts of infiltration, while precipitation over highly impervious areas (e.g. urban areas) generates high amounts of runoff and low amounts of infiltration.

[5] The City of Philadelphia began its innovative program after reaching an agreement with the United States Environmental Protection Agency to reduce its combined sewer overflows. Because the City of Mississauga does not have combined sewers, it does not believe that an incentive program to cover capital costs for GSI retrofits on private properties is a suitable addition to its stormwater programming (City of Mississauga, 2020b).

all case studies discuss co-benefits, the Southdown case study quantifies the co-benefits of trees planted in GSI facilities.

Collaboration across municipal departments—planning, operations, parks, transportation, engineering, and finance—is vital for successful wide-scale GSI implementation that optimizes co-benefits. Such collaboration helps to ensure that investments in GSI produce expected results and achieve multiple policy objectives. Cross-departmental integration features in the Vancouver, Kitchener, and Edmonton case studies.

4.5.1 Synergies with Other Municipal Policy Objectives: Kitchener

Kitchener's ISWM-MP Implementation Plan recognizes that "[I]ntegration across city departments is the corner stone of a modern approach to stormwater management and will be essential for the City of Kitchener in the implementation of the ISWM-MP in order to maintain and improve the condition and health of the City's subwatersheds" (City of Kitchener, 2016b, pg. vii). Such collaboration on stormwater management projects could promote other policy objectives—increasing the urban tree canopy, constructing new trails and cycle lands, expanding transit capacity, rehabilitating parks, calming traffic, increasing on-street parking, and beautifying Kitchener's communities (City of Kitchener, 2016b, pg. v).

Figure 7 shows a decision-making flowchart for choosing between GSI types given different policy objectives and site characteristics. As discussed in **Section 4.1.2.1**, Kitchener defaults to using exfiltration trenches as the main method for meeting the RVCT on account of their cost-effectiveness. However, other more expensive GSI types will be selected if they can meet additional municipal policy objectives. Achieving multiple policy objectives using GSI increases the return from investments in stormwater management.

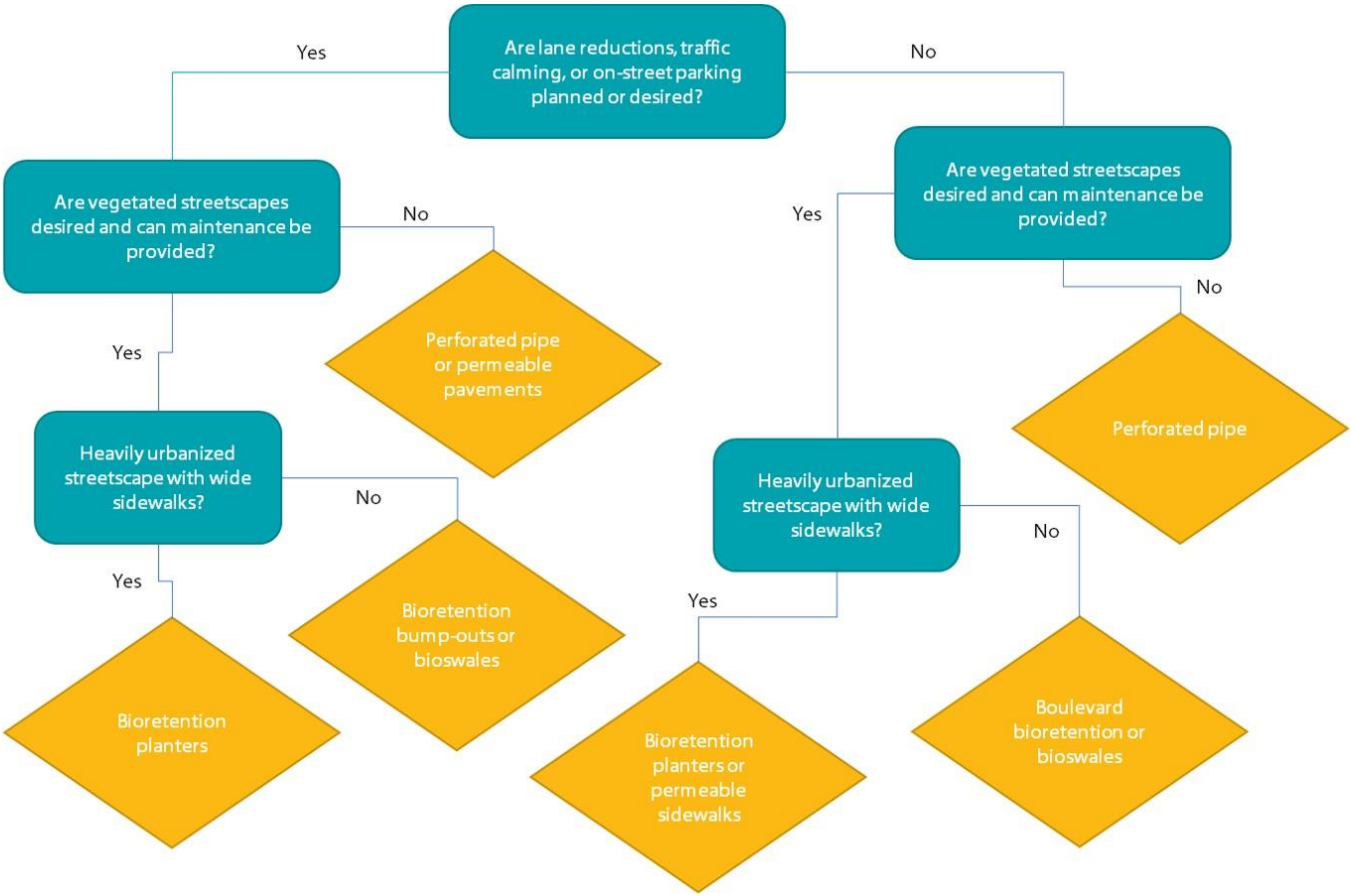


Figure 7: Flowchart used to determine the type of GSI practice best suited to a site. Adapted from the City of Kitchener, 2016, pg. 44

4.5.2 Synergies with Other Municipal Objectives: Vancouver

Vancouver's Rain City Strategy has set ambitious targets for rainwater management: to capture and clean a minimum of 90 per cent of Vancouver's average annual rainfall for 40 per cent of the city's impervious surfaces by 2050. This vision, which embraces rainwater "as a valued resource for our communities and natural ecosystems" (City of Vancouver, 2019, pg. 2), sets the tone of the holistic approach to meeting these targets.

The Rain City Strategy puts co-benefits front and centre for GRI, rather than considering them nice-to-haves. The Strategy's objectives include enhancing "Vancouver's livability by improving natural and urban ecosystems," removing pollutants from water and air, harvesting and reusing rainwater, mitigating the **urban heat island effect**, and increasing the city's total greenspace (City of Vancouver, 2019, pg. 2). Furthermore, the Rain City Strategy aims to distribute the benefits and burdens of adopting the plan equitably among stakeholders.

Urban heat island effect occurs because urban areas are covered with surfaces that retain heat—concrete, brick, and asphalt—so their temperatures are higher than surrounding rural or natural areas. Also, because they have little vegetation, they do not benefit from the cooling effects of **evapotranspiration.**

Although utility departments are usually responsible for stormwater management, the Rain City Strategy recognizes that GRI is more than a drainage management tool. GRI constitutes a broader "approach to water management and natural systems" (City of Vancouver, 2019b, pg. 7). For this reason, the Rain City Strategy "is a joint effort between the City of Vancouver's Engineering Services department; Planning, Urban Design, and Sustainability Department; Development, Buildings, and Licensing Department; Real Estate and Facilities Management and the Vancouver Board of Parks and Recreation; with indispensable support from Business Planning and Project Support, and Finance, Risk and Supply Chain Management Department." (City of Vancouver, 2019b, pg. 25).

4.5.3 Synergies with Other Municipal Objectives: EPCOR

Working with Edmonton's Climate Change Adaptation initiative, EPCOR identified stormwater practices that provide benefits in addition to mitigating flood risk. This sharing of information will allow the Climate Change Adaptation initiative to track the cumulative effects of EPCOR's GSI implementation on Edmonton's climate change preparedness.

EPCOR is also looking into collaborating with other municipal departments to share in planning for and maintaining vegetated GSI practices. For example, when EPCOR builds a treed soil cell, it provides the soil in consultation with the city's Urban Forestry department, which, in turn, chooses, supplies, installs, and maintains the trees.

4.5.4 Quantifying Co-benefits

Poor air quality and the urban heat island effect are common in the Southdown district. For these reasons, the project team included tree and native meadow plantings in the enhanced grass swales in the private property design scenario. Given a three-metre distance between each tree planting, this amounted to 343 trees. We selected tree species based on past renaturalization projects and CVC's *Plant Selection Guidelines* (CVC, 2018c). These past projects also provided a basis for estimating site preparation (including invasive species management) and tree planting costs. Benefits were estimated using i-Tree Design, a free software tool hosted by the U.S. Environmental Protection Agency. Projected life-cycle costs (over 50 years) for the tree and native meadow plantings are $25,300 (see **Table 27** and **Table 28**) and projected benefits (over 50 years) are $83,000 (**Table 29**).

4.6 Summary

The case studies examine in detail the themes discussed in this section. While each case study subject is unique, they share the same goal—improved stormwater management. The organizations have found that wide-scale GSI implementation is a key part of a well-thought-out business plan for addressing stormwater management challenges.

5.0 CITY OF KITCHENER CASE STUDY

Key findings:

- The City of Kitchener has developed a systematic plan to address a 75 per cent stormwater infrastructure gap and to improve municipality-wide level of service.
- All development and redevelopment projects, city-wide, must prevent at least 12.5 millimetres of precipitation from entering the stormwater sewer network after a rainfall event.
- Bundling road reconstruction projects with GSI adds only four per cent, on average, to the total project cost.
- Cost of improving stormwater management level of service city-wide is now shared by the city and private development.

5.1 Background

Since adopting a new Integrated Stormwater Management Master Plan (City of Kitchener, 2016a) in 2016, the City of Kitchener has moved beyond pilot projects to widespread adoption of **green stormwater infrastructure (GSI)**. A 12.5-millimetre **runoff volume control target (RVCT)** is the key driver for developing the GSI implementation program. Kitchener's experience has shown that:

- Bundling GSI with road reconstruction projects increases total project costs by only three to six per cent (Wilson, 2019). To put this in perspective, changes in oil market prices can account for greater cost variability, from −30 to +17 per cent of total project costs (Wilson, 2019).
- Streamlining the design and construction process through standard design drawings, design briefs, and clear communication with

Green stormwater infrastructure is a stormwater management strategy that seeks to mitigate the impacts of increased **runoff** and stormwater pollution. GSI practices manage runoff as close as possible to the source in order to preserve or restore pre-development **hydrologic** and ecological functions. To preserve pre-development functions, GSI uses design to minimize runoff and to protect natural drainage patterns. To restore pre-development functions, GSI uses distributed structural practices that filter, **detain**, **retain**, **infiltrate**, **evapotranspire**, and **harvest stormwater**. GSI practices can effectively remove sediment, nutrients, pathogens, and metals from runoff, and they reduce the volume and intensity of stormwater flows. Also known as low impact development (LID)

A **runoff volume control target (RVCT)** requires that stormwater systems capture and retain the first portion of precipitation from a rainfall event (e.g. 12.5 millimetres). This keeps the rainwater from entering the piped storm sewer network as runoff.

contractors lowers upfront costs and reduces the potential for expensive errors.

- Some GSI practices, such as **exfiltration systems**, are more cost-effective for meeting the RVCT in road reconstruction projects than others. But other practices (e.g. **bioretention**) may provide more **co-benefits** and may be selected if they promote municipal policy objectives such as greening neighbourhoods or increasing on-street parking.

Exfiltration system: a **GSI** practice in which surface **runoff** is collected by drainage inlets and delivered to a perforated pipe, usually surrounded by gravel, from where it **infiltrates** into the native soil.

Bioretention: a **GSI** practice that uses soil and vegetation to capture, filter, **infiltrate**, and **evapotranspire** stormwater. Bioretention practices vary in complexity based on soil types, design objectives, and available resources, from simple landscaped depressions to complex systems with impermeable liners, gravel storage layers, special soil mixtures, and underdrains.

Co-benefits: positive effects of **GSI** that are not directly related to traditional stormwater management goals. Co-benefits include air pollution removal, **urban heat island** reduction, habitat creation, energy savings, and greenhouse gas reduction.

5.2 Characterizing the Challenges

5.2.1 Impacts of Urbanization

Kitchener's urban footprint was 139 square kilometres in 2016 (City of Kitchener, 2016a, Appendix B). In 2020, along with Waterloo and Cambridge, Kitchener had the fasting growing population in Canada (CBC, 2020). As development and intensification continue to increase **runoff**, the risks of surface and groundwater quality degradation, flooding, and vulnerability to the effects of climate change increase.

Runoff: rainwater that flows over hard surfaces such as roofs and roads as runoff instead of **infiltrating** into the ground. Urban runoff carries heavy metals, nutrients, bacteria, and other pollutants into local streams, adversely affecting human, animal, and plant life.

The city is situated on the Waterloo Moraine. A series of large aquifers in the Waterloo Moraine provides about 80 per cent of the drinking water for the Region of Waterloo (City of Kitchener, 2016a); the remaining 20 per cent comes from the Grand River. As a result, maintaining groundwater recharge and protecting water quality is a priority.

A 2014 assessment of the Waterloo Moraine's aquifers found that these drinking water sources are under stress. Some of these aquifers are under moderate or significant stress in terms of quantity, which could limit the capacity for future development in the region. In terms of quality, these aquifers face threats from urban development and industrial and agricultural activities (Sousa, Rudolph, and Frind, 2014).

Kitchener assessed the impact of urbanization on watershed health in 2016. Out of 25 subwatersheds, 4 were rated “good” or “excellent,” while the remaining 21 were rated “poor” or “fair” (City of Kitchener, 2016b).

Climate change will aggravate the effects of urbanization as more intense storms and larger amounts of precipitation result in more frequent flooding, pollutant loading, surface and groundwater quality impairment, and potential damages to the infrastructure.

5.2.2 Lack of Stormwater Management Controls in Older Urban Areas

Like most cities across Ontario and Canada, the majority of Kitchener was built before the introduction of stormwater quantity and quality standards, and there is little stormwater infrastructure within the City’s **legacy development** areas (**Figure 8**). Stormwater management started to be practised in Kitchener in the 1970s and has continued to evolve. It now includes water quantity (flooding control), quality, erosion control, and **water balance**. In 2016, 2,865 of the 11,371 hectares (25.2 per cent) of urban area in Kitchener had stormwater infrastructure for flood control (**Figure 9**). This means that in 2016, about 75 per cent of Kitchener was without the infrastructure for flooding control, water quality treatment, erosion control, or water balance. The current and historical gap in stormwater treatment has left most of Kitchener’s local subwatersheds in fair to poor condition.

Legacy developments: urban areas that were built before quantity or quality controls became requirements for new development in Canada. Typically, legacy developments only have infrastructure to convey stormwater from built-up areas to receiving water bodies.

Water balance: the accounting of inflow (precipitation) and outflow of water in a system according to the components of the **hydrologic cycle** (precipitation, **runoff**, **infiltration**, groundwater flow, and **evapotranspiration**). Precipitation over natural areas generates low amounts of runoff and high amounts of infiltration, while precipitation over highly impervious areas (e.g. urban areas) generates high amounts of runoff and low amounts of infiltration.

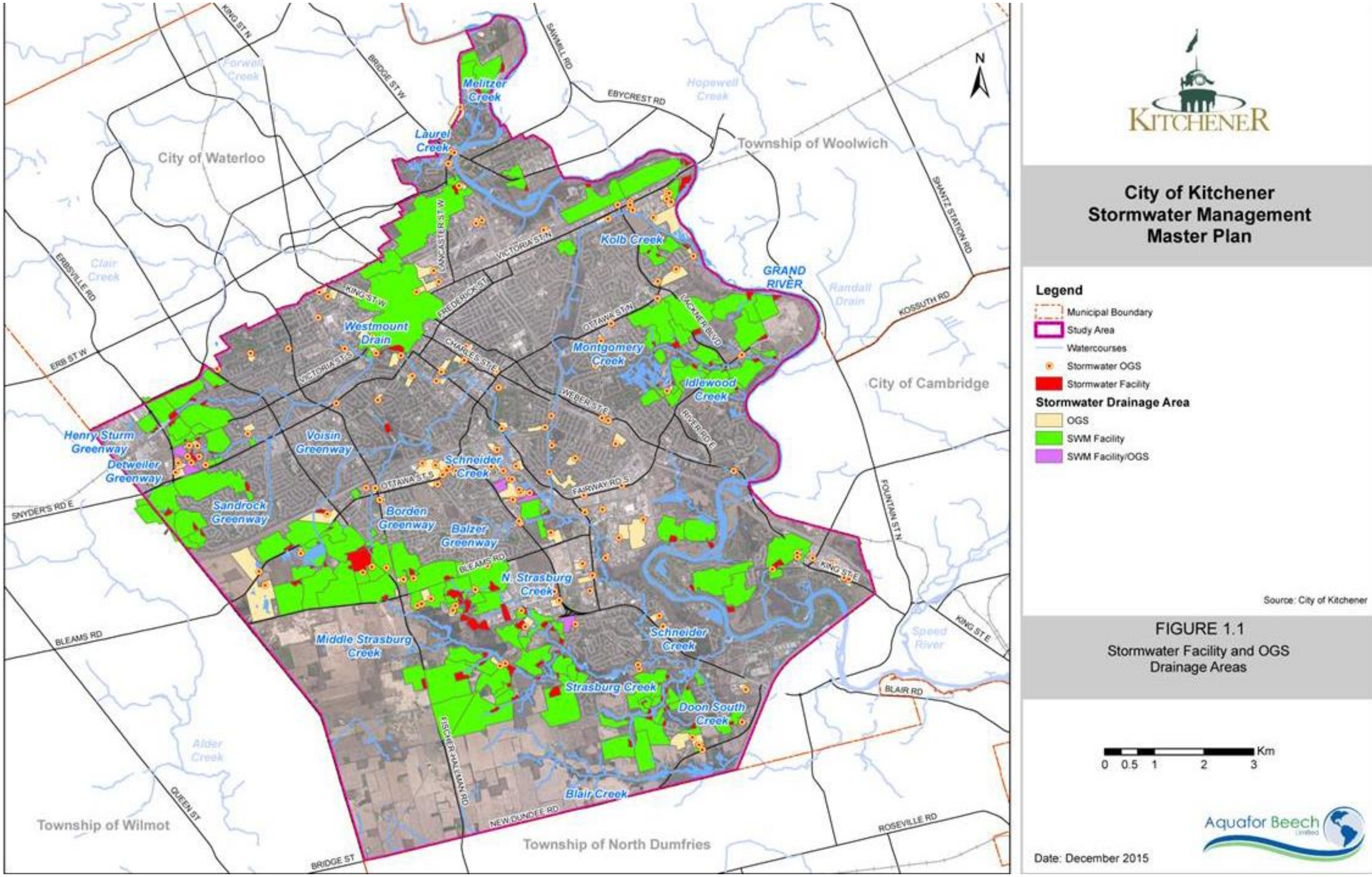


Figure 8: Kitchener stormwater facility and oil and grit separator drainage areas.
Abbreviations: OGS, oil and grit separator; SWM, stormwater management.
Source: Wilson, 2019

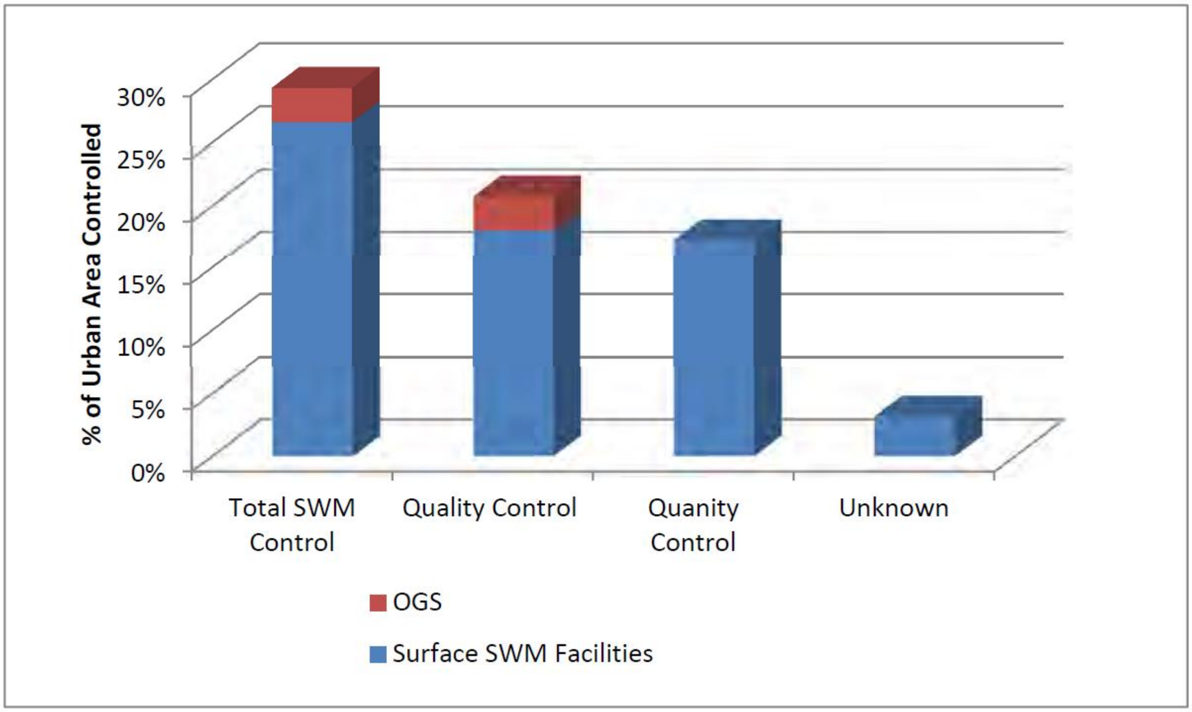


Figure 9: Percentage of area of Kitchener controlled by stormwater management assets.
Abbreviations: OGS, oil and grit separator; SWM, stormwater management.
Source: City of Kitchener, 2016a

5.2.3 Lack of Sustainable Funding for Stormwater Infrastructure

Kitchener used to fund stormwater services and infrastructure through property taxes. This meant that stormwater services competed with other city services such as parks, roads, and social services for a share of the budget. Such competition for budget allocation is a problem as stormwater infrastructure assets—worth $265 million in 2011—continue to age and need replacing.

In 2016, Kitchener had a total of 142 active stormwater management facilities, with 105 owned and operated by the city, 27 yet to be assumed, and 10 natural ponds used as stormwater management facilities (City of Kitchener, 2016a). At that time, 18 facilities were planned but not yet constructed. Kitchener also had 158 **oil and grit separators** (OGSs) and was responsible for operating and maintaining 65, with 94 owned privately and 8 owned by the Region of Waterloo (City of Kitchener, 2016a). The OGS units control runoff from a drainage area of about 311 hectares (City of Kitchener, 2016a).

The stormwater management group also has myriad smaller responsibilities, all of which require a portion of the city's budget, including inspection and maintenance, repair of pavement damage from poor drainage, meeting increasing regulatory requirements, addressing increasing levels of service liability, handling calls to do with backyard and basement flooding damage, and addressing claims and development application reviews of proposed stormwater infrastructure (City of Kitchener, 2011).

The cost to provide these services, maintain and replace aging infrastructure, and address the existing stormwater infrastructure gap was not tenable through property taxes alone. In 2010, Kitchener's stormwater budget was about $8.9 million, while the required budget was $13.1 million (City of Kitchener, 2010). This yearly $4.1 million budget deficit highlighted the need for consistent, sustainable funding (City of Kitchener, 2010), particularly considering the demands placed by climate change.

5.2.4 The Challenge of Implementing GSI Using an Opportunistic Approach

Like most Ontario municipalities, Kitchener's use of GSI was initially limited to an opportunistic approach based on funding and site availability. Early projects were used to showcase new GSI technologies. These types of demonstrations tend to be more expensive as they can include detailed landscaping, signage, public amenities such as seating, specialized monitoring equipment, and a higher level of maintenance.

Kitchener's King Street bioretention planters were one of the city's first GSI projects. The city implemented the planters as part of the award-winning Streetscape Master Plan that integrated street parking, pedestrian seating, stormwater management, and aesthetics (**Figure 10**). The bioretention planters have been in operation since 2013 and have been a source of valuable information for ongoing and future GSI projects.

Plant and tree survivability, irrigation, inlet clogging, and general maintenance have all been difficult (The Record, 2014). This is not uncommon for a municipality's initial GSI projects. The King Street planters were critical in helping Kitchener learn about how to implement GSI effectively and efficiently on a large scale across the city.

Figure 10: King Street bioretention planters.
Source: City of Kitchener

5.3 Setting Objectives

5.3.1 Pathway to Improve Levels of Service

To address the challenges described in **Section 5.2**, Kitchener decided to make changes to the funding structure, planning, and policy of stormwater management. The city chose to adopt a **stormwater charge** and credit program as well as to update their stormwater master plan. The master plan contains a 12.5-millimetre RVCT and implementation strategies for both new and existing urban areas, including road projects (City of Kitchener, 2016a).

Stormwater charges are annual fees charged to landowners by municipalities. The charges are for providing stormwater services. Stormwater charges are separate from general property taxes and provide a dedicated revenue source for maintaining, operating, and revitalizing stormwater infrastructure.

Kitchener now has a funding model in place to recover the costs of stormwater infrastructure including capital costs, replacement, planning, and maintenance. Together these elements also allow Kitchener to invest in and incorporate GSI into road construction projects alongside traditional stormwater management controls. This provides an opportunity to encourage **infiltration**, improve water quality, and adapt to climate change conditions.

Infiltration is the passing (or penetration) of water through the ground's surface.

5.3.1.1 Sustainable Funding: Implementing the Stormwater Management Charge

Historically, stormwater management in Kitchener was funded through property taxes. This method provided an inconsistent funding source that did not cover the cost of the service provided to residents and businesses. Stormwater services had to compete with other city assets and services, making it difficult for long-term capital planning, maintenance, and improvement of level of service.

Upon review in 2010, the Kitchener City Council approved a tiered flat fee stormwater utility rate model. This tiered flat fee structure was made for four broad property classes: single family, multi-family, non-residential, and tax-exempt non-residential. The fee structure is further separated into a series of rate tiers. The user fee is based largely upon a property's impervious area (driveways, parking areas, building footprint, patios, sidewalks, etc.). This approach to allocating the costs of stormwater management to all property owners is fairer than basing it on property value (City of Kitchener, 2011).

All properties in Kitchener are billed a stormwater charge that generates about $15 million annually for programs and projects. This approach provides a reliable funding source that:

- allows for effective planning;
- makes it possible to establish a sustainable level of service for stormwater programs including operations, maintenance, and capital projects; and
- can be used to incorporate more GSI projects to address gaps in stormwater management infrastructure.

5.3.1.2 Sustainable Funding: Implementing the Credit Program to Recognize and Encourage Onsite Stormwater Management

As part of the stormwater utility, the City of Kitchener implemented a credit policy in 2012 to reward environmental stewardship and reduce the property owner's monthly stormwater charge. The intent of the credit policy was to encourage property owners to construct at-source controls (like GSI) and other best management practices that improve level of service for the overall system. Such practices would reduce their individual stormwater runoff and pollutant loading on the municipal stormwater system. Every property can apply for credits to reduce stormwater charges by up to 45 per cent.

Examples of credit-worthy practices include rain barrels, cisterns, rain gardens, **permeable pavements**, and other practices that promote infiltration and onsite control of stormwater runoff. The aim of the credit policy is to restore the natural **hydrologic cycle** and benefit from holistic improvements to the urban environment (City of Kitchener, 2011).

Permeable pavements: a type of **GSI** practice that allows precipitation to **infiltrate** through surface pores (permeable asphalt and concrete) or through joints between pavers.

The **hydrologic cycle** is the circulation of water from the atmosphere to the earth and back, through precipitation, **runoff**, **infiltration**, groundwater flow and **evapotranspiration**. See **water balance**.

Controlling runoff from industrial and commercial areas is a prime objective of Kitchener's stormwater credit program. Focus is given to industrial and commercial areas over residential areas because of the greater benefits for the municipal stormwater system. First, 80 to 100 per cent of industrial and commercial properties are impervious, compared with 30 to 50 per cent of typical residential areas in Kitchener. Second, residential landowners are limited to smaller-scale practices, while industrial and commercial landowners may undertake larger-scale projects to gain maximum credits, with greater benefits to the overall stormwater system (City of Kitchener, 2016a).

Since adopting the credit policy in 2012, Kitchener has issued over 4,000 credits—a six per cent uptake (City of Kitchener, 2016a). Most of these credits have been distributed in residential areas, with very few in industrial and commercial areas.

5.3.1.3 Creating a Systematic Approach to Implementing GSI: Adoption of the Integrated Stormwater Management Master Plan and Implementation Plan

Kitchener's Integrated Stormwater Management Master Plan (ISWM-MP) was released in 2016. It is a decision support tool that helps prioritize projects and establish stormwater management guidelines and policies for the next 15 years. The ISWM-MP combines the use of GSI with conventional stormwater practices.

Kitchener also created an implementation plan to supplement the ISWM-MP (City of Kitchener, 2016b). The city completed extensive market-based research to understand the wants and needs of residents and businesses. Based on the results of this research, the implementation plan recommended approaches and incentives to increase participation in the credit program. The goal is to achieve a 20 per cent uptake over five years to secure source-level stormwater management measures by just over 25 per cent of non-residential properties by 2021 (City of Kitchener, 2016a).

The implementation plan prioritizes the recommendations from the ISWM-MP based on priority subwatersheds and recommends an implementation schedule, funding allocation, and necessary policy development.

The ISWM-MP outlines key objectives that target the environmental impacts, lack of stormwater infrastructure, and lack of sustainable funding affecting Kitchener. The key objectives include improvements in water quality, water quantity, erosion control, the natural environment, water resource sustainability, infrastructure, and policy and implementation.

To achieve these objectives, the city developed new policies to support the implementation of the ISWM-MP's recommended approach. One of these policies included establishing a minimum RVCT and applying stormwater management targets for new development, redevelopment, and linear projects (i.e. road construction). This policy requires that all sites within Kitchener continue to control runoff for flood control and erosion, achieve infiltration targets to maintain the existing water balance, and control for water quality by retaining a minimum of 12.5 millimetres of runoff from all surfaces. Private landowners must also enrol in the credit program (City of Kitchener, 2016a).

If a new or redevelopment parcel of land is unable to meet the RVCT, a one-time stormwater management fee of $100,575 per hectare is applied (see **Figure 11**). If the site meets the RVCT, no fee is applied; if it meets the target partially, an equivalent portion of the fee is applied (Gollan, 2019). This fee allows the city to implement compensatory measures elsewhere.

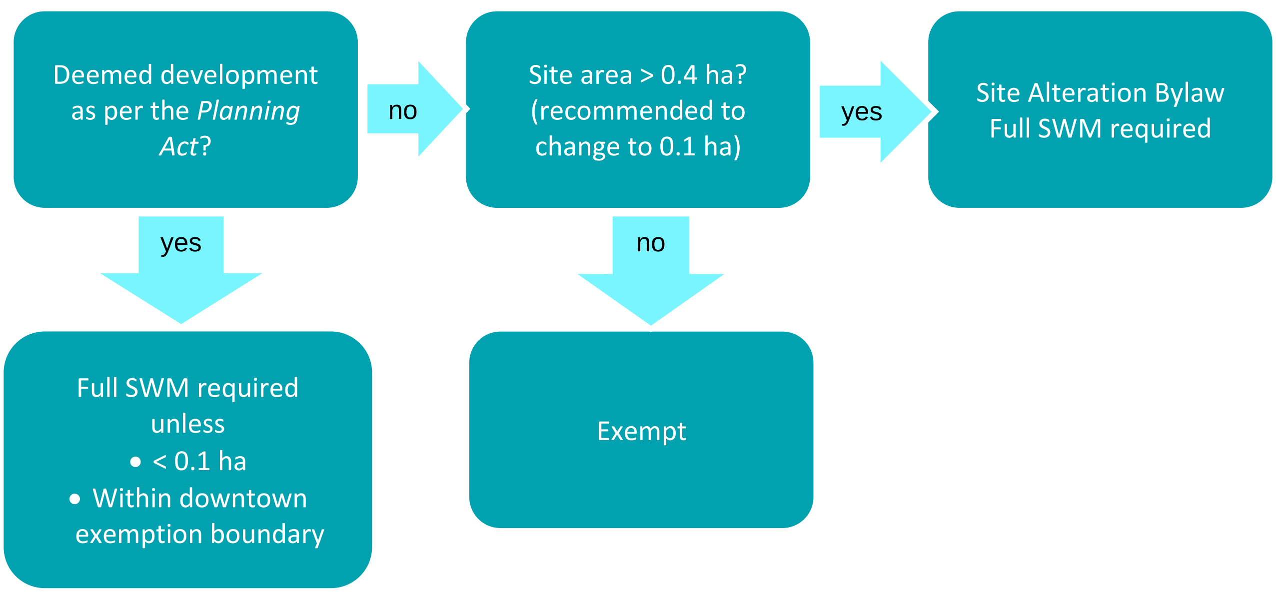


Figure 11: Process flowchart for the application of a stormwater fee if the runoff volume control target is not met or is only partially met.
Abbreviations: ha, hectare; SWM, stormwater management.
Source: Gollan, 2019

This RVCT and stormwater management fee contributes to improving water quality, preventing **urban flooding**, maintaining pre-development groundwater recharge, preserving the hydrologic cycle, mitigating thermal pollution in urban streams, and preserving groundwater supply (City of Kitchener, 2016b).

Urban flooding: also known as "pluvial flooding," urban flooding includes **surface flooding** and **sanitary sewer surcharging**. Urban flooding results from intense or prolonged rainfall in urban areas, overwhelming the capacity of the stormwater management system and causing flooding in low-lying areas. This can cause damage in many ways, chiefly through sanitary sewer backups (from **inflow and infiltration**) and from stormwater directly entering buildings.

5.4 Developing a Cost-Effective Strategy and Systematic Approach for GSI

For most municipalities across Canada, the approach to GSI has been informal, exploratory, and opportunistic. These showcase projects tend to lack integration and to be more costly than is necessary. But these exploratory first steps allow municipal staff and the community to become more comfortable with building, operating, and living with GSI. Integrating GSI into a municipal stormwater master plan and an implementation plan is the next logical step.

A systematic approach to GSI increases the likelihood that constructed facilities will operate as planned. Such an approach becomes more cost-effective by:

- allocating yearly funding with specific targets for applying GSI through an implementation plan;
- choosing the right locations to implement GSI with the help of feasibility studies and by avoiding problem areas;
- coordinating across municipal departments to achieve multiple policy objectives;
- choosing cost-effective GSI measures specific to the project; and
- developing design standards, conceptual design briefs, and construction standards and specifications.

5.4.1 Creating an Implementation Plan

As discussed in **Section 5.3.1.3**, Kitchener coupled an implementation plan with its stormwater master plan to support the recommended strategies (City of Kitchener, 2016b). The Kitchener City Council approved the implementation plan in October 2016 with the following objectives:

1. "Prioritize all the works based on the watersheds in the most need and where there are opportunities to maintain and/or improve conditions through the elements of the recommended approach;
2. Recommend funding allocation and develop an implementation schedule using existing funding sources; and
3. Develop supporting policy" (City of Kitchener, 2016b, pg. ii).

The implementation schedule allows Kitchener to manage staff and equipment requirements, build municipal capacity, and align with other municipal projects and programs (Gollan, 2019). The implementation plan also elaborates on the six key stormwater management elements the ISWM-MP identified and, for each element, it lays out a strategy for achieving the objectives outlined in the ISWM-MP. **Table 6** details these implementation streams along with their associated budgets.

Table 6: Recommended approaches and estimated costs for the key stormwater management elements of the Integrated Stormwater Management Master Plan, from 2017 to 2030

Stormwater management program element		Recommended approach	Capital cost estimate* ($ millions)
1	Municipal pollution prevention, operations, and maintenance practices	OGS maintenance (high, moderate, and low priority)	0.2
		Sediment removal from each catchbasin in priority areas	0.3
2	Market-based strategies for private property (source controls)	Market-based instruments Includes both broad-based and targeted marketing of at-source stormwater management 0% interest loan program to non-residential customers as well as site consultation and design guidance	3.5
3	Stormwater for the Capital Roads Program (conveyance controls)	Implementation of conveyance controls using a combination of traditional stormwater management controls (i.e. OGS units) and LID approaches:	
		107 planned road reconstruction and resurfacing projects	1.9–11.1
		22 laneway projects identified within the Capital Forecast	−0.3 to +1.7
4	Stormwater management facilities	Sediment removals (high, moderate, and low priority) from dry and wet ponds (45 stormwater management facilities)	2.7
		Planned retrofits (9 facilities)	7.0
		Park rehabilitation and enhancements—12 new SWM facilities	36.4–49.3
5	Watercourse and erosion restoration	12 primary opportunities (erosion site and restoration reaches)	14.0–20.0
6	Urban flood management and stormwater infrastructure	Expansion of the existing sewer network model into areas identified for future study as part of the ISWM-MP implementation plan. The model expansion will permit Kitchener to evaluate and select the preferred remedial approaches to improve the level of service	40.0
Total			**102.2–135.8**

Abbreviations: GSI, green stormwater infrastructure; ISWM-MP, Integrated Stormwater Management Master Plan; LID, low impact development; OGS, oil and grit separator; SWM, stormwater management.
* Rounded to the nearest $100,000. All values in 2016 Canadian dollars.
Source: City of Kitchener, 2016b. Stormwater Management Program Elements 2 and 3 primarily direct GSI implementation, with Element 2 outlining the approach to source controls and Element 3 outlining conveyance controls.

These basic elements of schedule and budget are common to all well-planned municipal projects. A detailed financial plan for GSI avoids interdepartmental conflict because municipal staff know that a budget has been allocated. In addition, a Council-approved plan gives weight and authority to the project and helps direct the efforts of staff and their departments. Less organizational struggle can mean less cost to build GSI.

5.4.2 Identifying Priority Watersheds and Choosing Locations that Address Risk and Site Constraints and Mitigate Costly Field Changes

Kitchener has 21 subwatersheds in fair to poor condition (see **Section 5.2.1**). These subwatersheds were ranked by priority to determine where needs are greatest and where opportunities are available to maximize net benefits of GSI. This prioritization process focuses on maximizing the benefits of GSI and avoids a blanket approach.

With priority watersheds identified, implementing two GSI program elements—the road-retrofit and market-incentivization programs—can be further refined. The Stormwater for the Capital Roads Program identified 203 roadway and 22 laneway reconstruction projects suitable for GSI (City of Kitchener, 2016b, pg. 41). To settle on this list, Kitchener completed a risk assessment of its groundwater supplies. This assessment defines where and how infiltration-based stormwater management controls can be planned and safely constructed. An important consideration is the approved source-protection planning policy under Ontario's *Clean Water Act* (City of Kitchener, 2016b, pgs. 42–46). Existing high risk for groundwater contamination precludes infiltration practices. Such high risks include having a wellhead protection area vulnerability score of eight or greater or being in an “issue-contributing area” with concentrations of nitrate, chloride, and sodium.

Figure 12 shows a decision-making flowchart for road reconstruction projects of local roads.

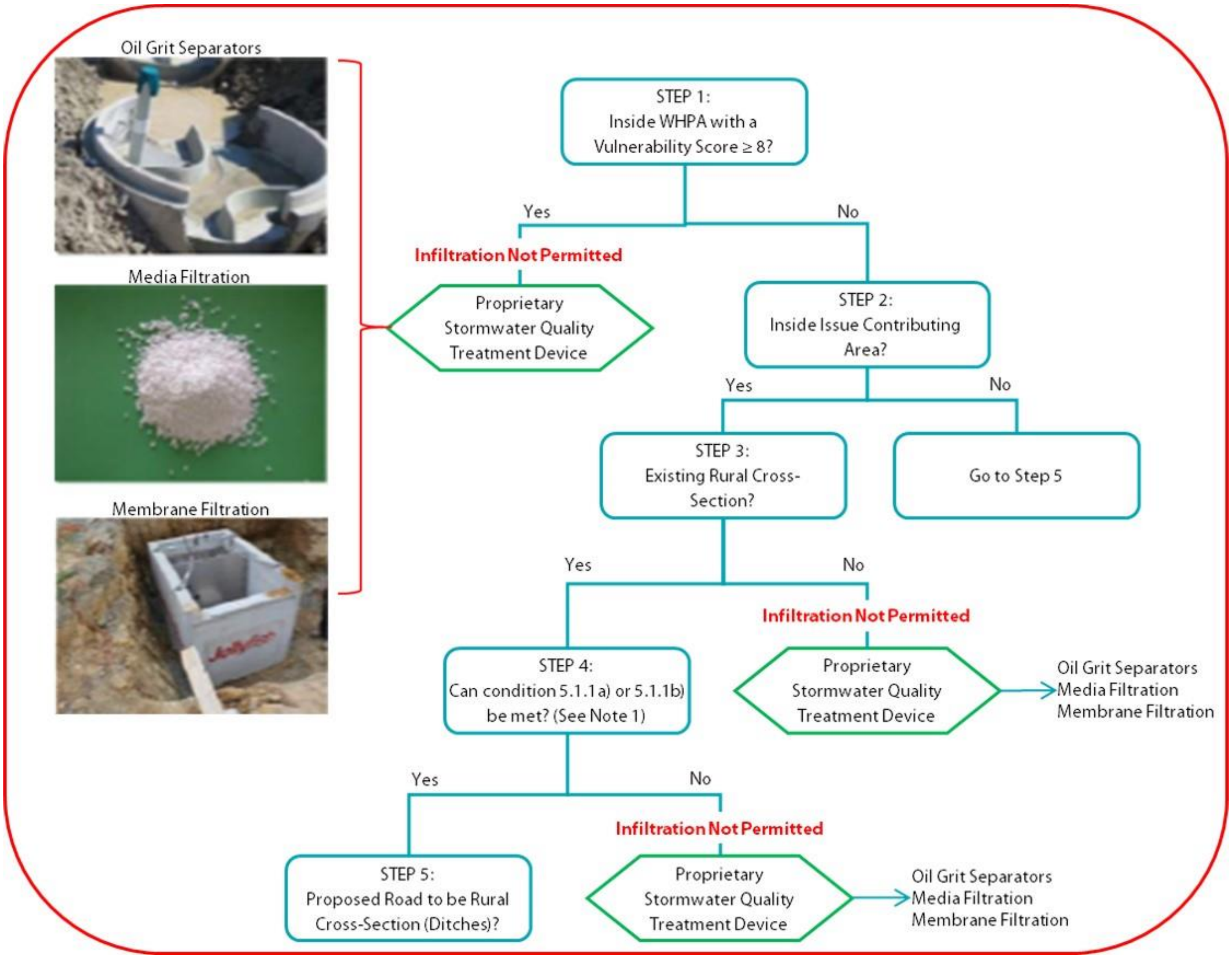


Figure 12: Decision-making flowchart for local road reconstruction projects.
Abbreviation: WHPA, wellhead protection area.
Source: City of Kitchener, 2016b, pg. 46

Furthermore, when road reconstruction projects are tagged for implementation in priority subwatersheds, Kitchener can tailor designs to meet watershed-specific targets or allocate proportionately higher budgets to those facilities. For the market-based strategies element, identifying priority subwatersheds gives the city the opportunity to offer incentives—for example, zero per cent interest loans for non-residential properties—within these areas.

Finally, knowing where *not* to build GSI avoids costly field changes due to site constraints. Unmarked utilities and seasonal high groundwater can disrupt construction. GSI practices need at least one metre between the bottom of the facility and the annual high groundwater level (Sustainable Technologies Evaluation Program, 2020). If project designs do not accurately place these facilities above the high groundwater level, they will not work. Proper planning avoids this outcome and expenses associated with field changes.

5.4.3 Identifying Implementation Synergies with Other Plans, Policies, and Projects

The implementation plan directs the sanitary and stormwater utilities division to promote other policy objectives by collaborating with other municipal departments. “Integration across city departments is the corner stone of a modern approach to stormwater management and will be essential for the City of Kitchener in the implementation of the ISWM-MP in order to maintain and improve the condition and health of the City’s subwatersheds” (City of Kitchener, 2016b, pg. vii). These policy objectives include maintaining and increasing the urban tree canopy, constructing new trails and cycle lands, expanding transit capacity, rehabilitating parks, calming traffic, increasing on-street parking, and beautifying Kitchener’s communities (City of Kitchener, 2016b, pg. v).

Kitchener can reach its policy objectives more cost-effectively by achieving multiple objectives in a single infrastructure project. For example, a single road reconstruction project could simultaneously improve stormwater management, increase tree canopy, and add cycle lanes. When bundled together in a single project, this costs less per functional element than if each respective municipal department acted alone.

Kitchener has built these considerations into its decision-making processes. If a local road reconstruction project passes the infiltration screening steps (see **Figure 12**), the project moves to the next stages in the decision-making process (see **Figure 13**).

The type of GSI chosen—a surface practice such as bioretention or a subsurface exfiltration system—depends on:

- the neighbourhood characteristics (e.g. the presence or absence of mature trees, the available space in the right of way);
- whether the neighbourhood residents and businesses want vegetated practices;
- whether vegetated practices can be maintained; and
- whether building vegetated GSI facilities synchronizes with other policy objectives or desired roadway characteristics (City of Kitchener, 2016b, pg. 41).

Vegetated GSI systems may be chosen even though their life-cycle costs typically exceed those for subsurface exfiltration systems.

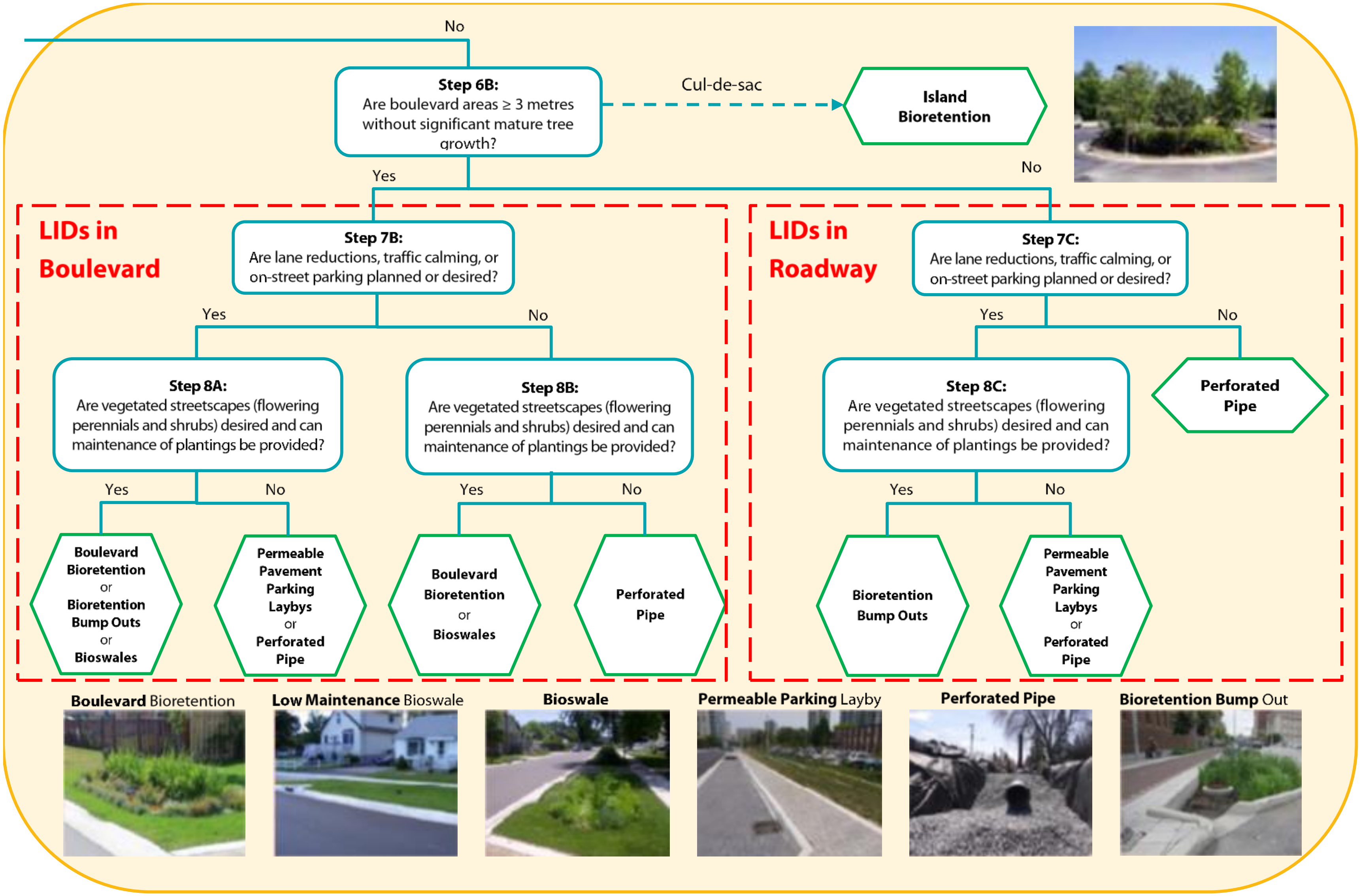


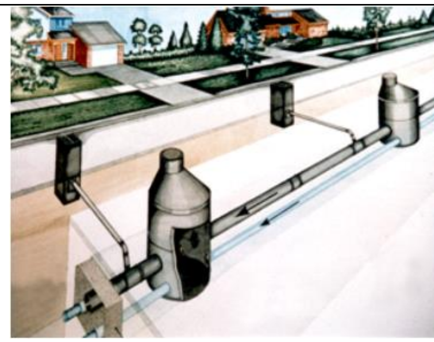
Figure 13: Decision-making flowchart to determine the type of GSI best suited to a site.
Abbreviation: LID, low impact development. Source: City of Kitchener 2016b

5.4.4 Choosing Cost-Effective Practices

Kitchener first identified GSI types suitable for various land uses to meet the RVCT. The idea was that by limiting the number and type of GSI practices Kitchener considered for their projects, the city would be better able to ensure that the GSI systems were properly designed, constructed, and maintained. This would lead to cost-efficiencies as processes improve over time.

Figure 14 shows the options that Kitchener considers suitable for GSI projects.

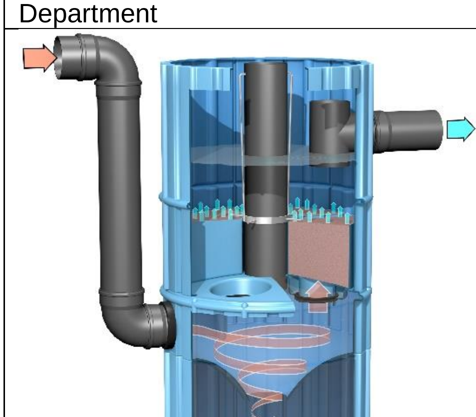
A centre-median bioswale on Mississauga Road in Brampton, ON.
Photo credit: CVC



The Etobicoke Exfiltration System (1994), Etobicoke, ON.
Image credit: City of Kitchener

Stormwater planter, treating downspout runoff, at Waterview Recreation Center, Philadelphia, PA, USA.
Photo credit: Philadelphia Water Department

Porous concrete at Lakeside Park in Mississauga, ON.
Photo credit: CVC



An oil and grit separator.
Image credit: 30 Technik UK

Curb extension on Queen Lane in Philadelphia, PA, USA.
Photo credit: Philadelphia Water Department

Figure 14: The options Kitchener considers suitable for GSI projects.

City of Kitchener staff also analyzed the cost-effectiveness of various GSI options for its road-retrofit program. In general, all GSI practices work to re-establish the natural hydrologic cycle through **retention**, **detention**, and infiltration. Assuming that meeting the RVCT is the sole objective, some GSI practices can reach this target more cost-effectively than others because they manage runoff from a larger drainage area.

Retention is the capture of stormwater for filtration, **infiltration**, and **evapotranspiration**. Retained stormwater does not become **runoff** or streamflow. **Detention** is the temporary storage of stormwater to control discharge rates and to allow for sedimentation. Detained stormwater is slowly released as **runoff** or streamflow. The facilities that detain stormwater do not help re-establish a natural **water balance**. See **hydrologic cycle** and **water balance**.

To illustrate this point, **Table 7** shows the capital cost comparison between three GSI types per hectare. Because exfiltration trenches have a larger acceptable drainage area (impervious/pervious ratio) than permeable pavers and bioretention, their cost per impervious hectare treated is significantly lower.

Table 7: Comparison of the cost-effectiveness of three GSI types in meeting Kitchener's runoff volume control target

GSI type	Hypothetical cost to construct 1 ha ($ millions)	Suitable I/P ratio	Acceptable drainage area (ha)	Cost per ha ($ millions)	Cost (%)
Permeable pavers	2.0	close to 1:1	1.25	1.6	100
Bioretention	2.0	10:1	10	.2	12.5
Exfiltration trench	2.0	20:1	20	.1	6.25

Abbreviations: GSI, green stormwater infrastructure; ha, hectare; I/P, impervious/pervious (ratio of drainage area).
Source: Wilson, 2019

Exfiltration systems are also less costly to maintain than most other GSI practices. Because they are subsurface, they do not require any landscape maintenance apart from mowing any grass that might cover them. They only require inspection and cleaning of pipes. Most municipalities have the staff and the necessary equipment to do this.

Moreover, catchbasin inlets to exfiltration systems (see **Figure 14**, top-right corner) can include a variety of proprietary pre-treatment devices that trap sediment before it reaches the exfiltration pipes. Improved pre-treatment prevents expensive pipe cleanouts and helps reduce overall life-cycle costs.

Given these cost-efficiencies, the road-retrofit program favours exfiltration systems unless there are compelling reasons otherwise.

5.4.5 Dynamic and Static GSI Sizing and the Implications for Greater Cost-Efficiencies

To drive cost-effectiveness, Kitchener city staff compared two different approaches to sizing GSI features: static equations and dynamic models. Static equations do not change due to localized conditions or projected performance. Dynamic models can show the performance of GSI sites in relation to local conditions and GSI size.

Kitchener used a dynamic **hydrologic** and **hydraulic** model to test whether GSI performance could be maintained with smaller GSI facilities under specific soil conditions. The model output shows that for native soils with infiltration rates of 5 millimetres or more, the size of the GSI practice does not need to increase significantly to meet increasing runoff control percentages (**Figure 15**). The model also shows that there is greater variance in GSI sizing using static equations (green line in **Figure 15**) to achieve increasing runoff control percentages.

Hydrology is the study of water on the earth's surface, flowing either above ground or beneath it. **Hydraulics** is the study of the flow of water through pipes and channels, such as rivers.

The implications of this modelling study for more efficient sizing of GSI when soil infiltration is five millimetres per hour or more are very positive. Smaller features cost less and take up less space.

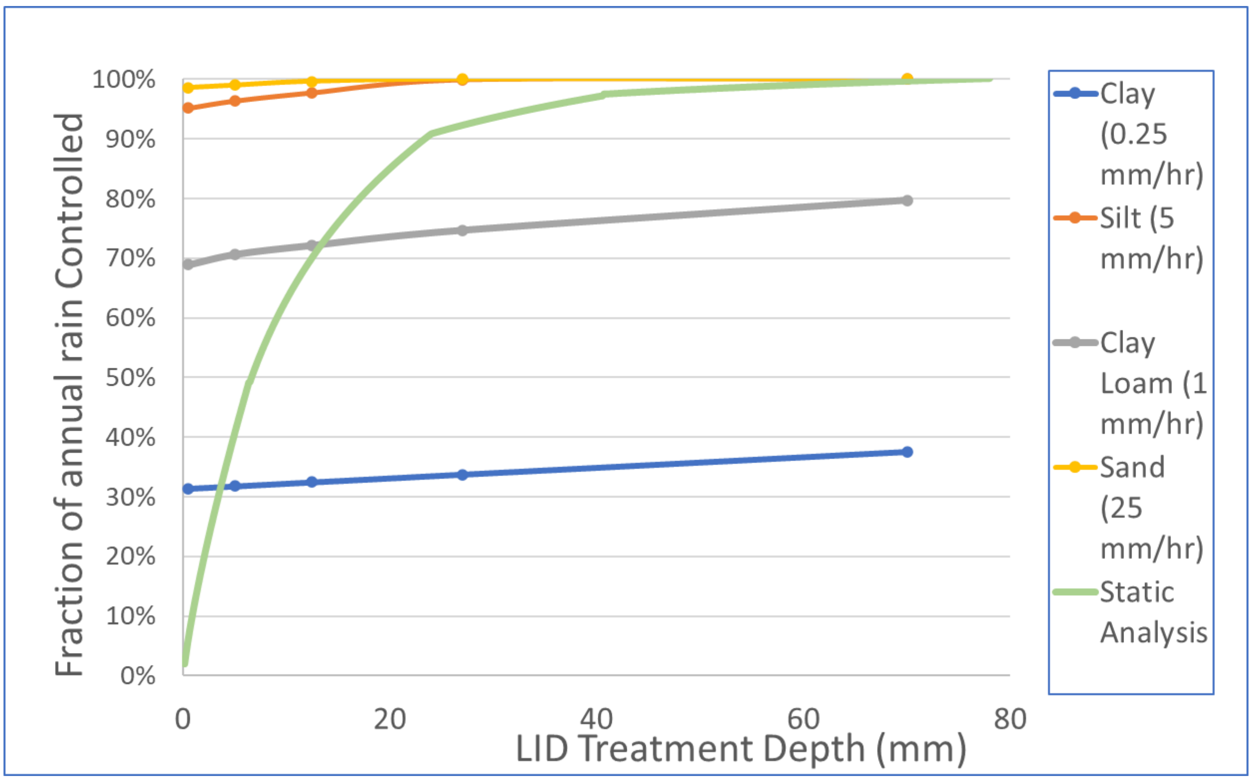


Figure 15: Comparative analysis of GSI sizing to meet increasing runoff control percentages using static analysis (green line) and dynamic analysis in different soils.
Abbreviations: GSI, green stormwater infrastructure; hr, hour; LID, low impact development; mm, millimetre.

Source: Wilson, 2020

5.4.6 Developing Design Standards

Design standards serve several functions:

- They help municipalities improve processes and lower costs for GSI design, review, and implementation.
- They make operations and maintenance easier since all facilities have the same basic layout and structure.
- They clarify the expectations that designers need to meet.

Kitchener has developed design standard drawings for soil cell bioretention systems, permeable concrete systems, permeable precast pavers (**Figure 16**), and perforated pipe exfiltration systems.

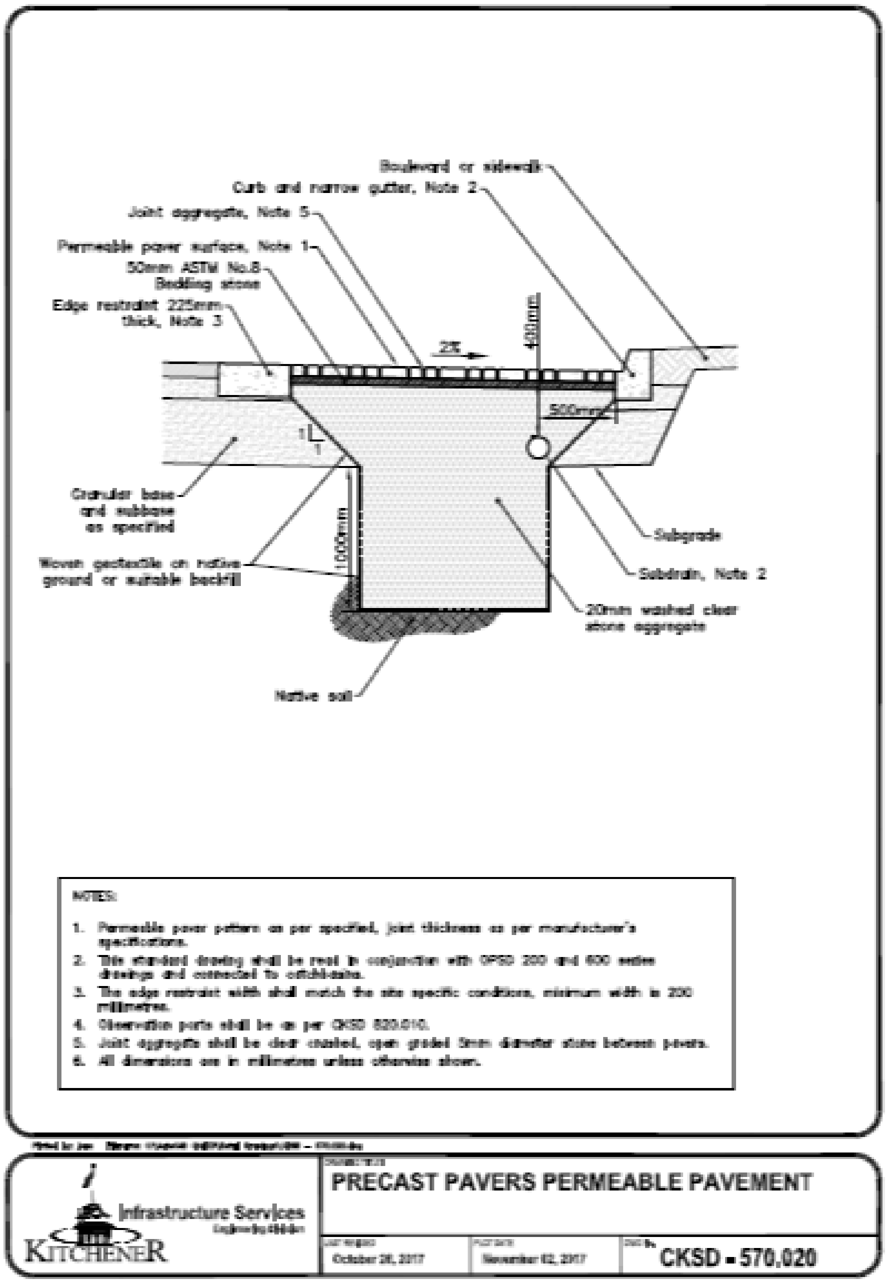


Figure 16: Kitchener's design standard drawing for precast permeable pavement pavers.
Source: City of Kitchener

5.4.7 Feasibility Studies, Conceptual Design Reports, and Integration of GSI into Road Standards (and 3D Rendering)

In addition to providing engineering consultants with design drawings, Kitchener aims to issue a conceptual design brief to facilitate the design process for the departments responsible for construction, such as Road Capital Projects. These reports assess the feasibility of GSI measures achieving stormwater management objectives, including the city's retention criteria and provincial water quality criteria. These briefs also transfer information and lessons learned from applying retention targets in completed road reconstruction projects.

This information helps consultants bid accurately, streamlines design, expedites review time, and reduces time spent researching basic information.

Figure 17, taken from the Guelph Street feasibility report, shows the placement of the exfiltration system in relation to the sanitary line, water main, and seasonal highwater mark. Having this information helps construction groups with context and site constraints during implementation, which helps avoid costly field changes.

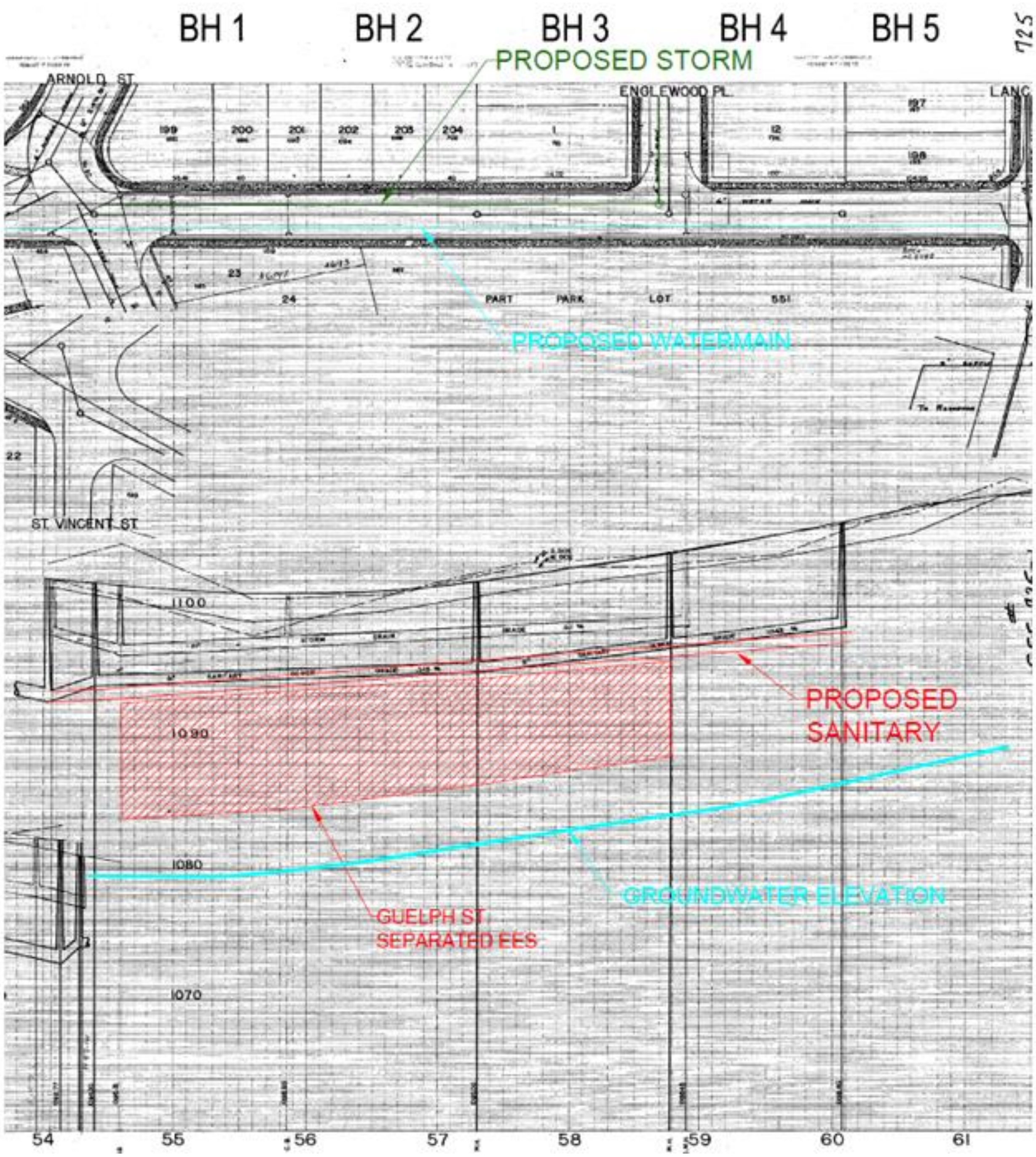


Figure 17: Conceptual design report illustrating placement of GSI in relation to seasonal high groundwater mark and utilities.
Source: City of Kitchener

Kitchener is also integrating GSI into city-wide planning and engineering manuals through the updated *Development Manual* and the *Complete Streets Kitchener* guide. GSI is included in standards for all road classifications, and conceptual renderings have been developed. Integrating GSI into these larger project documents is critical for several reasons:

- It helps ensure that GSI becomes a standard practice for stormwater management.
- It encourages the application of GSI on a mass scale, helping to drive down costs.
- It creates a local community of practice of designers, contractors, and maintenance personnel and gathers lessons learned for updates to design and specifications manuals.
- It means GSI standards are updated every five years based on updates in the *Development Manual* and the *Complete Streets Kitchener* guide.
- It acts as an effective tool to communicate the technical feasibility and the aesthetics of GSI on rights-of-way.

Figure 18 and **Figure 19** show road standards and complete street renderings that include GSI.

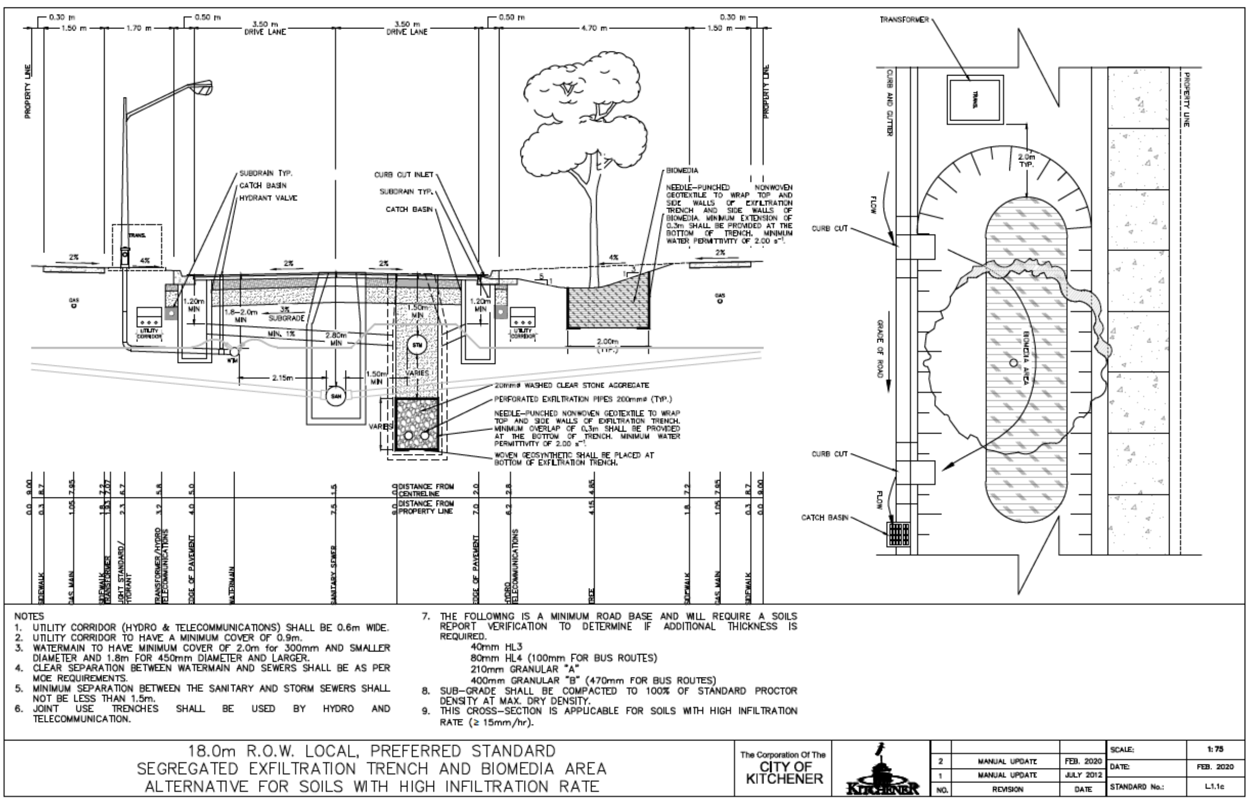


Figure 18: Integration of biomedia area and exfiltration trench into local road standards as part of Kitchener's updated *Development Manual*.
Source: Kitchener, 2020

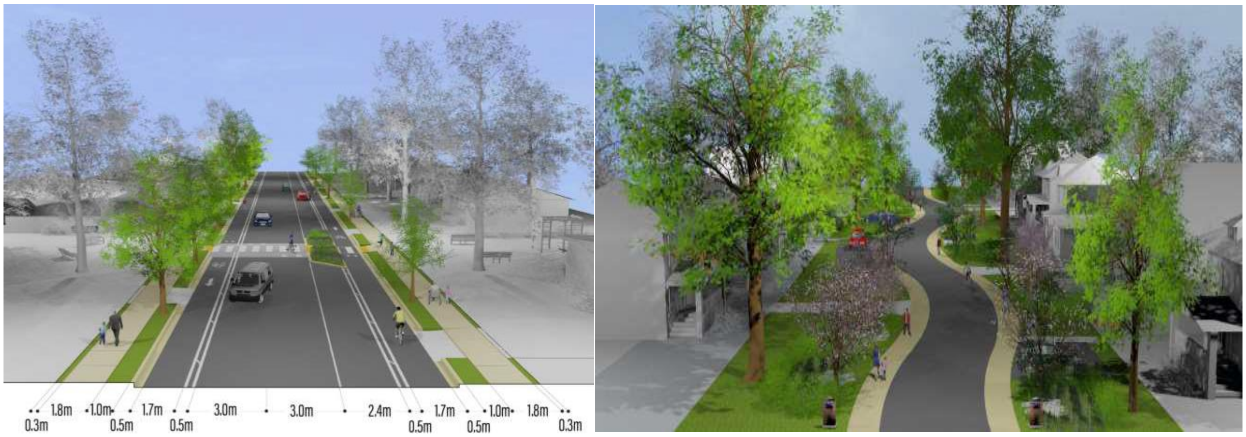


Figure 19: Inclusion of GSI in complete street renderings.
Source: Kitchener, 2020b

Finally, Kitchener also makes its expectations clear to contractors through a series of standard specification documents. When awarded a contract to construct an infiltration system, for example, contractors must submit a work plan detailing construction sequencing, material suppliers, and methods for avoiding contaminating materials and the facility (City of Kitchener, 2018, Standard Specification 480). Clarity about material specifications and how the work will be carried out reduces the potential for mistakes from miscommunication and field changes.

5.4.8 Cost Comparisons with Conventional Grey Infrastructure: The Right Way to Compare GSI Costs

Initial municipal projects helped Kitchener compare the cost of GSI with grey infrastructure. For example, a post-construction financial analysis compared the cost of the materials used in two options: a permeable paver parking lot and a similar-sized traditional asphalt parking lot with an oil and grit separator (OGS) to treat water quality.

The permeable paver parking lot is in a public park, Huron Natural Area (**Figure 20**). The 550-square-metre parking lot uses 80-millimetre pavers, a bedding course, a granular reservoir (Gran O), filter fabric, and chip stone for between the joints.

Figure 20: Permeable pavement parking lot under construction at the Huron Natural Area.
Source: Wilson, 2019

The GSI option costs $11,000 less than the asphalt-plus-OGS option (see **Table 8**). Only the materials used in the construction of the permeable pavement parking lot were compared to relevant materials used in a similar-sized asphalt parking lot. Total project cost for the Huron Natural Area project would be $40,000 higher ($105,831 in total) than what is shown in **Table 8**. This amount would also include costs for an asphalt laneway and large gardens.

Table 8: Comparison of costs of materials for parking lot permeable pavers and for asphalt and oil and grit separator

Huron Natural Area GSI material costs		Similar-sized asphalt parking lot with OGS	
Item	**Tender costs ($)**	**Item**	**Estimated costs ($)**
Geotextile – Mirafi RS 380i	960	Granular A + B	9,089
Filter Fabric – 270R	522	Asphalt (HL3)	5,338
Gran O	19,758	Asphalt (HL4)	5,569
ASTM No. 8 (5–6 mm chip stone)	1,755	MH & CB (1)	5,500
ASTM No. 57 (20 mm clear stone)	2,430	Catchbasin leads	–
Excavation	7,500	Stormwater sewer	12,000
Permeable pavers	32,086	Excavation	3,750
–	–	OGS	35,000
GSI cost from tender (includes labour)	65,011	Asphalt cost (includes labour)	76,247

Abbreviations: GSI, green stormwater infrastructure; mm, millimetre; OGS, oil and grit separator.
Source: Wilson, 2019

Unrelated costs are often lumped in with GSI construction costing. Kitchener staff were careful to separate out other construction activities (such as building upgrades and landscaping) to compare costs more accurately.

When comparing the construction cost of GSI against traditional development, the important metric is not the cost of the GSI facility itself. What is important to measure is the cost difference between a GSI facility (with dual functionality and a conventional road, roof, garden, or parking lot) with applicable **grey stormwater infrastructure**. Taking this dual-purpose flexibility into account strengthens the **business case** for GSI meeting high stormwater management standards.

Grey stormwater infrastructure: Grey stormwater infrastructure uses centralized facilities—typically stormwater ponds as well as curbs, catchbasins, and pipes—and does little to re-establish the natural **hydrologic cycle**. In **legacy developments**, grey stormwater systems typically discharge collected stormwater directly into waterways, without quality treatment or quantity control.

Business case: a financial, economic, or scientific justification for public investment in a project to realize “specific outcomes in support of a public policy objective” (Government of Canada, 2020).

5.4.9 Improving Stormwater Management Level of Service City-Wide through Private Property Development and Redevelopment

As discussed in **Section 5.3.1**, Kitchener has set a city-wide RVCT. If the RVCT cannot be met by the development or redevelopment parcel, the full fee of $100,575 per hectare is applied. If the RVCT can be only partially met, a fee proportional to the volume of controlled runoff is applied.

By developing such a strategy, Kitchener has created a cost-effective public–private partnership, sharing the expense of improving the stormwater management infrastructure by applying GSI. Shifting the financial burden from the municipality to numerous parties is critical in areas where little to no stormwater infrastructure exists.

5.5 Employing the Strategy

In 2018, Kitchener completed six road retrofits that included GSI facilities. The total cost for the GSI facilities was about $700,000, while the total cost for the road reconstruction projects was about $16.5 million (see **Table 9**). The key measure here is the additional cost of bundling GSI with each road retrofit. This amounted to only three to six per cent of the total project costs.

In 2017, the then Ontario Ministry of the Environment and Climate Change released the draft *Low Impact Development (LID) Stormwater Management Guidance Manual*. This draft manual recommended an RVCT that would require Ontario municipalities to capture 90 per cent of the average annual rainfall on all road reconstruction projects. The reception of this draft guidance manual in the stormwater community was mixed; many considered the cost to implement this requirement prohibitive. However, as Kitchener demonstrates, if municipalities take a systematic approach to implementing an RVCT, the incremental cost increase does not need to be excessive.

Ontario's Ministry of the Environment, Conservation and Parks is currently reviewing the draft guidance manual. It is expected to be released in 2020/2021.

Table 9: Incremental cost of GSI facilities in six road reconstruction projects in Kitchener in 2018

Road	GSI type	Total cost of road reconstruction ($)	Total GSI cost ($)	Traditional SWM cost ($)	GSI cost (total GSI cost minus traditional SWM) ($)	Cost increase (%)
Guelph	Porous concrete parking lay-bys	3,117,444	119,408	22,002	97,406	3
Patricia	Combined exfiltration system	5,566,372	299,072	46,015	253,057	5
Hillview	Separated exfiltration system	3,708,587	208,511	28,780	179,731	5
Oxford	Combined exfiltration system	2,558,311	90,830	13,008	77,822	3
Dieppe	Bioretention boulevard	761,834	40,000	6,000	34,000	5
Hett	Combined exfiltration system	825,320	61,984	9,297	52,687	6

Abbreviations: GSI, green stormwater infrastructure; SWM, stormwater management.
Source: Wilson, 2019; Gollan, 2019

Adhering to the RVCT of 12.5 millimetres for private sector development and redevelopment projects has also been shown to be financially feasible. At three development or redevelopment sites, meeting the 12.5-millimetre RVCT was, for the most part, more cost-effective than paying the stormwater fee (see

).

Table 10: Application of the stormwater fee to development and redevelopment projects in Kitchener

Site name	Size (ha)	GSI features employed	Amount (mm) [portion (%) of RVCT met]	Fee without GSI ($)	Fee with GSI ($)	Fee reduction ($)	Cost of GSI ($)	Savings ($)
Homer Watson Boulevard (Redevelopment)	1.77	OGS and rooftop infiltration galleries	8.75 [70]	171,106	51,332	119,774	85,000	34,774
1241 Strasburg Road (Redevelopment)	0.41	Chamber system	12.5 [100]	41,235	0	41,235	64,880	−23,645
Seabrook Drive (Development)	2.90	Infiltration galleries, infiltration trenches, perforated pipes	12.5 [100]	291,667	0	291,667	142,049	149,618

Abbreviations: GSI, green stormwater infrastructure; ha, hectare; mm, millimetre; OGS, oil and grit separator; RVCT, runoff volume control target.
Adapted from Wilson, 2019

5.6 Conclusion

Kitchener's development and use of a stormwater master plan that includes an RVCT and associated stormwater fees is still in its early days. The expectation among City of Kitchener staff is that costs for GSI retrofits will continue to decrease. Nick Gollan, Manager of the Sanitary and Stormwater Utilities Division, harkens to the Law of the Five Ps—"prior preparation prevents poor performance"—and luck—"a combination of preparation and opportunity" (Gollan, 2019). These inferences appear to be true: Kitchener's work is encouraging for the business case for GSI. An incremental cost of three to six per cent to total project cost is very small, given the numerous benefits that GSI can provide. However, the success to date is also due to the systematic approach Kitchener has taken with stormwater management and its city-wide application. It has laid a strong foundation for success and is a great example for municipalities across Canada.

6.0 CITY OF EDMONTON CASE STUDY

Key findings:

- The City of Edmonton's stormwater utility provider, EPCOR, developed and adopted its Stormwater Integrated Resource Plan to combat flooding and reduce damages from high-intensity storms.
- Adopting this plan led to Edmonton's flood preparedness ranking increasing from a "C" in 2015 to a "B+" in the Intact Centre's 2021 ranking of Canadian cities' flood preparedness.
- The plan's focus is risk reduction rather than meeting design standards. This involves systematically evaluating flood vulnerability across the city and engaging residents to rank priorities.
- EPCOR is using **green stormwater infrastructure (GSI)** and **dry ponds** as a low-cost method to reduce flood risk.
- EPCOR's plan will cost $1.6 billion over 30 years. Edmonton's previous plan, which used grey infrastructure only, would have cost between $2.2 billion and $4.6 billion over 80 years and been less effective at reducing flood risk.

6.1 Background

In 2017, the City of Edmonton's drainage services were transferred to EPCOR. At that time, EPCOR began developing its Stormwater Integrated Resource Plan (SIRP). SIRP differs from the previous City-Wide Flood Mitigation Plan in key respects. SIRP:

- uses more refined risk-assessment methods;
- focuses on reducing risk rather than achieving design standards;
- leverages knowledge from the insurance sector;
- uses GSI with **dry ponds** to mitigate flood risk; and
- works with other municipal departments to share maintenance burden.

Dry pond: an open area that can be used to detain stormwater during intense storm events. Dry ponds can have dual purposes; for example, they can be outdoor facilities such as soccer fields, baseball diamonds, public parks, urban forests, and outdoor cultural spaces.

Green stormwater infrastructure (GSI): also known as low impact development (LID), green stormwater infrastructure is a stormwater management strategy that seeks to mitigate the impacts of increased **runoff** and stormwater pollution. GSI practices manage runoff as close as possible to the source in order to preserve or restore pre-development **hydrologic** and ecological functions. To preserve pre-development functions, GSI uses design to minimize runoff and to protect natural drainage patterns. To restore pre-development functions, GSI uses distributed structural practices that filter, **detain**, **retain**, **infiltrate**, **evapotranspire**, and **harvest stormwater**. GSI practices can effectively remove sediment, nutrients, pathogens, and metals from runoff, and they reduce the volume and intensity of stormwater flows.

The associated capital investment plan will cost $1.6 billion over the 30 years it takes to implement and integrate grey and **green stormwater infrastructure (GSI)**.

The previous City-Wide Flood Mitigation Plan was estimated to cost between $2.2 billion and $4.6 billion and take about 80 years to implement. This plan also relied almost exclusively on **grey stormwater infrastructure**.

Grey stormwater infrastructure: Grey stormwater infrastructure uses centralized facilities—typically stormwater ponds as well as curbs, catchbasins, and pipes—and does little to re-establish the natural **hydrologic cycle**. In **legacy developments**, grey stormwater systems typically discharge collected stormwater directly into waterways, without quality treatment or quantity control.

EPCOR's plan is to mitigate flood risk where it is highest, making more effective use of ratepayer funds than the previous plan. It will also provide these services over a much shorter time.

Owned by the City of Edmonton, EPCOR is an independent public–private utility that provides electricity, water, wastewater, stormwater, and natural gas services to communities across North America.

EPCOR operates as a regulated utility, reporting to the Utility Committee, a subcommittee of Edmonton's City Council.

EPCOR needs to demonstrate that its capital and operations plans will provide a positive return on investment for its sole shareholder, the City of Edmonton.

EPCOR plans to use GSI as a key tool in reducing flood risk while capitalizing on **co-benefits** such as water quality improvements, greenhouse gas reduction, community greening, and air quality improvements. Because GSI can be easily integrated into existing **legacy developments**, it is a cost-effective measure for reducing flood risk, decreasing the need to rely on more costly grey infrastructure projects.

SIRP comprises five themes. These are labelled as "slow," "move," "secure," "predict," and "respond." **Figure 21** shows the importance given to GSI as a "slow" flooding control measure. Total capital investment over a 30-year period is estimated at $1.6 billion, with the GSI and dry pond components each costing about $470 million.

Co-benefits: positive effects of **GSI** that are not directly related to traditional stormwater management goals. Co-benefits include air pollution removal, **urban heat island** reduction, habitat creation, energy savings, and greenhouse gas reduction.

Legacy developments: urban areas that were built before quantity or quality controls became requirements for new development in Canada. Typically, legacy developments only have infrastructure to convey stormwater from built-up areas to receiving water bodies.

Slow	• Use dry ponds and GSI to keep stormwater from the existing stormwater system, increasing its capacity during storm events • Dry ponds ($470 million) and GSI ($470 million)
Move	• Quickly and safely convey excess water away from at-risk areas • Pipe upgrades and combined sewer separation ($300 million)
Secure	• Encourage landowners' flood-proofing measures in at-risk areas ($60 million) • Reduce inflow and infiltration ($100 million) • Upgrade outfalls and control gates ($30 million)
Predict	• Use smart sensors and technologies to predict and manage stormwater flows through the system ($70 million)
Respond	• Communicate with the public during storm events, roll out flood barriers and traffic diversions, etc. • Secure emergency response equipment ($45 million)

Figure 21: Breakdown of the Stormwater Integrated Resource Plan**—**Capital and Operational Plan into its five investment themes (EPCOR, 2019).
Abbreviation: GSI, green stormwater infrastructure.
Source: adapted from EPCOR, 2019

6.2 Characterizing the Challenges

Edmonton regularly experiences short-duration, high-intensity convection storms in the summer (see **Figure 22**). These storms pose a threat to public safety, cause damage to property and infrastructure, displace residents, impact essential services, damage the environment, and affect public health including mental health. In 2004 and 2012, severe rainstorms flooded nearly 5,700 homes (EPCOR, 2018b, Appendix 1).

The Insurance Bureau of Canada reported in 2018 that it cost an average of $43,000 to repair a basement flood (IBC, 2018). In 2020 dollars, the overall cost of repairs after such floods would amount to about $245 million.

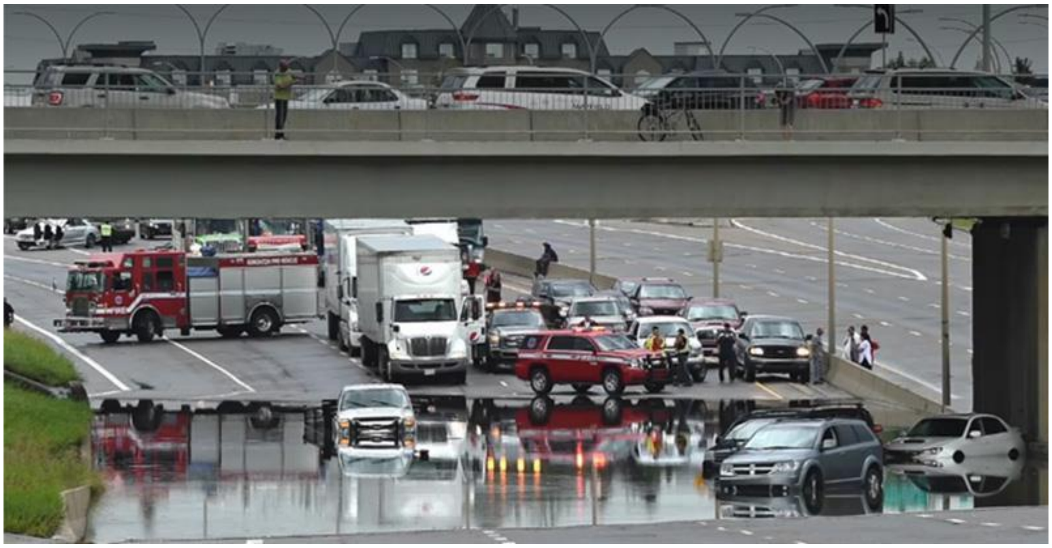


Figure 22: Underpass flooding on Edmonton's Whitemud Drive.
Source: EPCOR

Such storms generate variable amounts of precipitation across a region. While some communities can receive 100 millimetres or more of rainfall over a short time, others just kilometres away may not receive any. **Figure 23** shows precipitation patterns for two recent storms over Edmonton.

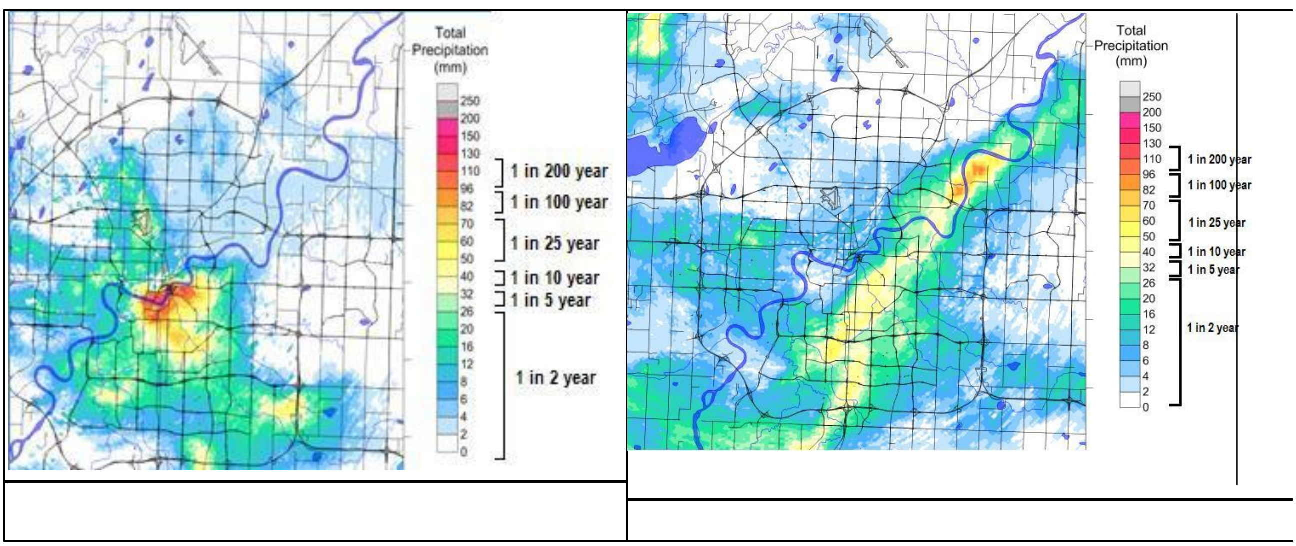


Figure 23: Total precipitation charts for two storms over Edmonton—July 27, 2016 (left) and August 5, 2017 (right).
Abbreviation: mm, millimetre.
Source: EPCOR, 2019, pg. 10

Edmonton adopted more stringent stormwater controls for new development in 1989 (EPCOR, 2018a, pg. 2), However, legacy developments built before 1990 make up the bulk of the city's urban area. These legacy developments typically have the greatest flood risk. Also, although post-1990 developments do have lower flood risk, the engineering practices used to design them did not account for changing weather patterns resulting from climate change.

This legacy has left many of Edmonton's homes, businesses, and infrastructure vulnerable to flooding.

EPCOR provided five reports to Edmonton's Utility Committee between February 2018 and May 2019 that describe SIRP and its development. This case study synthesizes these reports. The plan was approved in May 2019.

Like many North American communities, most urban development in Edmonton occurred before stormwater controls became common. Over the past 50 years, stormwater management has gone through distinct phases, though the timing for these eras differs from municipality to municipality.

- 1970s/1980s: focus on **peak flow control**. Little concern with water quality or volume reduction.
- 1990s: added quality and volume controls. Focus on end-of-pipe methods (stormwater ponds, oil and grit separators, etc.).
- 2000s to present: while end-of-pipe methods are still the most common, many municipalities are moving to GSI.

6.3 Setting Objectives

EPCOR adopted an integrated resource-planning methodology. This methodology takes a holistic approach to infrastructure planning and management that "integrates environmental and social externalities; operational, planning and infrastructure responses; risk assessment and management; financial analysis; and an open participatory process that incorporates continuous improvement" (EPCOR, 2018a, pg. 1).

EPCOR developed a robust risk-ranking methodology to determine where and how to invest in stormwater management improvements. Working with Edmonton's Climate Change Adaptation initiative, EPCOR identified four climate hazards related to stormwater management: **urban flooding**, **riverine flooding**, rain-on-snow, and hail. These will increase in frequency and duration in coming years.

Urban flooding: also known as "pluvial flooding," urban flooding includes **surface flooding** and **sanitary sewer surcharging**. Urban flooding results from intense or prolonged rainfall in urban areas, overwhelming the capacity of the stormwater management system and causing flooding in low-lying areas. This can cause damage in many ways, chiefly through sanitary sewer backups (from **inflow and infiltration**) and from stormwater directly entering buildings.

Riverine flooding: also known as "fluvial flooding," riverine flooding occurs when a river overflows its banks, causing water to flow across its flood plain.

SIRP primarily focuses on urban flooding, which includes **surface flooding** and **sanitary sewer surcharging**.

Unlike Edmonton's previous stormwater plan, SIRP does not aim to achieve a certain design standard for legacy developments. Instead, SIRP aims to "provide an incremental improvement that can be incorporated into a community over time without conflicting with an ultimate level or service goal" (EPCOR, 2018d, pg. 14). This focus on incremental improvements to existing communities opens room for distributed, at-source GSI that mitigates flood risk. This approach is also more cost-effective.

Sanitary sewer surcharging occurs when wastewater systems reach capacity or are obstructed. This causes sewage to back up along the sewer line and can result in sewage overflowing into buildings.

Surface flooding occurs when water reaches an opening (e.g. a basement window) in a building or inundates vehicles, destroys landscaping, etc.

6.3.1 Risk-Ranking Edmonton's 1,300 Subbasins: Outlining the Approach

EPCOR used a five-step geospatial analytics process to rank communities according to their risk of damage from extreme rainfall events and to allocate resources:

1. Determine storm scenarios and plot them on a likelihood scale using five return-period storms (1:20, 1:50, 1:75, 1:100, 1:200).
2. Determine the likelihood of each type of flooding for each **subbasin** based on the current capacity of the stormwater infrastructure.
3. Evaluate the condition of existing stormwater assets and adjust models or risk-rankings accordingly.
4. Use capacity indicators to rank each subbasin's flood risk in four impact categories: health and safety, environmental, social, and financial.
5. Conduct public opinion research to develop weightings for each of the four impact categories.

Subbasin: an urban area that drains stormwater to a single trunk sewer or outlet. See also **catchment**.

EPCOR allocates resources based on communities' relative risk rankings.

6.3.2 Step One: Determine Storm Scenarios and Plot Them on a Likelihood Scale

Edmonton's previous City-Wide Flood Mitigation Plan used the traditional approach of restricting the return-period storms used in flood modelling to those that provide design standards for current development, that is, 1:50- and 1:100-year storms. The $2.2 billion to $4.6 billion capital investment scenarios were meant to improve stormwater quantity management in legacy developments to the design standards described in **Table 11** (EPCOR, 2018b, pg. 6; EPCOR, 2019, Appendix A).

Table 11: Design storm scenarios used by Edmonton's previous City-Wide Flood Mitigation Plan

Climate hazard	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Urban flooding	1:100-year storm impacting 20 km^2	1:100-year storm impacting 5 km^2	1:50-year storm impacting 20 km^2	1:50-year storm impacting 5 km^2
Cost to upgrade ($ billion)	4.6	2.6	3.4	2.2

Abbreviation: km^2, square kilometre.
Source: EPCOR, 2019, Appendix A

Rather than focusing on two return-period storms, EPCOR adopted more precise insurance industry practices. Based on this wider range of storm scenarios (see Table 12; EPCOR, 2018d, pgs. 14–15), EPCOR can identify those subbasins that have higher risk of flooding from more frequent storms and a wider range of storms.

Table 12: Storm scenarios, percentage likelihood over time, and the Stormwater Integrated Resource Plan likelihood scale

Storm scenario	Likelihood over time (%)			SIRP likelihood scale
	Over 1 year	Over 30 years	Over 100 years	
1:20	5.00	78.54	99.41	4.5
1:50	2.00	45.45	86.74	4
1:75	1.33	33.15	73.88	3.5
1:100	1.00	26.03	63.40	3
1:200	0.50	13.96	39.42	2

Abbreviation: SIRP, Stormwater Integrated Resource Plan.

These likelihood rankings were then plotted along the x-axis of a risk grid (see **Figure 24**). The likelihood rankings—the probability that a subbasin will experience an intense storm—are the same for all 1,300 subbasins across Edmonton. Scores along the y-axis indicate the severity of consequences if flooding results from any of the scenario storms listed in **Table 12**. The coloured bands on the risk grids indicate overall risk level.

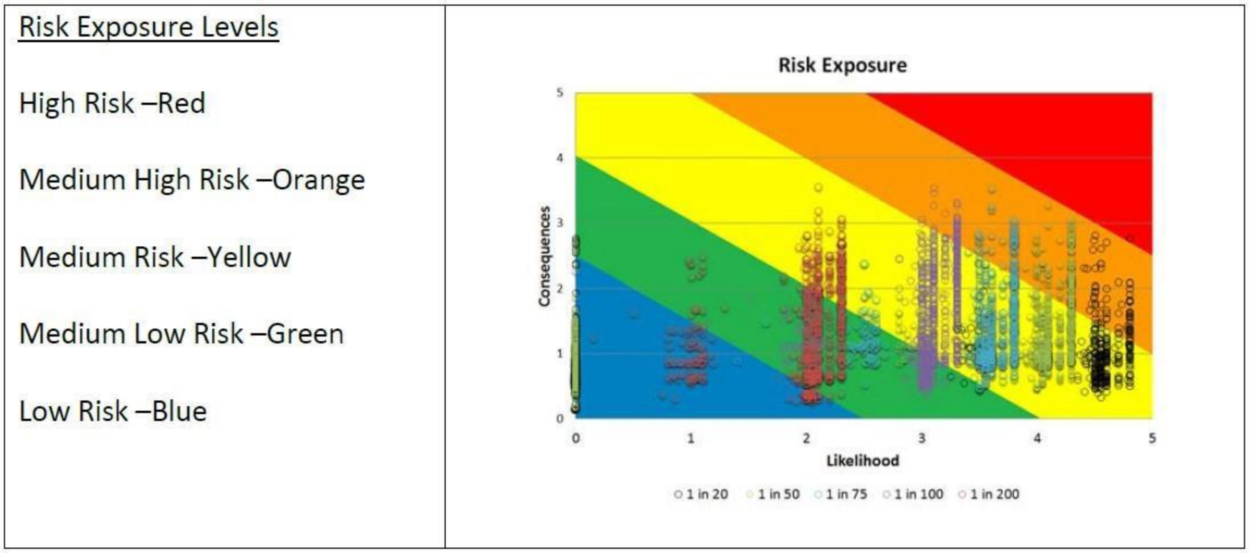


Figure 24: EPCOR's sample risk grid.
Source: EPCOR, 2018d, pg. 13

6.3.3 Step Two: Determine the Likelihood of Flooding Based on Current Stormwater Infrastructure Capacity

After dividing the city into approximately 1,300 subbasins, EPCOR evaluated the capacity of the stormwater infrastructure in each subbasin and its vulnerability to flooding. To do this, EPCOR used information from several sources: previous modelling studies; flood maps purchased from the insurance industry; city records from past flooding events (e.g. 311 calls); and design standards in place at the time of development.

This information was then mapped onto each of Edmonton's 1,300 subbasins using a georeferenced database. EPCOR compared each source of extracted information with the other information sources from the database and decided which information source would determine the risk-ranking. Typically, the worst-case scenario governed the risk-ranking: if a modelling study showed low risk, but the insurance industry maps showed high risk, the subbasin in question was classified as high risk. If this led to risk-rankings that appeared overly cautious, these risk-rankings were reanalyzed. For example, past flood reports usually acted as a risk modifier. If a subbasin had past flood reports, but models or insurance maps did not consider it high risk, its risk-ranking would increase by a prescribed factor. Conversely, if there were no past flood reports for a subbasin, but models or insurance maps considered it high risk, its risk-ranking would decrease by a known factor.

EPCOR then mapped results from this geospatial analysis exercise onto ranges for each type of flooding.

Table 13 shows the ranges used for surface flooding and sanitary sewer surcharging. Note that the results from this step indicate only that some type of flood risk can occur to a certain degree under the storm scenario in question. To determine whether the predicted level of flooding would result in damages, EPCOR used the results from this step and analyzed them through the lens of its chosen impact categories in Step 4 (see **Section 6.3.5**).

Table 13: Consequences of extreme rainfall used to develop severity rankings for urban flooding

Consequence	Description	Damage thresholds for urban flood risk
Sanitary sewer surcharge	If a sanitary sewer surcharge reaches the floor level of a basement (typically 2.5 m below ground), sewage can enter the building and cause damage.	More than 2.5 m below ground Between 2.5 and 1.5 m below ground Between 1.5 m below ground and ground level
Surface flooding	When water reaches an opening (e.g. a basement window) in a building or inundates vehicles, destroys landscaping, etc.	Between ground level and 35 cm above ground Between 35 and 50 cm above ground Between 50 and 75 cm above ground Over 75 cm above ground

Abbreviations: cm, centimetre; m, metre.
Source: EPCOR, 2018c, pg. 6

6.3.4 Step Three: Evaluate the Condition of Existing Stormwater Assets and Adjust Models or Risk-Rankings

Legacy stormwater management systems typically include trunk sewers, local sewers, catchbasins, wet and dry ponds, pump stations, control gates, weirs, and outfalls. Using inspection, maintenance, and operations data gathered by the City of Edmonton, EPCOR ranked these stormwater assets for risk of failure. It incorporated these condition risk-rankings into the overall risk-ranking (EPCOR, 2018c, pg. 9). The potential risk of failure of some trunk and combined sewers, pump stations, and control gates affected the risk-ranking for multiple subbasins.

While assessing the condition of Edmonton's existing stormwater assets, EPCOR also noted road conditions so that it can coordinate with Edmonton's Neighbourhood Renewal program. Road repaving or reconstruction offers a cost-effective opportunity to implement GSI (see also the Kitchener case study).

6.3.5 Step Four: Use Capacity Indicators to Rank Each Subbasin's Flood Risk

EPCOR used the capacity and condition risk-rankings to determine risk scores for four impact categories: health and safety, environmental, social, and financial. All risk scores are set between zero and five. Below we show how EPCOR used capacity and condition risks to risk-rank the social and financial impact categories.

6.3.5.1 The Social Impact Category

For the social category, EPCOR identified subbasins containing critical infrastructure or essential utilities that are susceptible to flooding or erosion damage. For example, if sanitary sewer surcharging occurred between 2.5 metres underground and ground level during a 1:20-

year storm in a subbasin with a hospital, the subbasin would receive a point on the y-axis of the risk grid (see **Figure 24**).

This subbasin would receive another point on that y-axis if it also contained an essential utility—for example, a natural gas line or watermain—and was near a creek that was susceptible to erosion. Finally, if a 1:20-year storm caused sanitary sewer surcharging between 1.5 metres below ground and ground level, the subbasin would receive another point for the potential displacement of residents for a long time. Because the likelihood for a 1:20-year storm on the risk grid is 4.5 and the score for this hypothetical subbasin is 3, the social impact risk-ranking for this subbasin would be medium high (EPCOR, 2018d, pg. 19; see **Figure 25**).

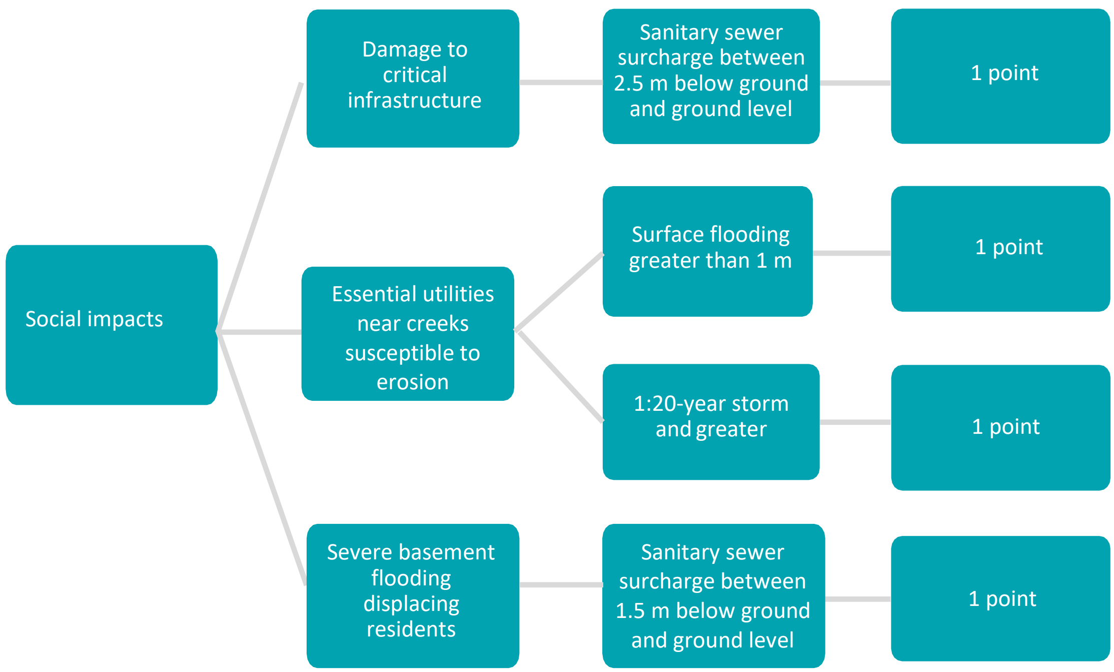


Figure 25: Social risk is determined by whether the subbasin contains critical infrastructure and predicted depth of flooding.
Abbreviation: m, metre.

6.3.5.2 The Financial Impact Category

The financial risk category takes modelled predictions about damage from basement flooding (caused by surface flooding or sanitary sewer surcharging) and plots them on the y-axis of the risk grid (see **Figure 24**). The percentage of a subbasin susceptible to basement flooding from any level of sanitary sewer surcharging or surface flooding (see

Table 13) determines basement flood risk. **Figure 26** shows how these thresholds map onto the five-point consequence scale. If the pipes in a subbasin were found to be in poor condition, that subbasin would receive an extra half point on its financial consequences score (EPCOR, 2018d, pg. 18).

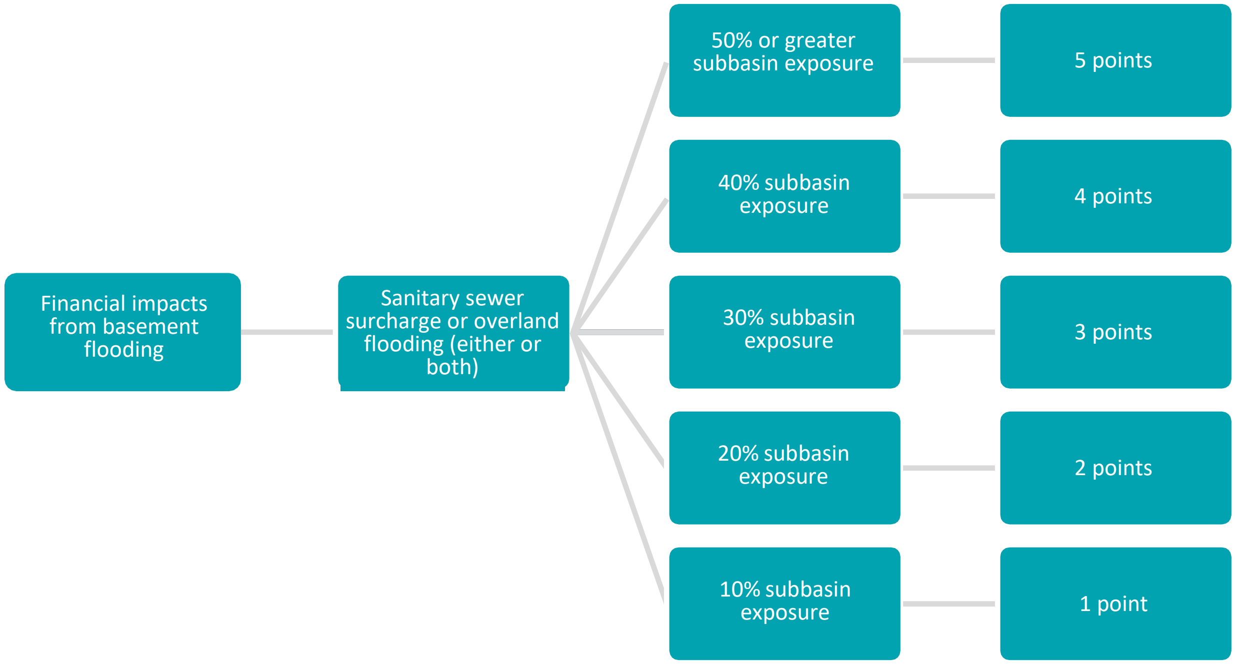


Figure 26: Breakdown of the risk-ranking methodology for financial impacts from basement flooding.

6.3.6 Step Five: Conduct Public Opinion Research to Develop Weightings for Each Impact Category

To allocate resources based on these impact categories, EPCOR needed to know how to prioritize each impact category relative to the others. To develop relative weightings for each impact category, EPCOR surveyed 1,500 Edmonton residents. This survey asked respondents about three levels of flooding impacts: moderate, major, and extreme. For moderate impacts, survey respondents selected five outcomes from a list and then prioritized them (EPCOR, 2018d, pgs. 4–12). For major and extreme events, respondents ranked lists of competing health and safety, social, environmental, and financial options from most to least important. See

Table 14 for the descriptions of the extreme impact scenarios.

Table 14: Descriptions of outcomes in the four impact categories used in EPCOR's public opinion survey for extreme impact scenarios

Extreme flood impact scenarios	
Health and Safety • The health authority intervenes after increased reports of residents and contractors in your neighbourhood falling ill (e.g. respiratory and digestive issues) through prolonged contact with sewage and mold. Homes/dwellings are condemned. • Basement flooding to ground-level puts residents at risk of drowning/death from not being able to escape to higher ground. • Due to flooding impacting the building, a local hospital with specialized services is forced to close, and surgeries and other critical procedures need to be cancelled, resulting in patient deaths or worsened conditions. • Stormwater floods streets in your neighbourhood and completely covers your property or lawn, touching the lower walls of your home/building. Access to your location is restricted until the area can be cleaned and sanitized. • An underpass or parking lot floods at a high rate of speed, increasing risk of drowning deaths of people unable to escape their vehicles.	Environment • A large natural area is permanently damaged and not able to be replanted, including vegetation in your yard, neighbourhood parks, playgrounds, and greenspaces. • The ecosystem (vegetation, insects, and wildlife) in the North Saskatchewan River is killed due to a large amount of chemical pollutant or sewage spilling into it. • Neighbourhood parks, trails, creeks, and sidewalks are damaged due to soil erosion, making them inaccessible for upwards of a year while being repaired. • The ecosystem (vegetation, insects, and wildlife) in a major natural area/whole watershed/drainage basin is killed as a result of a flood-related accident involving a truck/train derailment spilling the chemicals, oil, or gases it is carrying. • Garbage clean-up in your neighbourhood is delayed for upwards of a year due to large amounts of garbage (e.g. discarded furniture, household items, and damaged drywall) piling up in yards, sidewalks, and roadways.
Social • A high-rise building with offices and residential condos experiences extensive damage, and utilities are unavailable. The building is inaccessible for upwards of a year. • Family members or close family friends are temporarily displaced from their home, requiring you to care for them or support them for upwards of a year. • Major roadways, bridges, or transit infrastructure are damaged, doubling your commute to and from your home for upwards of a year. • Agencies that support homeless or vulnerable citizens are temporarily displaced for upwards of a year and unable to get enough essential services they need such as food, shelter, or addiction/mental health support. • Your neighbourhood loses an essential utility (such as power, natural gas, or drinking water) for upwards of a year. Your neighbourhood is evacuated—at the time of the flood. • The impacts of flooding cause life-long chronic mental and physical health issues. Some may go on long-term disability as a result of the impacts. • Emergency services buildings (police, fire, EMS) are destroyed, staff and services are relocated, and response times may be impacted. Services from the destroyed building are unavailable for months.	Financial • Local businesses and services (e.g. local mail, recreation centre, businesses you frequent, etc.) are forced to close for upwards of a year. • Your employer's building (or a family member's employer) is temporarily inaccessible until repairs are completed, causing lost wages for upwards of a year. • Homes and properties in your neighbourhood experience serious outdoor damage (e.g. damage to fencing, vehicles, gardens, etc. outside the home). Homeowners are out-of-pocket hundreds of thousands of dollars to replace or fix. • Residential properties in your neighbourhood are so damaged they require demolition (single family homes and condos/apartment buildings). • Vehicles in parkades, garages, and parking lots in your neighbourhood are completely damaged because vehicles are entirely submerged in stormwater. Vehicles are written off and parking areas require repairs taking upwards of a year. • Low-income individuals are unable to afford repairs to their homes without assistance, forcing them to leave their homes permanently.

Source: EPCOR, 2018d, pg. 31

Survey respondents consistently put health and safety and social concerns first and environmental concerns last. Preventing flood damage to hospitals and essential utilities especially concerned respondents.

EPCOR had initially proposed that each consequence category be given equal ranking, set at 25 per cent each. After reviewing the public opinion survey results, it developed an alternative ranking for the Edmonton's Utility Committee to evaluate: 30 per cent each for the health and safety and social categories, 25 per cent for the financial category, and 15 per cent for the environmental category (EPCOR, 2018d, pg. 23).

In May 2019, Edmonton's Utility Committee endorsed the risk category weightings that accounted for the public opinion survey results. **Figure 27** shows the overall risk map generated by these weightings. The change in relative weightings did not change the locations that were high or medium high risk. The weightings adjusted the priority order for implementing the risk-mitigation measures over the next 20 years.

Scenario 2 – Public Opinion Survey Preference	Number Basins by Risk group	
Health and Safety – 30% Environment – 15% Social – 30% Financial – 25%	Group A – 1 Group B – 9 Group C – 51 Group D – 39 Group E – 66 Group F – 139 Group G – 543 Group H – 462	<u>Groups A-C</u> include High Risk Basins <u>Groups D-F</u> include Medium High-Risk Basins <u>Group G</u> is Medium Risk Basins <u>Group H</u> is Medium Low and Low Risk Basins
Scenario 2 – Public Opinion Survey Preference Map		

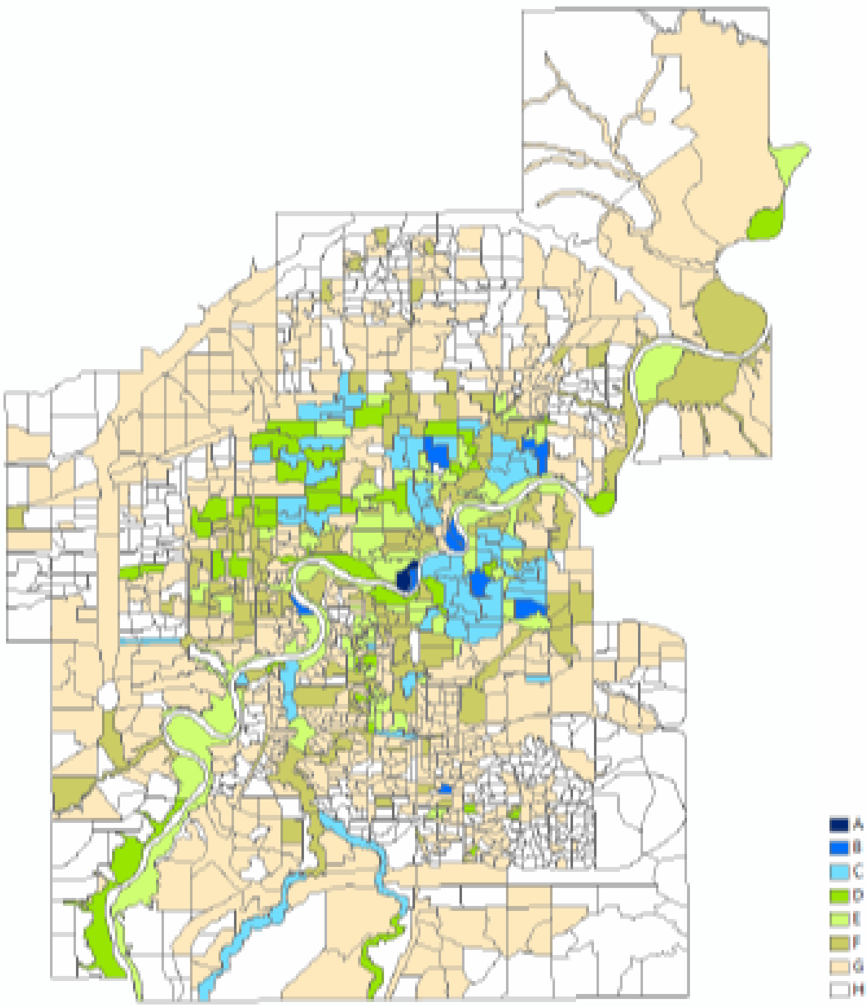


Figure 27: Overall risk-ranking using the category weightings developed with survey responses.
Source: EPCOR 2018d, pg. 23

The high- and medium high–risk subbasins form the focus of the 30-year SIRP capital investment plan (see **Section 6.4**). Subbasins containing critical infrastructure or where flooding could be a health and safety hazard will have their risk level reduced to the medium-low category; other high- and medium high–risk subbasins will have their risk lowered to the medium level. Actions that reduce flood risk would also occur in the remaining lower-risk subbasins, but will focus on implementing GSI with other planned infrastructure improvements, especially road reconstruction projects.

6.4 Developing a Cost-Effective Strategy: The Role of GSI

SIRP has five investment themes: “slow,” “move,” “secure,” “predict,” and “respond.” (see **Figure 21**). The plan exemplifies an integrated resource management approach to stormwater infrastructure. It uses various stormwater management practices where these are most cost-effective.

Because the “slow” options—dry ponds and GSI—cost less to implement than the “move” options—sewer separation and pipe upgrades—the SIRP strategy slows where feasible and moves where necessary. It’s more cost-effective to keep stormwater from entering the existing piped network than to upgrade that network, and GSI plays a key role in EPCOR’s plan to accomplish this.

Whether dry ponds or GSI are chosen as the primary strategy for a priority subbasin depends on the extent of **ponding** and the configuration of the community. If ponding is localized, using GSI along with flood-proofing at-risk buildings reduces implementation costs. It is therefore EPCOR’s preferred investment (EPCOR, 2019, pgs. 20–21). For other subbasins, dry ponds are the primary method for keeping stormwater from the piped system during storms. Generally, however, a combination of the two will be used.

Ponding is the unwanted collection of stormwater on surface depressions or roofs.

While implementing the “slow” and “move” themes will provide the greater amount of flood-risk mitigation and make up the bulk of SIRP, it takes time to plan, design, and construct these measures.

For this reason, the “secure” theme forms the initial focus for EPCOR’s capital expenditures. Flood-proofing at-risk properties, reducing **inflow and infiltration** into the sanitary system, and upgrading outfall and control gates can be accomplished more quickly than the “slow” and “move” measures. Moreover, this initial focus on the “secure” theme will immediately reduce the risk to those properties most likely to have flood damage.

Inflow and infiltration occur when stormwater enters the sanitary sewer system, either through maintenance access holes (inflow) or by entering cracked pipes underground (infiltration).

6.4.1 Using GSI for Cost-Effective Flood-Risk Mitigation

EPCOR evaluated the potential of GSI to mitigate flood risk using research completed under Edmonton's previous City-Wide Flood Mitigation Plan. Rain gardens, **bioretention** basins, box planters, and treed soil cell systems were found to have greater **retention** and **detention** capacity than, for example, **permeable pavements**. The facilities shown in **Figure 28** are all variations on bioretention as they use soil and plants to filter, detain, and retain stormwater.

Bioretention: a **GSI** practice that uses soil and vegetation to capture, filter, **infiltrate**, and **evapotranspire** stormwater. Bioretention practices vary in complexity based on soil types, design objectives, and available resources, from simple landscaped depressions to complex systems with impermeable liners, gravel storage layers, special soil mixtures, and underdrains.

Retention is the capture of stormwater for filtration, **infiltration**, and **evapotranspiration**. Retained stormwater does not become **runoff** or streamflow (unlike detained stormwater). Retaining of stormwater helps to restore a natural **water balance**.

Detention is the temporary storage of stormwater to control discharge rates and to allow for sedimentation. Detained stormwater is slowly released as runoff or streamflow. The facilities that detain stormwater do not help re-establish a natural water balance. See **hydrologic cycle** and **water balance**.

Permeable pavements: a type of **GSI** practice that allows precipitation to **infiltrate** through surface pores (permeable asphalt and concrete) or through joints between pavers.

Rain gardens are depressions in the soil that collect rainwater. The rainwater is absorbed into the soil or evaporates or is transpired by plants.
Photo location: Credit Valley Conservation, Alton, ON
Photo credit: CVC

Bioretention basins are an engineered variation on rain gardens. They can include underdrains to convey excess flows into the stormwater system and underground storage (e.g. gravel layers) to increase their retention capacity.
Photo location: Toronto and Region Conservation Authority, Kortright Centre, Vaughan, ON
Photo credit: TRCA

Box planters are similar to bioretention basins, but they are contained within a concrete structure. They are ideal for tight spaces.
Photo location: Lake Simcoe Region Conservation Authority's head office in Newmarket, ON
Photo credit: LSRCA

Treed soil cells use underground structures that prevent soil compaction and make sure that tree roots are in loose soil to encourage healthy growth.
Photo location: Credit Valley Conservation, Central Parkway, Mississauga, ON
Photo credit: CVC

Figure 28: GSI practices EPCOR chose to implement in Edmonton.
Adapted from EPCOR, 2019, pg. 19

EPCOR found the detention capacity of these GSI measures to be useful for mitigating flood risk. The risk-ranking methodology examined storms other than the 1:100-year storms traditionally used as design standards, that is, 1:20-, 1:50-, and 1:75-year storms. Also, the risk-ranking grids EPCOR used show that many of the highest-risk subbasins are projected to have flooding in 1:20-

or 1:50-year storms. By detaining the first 25 to 35 millimetres dropped by an intense storm, GSI can turn peak flows associated with a 1:20-year storm into ones associated with a 1:10-year storm, peak flows associated with a 1:50-year storm into ones associated with a 1:20-year storm, and so on. For this reason, GSI plays a significant role in EPCOR's plan to incrementally reduce flood risk.

EPCOR's fine-grained approach to measuring flood risk shows the value of vegetated GSIs for flood-risk mitigation. This capability of GSI to mitigate flood risk is often overlooked when engineers focus on achieving a specific design standard. Previous efforts sought to bring the same level of flooding control to newer developments and to legacy developments. The City-Wide Flood Mitigation Plan called for increasing conveyance capacity, separating combined sewers, and detaining stormwater in large dry ponds to meet one of four design storm scenarios (see **Table 11**; EPCOR, 2019, Appendix A). This plan would have required $2.2 billion to $4.6 billion to implement—$800 million to $3 billion more than EPCOR's capital investment plan—and would have taken about 50 years longer.

By focusing on reducing risk by using GSI and dry ponds rather than meeting a specific design standard, SIRP costs hundreds of millions of dollars less while more effectively directing resources to the subbasins with the highest risk. The plan provides this relief much sooner too.

If two storms hit in close succession, will GSI that uses soil to detain stormwater have the capacity to function for the second storm? EPCOR found that even when 50 per cent saturated, their chosen facilities performed nearly as well as they would if starting from an unsaturated state (see **Figure 29**). Bioretention basins, box planters, rain gardens, and soil cells can be designed with underdrains that convey stormwater away when they also become saturated. This drain-down time is usually set to 24 hours, with a significant safety factor built in.

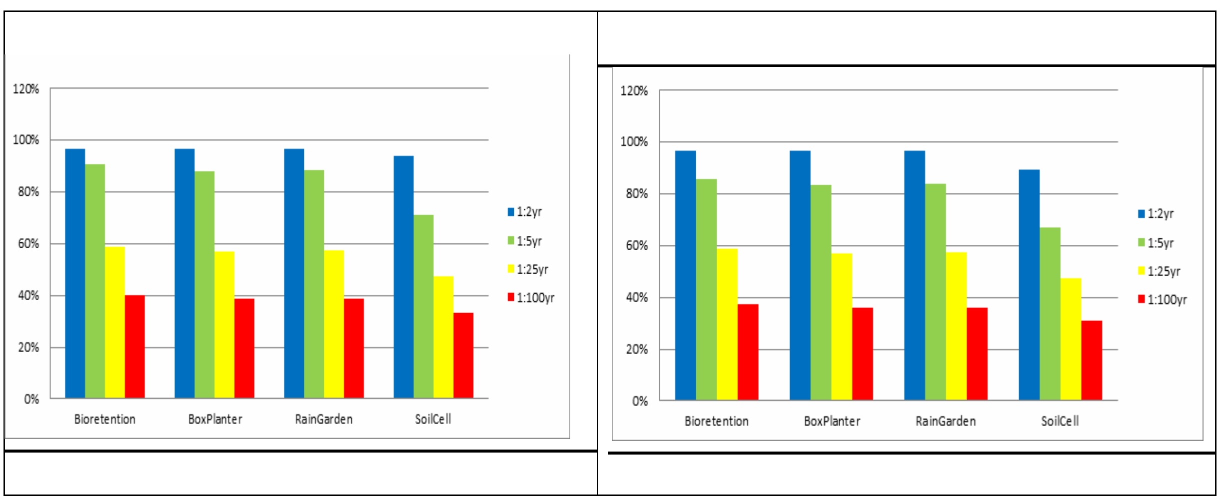


Figure 29: Runoff reduction capacity for EPCOR's four chosen GSI facilities.
Abbreviations: GSI, green stormwater infrastructure; yr, year.

Figure 30 shows the precipitation depths across Edmonton during a six-hour storm in July 2016. During a short-duration, high-intensity convection storm of the type that most commonly causes urban flooding in Edmonton, one subbasin may receive 1:200-year storm levels of precipitation while another only kilometres away may receive none. GSI can capture the lower amounts of precipitation at the edges of an intense storm cell, increasing sewer system capacity in the immediate path of the storm (EPCOR, 2019, pg. 20).

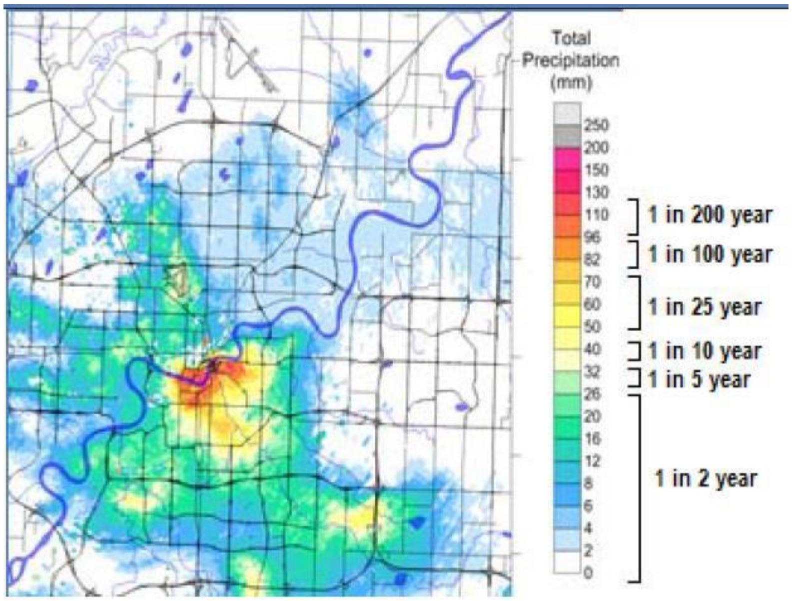


Figure 30: Precipitation depths resulting from an intense summer storm in Edmonton on July 27, 2016. Abbreviation: mm, millimetre.
Source: EPCOR, 2019, pg. 20

Furthermore, GSI can be woven into the fabric of an existing community without changing land uses. Box planters can fit neatly into existing parking lots, and treed soil cells can be constructed under impervious surfaces such as roads and sidewalks. Bioretention facilities and rain gardens can be shaped to fit existing space (see textbox "Performance under pressure: bioretention on Elm Drive in Mississauga" in **Section 4.2**). Subsurface **infiltration chambers**, though not identified in SIRP, can provide significant peak flow and volume reduction while coexisting with most surface land uses, whether on private or public property. This flexibility fits neatly with an integrated resource-planning approach to stormwater management that emphasizes incremental improvement within an existing community (EPCOR, 2018d, pg. 14). It also reduces the need to purchase and dedicate land for large stormwater management facilities (see **Section 8.4.4.2**).

Infiltration chambers: underground storage chambers that are designed to capture large volumes of stormwater. They reduce flood risk and allow precipitation, such as rainwater and snowmelt, to get under and **infiltrate** below hard surfaces, such as parking lots.

6.4.2 Using Dry Ponds for Cost-Effective Flood Mitigation

The previous City-Wide Flood Mitigation Plan identified 51 parcels of land in places where they could intercept water before it reaches stormwater sewers. In other words, these parcels had the **hydraulic** potential to become dry ponds. This list was restricted to parcels one hectare or larger across Edmonton.

Hydraulics is the study of the flow of water through pipes and channels, such as rivers.

EPCOR looked at the proposed locations for these ponds and found that 31 were in high-risk subbasins and should move to the next step for implementation (EPCOR, 2019, pg. 14).

Further analysis showed that the minimum requirement of one hectare ruled out many locations that could be used to mitigate localized flooding. Adding these smaller parcels to the list of potential dry ponds would allow for a greater variation in pond design. This gives EPCOR more flexibility during discussions with community members about how these spaces should fit within their communities.

Constructing a dry pond within a community means repurposing an existing open area to detain stormwater during intense storm events (see **Figure 31**). Dual-purpose designs—converting an existing outdoor amenity area to detain stormwater—is much more resource-effective than, say, constructing single-use wet ponds. EPCOR works with the City of Edmonton and local communities to determine how these areas can continue to be valuable assets for communities' day-to-day use. For the most part, these facilities will be soccer fields, baseball diamonds, public parks, urban forests, and even outdoor cultural spaces. Making these dry ponds dual use avoids costly land acquisitions dedicated solely to stormwater management.

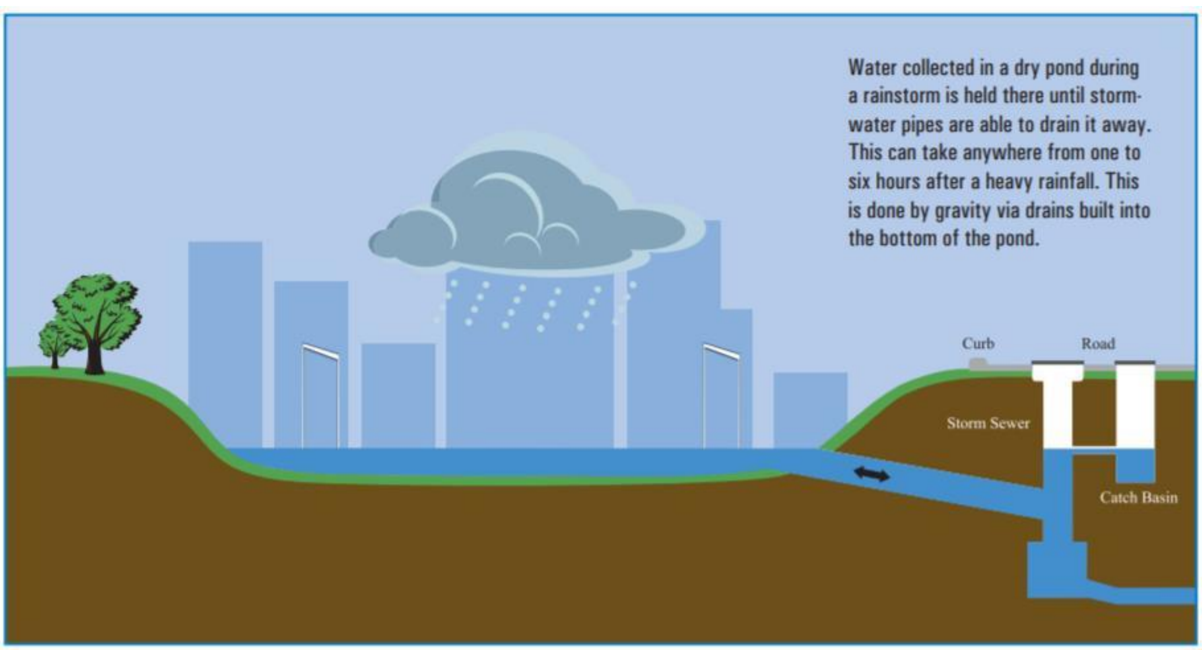


Figure 31: An existing open area repurposed into a dry pond to detain stormwater during intense storm events.

Source: EPCOR 2019

6.5 Employing the Strategy

6.5.1 Coordinating with Other City-Led Initiatives for Co-benefits and Sharing the Maintenance Burden

EPCOR has been sharing information with Edmonton's Climate Change Adaptation initiative to identify stormwater practices that provide climate change adaptation advantages beyond mitigating flood risk (EPCOR, 2018d, pg. 2). The initiative can quantify how EPCOR's GSI implementation activities will help Edmonton adapt to expected consequences of climate change, including increased **urban heat island effect**, longer drought cycles, poor air quality, and stress on ecosystems.

Urban heat island effect: because urban areas are covered with surfaces that retain heat—concrete, brick, and asphalt—their temperatures are higher than surrounding rural or natural areas. Also, because they have little vegetation, they do not benefit from the cooling effects of

EPCOR is working with other City of Edmonton departments to share the capital, operational, and maintenance costs of GSI practices. While the primary function of implementing GSI is to mitigate flood risk, GSI facilities provide multiple co-benefits. The other city departments recognize that these co-benefits should not be the burden of EPCOR alone.

For example, if SIRP calls for treed soil cells, EPCOR would build the cell and provide the soil in consultation with the Urban Forestry department. The Urban Forestry department would choose, supply, and maintain the trees needed for the system to function. Other departments will provide in-kind contributions, based on their expertise, to build and maintain those aspects of the facilities that meet their organization's goals and use each department's expertise.

6.5.2 Working with Edmonton's Building Great Neighbourhoods Program

For non-priority subbasins—subbasins at medium or lower risk that do not contain key infrastructure—GSI implementation will occur in conjunction with work scheduled by Edmonton's Building Great Neighbourhoods program. This will gradually lower flood risk across the entire city.

To further lower implementation costs, capital investments for these GSI projects are scheduled to coordinate with Building Great Neighbourhoods program projects over the next 30 years, as opposed to 20 years for priority subbasins (EPCOR, 2019, pg. 21). If the program plans work in a priority subbasin, added GSI will further reduce risk on top of the risk reduction resulting from EPCOR's independently scheduled capital investment activities. This approach mirrors Kitchener's, which ties GSI construction to road reconstruction initiatives.

6.5.3 Developing Operating Standards

Through the SIRP capital investment plan, EPCOR will be taking on the task of maintaining vegetated GSI features and will need to train its staff. To streamline this process, EPCOR will be opening a “GSI university” where EPCOR and municipal staff can learn about GSI facilities and how best to maintain them. This is also coupled with an effort to standardize designs, as seen in the Kitchener case study. The training site will house examples of EPCOR’s four chosen GSI measures—rain gardens, bioretention facilities, box planters, and treed soil cells. By maintaining these facilities, staff will be learning to effectively maintain GSI practices in the field.

6.6 Conclusion

While the City-Wide Flood Mitigation Plan focused on upgrading Edmonton’s stormwater pipe network to specific design standards, EPCOR aims to methodically reduce flood risk to acceptable levels across Edmonton’s legacy developments. SIRP uses a detailed risk analysis to measure the effects of flooding from five return-period storms across four impact categories: health and safety, environmental, social, and financial.

While SIRP costs hundreds of millions of dollars less to implement than the City-Wide Flood Mitigation Plan, it will not be achieving the same outcomes because the objectives of the two plans differ. Moreover, neither the City-Wide Flood Mitigation Plan nor SIRP included the monetary benefits of their respective plans, so a cost-benefit comparison is not available.

However, the SIRP approach to determining risk using several return-period storms means that resources will go toward lowering risk where it is highest, rather than uniformly across the city. Taking this approach means that resources will not be expended where risk is low except when other planned infrastructure is in the works. In addition, completion of the SIRP capital investment plan does not preclude further investments in flood reduction investments in the future should they be judged necessary once SIRP has run its course.

Furthermore, EPCOR’s use of four impact categories for risk assessment constitutes a holistic, triple-bottom-line economic analysis as it considers the social, environmental, and financial effects of flood risk and of its infrastructure spending plan. Finally, input from Edmonton’s residents to develop relative rankings for the four impact categories means that the risk-rankings reflect the triple-bottom-line outcomes that Edmontonians care about the most.

EPCOR’s refined approach to risk analysis shows how GSI can be cost-effective at mitigating flood risk in legacy developments. In addition, GSI practices provide a host of benefits other than peak flow reduction and attenuation. While GSI facilities remove pollutants from stormwater, reduce erosion, and restore water balance, they also clean the air, reduce the urban heat island effect, raise property values, protect natural features, provide wildlife with natural habitat, and double as recreational greenspace. These co-benefits are also discussed in the other case studies.

7.0 CITY OF VANCOUVER CASE STUDY

Key findings:

- The City of Vancouver aims to retrofit over 40 per cent of the city's impervious surfaces with **green rainwater infrastructure (GRI)** by 2050.
- Combining grey and **green infrastructure** upgrades would reduce Vancouver's **combined sewer overflows (CSOs)**, manage rainwater runoff, and save on costs.
- Costs and responsibilities for wide-scale implementation of GRI will be shared with private developers.

7.1 Background

The City of Vancouver's **combined sewer system** faces some long-standing and emerging challenges that drive the need to rethink how the city manages water in an urban environment. As in many Canadian cities, much of Vancouver's underground sewer and drainage system was built in the early to mid-1900s. Much of the system is reaching the end of its life cycle and needs to be replaced.

Combined sewer systems: collect and convey both stormwater and wastewater.

With the pressures to upgrade the system to serve population growth, improve receiving water quality through increased treatment, adapt to rainfall patterns altered by climate change, and address the infrastructure renewal gap, the expected cost of Vancouver's sewer and drainage infrastructure is in the billions of dollars. Consequently, there is a strong economic, environmental, and social imperative to deliver the services efficiently, cost-effectively, and with high value for money.

Adopted by Vancouver City Council on 5 November 2019, the Rain City Strategy is an ambitious yet pragmatic 30-year strategy that directly addresses Vancouver's water challenges. The strategy puts a renewed focus on the health of receiving water bodies, reducing flood risk, creating spaces for water in the city, and advancing water harvest and reuse (see **Figure 32**). The Rain City Strategy is a long-term road map for holistic urban rainwater management. The strategy integrates **green rainwater infrastructure (GRI)** solutions into land use, infrastructure upgrades, community plans, and urban design. It identifies rainwater management needs and opportunities across the city (for example, **Figure 33**) and examines how Vancouver can most efficiently implement GRI approaches on roads, public spaces, civic buildings, private property, parks, and beaches.

What is green rainwater infrastructure (GRI)?
In this case study, "green rainwater infrastructure" refers to a suite of rainwater management tools that use both engineered and nature-based solutions to protect, restore, and mimic the natural **water cycle** (City of Vancouver, 2019b).

Figure 32: Depiction of a water-sensitive Vancouver.
Source: City of Vancouver, 2019b

The Rain City Strategy identifies programs and actions that call for GRI implementation on both public and private lands. Three action plans have been developed. These focus on streets and public spaces; buildings and sites; and parks and beaches.

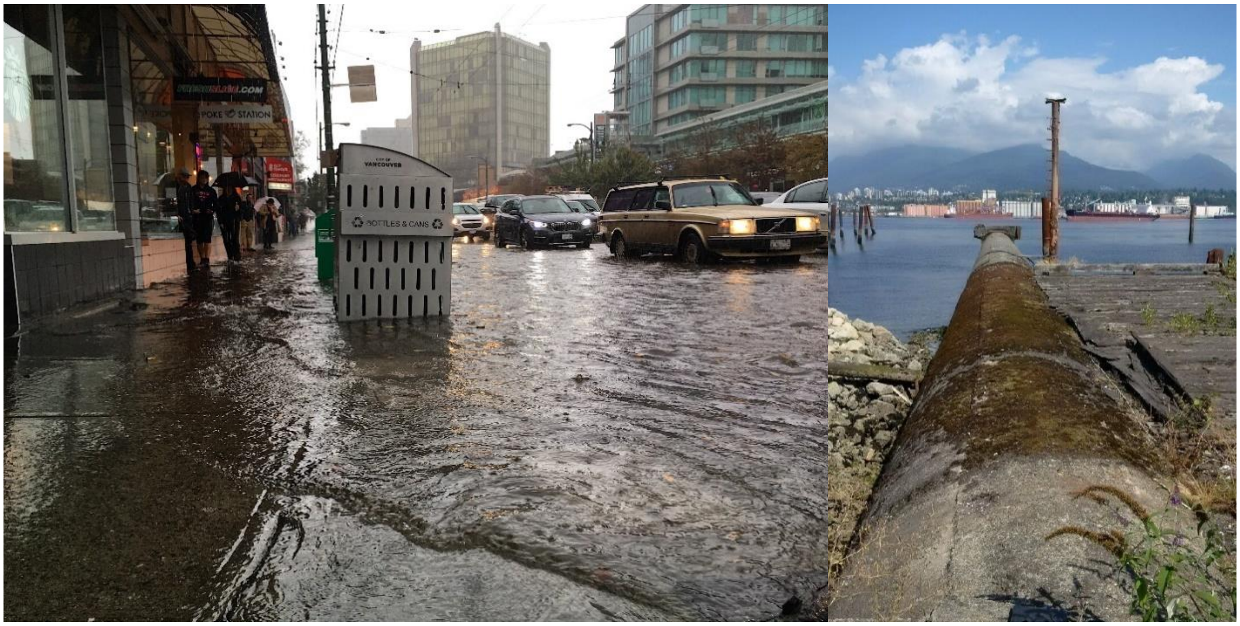


Figure 33: Aging rainwater infrastructure outfall pipe and urban flooding in Vancouver.
Photo Sources: The City of Vancouver

As private property accounts for over half of the impervious area in Vancouver, it can play an important role in reducing the volume of rainwater entering the sewer and drainage system, preserving capacity and contributing to water quality goals.

A holistic and integrated urban water management approach can do much more than serve the basic water needs of a community. Beautifying the city, providing greenspace for passive and active recreation, ensuring cleaner waters to support the environment and recreation, and increasing tree and vegetation cover to reduce the **urban heat island effect** are just a few of the **co-benefits** of GRI.

This smart "**One Water**" approach to wide-scale GRI implementation will be seen throughout Vancouver. This approach will ensure that the city can capture and clean 90 per cent of its rainwater and reach its goal of becoming the greenest city in the world.

Urban heat island effect: because urban areas are covered with surfaces that retain heat—concrete, brick, and asphalt—their temperatures are higher than surrounding rural or natural areas. Also, because they have little vegetation, they do not benefit from the cooling effects of **evapotranspiration**.

Co-benefits: positive effects of **GSI** that are not directly related to traditional stormwater management goals. Co-benefits include air pollution removal, **urban heat island** reduction, habitat creation, energy savings, and greenhouse gas reduction.

One water: A "one water" approach looks at the full water cycle in all its forms: drinking water, wastewater, rainwater, surface water, and groundwater (City of Vancouver, 2019).

Vancouver is working on a long-term financial plan to identify equitable and sustainable funding approaches to guide the pace and magnitude of investment needed to implement GRI and meet the Rain City Strategy targets. The following sections outline some of the challenges specific to Vancouver, the objectives and targets of the Strategy, and how the city is working toward implementing the Strategy through new projects.

7.2 Characterizing the Challenges

Vancouver is a coastal community defined by its proximity to the ocean, rivers, and mountains. The Salish Sea lies to the west, Burrard Inlet to the north, and the north arm of the Fraser River to the south. Vancouver acknowledges that it is situated on the unceded traditional territories of the Musqueam, Squamish, and Tsleil-Waututh Nations, who carry a deep connection to these lands and water. Many residents value the local waterways in terms of recreation and resources and are concerned about protecting this environmental ecosystem.

The following sections detail Vancouver's water quality and quantity challenges and what GRI can offer.

7.2.1 A Growing City

Like many Canadian cities, Vancouver's underground sewer and drainage systems were built in the early to mid-1900s as a combined system (**Figure 34**). Population growth and increased density have had a large impact on the city's sewer and drainage infrastructure. Increased annual rainfall due to climate change is also leading to capacity constraints in the sewer and drainage system, exacerbating **combined sewer overflows (CSOs)** into the local water bodies (City of Vancouver, 2019b).

Combined sewer overflows occur when **combined sewer systems** overflow or when wastewater treatment plants bypass incoming flows, releasing untreated sewage into receiving water bodies.

British Columbia has consistently been the largest contributor to CSOs in Canada (Statistics Canada, 2018). In 2018, nearly 33 billion litres of combined sewage (wastewater diluted with rainwater **runoff**) was discharged into the waters surrounding Vancouver (City of Vancouver, 2019). These CSOs were generated by the Vancouver Sewerage Area, which includes most of Vancouver and some of the City of Burnaby's highest density neighbourhoods, including Brentwood and Metrotown.

Runoff is rainwater that flows over hard surfaces such as roofs and roads as runoff instead of **infiltrating** into the ground. Urban runoff carries heavy metals, nutrients, bacteria, and other pollutants into local streams, adversely affecting human, animal, and plant life.

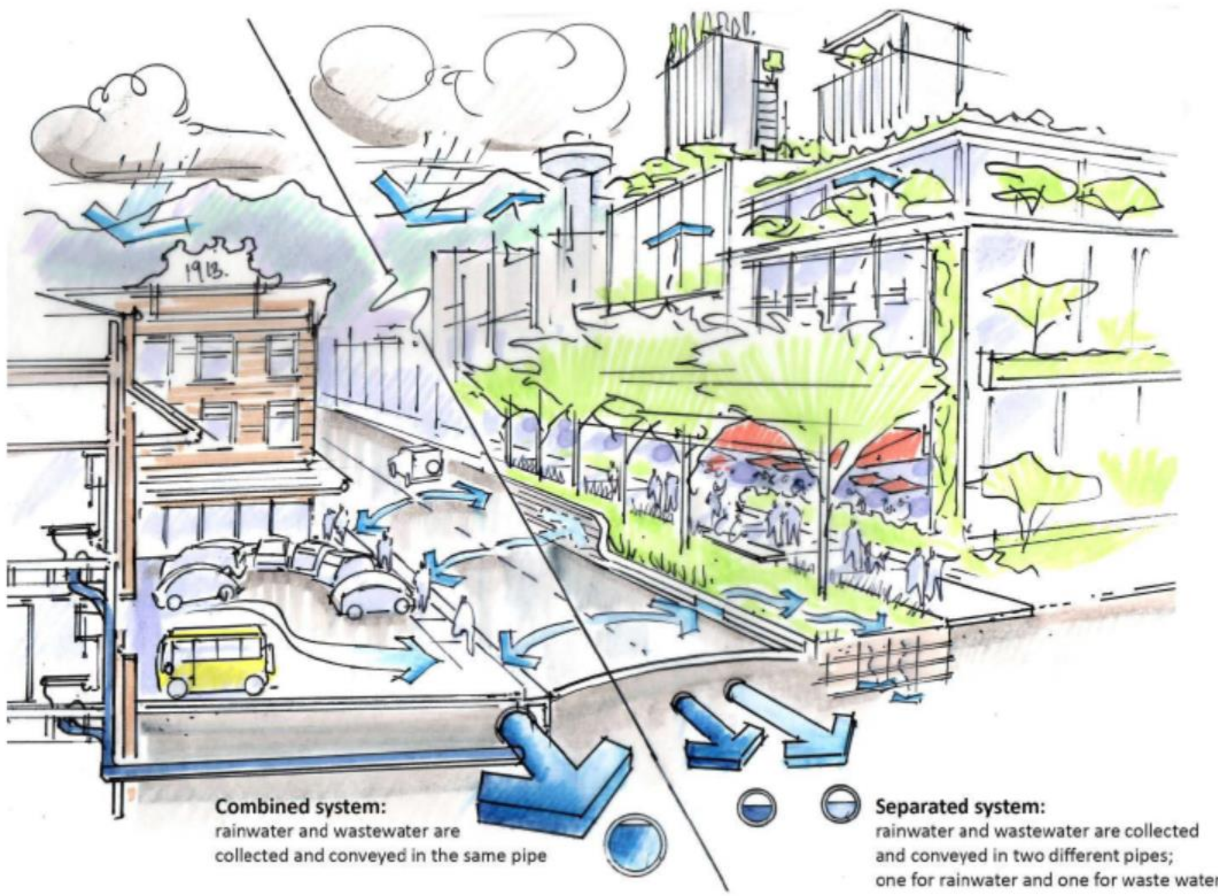


Figure 34: Depiction of rainwater runoff managed using green rainwater infrastructure features and combined and separate sewer systems.
Source: City of Vancouver, 2019b

Since the 1970s, sewer separation has been the primary strategy to address CSOs. The system of combined and separated pipes is highly complex. Many separated pipes subsequently flow into combined sewer trunks that may continue to overflow when the system is over capacity (see **Figure 35** and **Figure 36**).

Even if all the combined pipes are completely separated, water quality in urban rainwater runoff remains a concern. When it rains, pollutants from urban areas are washed into local water bodies. These pollutants are detrimental for local waterways and beaches.

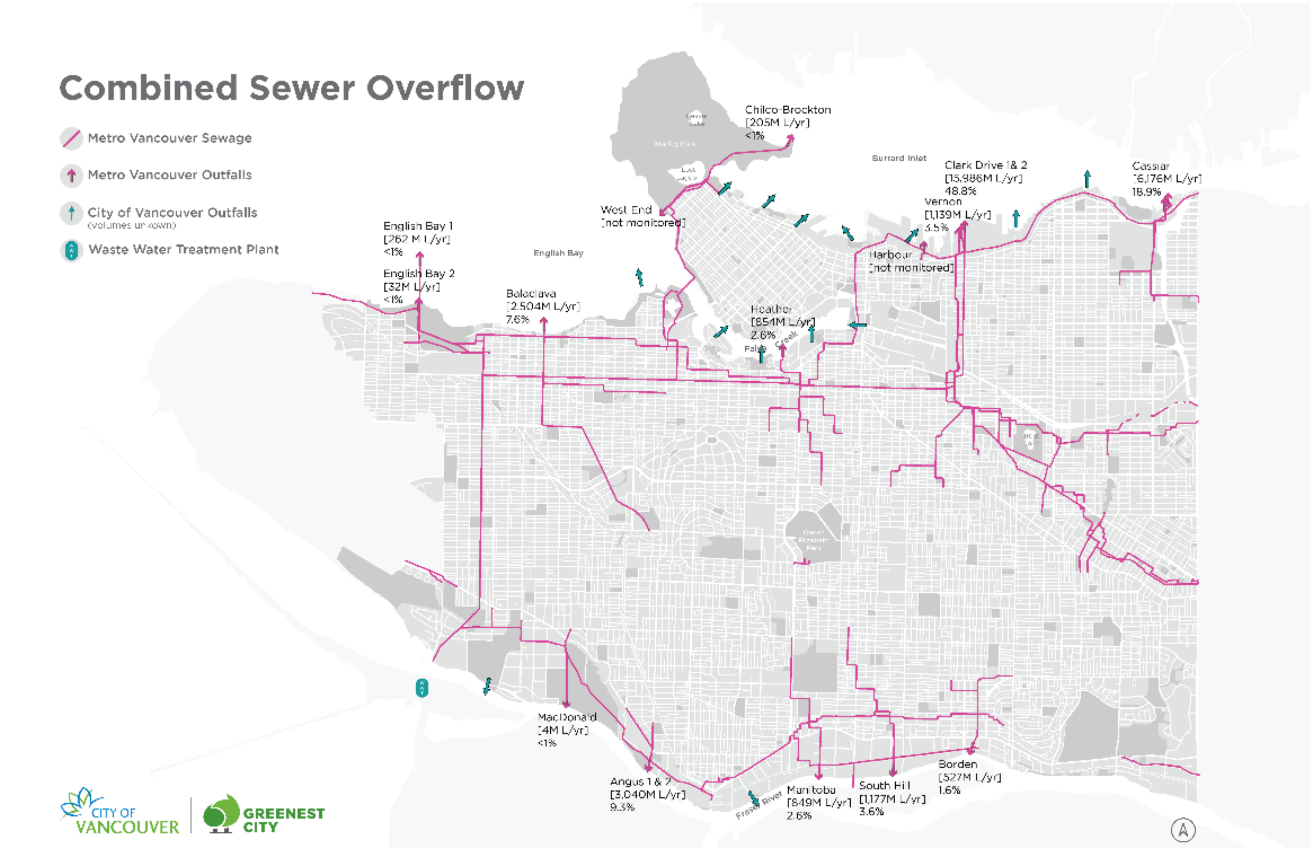


Figure 35: Locations of combined sewer overflows.
Source: City of Vancouver, 2019b

7.2.2 Cost to Renew Water Infrastructure

Vancouver faces increasing financial pressures associated with maintaining, renewing, and expanding the sewer and drainage system. The city continues to expand and become denser, and older pipes are not sized to meet current conditions and expected demands.

The current approach to managing drinking water, wastewater, and rainwater is primarily based on grey infrastructure systems, with **green infrastructure** making up a small component:

- $2.4 billion in potable water infrastructure;
- $6.1 billion in sewer and drainage infrastructure; and
- $0.02 billion in GRI (all in 2018 replacement values).

Green infrastructure is "the natural vegetative systems and green technologies that collectively provide society with a multitude of economic, environmental and social benefits" (Green Infrastructure Ontario, 2020a).

As with many other major cities, asset renewal and expansion will be a significant expenditure in the coming decades. As much as 23 per cent of sewer mains are in poor or very poor condition.

Over the next 10 years, their condition is expected to continue to deteriorate. By 2039, 29 per cent, or nearly one-third of the overall system, is likely to be in poor or very poor condition.

The poor condition of aging infrastructure is a challenge and an opportunity. It does provide a chance to explore a combination of grey and green infrastructure investments.

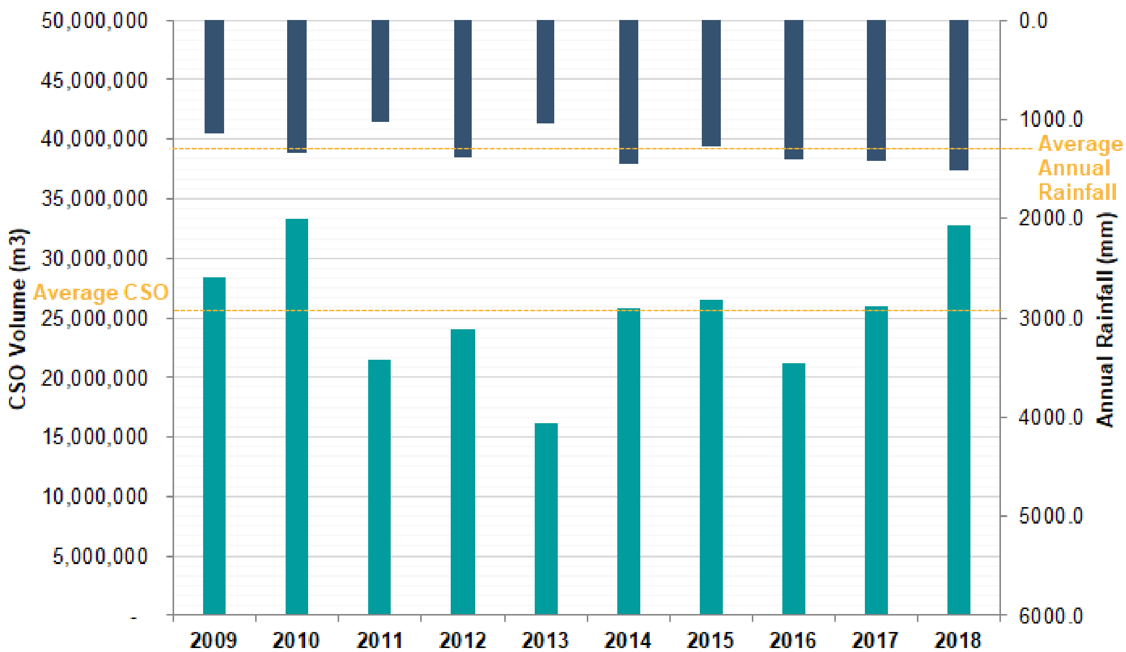


Figure 36: Annual rainfall depths and combined sewer overflow volumes.
Abbreviations: CSO, combined sewer overflow; m^3, cubic metre; mm, millimetre.
Source: City of Vancouver, 2019b

7.2.3 Rainwater Issues and Increases in Extreme Rainstorms

Vancouver needs to manage significantly more rainfall than other places in Canada. Between 1,200 and 1,600 millimetres of rain falls each year, on 160 days or more. Two-thirds (about 70 per cent) of this rainfall volume falls as light showers (less than 24 millimetres per day), one-fifth (20 per cent) falls as rainstorms (24–48 millimetres per day), and the remaining 10 per cent falls as extreme rainstorms (more than 48 millimetres per day) (see **Figure 37**). These large rainstorms are predicted to increase in intensity and frequency due to climate change (City of Vancouver, 2019b).

The rainfall in Vancouver means that the design challenges differ from other Canadian municipalities. Site characteristics, site **infiltration** rates, topography and grading, and the nature of the development and built form all need to be carefully considered in order to meet Rain City Strategy targets.

Infiltration is the passing (or penetration) of water through the ground surface.

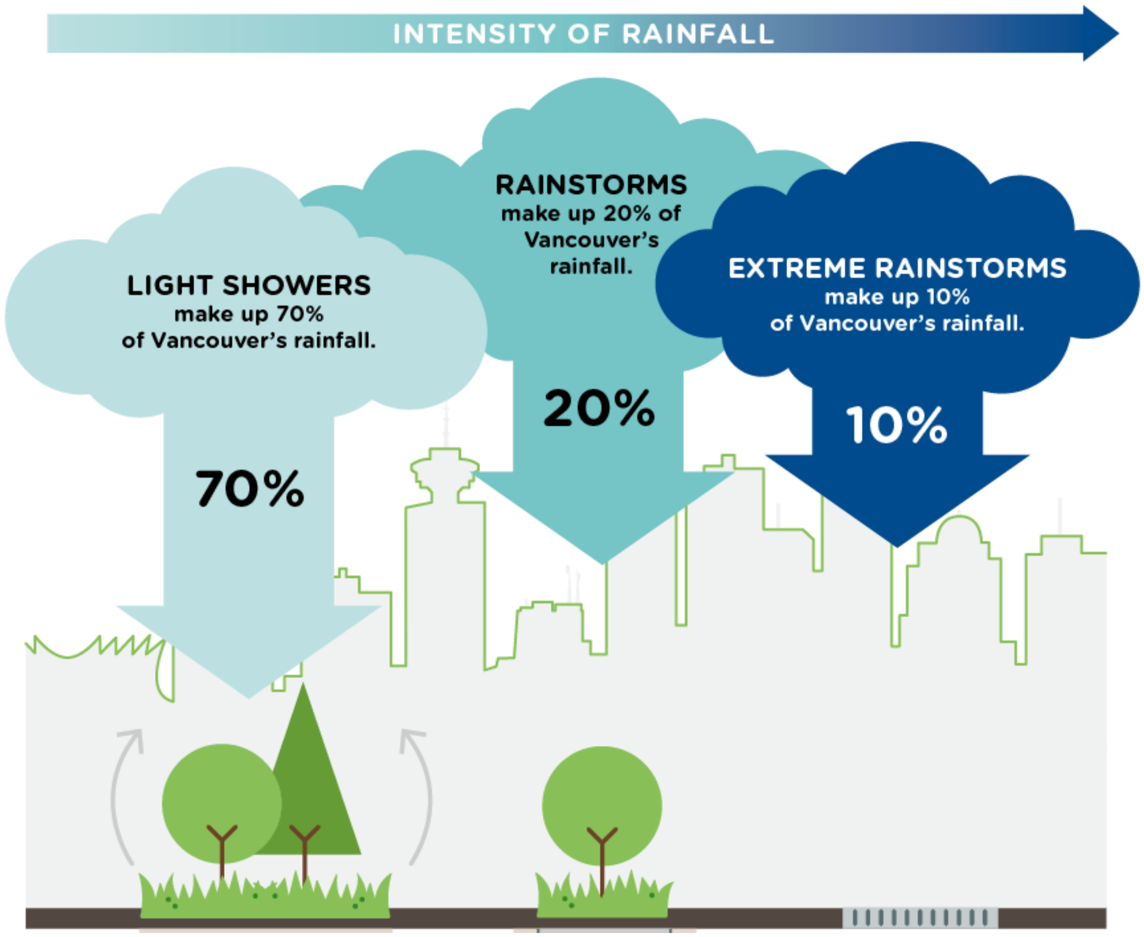


Figure 37: Vancouver's rainfall patterns.
Source: City of Vancouver, 2019b

7.2.4 Impacts of Climate Change and Runoff

As a result of climate change, Vancouver faces the potential for rising sea levels and more extreme rainfall events, increasing the risk of coastal and overland flooding and triggering more CSOs. Most of Vancouver's rain falls during the fall and winter months, and the summer is typically warm and dry. These differences in rainfall patterns between the seasons are likely to be exacerbated as the climate continues to change (**Table 15**).

Table 15: Past and projected total precipitation over seasons and years for Metro Vancouver (23 municipalities including Vancouver)

Season	Average rainfall (mm)	2050s			2080s		
		Projected rainfall (mm)	Change compared to 1971–2000 (%)		Projected rainfall (mm)	2080s change compared to 1971–2000 (%)	
			Average*	Range		Average*	Range
Fall	580	642	11	−1 to 24	693	20	10 to 38
Winter	683	714	5	−3 to 12	780	14	2 to 27
Spring	400	430	8	−4 to 15	447	12	3 to 25
Summer	206	168	19	−41 to 1	147	29	−53 to −6
Annual	1,869	1,954	5	−1 to 9	2,067	11	2 to 17

Abbreviation: mm, millimetre.
* Average rainfall is based on the rainfall in the years 1971–2000.
Source: Metro Vancouver, 2016

Climate change models also predict more consecutive dry days in the summer in Vancouver. Combined with the urban heat island effect, this will affect human health, water consumption, and the health of natural systems. Heat is a stressor for many trees, plants, and wildlife, including fish and other aquatic species.

In 2019, the City of Vancouver declared a climate emergency to accelerate climate change mitigation and adaptation measures, and it approved the *Climate Emergency Response* report. The city defines climate mitigation as “the ongoing attempts to prevent significant climate change through the reductions of greenhouse gases in the atmosphere.” Climate adaptation refers to “actions taken to respond to the impacts of climate change by taking advantage of opportunities or reducing the associated risks” (City of Vancouver, 2019a).

GRI can be used to both mitigate and adapt to climate change. Trees and other vegetation as well as soil alone can reduce greenhouse gas emissions by sequestering carbon dioxide. Blue and **green roofs** reduce energy use for heating and cooling by providing insulation and reduce greenhouse gas emissions.

Green roofs are a thin layer of vegetation and growing medium installed on top of a conventional flat or sloped roof for capturing and treating stormwater. Also referred to as living roofs or rooftop

GRI is built at surface level, which makes it easier to expand or modify to accommodate larger volumes of rainfall, for example. Grey infrastructure is usually buried deep underground, making it inconvenient and costly to dig up and replace.

Although the main focus of the *Climate Emergency Response* report is reducing carbon emissions, some of the outcomes described will help build and expand Vancouver's work on GRI.

7.2.5 Drinking Water Sources

Melting snowpack and collected precipitation contained in reservoirs surrounding Vancouver provide the city with its main drinking water source. Projected milder winters mean less snowpack in the drinking watershed and less recharge of the reservoirs in the spring and summer. At the same time, demand on drinking water has increased due to the increase in population.

Water conservation efforts can offset some of the demand, and repurposing rainwater for non-potable uses will take some strain off the drinking water supply.

GRI offers several benefits in addition to rainwater management. Implementation on a larger scale will help cool the urban environment, reduce potable water use, mitigate flooding, and create non-potable water supplies to supplement municipal potable water. These are smart ways of ensuring the water resources in the Vancouver area are protected for environmental and human needs.

The *Climate Emergency Response* report also refers to actions that make communities more walkable, increase the safe and convenient use of active transportation and transit, and, by 2030, have 50 per cent of the kilometres driven by zero emission vehicles. These actions will reduce carbon pollution in the urban landscape and may also improve the quality of rainwater runoff flowing over these surfaces. Combining efforts on various grey–green projects and climate emergency responses will result in multiple co-benefits for Vancouver.

Environmental studies of the larger watershed surrounding Vancouver, which includes other parts of British Columbia as well as Washington state, show the detrimental effect rainwater has on aquatic species. Scientists found that Coho salmon became sick when exposed to polluted rainwater in as little as two-and-a-half hours (*The Seattle Times*, 2016). Salmon that were exposed to polluted stormwater for more than a day died.

One of the easiest solutions to this issue is to reduce the quantity of rainwater runoff that enters the sewer and drainage system, and to capture and treat the runoff through different GRI techniques.

Figure 38: Pollutants on hard surfaces in urban areas.
Rainwater washes pollutants such as oil and grease, as well as nutrients, off hard surfaces in urban areas and into the sewer system. This rainwater is then piped directly into local water courses and, ultimately, the ocean, leading to water quality issues.

Source: The City of Vancouver

All the pressures on the current system necessitate change. Vancouver has chosen to go with performance-based targets so that the change is measurable. Performance targets allow Vancouver to incorporate GRI into sewer and drainage assets not as an add-on but as an important piece of infrastructure that provides a service to the community. Combining green and grey infrastructure upgrades and implementation will give the best value for the goals and targets.

7.3 Setting Objectives

7.3.1 Key Features of the Rain City Strategy

To address the challenges described, the Rain City Strategy sets clear goals, targets, and actions for rainwater management and reuse in Vancouver, and provides a framework of programs, timelines, and projects to meet these requirements. The Strategy is a long-term road map for advancing and evolving rainwater management.

The “One Water” approach to water resources is more integrated than previous strategies. This will be a holistic approach to upgrading sewer and drainage utility services, protecting water quality, and supporting resilience and enhanced livability.

Integrating GRI solutions into land use, infrastructure upgrades, community plans, and urban designs helps City departments and private and public property share responsibility for managing rainwater because of the connections between water, parks, public spaces, private land, and infrastructure features. With these objectives, an overarching strategy will ensure a systematic approach to applying GRI while achieving cost and process efficiencies.

7.3.2 Costs for Various Rainwater Solutions

Vancouver views GRI as an effective tool to collect, treat, and infiltrate rainwater where it lands. Doing so reduces the volume of rainwater entering the sewer and drainage systems. Keeping sufficient rainwater from entering the combined sewer system will preserve its capacity and lower the likelihood of CSOs occurring (see **Figure 36**).

Combined grey–green rainwater infrastructure approaches have been cost-effective in New York City, Portland, and Philadelphia.

GRI tools are about three to six times more cost-effective at managing rainwater per $1,000 invested than grey infrastructure. Every fully vegetated acre of GRI provides approximately $8,000 in reduced energy demand, $160 in reduced carbon dioxide emissions, $1,000 in improved air quality, and $4,725 in increased property values annually. Implementing GRI also leads to savings in health care costs, disaster recovery, climate adaptation, and energy use in buildings.

7.3.3 Guiding Principles to Transform Vancouver into a Water-Sensitive City

City staff, residents, property owners, businesses, and other organizations will work together to transform Vancouver into a water-sensitive city. The Rain City Strategy will help address water quality issues and make neighbourhoods more livable through new development, redevelopment, and retrofit projects on private and public property. This will contribute to a strong economy, equitable and vibrant neighbourhoods, and a city that meets the needs of generations to come.

The Rain City Strategy identifies some guiding principles to becoming a water-sensitive city:

- Design the city as a water supply **catchment**.
- Design the city and infrastructure to deliver ecosystem services.
- Design the city for water resilience, adaptability, and flexibility.
- Design the city to encourage collaborative action and enable water-wise behaviours.
- Design the city to support an equitable water future (City of Vancouver, 2019b).

In **hydrology**, a **catchment** is an area of land that drains rainfall to a single point. Water leaves the catchment from this point. If an area of land drains to a single pipe or outlet, it can be defined as a catchment. **Subcatchments** are themselves catchments within other, larger catchments. Researchers apply these terms iteratively depending on the scale at which they are working. In urban areas, catchments and subcatchments are typically defined by the municipal storm sewer system. At the smallest scale, even small surface depressions—puddles, essentially—can be defined as subcatchments.

7.3.4 Vision and Goals

The vision of the Rain City Strategy is for Vancouver to embrace rainwater as a valued resource for its communities and natural ecosystems. The three main goals are to:

- improve and protect water quality;
- increase resilience through sustainable water management; and
- enhance livability by improving natural and urban ecosystems (City of Vancouver, 2019b).

Six objectives support the vision and goals of the Rain City Strategy:

- Remove pollutants from water and air.
- Increase managed impermeable area.
- Reduce volume of rainwater entering the pipe system.
- Harvest and reuse water.
- Mitigate urban heat island effect.
- Increase total greenspace (City of Vancouver, 2019b).

7.3.5 Targets

Vancouver has an ambitious target to capture and treat 90 per cent of the average annual rainfall across the city. The Rain City Strategy aims for 40 per cent of the impervious surfaces across the city to meet this target by 2050. An updated design standard for GRI to capture and clean 48 millimetres of rainfall per day has been adopted. This design standard applies whenever rainwater management objectives are part of a project and will apply immediately to all public spaces and municipal buildings. The Strategy aims to extend the 48-millimetre rainfall capture-and-clean design standard to private development by 2022. Vancouver plans to tackle this target and act as an early adopter by implementing GRI in public spaces, streets, parks, and municipal facilities. As this target becomes the standard, it will be easier to work with partners to encourage the implementation of GRI on private properties.

Vancouver looked at four different scenarios to understand what proportion of the impervious surface could be managed. Each scenario had to take into account that 49 per cent of Vancouver is impervious and that not all impervious surfaces connect to a sewer or drainage system.

City staff looked at various factors to set achievable targets that were beneficial and feasible. In addition to reviewing historical climate and rainfall data, staff reviewed policies and technical standards from many different areas across North America. Many areas aim to capture and clean 90 per cent of their rainfall, which helped to support Vancouver city staff in building the case for the target of 90 per cent or 48 millimetres of rainfall.

To achieve this city-wide target of managing the rainwater from 40 per cent of the impervious surfaces by 2050, Vancouver will require all redevelopment and infrastructure renewal of streets and public spaces, parks, and private sites to include GRI (**Figure 39**). Strategic GRI retrofits will also need to be completed across the city.

To adapt to climate change and improve water quality, a strong public–private partnership is necessary. Public land to manage rainwater and meet all the targets is limited in this dense urban centre. Private property currently needs to manage rainwater in accordance with the Rainwater Management Bulletin. Vancouver will be looking at mechanisms such as policy changes and/or bulletin updates to meet the 48-millimetre capture-and-clean standard by 2022.

Vancouver continues to look at other options to develop policy and ensure targets are being met across all land uses in environmentally and financially sustainable ways.

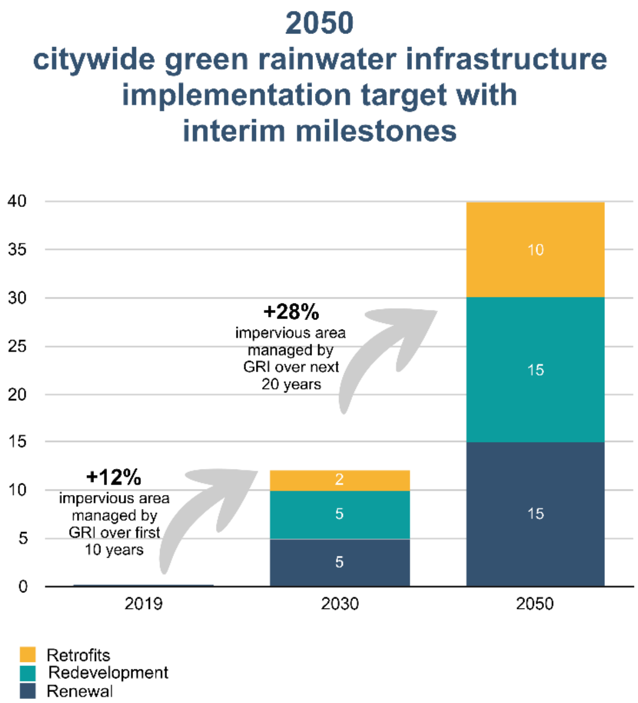


Figure 39: City-wide implementation plan for green rainwater infrastructure.
Abbreviation: GRI, green rainwater infrastructure.
Source: City of Vancouver, 2019b

These targets will help to improve and protect the water quality in and around Vancouver. The existing infrastructure will become more resilient as GRI measures take pressure off the pipe system. This target will also enhance the city's livability by improving natural and urban ecosystems.

7.3.6 Directions and Action Plans

Nine transformative directions have been developed to help implement the Rain City Strategy:

1. Strive to become a water-sensitive city that integrates water, community, land use, urban design, and infrastructure planning.
2. Respond urgently to climate change and use GRI to advance mitigation, adaptation, and water resilience.
3. Accelerate the protection of the health and vitality of surrounding water bodies by developing a clean water plan to expedite the mitigation of pollutants discharged into local waters.
4. Revitalize 19 urban watersheds to enable communities and natural systems to thrive.
5. Shape systems to integrate and value all forms of water by developing an integrated water-utility planning framework.

6. Explore intersectionality, equity, and reconciliation with Indigenous Peoples through urban water management by cultivating relationships and a shared understanding of histories and values.
7. Drive innovation and system effectiveness through data collection and analytics for our community, land, and water systems.
8. Enable a culture of collaborative GRI implementation by facilitating a shift in governance structures, processes, and practices.
9. Invest in education, capacity building, and partnerships to mobilize action within the community, industry, academia, the not-for-profit sector, and others.

Three detailed action plans have been created. These focus on streets and public spaces; buildings and sites; and parks and beaches. These plans ensure that each land use has the relevant implementation and enabling programs and information to guide GRI implementation. Clear action plans help with widespread implementation and provide professional guidance to different industries.

Start-up funding for these action plan programs will be allocated through the existing capital plan and operating budgets through to 2022. These programs include asset management, research and innovation, education and training, and monitoring so that city staff and partners have current information on methodologies and so that GRI features function as intended over the long term.

7.4 Developing a Cost-Effective Strategy for Green Rainwater Infrastructure

Vancouver conducted extensive research on the findings of other North American cities that used widespread GRI and smart grey–green approaches to rainwater management. The city is currently working on a more detailed cost analysis as financial information needs to stay current and accurately reflect wide-scale implementation.

An investment in GRI serves many functions apart from rainwater management. Grey infrastructure typically serves only very specific and limited functions related to rainwater and wastewater conveyance. The functions focus on protecting public health and preventing properties from flooding. GRI manages and filters rainwater and provides landscaping features as well as other social, environmental, and economic benefits.

Other municipalities have demonstrated that using a mix of traditional grey infrastructure and GRI reduces overall system costs, allows public–private sharing of responsibilities, costs, and risks, and improves sewer and drainage services (**Figure 40**). These municipalities also reported many other benefits.

Vancouver benchmarked programs in other cities and found that, in addition to meeting water quality and quantity goals, ambitious and sustained investments in GRI have benefits in terms of economic development, accessible employment opportunities, energy and cost savings for heating and cooling buildings, and health care.

7.4.1 Working with the Private Sector

The City of Vancouver, in close collaboration with the private sector, will be looking to refine current rainwater management policies and regulations and to implement new regulations on private property. The intent is to gradually adopt the 48-millimetre design standard by 2022.

Advocacy, education, partnerships, and collaboration will help support and catalyze actions on private property.

Undertaking a comprehensive and detailed analysis of the full life-cycle costs, benefits, potential for cost-avoidance, risk mitigation, and regulatory compliance potential will be an important part of the work. There are many types of GRI solutions. Investigating the optimal combination of GRI with grey infrastructure to meet servicing, CSO, water quality, and climate adaptation needs is complex. Work is currently underway to explore the most cost-effective grey–green infrastructure investments.

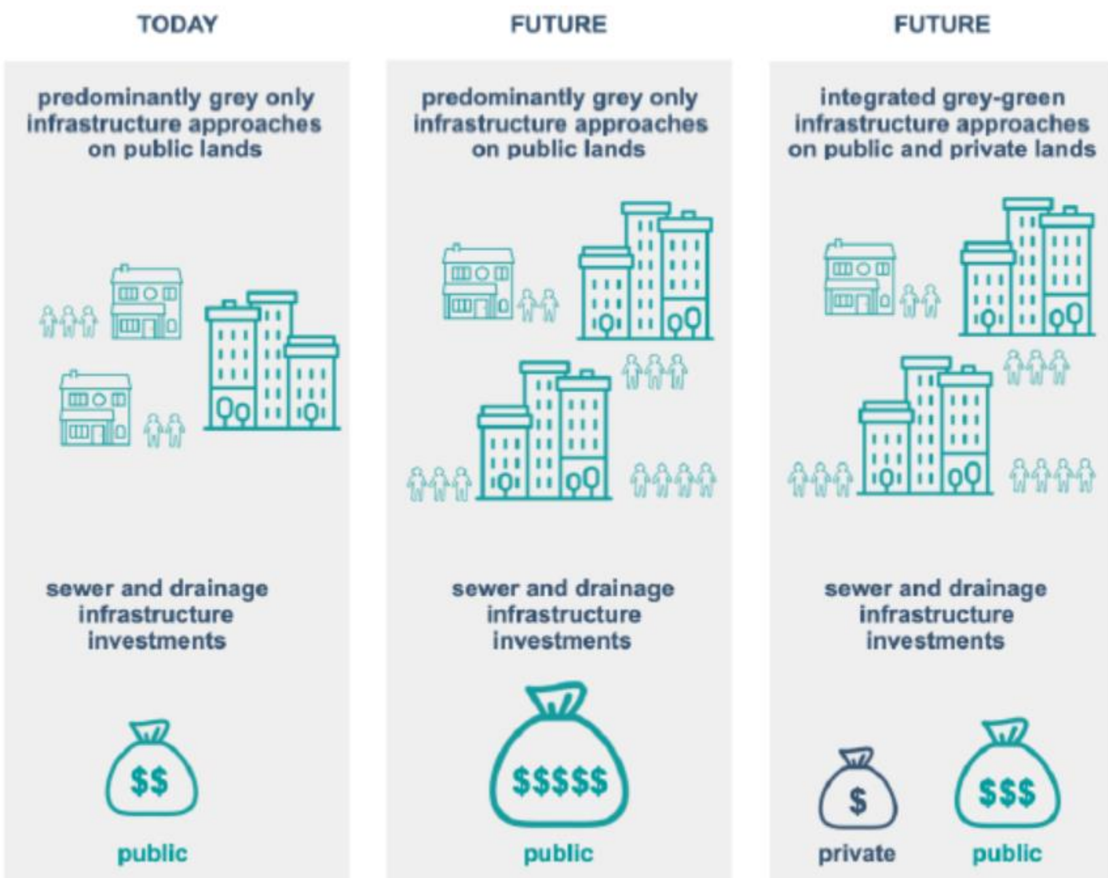


Figure 40: Financial implications of green rainwater infrastructure implementation.
Source: City of Vancouver, 2019b

7.4.2 Upgrading Infrastructure and Using Green Rainwater Infrastructure in a Grey–Green Approach

There are more than 240 GRI assets across Vancouver (**Figure 41**). The more GRI features implemented, the more rainwater will be collected, filtered, and infiltrated back into the ground or will evapotranspire into the atmosphere. This reduces the amount of polluted rainwater runoff that enters the sewer and drainage system.

Updating design standards to capture and clean 48 millimetres of rainfall and implementing the city-wide target of managing 40 per cent of impervious areas by 2050 will have cost implications for public and private sites. Not all costs will be net new costs, but rather result in shared responsibilities, as developers generally pay for utility upgrades when density increases. For instance, many new developments in Vancouver may require significant water, sewer, and drainage infrastructure upgrades to provide sufficient capacity to service the increased density on that land. In some cases, this can trigger upgrades costing millions or hundreds of millions of dollars.

Greater onsite management of rainwater through GRI practices and appropriately designed utilities to handle excess flow and extreme events will be a cost-effective approach to reduce the scale and cost of major sewer and drainage system upgrades. An integrated grey–green infrastructure approach is expected to shift or potentially reduce the overall utility costs for new development compared to a grey infrastructure–only approach.

As GRI design and implementation mature in Vancouver and as developers become accustomed to GRI design, implementation, and life-cycle management, GRI measures will become increasingly cost-effective and standard. A parallel approach has been achieved with green building practices. Leadership in Energy and Environmental Design (LEED) silver certification, for example, was considered onerous by many developers, but as the market matured across the value chain, this certification has become commonplace.

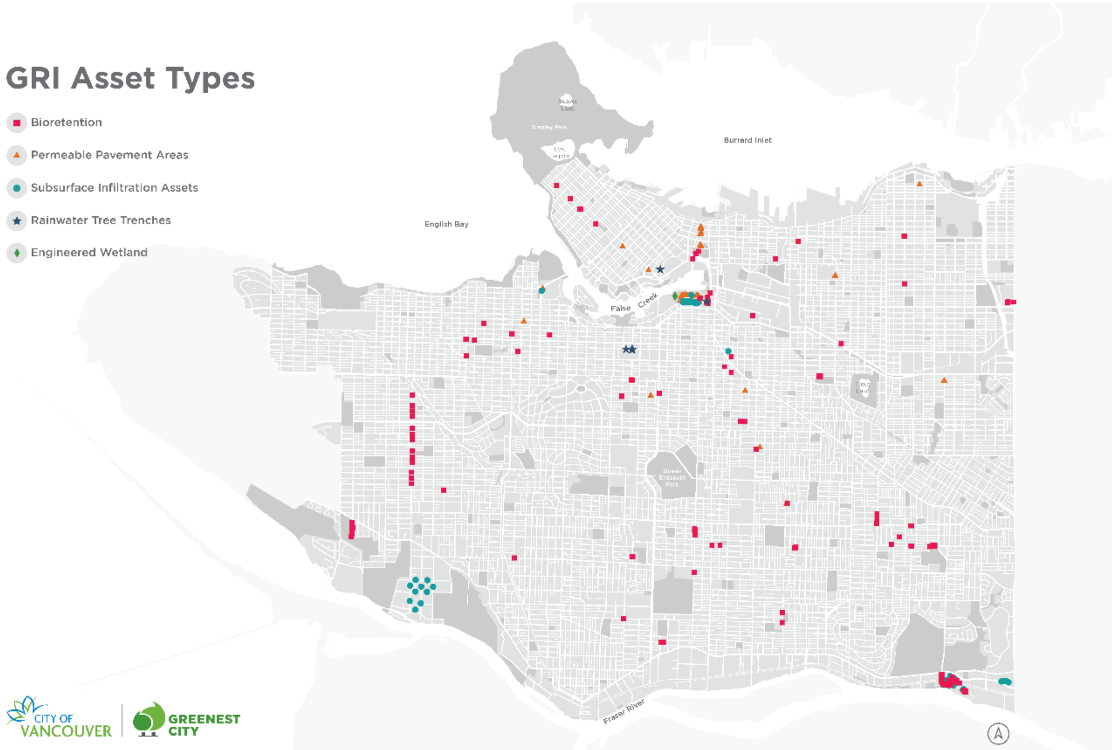


Figure 41: Current green rainwater infrastructure assets across the City of Vancouver.
Abbreviation: GRI, green rainwater infrastructure.
Source: City of Vancouver, 2019b

7.4.3 Vancouver's Green Rainwater Infrastructure Capital and Operating Budget and Funding Sources

Securing funding for GRI implementation, operation, and maintenance is often a challenge because of competing municipal budget demands. Budgets can change from year to year, and crises such as the COVID-19 pandemic can have huge impacts. But deciding on and allocating funds to GRI is critical to support the Rain City Strategy.

Prior to the COVID-19 pandemic, Vancouver City Council approved the 2019 to 2022 capital plan totalling $2.8 billion (**Figure 42** and **Figure 43**). Of this $2.8 billion, $616 million is dedicated toward "One Water," which includes water, sewer, drainage, and GRI. Of this $616 million, $529 million is intended for the maintenance and renewal of aging assets and existing water, sewer, drainage, and GRI, and $87 million is intended for adding new or upgrading existing water, sewage, drainage, and GRI (City of Vancouver, 2018b).

Vancouver had these guiding principles to consider when allocating the capital budget:

- Unify the planning and management of drinking water, groundwater, surface water, rainwater, and wastewater.
- Ensure that existing assets are well managed and robust to support resilience.

- Implement policies to manage water, in all its forms, to optimize investments to achieve city objectives over the long term.

Of the $62 million GRI budget:

- $1 million has been allocated to renew and refresh 30 existing green infrastructure features so that they remain in good working order;
- $53 million has been allocated to planning, designing, and constructing new GRI features across Vancouver;
- $7 million has been allocated to city-wide integrated grey–green system and watershed planning; and
- $1 million has been allocated to water quality and GRI monitoring (City of Vancouver, 2018b).

Recent budget pressures due to the economic effects of the COVID-19 pandemic are likely to affect the revenue supporting this work, and expenditures are expected to decline. Exact revised numbers have yet to be confirmed.

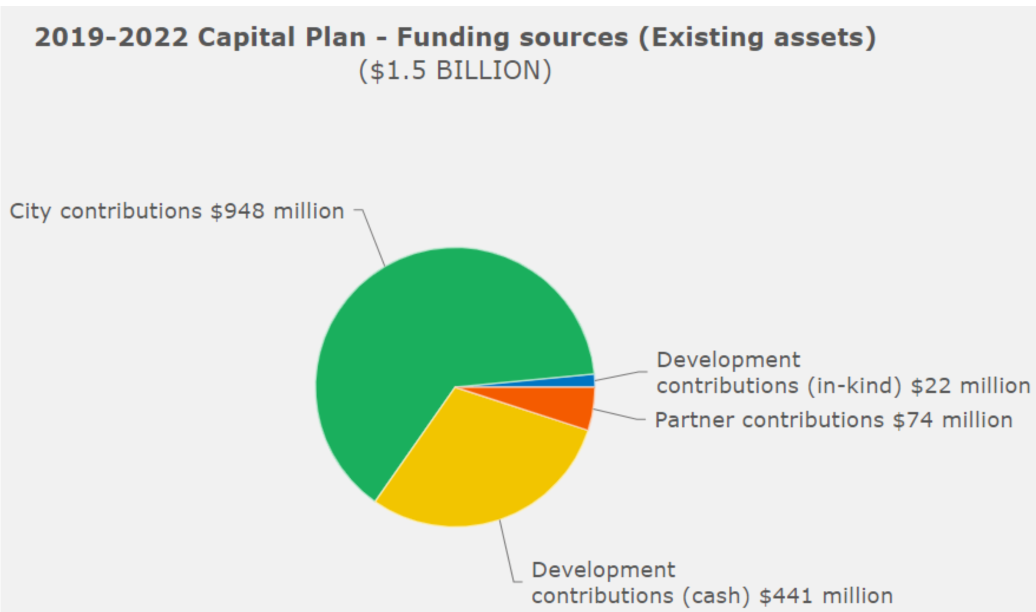


Figure 42: Funding sources dedicated to existing assets from 2019 to 2022.
Source: City of Vancouver, 2018b

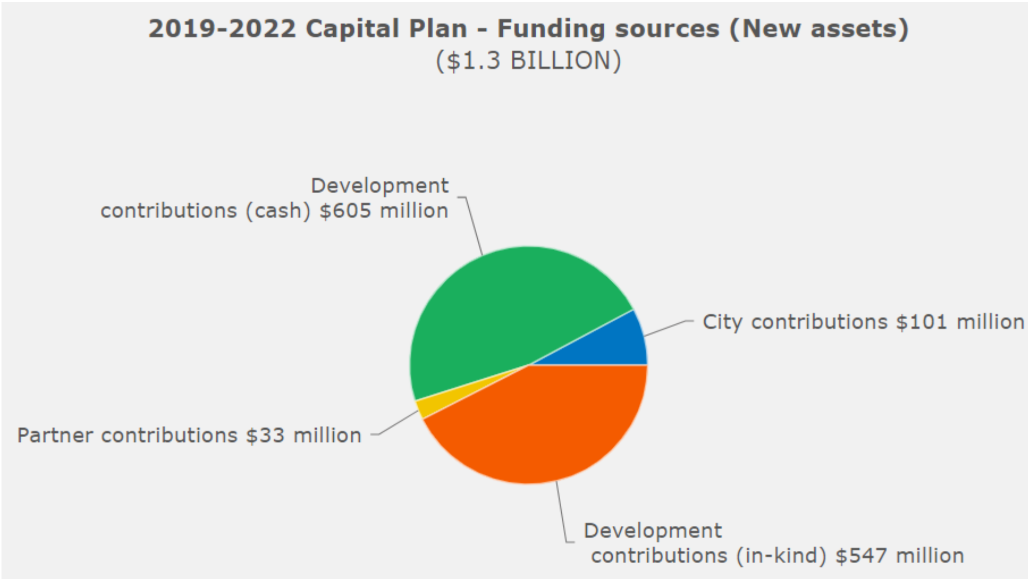


Figure 43: Funding sources dedicated to new assets from 2019 to 2022.
Source: City of Vancouver, 2018b

The funding for maintenance and renewal of existing infrastructure and amenities comes primarily from city contributions, including property tax, utility fees, parking revenues, and other operating funds.

Funding for new, expanded, and upgraded infrastructure comes primarily from development contributions through:

- development cost levies (DCLs) and utility development cost levies (uDCLs);
- community amenity contributions; and
- connection fees.

In 2017, Vancouver included water, sewer, and drainage infrastructure as eligible services covered by DCLs. In July 2018, Vancouver City Council developed a new uDCL to pay for upgrades to water, sewer, and drainage systems including GRI. The previous DCL no longer covers water, sewer, and drainage infrastructure, but funds housing, parks, childcare, and transportation costs.

To date, most of Vancouver's GRI funds come from the new uDCL. The city continually reviews the capital plan to analyze the economic and financial changes. To 2022, $62 million has been dedicated to GRI. Only $7.4 million will come from the city (e.g. property tax, utility fees, and parking revenues), while $54.6 million will be generated through the uDCL.

uDCLs ensure the city has the financial support to sustain and maintain their current assets as well as new infrastructure (inclusive of GRI) that is changed and upgraded according to development needs. Having the private sector front funds helps to alleviate costs to the city and allows infrastructure to function and provide the necessary services. Due to economic and development changes and needs over time, the amount of funding produced by the uDCLs can potentially change, making it difficult to forecast the exact amount of financial support.

7.5 Employing the Strategy

7.5.1 Integrated Water Management Approach in the Cambie Corridor

The Cambie Corridor (**Figure 44**) provides sustainable transport and connections to various neighbourhoods (as one of the main north–south routes through the middle of Vancouver and the main route for the Canada Line SkyTrain built for the 2010 Winter Olympics). Since the opening of the Canada Line in 2009, the residential development and urban transformation along Cambie Street and the connecting neighbourhoods has been significant.

Vancouver aims to build on current connections and add some of the surrounding neighbourhoods and arterials to create a system of complete neighbourhoods, making housing more diverse and affordable and providing new jobs and community amenities as well as a new Municipal Town Centre.

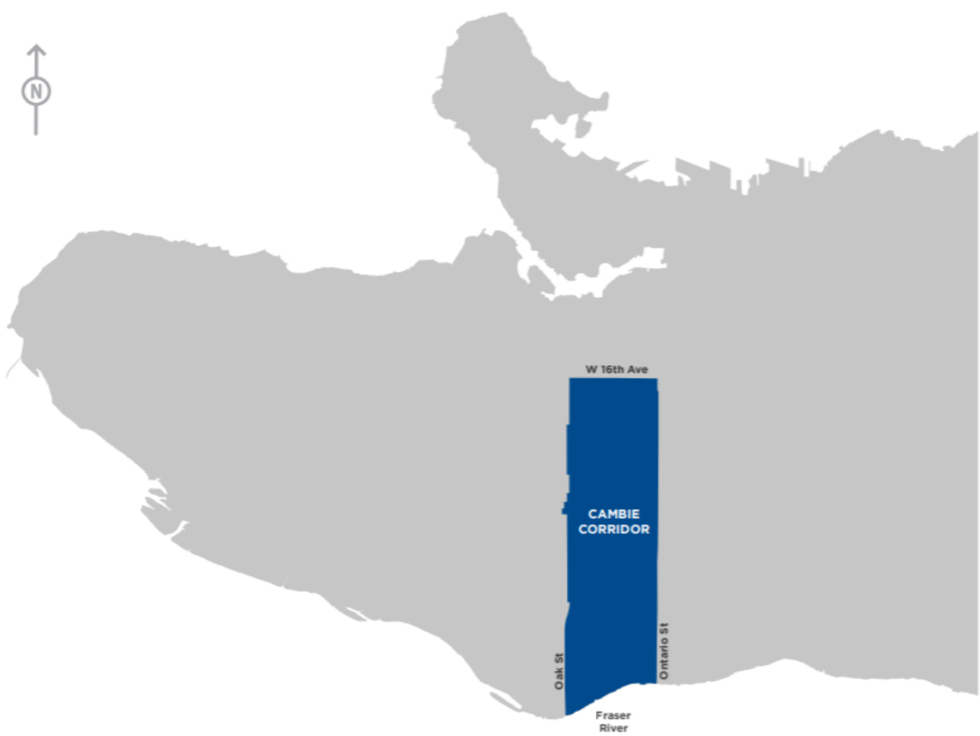


Figure 44: Study area in the Cambie Corridor.
Source: City of Vancouver, 2018a

The Cambie Corridor project will redevelop about 10 per cent of Vancouver. This will be a key time to implement progressive, integrated planning techniques and to work with both public and private sector stakeholders to upgrade and replace existing infrastructure.

The Rain City Strategy was developed at the same time as the Cambie Corridor study. Because the Cambie Corridor project focuses on redevelopment, the location of utilities and current infrastructure need to be considered. Some will be replaced, and others modified through GRI features. The Rain City Strategy will be a key reference in the design and planning of the Corridor redevelopment as rainwater management targets and goals need to be met.

A team of consultants the City of Vancouver has hired will undertake an options analysis for the Cambie Corridor. A cost-benefit analysis of the options under consideration will follow. The options analysis will cover both the public and private lands, as well as policy development and project planning. A big focus of this project will be the district-scale and neighbourhood-scale opportunities for improved water management. These opportunities will include implementing non-potable water reuse systems and larger GRI projects. This “One Water” approach will help deliver optimized water-servicing solutions (City of Vancouver, 2020).

There are about 100 kilometres of sewer mains in the Cambie Corridor study area. About 60 per cent are combined sewers carrying both sewage and rainwater. Because the Cambie Corridor is so large, GRI will be applied extensively on all the different land-use areas, on both private and public property, to divert as much rainwater as possible away from the municipal drainage system. The rainwater will be managed and infiltrated where it lands or will be used as a non-potable resource. This will reduce rainwater loading on the municipal system and CSOs.

A retrofit and redevelopment project of this size is a great opportunity to build on economies of scale and design, construct, and implement GRI across private and public properties. Forming public–private partnerships is critical for the success of large projects like this. Investing in GRI as partners will be a cost-effective complement to existing grey infrastructure systems.

The numerous resulting co-benefits will include increased tree cover and beautification, attractive public spaces, and water conservation and reduced urban heat island effects and flood risk. This ties into the Rain City Strategy goals and targets of meeting future needs as well as alleviating CSO issues. In areas where grey infrastructure cannot be updated or changed extensively, installing additional GRI will help take the pressure off those older systems.

The ambitious targets of the Rain City Strategy will lay a foundation for integrating a grey–green infrastructure approach for a cost-effective rainwater management solution. This is a long-term redevelopment plan. Different **hydraulic** and **hydrologic** models will be used to identify rainwater management targets to accommodate increases in area density, reduce the number of CSOs, and mitigate the effects of climate change.

Hydrology is the study of water on the earth’s surface, flowing either above ground or beneath it. **Hydraulics** is the study of the flow of water through pipes and channels, such as rivers.

For instance, Vancouver is looking to implement district-scale systems that collect and hold rainwater either for non-potable uses or for slow release and infiltration into the ground. These rainwater **retention** and infiltration systems could be located where space is limited or where amounts of impervious cover are high—for example, under roadways, laneways, and public spaces such as parks.

Retention: the capture of stormwater for filtration, **infiltration**, and **evapotranspiration**. Retained stormwater does not become **runoff** or streamflow (unlike detained stormwater; see **detention**). Retaining of stormwater helps to restore a natural **water balance**.

7.6 Conclusion

The Rain City Strategy has goals, targets, and action plans that were developed to be attainable and effective. Organization and clear guidance make implementation easier as the information is standardized and tailored. With dedicated funds through Vancouver's capital plan and uDCLs, the GRI projects will have adequate resources to be implemented and maintained long term.

The Cambie Corridor redevelopment area will showcase the "One Water" approach to wide-scale GRI implementation. The approach will then be expanded across the city to capture and clean 90 per cent of the city's rainwater and support Vancouver's goal of becoming the greenest city in the world.

8.0 SOUTHDOWN CASE STUDY

Key findings:

- Communal systems on private property are more cost-effective than centralized stormwater management facilities on public property.
- GSI retrofits on private property would cost about $208,300 per hectare over a 50-year period. End-of-pipe stormwater management ponds on public property would cost $377,000 over the same time frame.
- GSI retrofits on private property would also provide a higher standard of stormwater management.
- Ontario's *Drainage Act* provides a process for building and maintaining communal drainage infrastructure on private property. It also allows for cost-sharing among private and public landowners and other stakeholders.

8.1 Background

Like many cities across Canada, the majority of Mississauga's urban area was built before stormwater quality, quantity, and **water balance** controls became development requirements. Mississauga's Southdown district, an industrial, commercial, and institutional (IC&I) neighbourhood in the south of Mississauga (see **Figure 45** and **Figure 46**), is no different.

Water balance is the accounting of inflow (precipitation) and outflow of water in a system according to the components of the **hydrologic cycle** (precipitation, **runoff**, **infiltration**, groundwater flow, and **evapotranspiration**). Precipitation over natural areas generates low amounts of runoff and high amounts of infiltration, while precipitation over highly impervious areas (e.g. urban areas) generates high amounts of runoff and low amounts of infiltration.

Some municipalities in the USA—most notably the City of Philadelphia—have developed financial incentive programs to motivate private IC&I landowners to engage in voluntary **green stormwater infrastructure (GSI)** retrofits through one-time grants and annual stormwater credits. Philadelphia has found that IC&I properties, which make up an appreciable portion of the city's impervious area, present a low-cost GSI retrofit opportunity as part of a larger plan for reducing the city's **combined sewer overflows (CSOs)** (see **Section 8.3**).

Green stormwater infrastructure (GSI): also known as low impact development (LID), green stormwater infrastructure is a stormwater management strategy that seeks to mitigate the impacts of increased **runoff** and stormwater pollution. GSI practices manage runoff as close as possible to the source in order to preserve or restore pre-development **hydrologic** and ecological functions. To preserve pre-development functions, GSI uses design to minimize runoff and to protect natural drainage patterns. To restore pre-development functions, GSI uses distributed structural practices that filter, **detain**, **retain**, **infiltrate**, **evapotranspire**, and **harvest stormwater**. GSI practices can effectively remove sediment, nutrients, pathogens, and metals from runoff, and they reduce the volume and intensity of stormwater flows.

This case study describes the initial results of a technical and financial feasibility study that evaluates aggregating multiple private IC&I properties for communal GSI retrofits in a Canadian context. Credit Valley Conservation (CVC) has developed good working relationships with several private IC&I landowners in the study area through past projects. When the City of Mississauga began updating the Southdown District Stormwater Servicing and Environmental Management Plan in 2018, this presented an opportunity to explore the cost-effectiveness of communal GSI retrofits on private property.

Combined sewer overflows occur when **combined sewer systems** overflow or when wastewater treatment plants bypass incoming flows, releasing untreated sewage into receiving water bodies.

The main objective of this case study is to evaluate the cost-effectiveness of two conceptual design scenarios at meeting stormwater management criteria. One scenario features communal GSI retrofits on private property (see **Section 8.4.3**), and the other features more traditional, end-of-pipe measures (wet ponds) on public property (see **Section 8.4.4**).

Our findings show that GSI on private property provides better stormwater management at a lower cost than the end-of-pipe facilities on public property. GSI on private property has per-hectare capital costs 44 per cent less than the capital costs for end-of-pipe facilities, per-hectare operations and maintenance (O&M) costs 53 per cent that of end-of-pipe facilities, and per-hectare life-cycle costs 45 per cent that of end-of-pipe facilities.

The case study has four secondary objectives:

- To evaluate processes for equitable cost sharing of communal GSI facilities among landowners (**Section 8.5.1**).
- To explore suitable incentives to meet private IC&I landowners' financial requirements (**Section 8.5.3**).
- To evaluate the **co-benefits** of planting trees in GSI facilities (**Section 8.4.3.2**).
- To review ways to ensure GSI facilities on private property are maintained (**Section 8.5.4** and **Section 8.5.5**).

Co-benefits: positive effects of **GSI** that are not directly related to traditional stormwater management goals. Co-benefits include air pollution removal, **urban heat island** reduction, habitat creation, energy savings, and greenhouse gas reduction.

8.2 Characterizing the Challenges

8.2.1 Lack of Stormwater Management Controls

Mississauga's urban area contains large areas without stormwater quantity or quality controls: while 20 per cent of its area has stormwater quality and quantity controls, 21 per cent has quantity control only and 59 per cent has no stormwater management controls at all (Region of Peel, 2017, pg. 79). This is common in municipalities in the Greater Toronto Area (see **Section 3.0**) because much of their development took place before stormwater management became a common requirement.

Situated in Mississauga's Southdown district, the 37-hectare study area comprises 13 IC&I properties (see **Figure 45**). The properties are part of the urbanized Sheridan Creek watershed.[6] Except for three **dry ponds**, the Sheridan Creek watershed lacks stormwater quality or quantity controls (CVC, 2011). **Runoff** generated by these properties eventually reaches Rattray Marsh, a provincially significant wetland, before discharging into Lake Ontario (**Figure 46**).

The study area has overland flow routes consisting of asphalt, gravel, swales, and a network of pipes that convey water from the railroad tracks that form its northwestern boundary to the municipal storm sewer system running along Royal Windsor Drive, its southeastern boundary.

Dry ponds are open areas that can be used to detain stormwater during intense storm events. Dry ponds can have dual purposes; for example, they can be outdoor facilities such as soccer fields, baseball diamonds, public parks, urban forests, and outdoor cultural spaces.

Runoff is rainwater that flows over hard surfaces such as roofs and roads as runoff instead of **infiltrating** into the ground. Urban runoff carries heavy metals, nutrients, bacteria, and other pollutants into local streams, adversely affecting human, animal, and plant life.

[6] The study area has a complex hydrology. Minor system flows are all directed through the municipal storm sewer to Sheridan Creek. Major system flows spill into the Lakeside Creek Watershed.

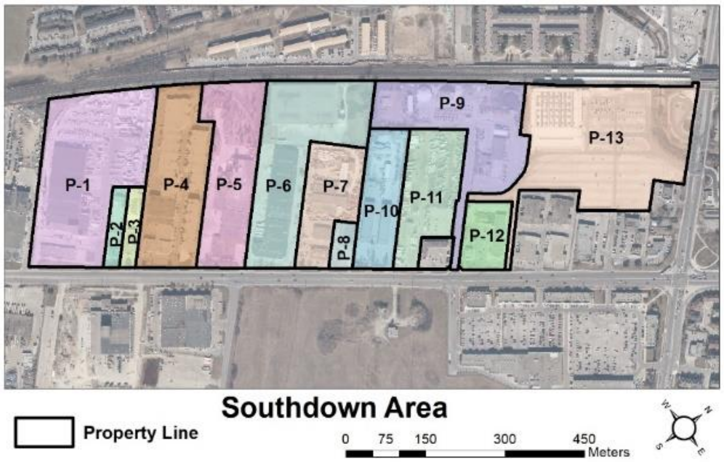


Figure 45: Properties in the study area.
Royal Windsor Drive is the study area's southeastern boundary at the bottom of the figure.
Abbreviation: P, property.

Figure 46: The study area within the Sheridan Creek watershed.
Abbreviation: km, kilometre.

Many of the properties in the study area have poor drainage. Moderate rainfall events cause frequent nuisance **ponding** (**Figure 47**). Surface flow across parking lots and access routes damages asphalt (**Figure 48**). Two property owners in the study area have recently reported flood damages.

Ponding is unwanted collection of stormwater on surface depressions or roofs.

Figure 47: Surface ponding on a property in the Southdown study area.
Photo credit: CVC

Figure 48: Damaged asphalt from overland flows.
Photo credit: CVC

The 13 properties in the study area contribute high sediment and phosphorus loadings to Sheridan Creek and Rattray Marsh each year (**Figure 49** and **Figure 50**). The study area is also known to contribute high amounts of **inflow and infiltration** into the wastewater system. This needlessly increases treatment costs and reduces the capacity of the nearby Clarkson Wastewater Treatment Plant.

Inflow and infiltration occur when stormwater enters the sanitary sewer system, either through maintenance access holes (inflow) or by entering cracked pipes underground (infiltration).

Figure 49: Removing sediment from Rattray Marsh.
In 2014 and 2015, CVC spent about $2.5 million in construction costs alone to remove excess sediment from Rattray Marsh.
Photo credit: CVC

Figure 50: The results of **nutrient pollution** in Sheridan Creek.
Photo credit: CVC

Nutrient pollution occurs when too many nutrients, mainly nitrogen and phosphorus, are added to water bodies, causing excessive growth of algae. These blooms consume the excess nutrients and die quickly. Their decomposition causes low levels of dissolved oxygen in the water, which can kill aquatic animals.

8.2.2 The City of Mississauga's Stormwater Management Initiatives

The City of Mississauga's Transportation and Works Department is responsible for building, maintaining, and operating the city's stormwater drainage system and associated programs.

Introduced in 2016, Mississauga's **stormwater charge** and credit program provides a dedicated revenue source for renewing, upgrading, and operating the city's public stormwater works. This was a key step toward heading off the deficit in stormwater infrastructure spending (see the **Introduction**.

Stormwater charges: an annual fee charged to landowners by municipalities for stormwater services. Stormwater charges are separate from general property taxes and provide a dedicated revenue source for maintaining, operating, and revitalizing stormwater infrastructure.

Introduction).

The city's stormwater business plans aim to systematically renew its aging drainage network, in part by developing a pipe renewal reserve fund. Renewal projects include:

- building new stormwater management facilities in priority areas;
- designing and building erosion mitigation measures along watercourses;
- implementing GSI measures to manage road runoff;
- reducing risk for communities vulnerable to flooding; and
- updating master drainage plans and conducting flood evaluation studies (City of Mississauga, 2020c).

In 2020, the city began developing a stormwater master plan.

The Transportation and Works Department also reviews the stormwater components of all development applications. For water quality, all new builds and redevelopments must include measures to reduce **total suspended solids** (TSS) loadings by 80 per cent. The exception is if the development parcel of land is upstream of an existing stormwater management facility (e.g. a wet pond).

Total suspended solids: the amount of particulate matter suspended in a water sample (Government of Canada, 2021).

For erosion control, new builds and redevelopments must capture and retain the first 5 millimetres of rainfall through infiltration, **evapotranspiration**, or reuse. The city's requirements for **peak flow control** vary depending on the watershed of the proposed development. Typically, new builds must reduce peak flows from a **1:100-year storm** under current conditions to levels associated with a 1:2-year storm under **pre-development conditions** (see textbox in 8.4) (City of Mississauga, 2020a).

Evapotranspiration is the combined loss of water to the atmosphere from land and water surfaces by evaporation and from plants by transpiration.

Peak flow control: reduction of the maximum flow of **runoff** from a drainage area during a storm using stormwater management technologies (e.g. wet stormwater ponds, **GSI**).

What is a 1-in-100-year storm? It's a designation that says that precipitation of a certain depth (say, 90 millimetres) and over a certain duration (say, four hours) has a one per cent chance of occurring in a location in any given year. This is called a return period and is expressed as a ratio (e.g., 1:5, 1:10, 1:100). Historical data determine the return periods for storms in a given area.

Depending on the type of storm, the affected area can be relatively small. If the storm lasts a short time, it's referred to as a high-intensity convection storm.

When engineers design stormwater infrastructure to manage a storm with a particular return period—say a 1:100-year storm—it is called a design storm. Stormwater infrastructure in many urban areas across Canada can only handle 1:10-year storms or less (called the "minor system"). Overland flow routes to safely convey flows caused by storms with a higher return period (called the "**major system**") and stormwater ponds for quality and volume control only became standard across Canada in the 1980s and 1990s.

After meeting these requirements, non-residential properties can apply for stormwater credits. These credits acknowledge the city's stormwater development requirements on new development (City of Mississauga, 2020a, pg. 15). The primary purpose of the credit program is to encourage non-residential and multi-residential properties to apply stormwater best management practices on their properties (City of Mississauga, 2020a, pg. 2).[7]

Although the Southdown district and the Sheridan Creek Watershed are not near-term priorities for stormwater capital or renewal works (City of Mississauga 2020c), Mississauga began working on the Southdown District Stormwater Servicing and Environmental Management Plan in 2018. The first phase, which characterizes the study area, was completed in 2019. Phase 2, which will make recommendations for the study area, is planned for 2021. Typically, master drainage plans for districts focus on necessary upgrades to existing storm sewers and outfalls, building new relief storm sewers and diverting channels where necessary, and constructing stormwater ponds on municipal or acquired property.

[7] Very few eligible landowners have applied for stormwater credits under Mississauga's current program, with less than 2 per cent participation in the program as of fall 2020 (City of Mississauga, 2020b). Renewal rates for properties that have participated in the past have also been lower than expected (Scott Perry, personal communication, February 11, 2021). Mississauga's experience in this regard is not unique. Other stormwater credit programs have had limited uptake, given high upfront costs and long payback periods (CVC 2016, City of Waterloo 2019).

CVC has been working with the city and study area landowners to explore the technical and financial feasibility of communal GSI retrofits on private property as a parallel study to the Southdown District Stormwater Servicing and Environmental Management Plan. This also fits with Mississauga's Climate Change Action Plan, released in 2019, which calls for the city to "explore the use of green infrastructure to manage stormwater on publicly and privately owned properties" (City of Mississauga, 2019, supporting action 12-3). Once the feasibility study is completed, the project team and study area landowners plan to proceed to a proof-of-concept implementation phase.

8.2.3 Air Quality and Urban Heat Island Effect

The study area also has poor air quality and suffers from the **urban heat island effect** (Region of Peel, 2015, Appendix E). Proximity to Royal Windsor Drive, a major trucking route, contributes to the poor air quality. Ambient air pollution studies for the Clarkson Airshed (which includes the study area) found that concentrations of respirable particulate matter ($PM_{2.5}$) regularly exceeded national standards. Levels of other pollutants—for example, volatile organic compounds (VOCs), nitric oxide (NO), and nitrogen dioxide (NO_2)—were frequently at levels that also cause health concerns (Halton Region, 2006).

The **urban heat island effect** occurs because urban areas are covered with surfaces that retain heat—concrete, brick, and asphalt—so their temperatures are higher than surrounding rural or natural areas. Also, because they have little vegetation, they do not benefit from the cooling effects of **evapotranspiration**.

For the urban heat island effect, thermal imaging completed for the Region of Peel's Tree Planting Priority Tool suggests that the study area has higher temperatures than the regional average during hot summer days (Region of Peel, 2015, Appendix E).

8.3 Setting Objectives

This case study has four main objectives:

- To compare GSI retrofits on private property with end-of-pipe stormwater ponds on public property for cost-effectiveness in meeting stormwater management criteria.
- To evaluate the co-benefits of GSI, specifically of tree planting in GSI facilities.
- To investigate fair cost-sharing arrangements between landowners and public agencies for communal GSI works on private property.
- To examine how municipalities can ensure the maintenance of GSI facilities on private property.

8.3.1 GSI on Private Property: Bridging the Public–Private Divide

Lack of space for managing runoff is a major barrier for improving stormwater management in **legacy developments**. Built-up areas do not have enough room for centralized, end-of-pipe facilities to manage the amount of stormwater generated by the impermeable roads, buildings, and parking lots that make up the average legacy development. This leaves municipalities with few options. They can buy property for end-of-pipe storage facilities, use property they already own for new stormwater management facilities, or engage in expensive sewer upgrades.

Legacy developments are urban areas that were built before quantity or quality controls became requirements for new development in Canada. Typically, legacy developments only have infrastructure to convey stormwater from built-up areas to receiving water bodies.

The City of Philadelphia found that working with private landowners can lead to significant savings on stormwater infrastructure investments. In 2011, it began an expansive GSI program to reduce the frequency and extent of its CSOs.

The strategy takes a comprehensive approach to “greening” the city, acre by acre, by using GSI techniques to retrofit highly impervious portions of the urban landscape to capture the first inch of rainfall. Two prongs of the program focus on development and redevelopment requirements and the city’s publicly owned properties, including roadways. The third prong gives financial incentives to private landowners willing to retrofit their properties (Valderamma and Davis, 2015).

The Philadelphia Water Department quickly found that offering stormwater fee reductions to landowners who implemented source controls was an inadequate financial incentive. The upfront costs of GSI measures are too high for the annual stormwater fee reductions to provide a reasonable payback. To address this low uptake, the Water Department began the Stormwater Management Incentives Program in 2012. This program offered rebates to landowners to offset capital costs.

While Philadelphia was initially spending US$250,000 to US$300,000 to green one acre of publicly owned property, it only cost US$100,000 per acre to green private industrial and commercial properties (Valderamma and Davis, 2015). Despite this, the Program only approved 36 applications during its first three years, which was fewer than expected from the city’s approximately 80,000 non-residential properties.

To address the Incentive Program’s deficiencies, the Philadelphia Water Department began the Greened Acre Retrofit Program (GARP) in 2014. GARP allows contractors or other third parties to submit applications on behalf of landowners, including aggregated properties. This reduces IC&I landowners’ administrative costs. Applications must be for a minimum of 10 acres, and the grant amount is not defined as a percentage of capital costs. Instead, the applications must meet minimum criteria (e.g. no more than US$200,000 per greened hectare).[8] This has made the application process competitive because lower-cost applications are more likely to be

[8] Although the Philadelphia Water Department’s early industrial and commercial retrofit projects cost approximately US$100,000 per greened acre, costs for subsequent projects have risen. This is likely because the lowest-cost GSI retrofits have been completed.

selected. Once the facilities are built, landowners also qualify for annual stormwater fee reductions, up to 90 per cent.

Incentive programs geared toward lowering capital costs for GSI retrofits on private property are increasingly common across the USA (Sustainable Prosperity Institute, 2016). Only a few Canadian cities have experimented with incentive programs, though, and these have generally focused on lot-level measures for residential homeowners (e.g. rain barrels).

CVC's Integrated Water Management team has established good working relationships with landowners in the study area through past projects. These projects included building a swale to improve drainage on multiple properties and creating pollution prevention plans and infrastructure (see **Figure 51**). Through its Greening Corporate Grounds program, CVC has worked with H.L. Blachford Ltd., one of the businesses in the study area, to renaturalize remnant forests on their properties. With the initiation of the Southdown District Stormwater Servicing and Environmental Management Plan, this study area became an ideal location to examine the cost-effectiveness of aggregating IC&I properties for communal GSI retrofits.

Figure 51: In 2010, CVC worked with Bernardi Building Supply, a study area landowner, to build a swale for improved drainage.
Photo credit: CVC

Unlike Philadelphia, Mississauga does not have **combined sewer systems**. For this reason, the city does not consider a grant program to be a suitable addition to its stormwater management initiatives (City of Mississauga, 2020a). However, combined sewers are common across Canada, and municipalities with combined sewers will find the analysis below helpful if they are considering IC&I retrofits to reduce CSOs. Furthermore, communal GSI on private property could also be evaluated alongside traditional stormwater management measures on public property when municipalities weigh options for stormwater works in legacy developments (CVC 2021e, forthcoming).

Combined sewer systems collect and convey both stormwater and wastewater.

8.3.2 Multiple Benefits: GSI Can Do What Grey Infrastructure Can't

GSI generates multiple co-benefits that traditional **grey stormwater infrastructure** does not. Grey conveyance infrastructure—curbs, catchbasins, and pipes—carry stormwater and do not provide any other benefits. Hydrodynamic separators remove sediment, oil, and debris from stormwater but do not restore water balance. And while stormwater ponds provide space for vegetation and wildlife in addition to water quality and quantity control, they provide little water balance restoration.

GSI, especially vegetated GSI practices, provide benefits beyond quantity and quality controls and water balance restoration (**Table 16**). GSI's co-benefits are often cited as a reason to prefer it to traditional grey stormwater infrastructure. If quantified and given an accurate monetary evaluation, these co-benefits would further improve the **business case** for GSI. Co-benefit evaluation of GSI practices is a developing science, and the best software tools currently available focus on quantifying the benefits of trees. For this reason, the case study focuses on incorporating trees into its conceptual designs.

Grey stormwater infrastructure: Grey stormwater infrastructure uses centralized facilities—typically stormwater ponds as well as curbs, catchbasins, and pipes—and does little to re-establish the natural **hydrologic cycle**. In **legacy developments**, grey stormwater systems typically discharge collected stormwater directly into waterways, without quality treatment or quantity control.

In the public sector, giving a **business case** means providing a financial, economic, or scientific justification for public investment in a project to realize "specific outcomes in support of a public policy objective" (Government of Canada, 2020).

Table 16: Types of GSI and their co-benefits

GSI type	Typical design purpose	Improve air quality	Reduce urban heat island	Increase greenspace / amenity space	Increase property values	Create wildlife habitats	Reduce greenhouse gases	Reduce pollutant load
Bioretention* facilities (all varieties)	Capture, clean, cool, evapotranspire, and infiltrate stormwater	✓	✓	✓	✓	✓	✓	–
Bioswales and **enhanced grass swales***	Convey, infiltrate and attenuate stormwater	✓	✓	✓	–	✓	✓	✓
Infiltration chambers*, soakaway pits, French drains, etc.	Capture and detain large volumes of stormwater during intense storms	–	–	–	–	–	–	✓
Permeable pavements* (pavers, asphalt, concrete, etc.)	Allow infiltration and storage underneath hard surfaces	–	✓	–	–	–	–	–
Urban trees	Intercept rainwater, evapotranspire, and promote infiltration	✓	✓	✓	–	✓	✓	–
Green roofs*	Manage stormwater on a rooftop	✓	✓	✓	–	✓	✓	–
Rainwater harvesting*	Capture rainwater for non-potable uses to offset potable water use	–	–	–	–	–	✓	–

Abbreviation: GSI, green stormwater infrastructure.
* See glossary for definitions.

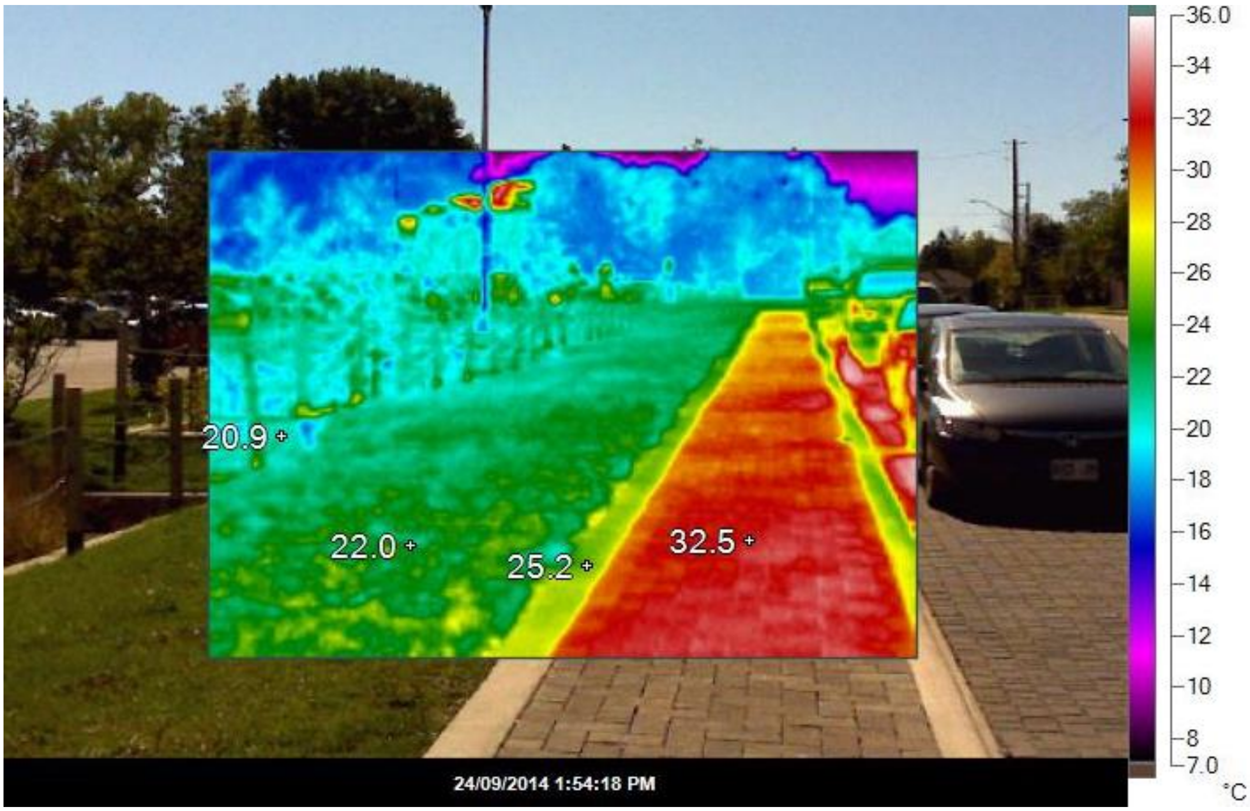


Figure 52: Surface temperatures (in degrees centigrade) of a bioretention facility and the sidewalk on Mississauga's Elm Drive.

8.3.3 Cost-Sharing Between Public and Private Sectors

Long payback periods are the primary reason for low uptake of stormwater credit programs (CVC, 2016; CVC, 2018a, City of Waterloo, 2019). In **Section 8.5.1**, we demonstrate that annual credits are inadequate incentives to motivate voluntary GSI retrofits. We then show what financial incentives would be adequate to reduce payback periods to a reasonable level. Cost sharing and cooperation between the public and private sectors would allow for cost-effective retrofitting of legacy developments. One-time grants could be awarded to help cover capital costs and adequate annual credits could help cover ongoing maintenance costs.

8.3.4 Securing the Investment: Ensuring GSI Maintenance on Private Property

Municipalities that consider incentivizing GSI retrofits on private property may view the maintenance of these GSI facilities as a barrier. If municipalities or other agencies use public funds to incentivize GSI on private property, they need to be certain that the funds will be used as intended—to improve stormwater management—and will benefit the public. **Sections 8.5.4** and **8.5.5** examine easements and Ontario's *Drainage Act* as two potential methods for ensuring that GSI facilities on private property are properly maintained.

8.4 Developing a Cost-Effective Strategy

To compare the cost-saving potential of GSI retrofits on private property against traditional stormwater management on public property, we developed four stormwater scenarios and modelled them using PCSWMM software.[9] We have also written a series of technical memos and reports that describe model and design development in detail.[10] To compare the scenarios financially, we focus on the context necessary to understand how each scenario performs.

The scenarios are:

- Scenario 1—the **pre-development conditions** scenario—describes the site's condition before it was transformed from its natural state to the IC&I neighbourhood that it is today.
- Scenario 2—the existing conditions scenario—describes the site's current conditions. With scenario 1, this scenario provides the information to create the two design scenarios and to evaluate their performance.
- Scenario 3—the max credit scenario—uses communal GSI retrofits on private property. The design goal for this scenario is to gain the maximum stormwater credit available to landowners based on Mississauga's 2020 stormwater charge rates.
- Scenario 4—the public property scenario—presents a traditional centralized end-of-pipe conceptual design on public property. This scenario provides a benchmark for evaluating the costs and performance of the max credit scenario.

The term **"pre-development conditions"** refers to the natural hydrologic conditions of the land before any human settlement or development takes place. Effective stormwater management requires that post-development peak flows match pre-development ones. When modelling pre-development conditions in the City of Mississauga, soil infiltration parameters and per cent imperviousness are set to achieve a volumetric runoff coefficient of 0.25 for the 1:100-year storm.

[9] PCSWMM is water management modelling software developed by Computational Hydraulics International of Guelph, Ontario (https://www.pcswmm.com/).

[10] CVC has written detailed information on model development for the pre-development and existing conditions scenarios as well as technical memos for each of the two design scenarios (CVC 2021a, 2021b, 2021c, 2021d). CVC will also be preparing an engineer's report to show how the *Drainage Act* could be applied to communal GSI retrofits in urban areas. The memos and the report will provide detailed information on scenario development and cost-sharing proposals.

8.4.1 Major and Minor System Subcatchments and Branch Drains

To describe the site's **hydrology** and **hydraulics**, we divided the study area's **major** and **minor system catchments** into **subcatchments**. The major and minor subcatchments are not coextensive; in some cases, the two systems have different boundaries (see Error! Reference source not found. and **Figure 54**).

Hydrology is the study of water on the earth's surface, flowing either above ground or beneath it. **Hydraulics** is the study of the flow of water through pipes and channels, such as rivers.

A **catchment** is an area of land that drains rainfall to a single point. Water leaves the catchment from this point. **Subcatchments** are themselves catchments within another, larger catchment.

Researchers apply the term "catchment" iteratively depending on the scale at which they are working. In urban areas, catchments and subcatchments are typically defined by the municipal storm sewer system. If an area of land drains to a single pipe or outlet, it can be defined as a catchment. At the smallest scale, even small surface depressions—puddles, essentially—can be defined as subcatchments.

It is also important to distinguish between **minor** and **major system** catchments and conveyance systems. In urban areas, the **minor system** manages flows from frequent storm events using conveyance systems such as pipes and swales. Larger flood events surcharge the **minor system**, causing water to follow an overland flow route. These overland flow routes are called the **major system**. The boundaries for major and minor system subcatchments can be the same or different.

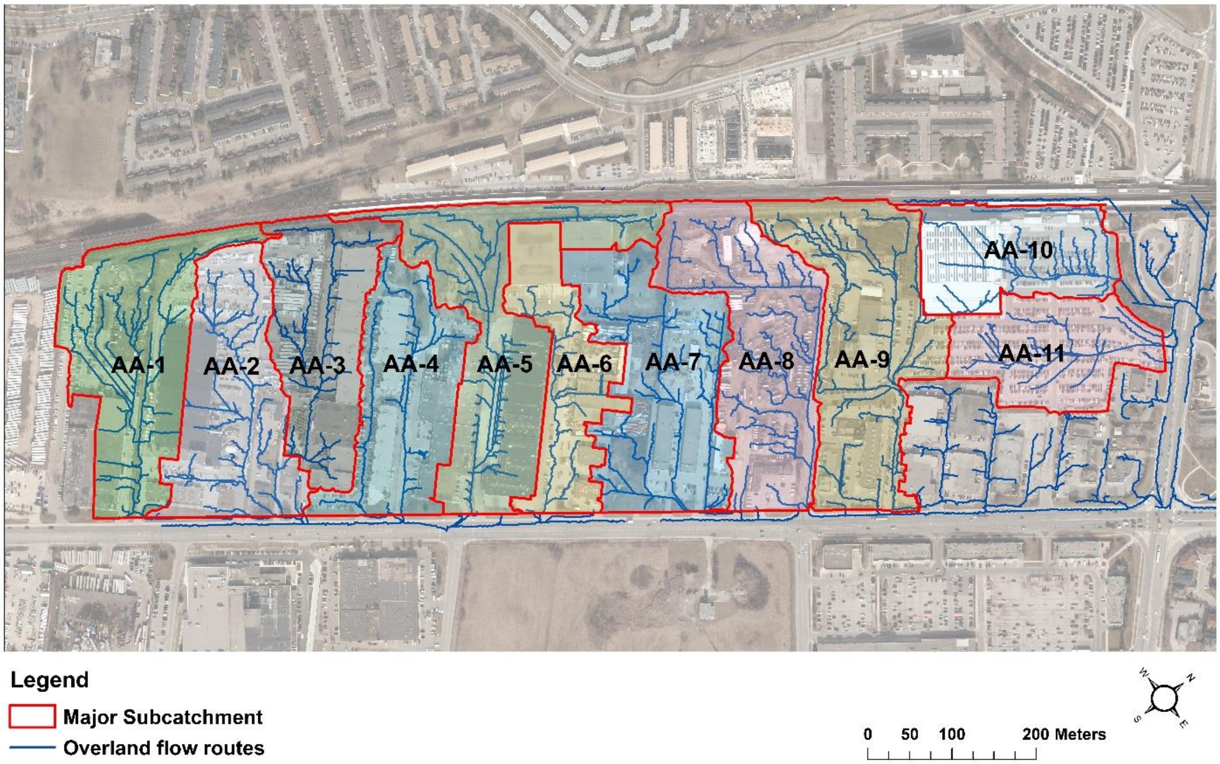


Figure 53: Major system subcatchments AA-1 to AA-11 in the study area.

To identify major system subcatchments, we use the names in Error! Reference source not found.—”AA-1”, “AA-2”, etc. We use these names in the discussions on the max credit scenario’s flood control aspects, that is, peak flow control and storage.

To characterize the study area’s minor system drainage network, we borrowed conventions developed by engineers working under the *Drainage Act*. We labelled the municipal stormwater sewer along Royal Windsor Drive as the main drain and the private drainage systems (pipes, catchbasins, and swales) that tie into the main drain as branch drains. Each branch drain (or “branch”) is then labelled (“Branch A”, “Branch B”, etc.), measured, and assigned station numbers. The following discussions of the max credit scenario’s water quality and water balance measures—its minor system features—use these names. **Figure 54** shows Branches A to O.

Note that the max credit scenario only applies to six branches, D to I, and four subcatchments, AA-5 to AA-8. We decided to take this approach to simplify the max credit scenario, which made it easier to model and allowed us to create detailed conceptual designs. With the conceptual designs for Branches D to I in place, we can confidently project costs for the remainder of the study area by taking the per-hectare cost for Branches D to I and applying it to the areas encompassed by Branches A to C and J to O.

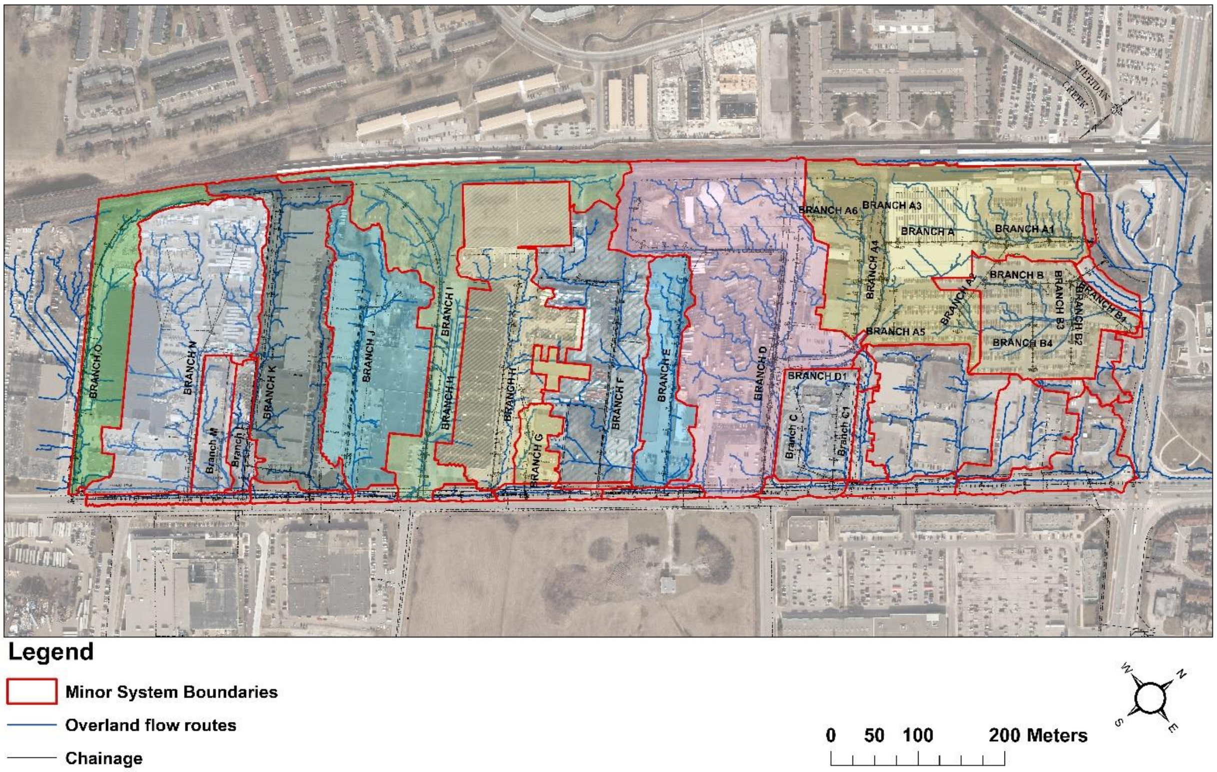


Figure 54: Minor system boundaries for the study area, with branch drains labelled.

8.4.2 Scenarios 1 and 2: Pre-development and Existing Conditions Scenarios

Scenario 1, the pre-development conditions scenario, looked at the hydrologic conditions that would have been in place prior to development. Scenario 2, the existing conditions scenario, presents the study area's current hydrologic and hydraulic state as an IC&I neighbourhood.

After completing detailed fieldwork, we developed a PCSWMM model to estimate, for both scenarios:

- water quality (**Table 17** and Table 18) and current water balance (using event and **continuous simulations**) (**Table 20**) (CVC, 2021); and
- peak flows under various return-period events (**Table 19**) and climate change scenarios (using **event simulations**).

Because the pre-to-post difference in values guided design scenario development, presenting the difference between the pre-development and existing conditions scenarios is critical for understanding them.

Table 17 shows that suspended solids in runoff after a 25-millimetre storm in the study area is 400 times higher under existing conditions compared with pre-development conditions. Total phosphorus in runoff has increased almost 150-fold. **Table 18** shows that sediment washed away from the study area over a year is currently 50 times pre-development levels, while phosphorus levels are 12 times higher.

Table 17: Water quality in the pre-development and existing conditions scenarios after a 25-millimetre rainfall event

Branch	Total suspended solids (kg)		Total phosphorus (kg)	
	Pre-development	Existing conditions	Pre-development	Existing conditions
D	0.00	44	0	0.07
E	0.02	35	0	0.06
F	0.00	22	0	0.05
G	0.04	6	0	0.01
H	0.27	30	0.002	0.08
I	0.04	17	0	0.04
Total	**0.37**	**154**	**0.002**	**0.31**

Abbreviation: kg, kilogram.

Table 18: Annual total suspended solids and total phosphorus loadings in the pre-development and existing conditions scenarios

Branch	Total suspended solids (kg)		Total phosphorus (kg)	
	Pre-development	Existing conditions	Pre-development	Existing conditions
D	19	1,273	0.1	1.9
E	8	730	0.1	1.2
F	11	616	0.1	1.2
G	4	132	0.0	0.3
H	25	702	0.2	1.9
I	7	413	0.1	0.9
Total	**74**	**3,866**	**0.6**	**7.4**

Abbreviation: kg, kilogram.

Table 19 shows that peak flow after a 1:100-year storm is on average three times higher than in pre-development conditions, depending on the study area subcatchment.

Table 19: Comparison of 1:100-year storm peak flow in the pre-development and existing conditions scenarios for a three-hour Chicago design storm

Subcatchment	Area (ha)		Pre-development peak flow (m^3/s)	Existing conditions peak flow (m^3/s)	Per cent increase* (%)
	Major system area	Minor system area			
AA-5	4.7	3.3	0.19	0.57	98
AA-6	2.6	4.0	0.37	0.63	51
AA-7	4.4	4.2	0.24	0.69	98
AA-8	4.0	5.5	0.18	1.00	138

Abbreviations: ha, hectare; m^3/s, cubic metre per second.
* Per cent increase = (post−pre)/((pre+post)/2) ×100

Table 20 shows that the portion of rainfall that becomes runoff is currently about 14 times pre-development values in the study area.

Table 20: Annual water balance values in the pre-development and existing conditions scenarios (continuous simulation)

Subcatchment	Pre-development					Existing conditions				
	Rainfall (m^3)	Infiltration (m^3)	Evaporation (m^3)	Runoff (m^3)	Runoff as a per cent of total rainfall (%)*	Rainfall (m^3)	Infiltration (m^3)	Evaporation (m^3)	Runoff (m^3)	Runoff as a per cent of total rainfall (%)
AA-5	29,950	28,300	37	1,620	5	29,950	9,300	1,170	19,500	65
AA-6	16,350	15,440	20	890	5	16,350	1,400	1,040	13,920	85
AA-7	28,110	26,580	39	1,500	5	28,110	7,560	1,390	19,190	68
AA-8	28,600	27,080	46	1,500	5	28,600	4,360	2,030	22,240	78
Total	**103,010**	**97,400**	**142**	**5,510**	**5**	**103,010**	**22,620**	**5,630**	**74,850**	**73**

Abbreviation: m^3, cubic metre.

* Runoff as a per cent of total rainfall = runoff/rainfall ×100

Figure 55 shows the extent of flooding predicted for a 1:100-year storm in the study area.

Figure 56 shows the total suspended solids hot spots for a 1:2-year storm.

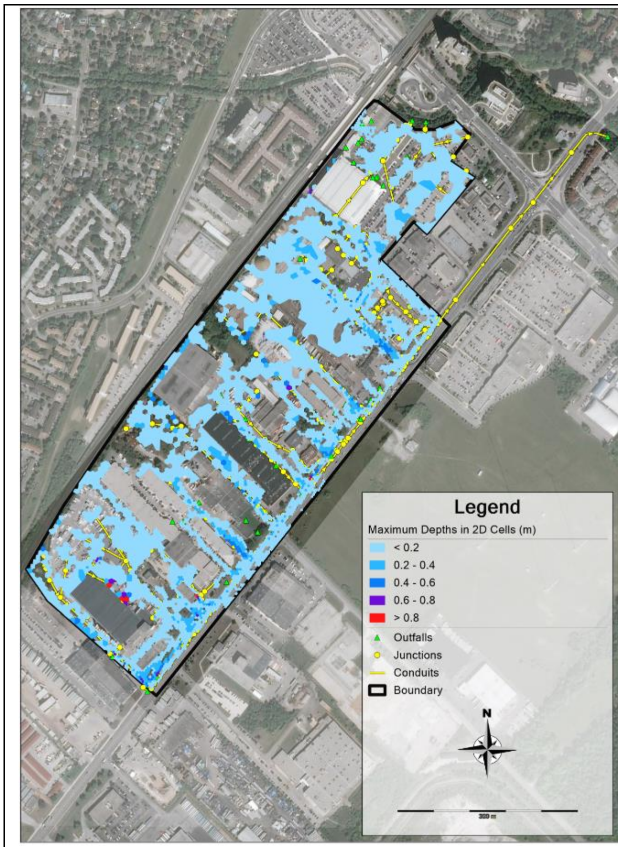


Figure 55: Extent of flooding in the study area from a 1:100-year design storm in the existing conditions scenario.
Abbreviation: m, metre.
Source: CVC, 2021

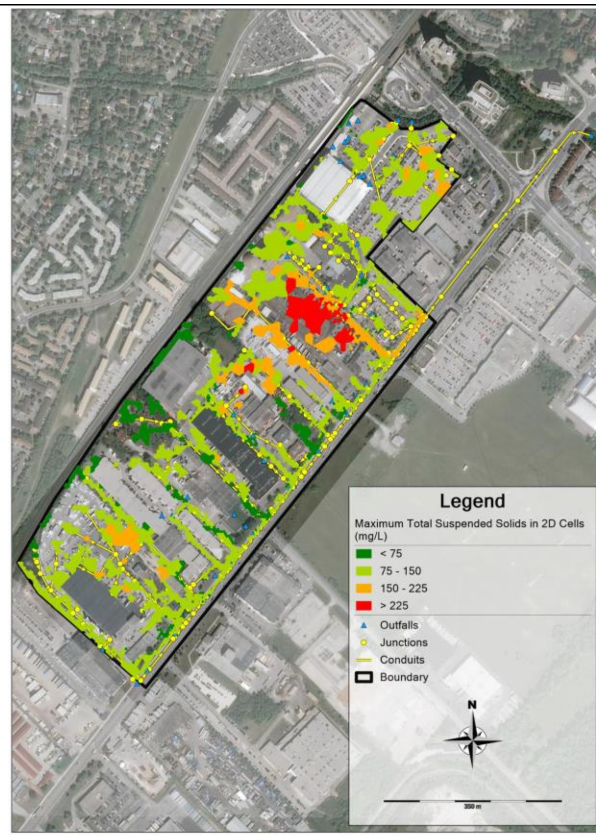


Figure 56: Predicted concentration of total suspended solids (sediment) in surface runoff after a 1:2-year design storm in the existing conditions scenario.
Abbreviation: mg/L, milligrams per litre.
Source: CVC, 2021

8.4.3 Scenario 3: Max Credit Scenario

The max credit design uses GSI measures on private property to gain the maximum amount of stormwater credit available to landowners at the lowest cost. Successful applicants can receive a maximum of 50 per cent credit on their annual stormwater charge for installing at-source GSI works and for developing property-specific pollution prevention plans. The amount of credit received depends on the benefits to the municipal stormwater system caused by:

- peak flow reduction—up to 40 per cent credit;

- runoff volume reduction (up to 15 millimetres of onsite **retention**)—up to 15 per cent credit;
- water quality improvement (anticipated removal of 80 per cent of total suspended solids)—up to 10 per cent credit; and
- property-specific pollution prevention plans—up to 5 per cent credit (City of Mississauga, 2015).

The max credit scenario would control peak flows to pre-development levels using subsurface chambers. The storage volumes of the subsurface chambers required for 1:100-year storm would be between 490 and 1,290 cubic metres, depending on the subcatchment (see **Table 21**). The max credit design model provides a slightly larger storage volume for each major system subcatchment. This would gain landowners a 40 per cent stormwater credit.

Note that the peak flow reduction credit is evaluated according to the site's impervious area, not the site's total area (City of Mississauga, 2015, pg. 18). However, the max credit scenario uses seven **infiltration chambers** sized for the whole catchment, not just its impervious area. **Figure 57** shows the locations of these infiltration chambers. Infiltration factors were applied to the various runoff coefficients for the various return periods to account for saturation conditions for larger, less frequent storms.

Retention: the capture of stormwater for filtration, **infiltration**, and **evapotranspiration**. Retained stormwater does not become **runoff** or streamflow (unlike detained stormwater; see **detention**). Retaining of stormwater helps to restore a natural **water balance**.

Infiltration chambers are underground storage chambers that are designed to capture large volumes of stormwater. They reduce flood risk and allow precipitation, such as rainwater and snowmelt, to get under and **infiltrate** below hard surfaces, such as parking lots.

Table 21: Required storage volume and storage volume provided by the max credit scenario for a 1:100-year storm

Subcatchment	Total area (ha)		Required storage volume (m^3)	Provided storage volume (m^3)
	Major system area	Minor system area		
AA-5	4.7	3.3	790	800
AA-6	2.6	4.0	490	500
AA-7	4.4	4.2	1,290	1,360
AA-8	4.0	5.5	1,190	1,200

Abbreviations: ha, hectare; m^3, cubic metre.

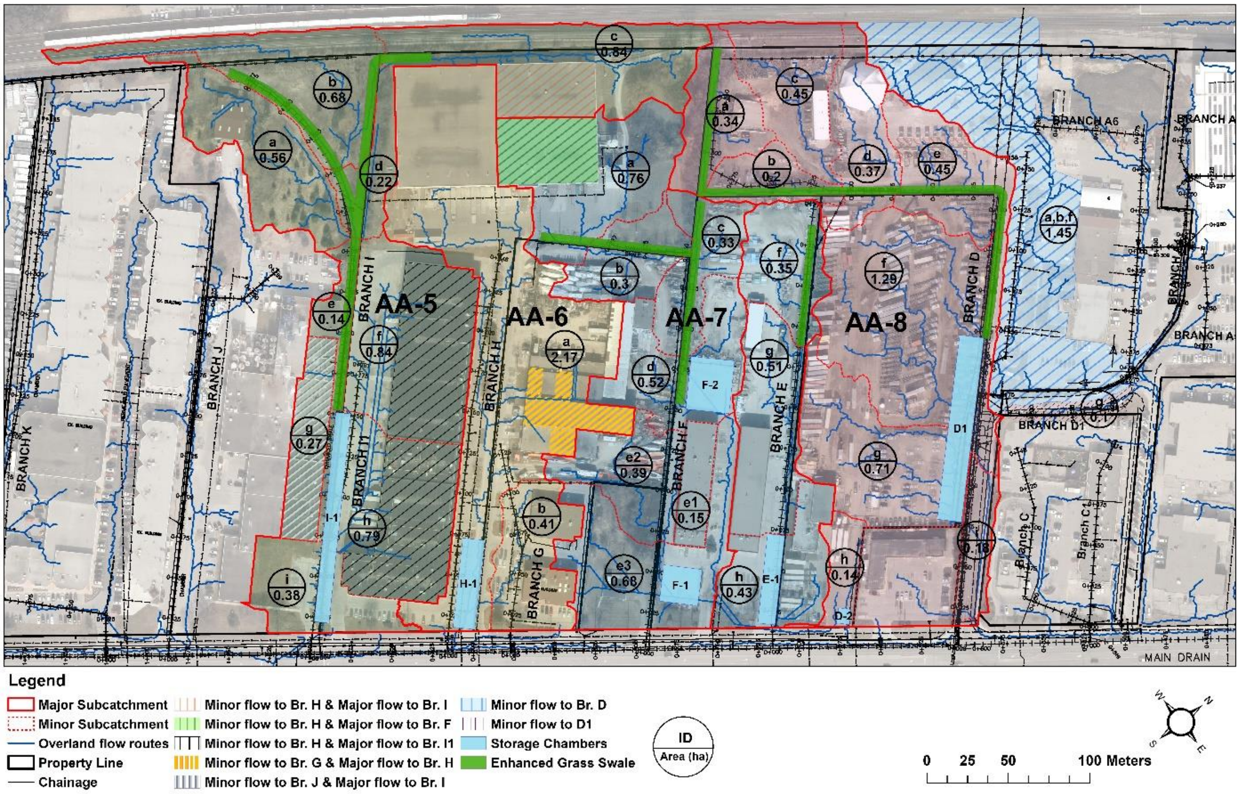


Figure 57: Locations of infiltration chambers and enhanced grass swales for the max credit conceptual design. The map also shows the subcatchments for each of the branch drains.

To achieve the remaining 10 per cent credit of the maximum 50 per cent credit, we included **enhanced grass swales** and **oil and grit separators** (OGSs) and added extra infiltration capacity to some infiltration chambers. Mississauga's stormwater credit guidelines require that practices reduce loadings of total suspended solids by 80 per cent.

As **Table 22**

and **Table 23** show, the max credit scenario outperforms the requirement to remove 80 per cent of the total suspended solids. The max credit scenario removes all or almost all the total suspended solids that are found in runoff after a 25-millimetre rainfall event under existing conditions. Total phosphorus loadings are reduced an average of 21 per cent of the existing conditions loading (**Table 22**

Enhanced grass swales are open channels that are covered with plants and are designed to convey, treat, and attenuate stormwater **runoff**. Also referred to as enhanced vegetated swales.

Oil and grit separators are a type of stormwater management technology that treats stormwater primarily by using gravity to remove settleable particles and phase separation to remove buoyant materials (free oils and grease) from water.

). Annual loadings of total suspended solids are reduced by up to 100 per cent and 98 per cent, respectively.

Table 22: Projected reductions in total suspended solids and total phosphorus after a 25-millimetre rainfall event under the max credit scenario

Branch	Total suspended solids			Total phosphorus		
	Existing conditions (kg)	Max credit (kg)	Loading reduction* (%)	Existing conditions (kg)	Max credit (kg)	Loading reduction/ (increase) (%)
D	44	0.90	98	0.07	0.09	(29)†
E	35	0.06	100	0.06	0.01	83
F	22	0.28	99	0.05	0.03	40
G/H‡	35	0.08	100	0.09	0.08	11
I	17	0.11	99	0.04	0.02	50
Total	**153**	**1.43**	**99**	**0.31**	**0.23**	**21**

Abbreviation: kg, kilogram.

* Loading reduction = 1 − max credit/existing conditions ×100

† Branch D showed an increase in total phosphorus loadings because we included regrading in the design to direct flows from subcatchment AA-9 into AA-8 (AA-8 contains Branch D). Also, we included regrading on one of the Branch D properties so that rainwater, which previously ponded, now flows into the GSI facilities.

‡ Branches G and H are smaller relative to the other branches, so we combined them in the max credit scenario's model.

Table 23: Annual total suspended solids and total phosphorus loadings for the existing conditions scenario and max credit scenario (continuous simulation)

Branch	Total suspended solids			Total phosphorus		
	Existing conditions (kg)	Max credit (kg)	Loading reduction (%)	Existing conditions (kg)	Max credit (kg)	Loading reduction* (%)
D	1,273	8.4	99	1.9	1.8	5
E	730	1.3	100	1.2	0.2	83
F	616	8.0	99	1.2	0.7	42
G/H	833	13.1	98	2.3	1.1	52
I	413	1.0	100	0.9	0.4	56
Total	**3,865**	**31.8**	**99**	**7.5**	**4.2**	**43**

Abbreviation: kg, kilogram.
* Loading reduction = 1 − max credit/existing conditions ×100

Lastly, **Table 24** shows the max credit scenario's water balance values. The max credit scenario would reduce runoff by 14.5 per cent when compared with the existing conditions scenario.

Table 24: Annual water balance values for the max credit scenario

Subcatchment	Rainfall (m^3)	Infiltration (m^3)	Evaporation (m^3)	Infiltration (through infiltration chambers*) (m^3)	Runoff (m^3)	Runoff as a per cent of total rainfall (%)†	
						Existing conditions scenario	Max credit scenario
AA-5	29,950	11,590	1,160	1,870	15,480	65	52
AA-6	16,350	1,410	1,040	990	13,000	85	80
AA-7	28,110	9,700	1,350	6,260	10,980	68	39
AA-8	28,600	7,560	1,980	-	19,120	78	67

Abbreviation: m^3, cubic metre.
* The infiltration chambers in AA-5 and AA-7 were given extra infiltration capacity by adding a gravel layer beneath the storage chambers. The chamber in subcatchment AA-6 did not need extra infiltration capacity in order to gain landowners the maximum credit available, since that subcatchment would already receive the full 10 per cent water quality credit. The infiltration chamber in AA-8 was given an impermeable liner as a safety precaution to prevent infiltration of petrochemicals.
† Runoff as a per cent of total rainfall = max credit/existing conditions.

8.4.3.1 Costing the Max Credit Design

We estimated life-cycle costs for all the design scenarios using the Sustainable Technologies Evaluation Program (STEP) life cycle costing tool (LCCT).[11] Updated in 2020, the LCCT allows users to estimate life-cycle costs for several GSI practices and stormwater ponds. This Microsoft Excel tool uses RSMeans construction database[12] unit costs and STEP model designs to generate:

- pre-construction costs (e.g. utility stakeouts, infiltration tests, erosion and sediment control, and land values);
- excavation, hauling, and disposal costs;
- practice-dependent materials and installation costs (e.g. chambers, maintenance access holes, pipe fittings, gravel, and soil media); and
- construction inspection and post-construction verification costs.

The tool requires users to determine engineering, design administrative, and other ancillary costs. These were collectively set at 15 per cent of construction costs for both design scenarios. The tool projects operation, maintenance, and rehabilitation costs over a user-specified period and at user-specified discount and inflation rates. To cost both design scenarios, we used a 50-year evaluation period, a three per cent inflation rate, and a five per cent **discount rate**.

Discount rate: the interest rate used to determine the present value of future cash flows.

The conceptual design of the max credit scenario resulted from several iterations. While peak flow controls were always part of the plan to gain 40 per cent of the stormwater credit, earlier designs used infiltration trenches to reduce runoff volume as a way to gain the final 10 per cent. However, using water quality controls—OGSs and enhanced grass swales—to gain the final 10 per cent costs less than a volume-reducing approach (CVC, 2021a).

Table 25 shows the life-cycle costs for retrofitting for Branches D to I with GSI.

[11] https://sustainabletechnologies.ca/lid-lcct/.

[12] https://www.rsmeans.com/.

Table 25: Total cost to retrofit the study area to gain landowners the maximum stormwater credit

Branch	Drainage area (ha)	Capital costs* ($)	Maintenance and rehabilitation† ($)	Life-cycle costs ($)	Per-hectare life-cycle cost ($)
D	5.5	997,400	151,000	1,148,400	209,100
E	1.3	337,400	68,000	405,400	312,600
F	3.1	694,700	62,000	756,700	241,800
G/H	2.6	510,200	61,000	571,200	221,900
I	4.7	628,900	75,000	703,900	149,200
Total/average	**17.2**	**3,168,600**	**417,000**	**3,585,600**	**208,300**

Abbreviation: ha, hectare.
* Construction, engineering, administration, and harmonized sales tax (HST).
† Over a 50-year evaluation period.

8.4.3.2 Evaluating the Costs and Benefits of Naturalizing Enhanced Grass Swales

Traditionally, enhanced grass swales are just that—grassed swales, perhaps with check dams or other features to attenuate or infiltrate stormwater. However, given the study area's known problems with air quality and the urban heat island effect, we decided to modify the max credit design by adding tree and native meadow plantings to the proposed swales. Trees and vegetation help to remove airborne pollutants, provide habitat for wildlife, and reduce the urban heat island effect, in addition to promoting infiltration, filtering stormwater runoff through phytoremediation, and lowering runoff volumes through **evapotranspiration**. The study area is also a flyway for migrating birds.

To develop a tree and native meadow planting plan for the site, we used information from previous naturalization projects on an industrial property in the study area (**Figure 58**). This project resulted from the collaboration of CVC's Greening Corporate Grounds program, CVC's Terrestrial Restoration and Monitoring services, CVC's Terrestrial Restoration and Management team, and H.L. Blachford Ltd., a study area landowner. We also consulted CVC's *Plant Selection Guideline* (CVC, 2018b).

Figure 58: The naturalized woodlot and meadow at H.L. Blachford Ltd. in 2018.
Photo credit: CVC

Naturalization projects typically plant trees three metres apart from one another. Because the swales are linear, this means planting a tree every three metres along their lengths. In those portions of the swales close to buildings, we selected coniferous species to provide winter energy savings (from reduced wind speed) and summer energy savings (from shading). **Table 26** gives a branch-by-branch breakdown of the number of trees that could feasibly be planted in each swale.

Table 26: Number of trees proposed for the swales

Branch	Swale Length (m)	Swale area (m^2)	Number of trees
D	363	1,814	121
E	74	352	25
F	218	1,145	73
G/H*	0	0	0
I	373	8,717	124
Total	**1,028**	**15,196**	**343**

Abbreviations: m, metre; m^2, square metre.
* Branch G/H has no swale proposed in the max credit scenario, so it includes no tree plantings.

Next, we calculated the capital cost to plant native trees and meadow species within the swales using data from previous renaturalization projects installed by CVC's Greening Corporate Grounds program and CVC's Terrestrial Restoration and Monitoring services (see **Table 27**). Depending on the particularities of the site, the capital stage of CVC's renaturalization that include meadow creation and tree planting progress in four phases:

1. Treating and removing invasive species.
2. Creating native meadow.
3. Applying touch-ups to manage invasive species and hydroseeding.
4. Planting trees

Table 27: Capital costs for tree and native meadow plantings in the proposed swales for the max credit scenario

Project phase	Branch D ($)	Branch E ($)	Branch F ($)	Branch I ($)	Total ($)
Treating and removing invasive species	1,226	238	774	1,513	3,800
Creating native meadow	541	105	342	668	1,700
Touch-up invasive species management and hydroseeding	617	120	389	761	1,900
Planting trees	2,444	499	1,469	2,512	7,000
Total	**4,828**	**962**	**2,974**	**5,454**	**14,400**

O&M costs for the renaturalization project were then projected over 50 years at a two per cent discount rate, as seen in **Table 28.** Some tasks, such as watering, would take place only in the first two years after planting. Vegetation replacement would take place in years 2, 5 and 10, and invasive species treatment would occur every five years throughout the 50-year period. The aim for renaturalization projects is to create a plant community that, with a little help at the start and periodic invasive species treatment, is self-sustaining.

Table 28: Fifty-year operations and maintenance costs for tree planting in the swales

Task	50-year cost ($)
Watering	1,500
Invasive species management	5,400
Vegetation replacement	2,800
Total	**9,700**

To evaluate the benefits from the tree planting plan, we used i-Tree Design, a free software tool hosted by the U.S. Environmental Protection Agency. i-Tree Design quantifies the benefits that result from tree plantings in five categories:

- avoided costs from reduced stormwater runoff;
- air quality improvements;
- carbon sequestration;
- winter energy savings; and
- summer energy savings.

Table 29 gives the results branch by branch.

Table 29: Benefit values for tree plantings, branch by branch

Branch	Benefits ($)					
	Stormwater runoff	Air quality	Carbon sequestration	Winter energy savings	Summer energy savings	Total
D	5,771	4,902	5,892	0	0	16,600
E	1,859	918	1,713	0	0	4,500
F	4,225	2,945	4,372	2,693	208	14,400
H	0	0	0	0	0	0
I	5,908	5,782	11,368	23,630	1,162	47,900
Total	**17,800**	**14,500**	**23,300**	**26,300**	**1,400**	**83,300**

* Totals were rounded to the nearest hundred.

Putting everything together, the estimated total life-cycle costs—capital costs of $14,400 (see **Table 27**) and operations and maintenance costs of $9,700 (see **Table 28**)—for the tree planting plan would be $24,000, and the benefits would be $83,400 over a 50-year period. However, since the design goal for the max credit scenario is to gain landowners the maximum credit at the lowest cost, these costs were not included in the analyses below.

While i-Tree Design is an easy-to-use tool, using it (or other tools) to evaluate the benefits that would result from municipal stormwater projects faces barriers, such as:

- reaching agreement among stakeholders on the appropriate model or tool to use to quantify co-benefits;
- reaching agreement among stakeholders on the methodology from which co-benefits are quantified or monetized or assigned; and

- making the case, based on benefits assigned, for different organizations to pay into a project together.

8.4.4 Scenario 4: Public Property Scenario

The public property scenario examines a wet pond on public property to provide a benchmark for comparing with the max credit scenario. We used the *Stormwater Management Planning and Design Manual* (Government of Ontario, 2003) to determine design criteria for stormwater management facilities for the public property scenario.

While minor system flows generated by the study area drain through the municipal stormwater sewer along Royal Windsor Drive into Sheridan Creek, major system flows—created when storm sewers surcharge—do not always follow the same routes. Instead, the study area divides into three major system catchments:

- The western catchment (in blue in **Figure 59**) collects runoff from major storms and discharges it onto Royal Windsor Drive. From there, the runoff eventually reaches Lakeside Creek.
- The central catchment (in green in **Figure 59**) also collects the runoff from major storms and discharges it along the study area's lower boundary, from where it spills onto Royal Windsor Drive. From there, these flows travel along the right-of-way before eventually reaching Sheridan Creek.
- The eastern catchment (in orange in **Figure 59**) comprises three major system subcatchments (AA-9, AA-10, AA-11 in Error! Reference source not found.). Runoff from each of these major system subcatchments follows its own route to Sheridan Creek.

We determined that it was not feasible to service the eastern catchment area using a wet stormwater pond because of the lack of open space between the catchment and Sheridan Creek.[13] The only option would be to use distributed GSI. For this reason, the public property scenario includes two ponds: one to service subcatchments AA-7 and AA-8, and the other to service subcatchments AA-1 through AA-6 (see **Figure 53**). Both hypothetical stormwater ponds are located on land Mississauga classifies as vacant industrial land.

[13] For peer review, CVC recruited Wood Consulting to assess the technical feasibility of the public property scenario. They found that it was technically feasible.

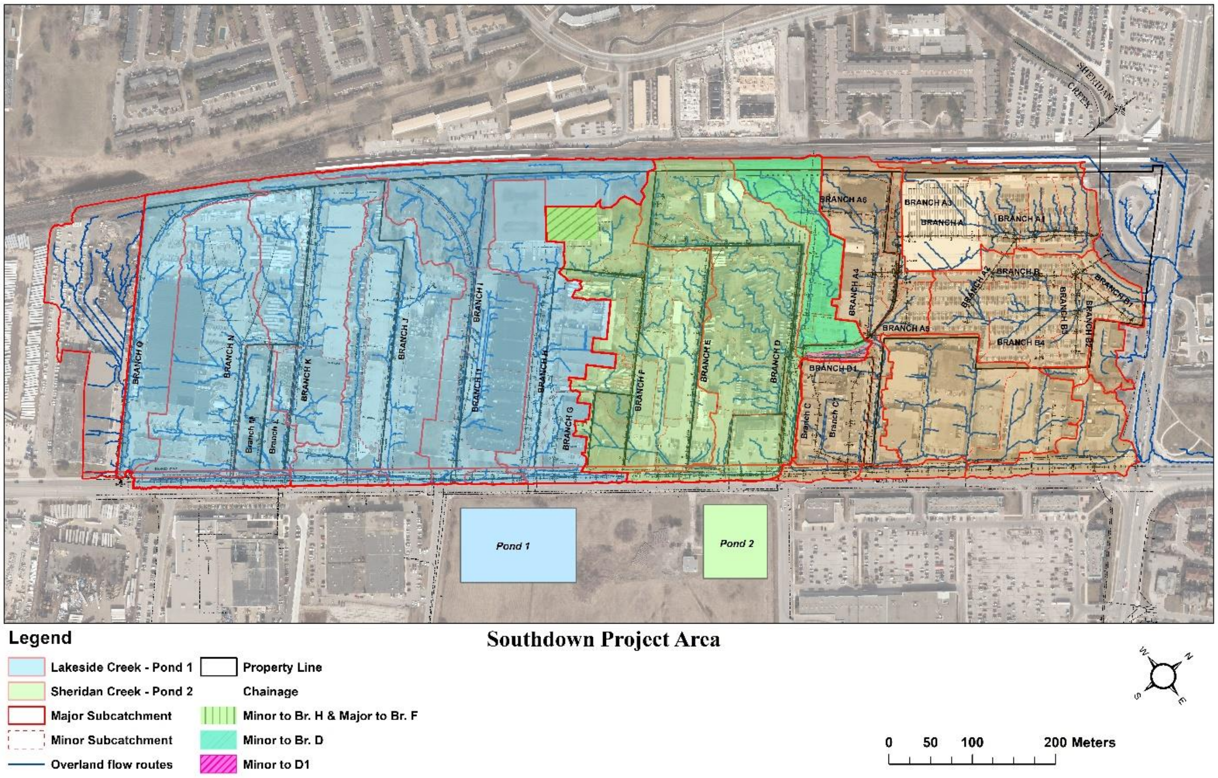


Figure 59: Major system catchments for the end-of-pipe public property scenario.

To evaluate the performance of the two ponds in meeting peak flow and water quality control criteria, we used published guidelines and design parameters from the Ministry of the Environment, Conservation and Parks (Government of Ontario, 2003):

- Peak flow control
  - Provide control of the 1:100-year storm event to levels associated with a 1:2-year storm under pre-development conditions

- Water quality storage volume
  - Enhanced protection (80 per cent total suspended solids removal)

- Other design criteria
  - A drainage area greater than 10 hectares
  - Extended **detention** storage requirement of 40 cubic metres per hectare
  - Forebay (the pond's initial collection point, where larger discrete particle settle out) volume of 20 per cent of permanent pool
  - Pond and forebay length to width ratio of 4:1
  - Wet pond permanent pool depth of 1.5 metres
  - Active storage depth of 1.5 metres
  - Freeboard (extra depth in the pond, which acts as safety factor for the water level) of 0.3 metres

- 10-metre buffer zone on all sides of the pond for maintenance access

> **Detention**: the temporary storage of stormwater to control discharge rates and to allow for sedimentation. Detained stormwater is slowly released as **runoff** or streamflow. The facilities that detain stormwater do not help re-establish a natural **water balance**. See **hydrologic cycle** and **water balance**.

8.4.4.1 Costing the Public Property Scenario: Including Land Values and Foregone Property Taxes

The project team used the STEP LCCT to estimate the 50-year life-cycle costs for the two hypothetical stormwater ponds. We included the cost to purchase land for the ponds and calculated—but did not include—the foregone property taxes.

Mississauga's Economic Development Office has provided information for industrial and commercial land sales from January 1 to September 30, 2018. The 15 transactions completed during this time had a mean sale price of $370 per square metre for undeveloped land (City of Mississauga, 2018). Because Mississauga considers the land allocated for these hypothetical ponds as vacant industrial land, we used the value of $370 per square metre for estimating land costs.

By purchasing land from the private sector for these ponds, Mississauga would forego future revenues from property taxes. Because the location for the hypothetical ponds is classified as vacant industrial land, we calculated foregone revenue for two ponds at a land value of $370 per square metre, the projected footprint required for the pond, and the 2019 property tax rate for industrial vacant land. The foregone property tax revenue over 50 years would be about $2.7 million for the western property and $1.9 million for the central property, as shown in **Table 30**. These are conservative values. This tax rate would increase if the property were developed.

Table 30: Foregone property taxes for land purchased for two hypothetical stormwater ponds given a land value of $370 per square metre, projected over 50 years at a two per cent discount rate

Major system catchment	Drainage area (ha)	Facility footprint (ha)	Property tax rate for vacant industrial land* (%)	Annual property tax† ($)	Foregone 50-year tax revenue‡ ($)
Western	21.1	1.39	1.679	86,300	2,713,300
Central	10.8	0.97	1.679	60,300	1,893,500

Abbreviation: ha, hectare.
* Based on 2014–2019 property tax rates.
† Source: City of Mississauga 2014–2019 tax rates.
‡ Based on a 50-year evaluation period, a two per cent discount rate, and a land value of $370 per m^2.

Table 31 shows the life-cycle cost estimates for the two hypothetical ponds. The life-cycle costs of the western and the central stormwater pond over a 50-year period would amount to $7,031,800 and $4,993,600, respectively.

Table 31: Life-cycle costs for the two hypothetical stormwater ponds, including land acquisition costs

Major system catchment	Capital costs* ($)	50-year O&M† ($)	Land costs ($)	Life-cycle costs† ($)	Per hectare capital costs†	Per hectare life-cycle costs
Western	947,100	929,900	5,154,800	7,031,800	289,200	333,300
Central	691,600	695,800	3,606,200	4,993,600	397,900	462,400
Total/average	**1,638,700**	**1,625,700**	**8,761,000**	**12,025,400**	**326,000**	**377,000**

Abbreviation: O&M, operations and maintenance.
* Construction, engineering, administration, harmonized sales tax (HST).
† Over a 50-year evaluation period. Land costs are included as a capital cost.

Note that the conceptual design for the public property scenario does not include inlet and outlet structures or estimate their costs. As the project moves forward, we expect to add these costs to the scenario. The inlet and outlet structures would be a major expense as they have to convey stormwater across Royal Windsor Drive, requiring tunnelling below the roadway or reconstructing a portion of it. For this reason, it is extremely unlikely that the City of Mississauga would consider placing ponds in the locations suggested in **Figure 59** for managing drainage from private properties.

However, we believe that the costing for this scenario presents an accurate benchmark for comparison with the max credit scenario, in part because it excludes inlet and outlet structures.

The purpose of the public property scenario is to have a comparison for the max credit scenario. If adding costing for the inlet and outlet structures makes the public property scenario unfeasible from the start, it would no longer be a practical point from which to draw general conclusions.

8.4.4.2 Counting Opportunity Costs: Using Urban Land for Wet Stormwater Management Ponds

Land acquisition costs make up most of the capital and life-cycle costs for the end-of-pipe public property scenario (see **Table 31**). In some cases, a municipality already owns the land required to retrofit a legacy development with improved stormwater infrastructure. But this does not mean that we shouldn't account for land values when assessing the cost of building on this land. After all, the municipality could sell the land and create a revenue source via property taxes and development charges or use the land to provide other public services. Municipalities forego significant **opportunity costs** by using owned land for stormwater management.

Opportunity costs are the foregone economic or financial gains from selecting one alternative from a set of mutually exclusive options.

To illustrate this point, consider the amount of land required to build the public property scenario ponds as a ratio of the areas of land they would drain. Even with reduced buffer zones, which are necessary for maintenance access and to provide adequate safety measures, the stormwater ponds' footprint will amount to between five and nine per cent of their respective drainage areas (see **Table 32**).

Table 32: Facility area to drainage area for the public property scenario

Major system catchment	Pond	Drainage area (80% impervious) (ha)	Facility area (ha)	Facility area as a percentage of drainage area (%)	
				With a 10 m buffer zone	With a 5 m buffer zone
Western	Lakeside Creek	21.1	1.39	7	5
Central	Sheridan Creek	10.8	0.97	9	7

Abbreviations: ha, hectare; m, metre.

Retrofitting highly impervious legacy developments with wet stormwater ponds that provide an enhanced level of water quality treatment, erosion control, and volume control means dedicating between 5 and 10 per cent of any heavily impervious urban drainage area for stormwater management.

Given standard wet pond design criteria, similar conclusions apply to legacy developments across Ontario. In urban centres across Canada, where land values are at a premium and municipalities are increasingly focused on promoting infill development, the foregone opportunity costs associated with this approach are enormous.

8.4.5 Comparing the Cost-Effectiveness of the Max Credit and Public Property Scenarios

Accurately evaluating the cost-effectiveness of the max credit and public property scenarios requires refining the costs given in sections **8.4.3.1** and **8.4.4.1** for unit-based comparison. Since the drainage areas between the max credit and public property scenarios differ in size, the best way to do this is through a per-hectare cost breakdown. **Table 33** shows that the life-cycle costs for the max credit scenario are 45 per cent less than the life-cycle costs for the public property scenario, per hectare.

Table 33: Per-hectare cost comparison between the max credit and public property scenarios

Design scenario	Drainage area (ha)	Capital costs* ($)		50-year O&M costs† ($)		Life-cycle costs ($)	
		Total	Per ha	Total	Per ha	Total	Per ha
Max credit	17.2	3,168,600	184,100	417,000	24,200	3,585,600	208,300
Public property	31.9	10,399,700	326,000	1,625,700	51,000	12,025,400	377,000

Abbreviations: ha, hectare; O&M, operations and maintenance.
* Construction, engineering, administration, harmonized sales tax (HST), and land acquisition.
† 50-year evaluation period, three per cent inflation rate, and five per cent discount rate.

The max credit scenario delivers better stormwater management outcomes at a lower cost than the public property scenario:

- Because the max credit scenario uses storage chambers on landowners' properties, flows that would cause nuisance ponding or flood these landowners' buildings are controlled (i.e. they mitigate urban flood risk). The public property scenario would not provide this benefit.
- While the public property scenario meets the requirements of the Ministry of the Environment, Conservation and Parks for enhanced water quality control, the max credit scenario would remove greater amounts of total suspended solids and total phosphorus.
- Because stormwater ponds do not infiltrate, they do not reduce, by an appreciable amount, the total amount of runoff generated. The max credit scenario does more to restore the natural water balance by lessening the total volume of runoff.
- Further opportunities to reduce infiltration and inflow and include communal rainwater harvesting can be more easily addressed by augmenting the max credit scenario than augmenting the public property scenario.
- The max credit scenario allows for cost-sharing opportunities that the public property scenario does not.

Table 34 summarizes the effectiveness of the max credit and the public property scenarios in terms of stormwater management outcomes.

Table 34: Comparison of per-hectare effectiveness of the max credit and public property scenarios in meeting stormwater management criteria.

Stormwater criteria	Max credit scenario	Public property scenario
Mitigates **riverine flood risk***†	Yes	Yes
Mitigates **urban flood risk**†	Yes	No
Improves water quality: removes 80 per cent of total suspended solids	Yes	Yes
Improves water quality: thermal mitigation	Yes	No
Erosion control	Yes	Yes
Improves water balance / reduces runoff volume	Yes	No

* In smaller urban watersheds, distributed GSI, if widely applied and designed to capture major system flows, can mitigate riverine flooding.
† See glossary for definitions of these terms.

8.5 Employing the Strategy

An incentive program for GSI retrofits on private IC&I properties would have to address two issues:

- how much of a financial incentive would have to be offered to landowners to shorten payback periods to reasonable levels; and
- how municipalities can ensure access, maintenance, and protection of GSI facilities constructed under an incentive program throughout their life cycle.

8.5.1 Payback Period Analysis: What Would Adequate Financial Incentives Look Like?

Long payback periods pose a significant financial barrier to non-residential property owners looking to capitalize on stormwater credit programs (CVC, 2016; CVC, 2018; City of Waterloo, 2019). Stormwater credit programs in other jurisdictions have not generated wide-scale uptake for this reason. However, the stormwater credit program in Mississauga was not intended to generate wide-scale uptake. Instead, the program provides financial compensation to property developers for meeting the city's development requirements and to landowners who are willing to dedicate their time and resources to stormwater initiatives.

The goal here is to examine what an incentive program would have to offer to motivate wide-scale uptake by private property owners.

Establishing the payback period for study area landowners for the max credit scenario requires three main steps:

1. Determine the capital investment required from each landowner to implement the communal design.

2. Determine how much each landowner would receive annually in stormwater credits.
3. Divide the capital costs by the annual credit received.

Because the designs are communal, with multiple properties using common GSI facilities, we needed to develop a cost-sharing approach that allocated costs to individual landowners based on their respective contribution to the facilities to determine the capital investment required from each landowner (Step 1).

Engineers working under Ontario's *Drainage Act* have developed a consistent and fair methodology for cost sharing between rural landowners. We adapted and expanded on this methodology for communal GSI retrofits in an urban area.

8.5.2 Cost-Sharing by Landowners: Payback Period

Works constructed under Ontario's *Drainage Act* are, in effect, user-pay infrastructure (see **Section 4.4.2**). While municipalities provide initial financing for both capital and maintenance costs, they recover these costs by charging each affected property a portion of the project cost. The portion of the cost is based on how much each property benefits from the work. The municipality calculates each share using a set of tables (called assessment schedules) developed by the project engineer.

The *Drainage Act* (sections 21 to 28) specifies how drainage engineers must apportion costs to affected landowners. Drainage engineers have developed a robust methodology to meet these cost-sharing requirements in a way that is fair to all landowners (Ontario Ministry of Agriculture, Food and Rural Affairs, 2018, pg. 81). The methods themselves and principles behind them are relatively straightforward. However, adapting the *Drainage Act* methodology quickly becomes complicated when applied to a drainage scheme in an urban area with multiple branch drains, multiple properties within each branch, varying land covers, possible storm connections to the sanitary sewer, divergent major and minor systems, and separate structures for conveyance, water quality, and flood storage.

As **Figure 60** shows, most properties contribute runoff to more than one branch, and four out of five branches have split drainage, where minor system flows one way and the major system flows spill another way. For the sake of simplicity, here we briefly discuss the three main principles of the methodology and give the results of our application of the process below.

The principles are:

1. Proportionate cost sharing: landowners whose properties use the drainage works should pay toward it based on the amount of runoff generated by their properties, the distance this runoff needs to travel, and the facilities their respective properties use to convey, attenuate, store, and treat this runoff.
2. Cost sharing based on benefit: stakeholders, including landowners whose properties increase in value or are more easily maintained, should pay for the drainage works based on the estimated monetary value of the benefit received.

3. Fair cost sharing: both types of cost sharing must be fair.

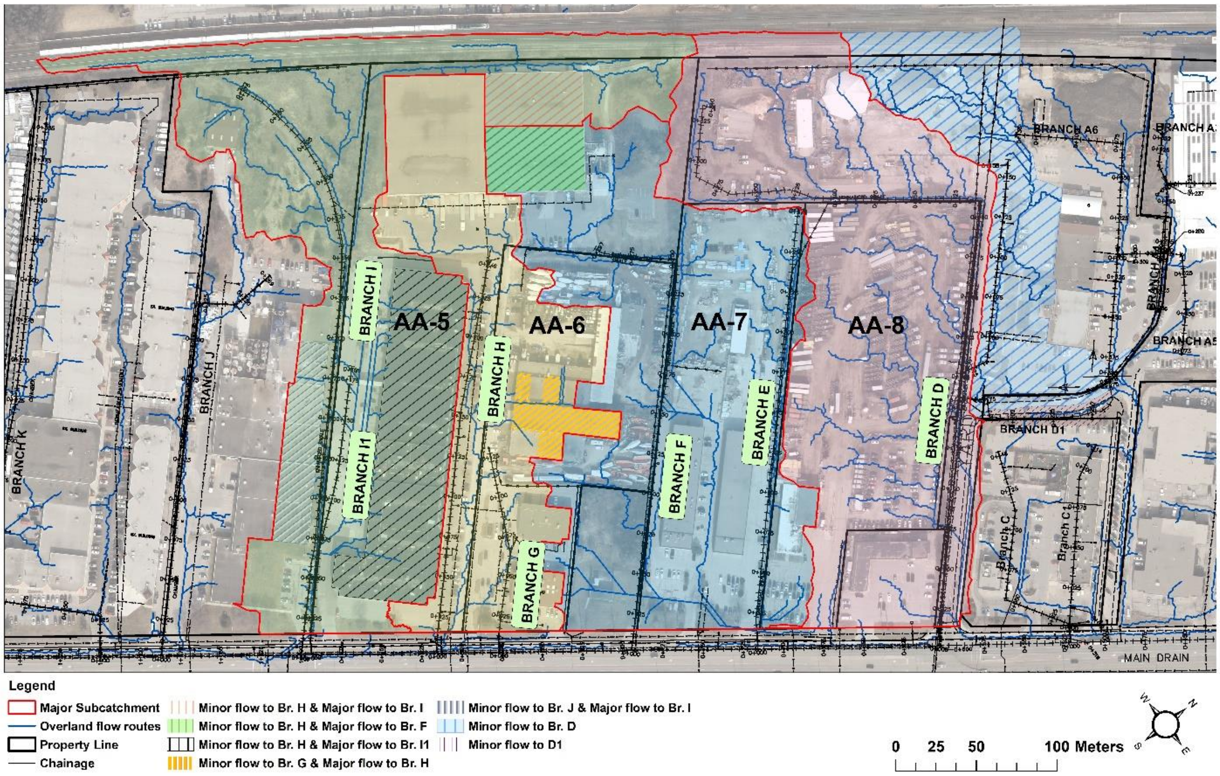


Figure 60: Branch drains D to I, with property boundaries and split drainage.

The project engineer uses the first and second principles to divide total project costs and apportion landowner contributions. For example, half of project capital costs could be determined by the amount of runoff generated by each property and the other half by the estimated benefit to each property. To establish payback periods for landowners, we assumed that the landowners are the only financial contributors and that total project capital costs are divided according to the proportionate cost-sharing principle.

To calculate the stormwater credit amount that each landowner would receive, we used Mississauga's billing rate, which in 2020 was set at $108.20 for every 267 square metres of impervious surface. We then divided by 267 the total impervious area that the max credit design treated for each property and multiplied the result by the billing rate. Dividing this result by half gave us the amount that each landowner would expect to receive in stormwater credits from the works proposed by the max credit design. **Table 35** shows the results from applying these calculations.

Table 35: Payback period analysis for properties using branches D to I

Property	Branch drains used	Capital cost per property*† ($)	Annual credit† ($)	Payback period in years
P-5	I	162,900	886	184
P-6	D, F, and G/H	837,800	10,242	82
P-7	F and G/H	414,400	3,583	116
P-8	F	54,000	140	385
P-9	D	433,300	5,160	84
P-10	D, E, and F	500,800	3,362	149
P-11	D and E	572,400	4,457	128
P-12	D	1,300	0	–
P-13	D	8,700	147	58
P-14	D and I	183,200	407	450
Total/average		**3,168,800**	**28,400**	**112**

* Construction, engineering, administration, and harmonized sales tax (HST).
† Columns may not add up due to rounding.

For context, market research conducted by CVC found that landowners typically expect a payback period of two to three years for capital investments such as stormwater management improvements or energy conservation measures (CVC, 2016, pg. 16). The City of Waterloo's research for its stormwater master plan states that five years is the standard expectation and 20 years is the maximum (City of Waterloo, 2019, pg. 13). Clearly, the 112-year average payback period shown in **Table 35** does not meet these requirements.

8.5.3 Sharing Costs Between Landowners and the Public Sector

Next, we examined how much a one-time grant would have to be to lower payback periods for capital costs to a reasonable level. To do this, we simply assigned percentages of the total capital costs as grants and re-calculated the payback period using the same methods described in **Section 8.5.2**. The grant amounts evaluated were 85 per cent, 90 per cent, and 95 per cent (see **Table 36**). The stormwater credit received by each landowner would be the same as in **Table 35**.

Table 36: Required capital grants to meet landowner payback period requirements

Total capital costs*: $3,168,600			
Grant percentage (%)	85	90	95
Total grant amount ($)	2,693,300	2,851,800	3,010,200
Per-hectare grant amount ($)	145,600	154,200	162,700
Property	**Payback period (years)**		
P-5	28	18	9
P-6	12	8	4
P-7	17	12	6
P-8	58	38	19
P-9	13	8	4
P-10	22	15	7
P-11	19	13	6
P-12	–	–	–
P-13	9	6	3
P-14	68	45	23

* Construction, engineering, administration, harmonized sales tax (HST), and allowances.

As **Table 36** shows, a 95 per cent grant would bring payback periods below 20 years for all except one landowner, and a 90 per cent grant would bring payback periods below 20 years for all except two landowners. An 85 per cent grant would do the same for all but four landowners.

Recall that the public property scenario would cost $377,000 per hectare in life-cycle costs. For capital costs only, it would cost $326,000 per hectare. Assuming a 90 per cent grant to landowners for the max credit scenario, the capital cost to the granting agency would only be $154,200 per hectare—less than half the capital cost of the public property scenario.

8.5.4 Securing the Investment: Agreements with Landowners

Historically, municipalities have provided stormwater services on public property, where they have direct control over these assets and do not need to rely on the private sector (or other public agencies) to keep these facilities operating as designed. Existing credit programs show how to foster compliance from private landowners or to allow municipalities to perform maintenance.

For all credit programs we surveyed, landowners take on the legal responsibility for ongoing maintenance of the facilities through bylaws, easements, or contracts.

Mississauga requires stormwater credit recipients to keep their facilities in good repair. The city also reserves the right to enter properties for inspections. If the city finds that a facility does not function as described in the stormwater credit application or if access for inspection is denied, the credit holder must pay back the total amount of credit received since the application was approved (City of Mississauga, Stormwater Fees and Charges, By-law 0135-2015). Credit holders must renew their applications every five years. The renewal application must include inspection and maintenance logs and planned changes to maintenance procedures.

Philadelphia's GARP has similar measures, but it also makes sure that recipients of capital grants and ongoing stormwater credit reductions maintain their facilities through their full life cycle rather than using a periodic renewal system. Upon receiving GARP grants, landowners must record an easement or deed restriction on their property such that the O&M proposal that is part of the application is registered against the property. If the property changes hands, the new property owner is bound by the same arrangement. The term of this easement must apply to the property for the useful life of the infrastructure or for 45 years, whichever is greater. GARP recipients who do not meet the terms of their maintenance commitments must pay back the total grant amount (Philadelphia Water Department, 2018).

Legal issues aside, a well-crafted incentive program would provide adequate financial motivation to landowners to keep their facilities in good working order. With capital costs covered by a one-time grant and ongoing stormwater credit reductions on offer, so long as the credit reduction amount exceeds the cost to maintain the facilities in question, it is in the landowner's financial interest to do so.

8.5.5 Securing the Investment in Ontario: Easements and Legal Protection Under the Drainage Act

The *Drainage Act* is an extremely useful tool to help Ontario municipalities retrofit private property IC&I properties in legacy developments. To understand why, consider how the *Drainage Act* operates:[14] in common law, surface waters have no right of drainage (Cameron, 1978). If an upstream parcel of land does not front onto a natural watercourse and a downstream landowner refuses to accept that parcel's runoff by building a berm, the upstream landowner has no legal recourse. The *Drainage Act* allows landowners without access to a natural watercourse for drainage to access one through other properties. They do so by

[14] For more information on the benefits of using the *Drainage Act* for urban GSI, see *A Guide for Engineers Working Under the Drainage Act in Ontario* (OMAFRA, 2018, publication 852), CVC's white paper *Making Green Infrastructure Mainstream* (CVC, 2017), and CVC's *The Drainage Act Approach to Urban Retrofits* (CVC, forthcoming).

petitioning the local municipality for improved drainage. This allows landowners, public or private, to cooperate for mutually beneficial drainage on their respective properties.

In brief:

1. Landowners (public or private) petition their municipality for improved drainage.
2. The municipality appoints a drainage engineer to investigate the petition.
3. If the engineer determines that the petition is valid, the engineer designs the necessary drainage works and creates tables (assessment schedules) for cost sharing to include in a drainage report.
4. After several readings and opportunities for landowners to appeal their cost assessments, the drainage report is passed as a bylaw.

The result of this process is communal drainage on private property, managed by the municipality. Landowners (public and private) who use the drain and benefit from it share the financial burden for both capital and O&M costs. Benefits for municipalities from using the *Drainage Act* include:

- a robust cost-sharing framework;
- community-driven, user-pay infrastructure;
- bylaw protection for works built under the act;
- legal access to private property for maintenance; and
- 50 per cent of the drainage superintendent's wages paid by the Ministry of Agriculture, Food and Rural Affairs.

Once built, these municipal drains have legal protection, and changes in property ownership do not affect the legal status of the drainage works.

8.5.6 Accounting for Land Value: Allowances Under the Drainage Act

Gaining this legal protection comes at an additional cost. Municipalities can gain an easement over private lands to build and maintain the drainage works. Because landowners cannot interfere with these works once they are built, they must be compensated for the value of the land used for the drainage works (*Drainage Act*, sections 29 to 33; O'Brien, 2010). Called "allowances," these payments for land used for drainage works, for future maintenance access, and for damages incurred during construction, are counted as an additional capital cost and shared among the landowners who use the drainage according to the cost-sharing principles discussed (see **Section 8.5.2**).

In consultation with drainage engineers with extensive experience working under the *Drainage Act*, we calculated the allowances required to build the GSI facilities described in the max credit scenario and added them as a capital cost. The allowances are an extra $1,580,800, and the per-hectare capital cost, with allowances added, is $274,200. For comparison, the capital cost per hectare for the public property scenario, including estimated land costs, is $326,000.

Table 37 recalculates the grants needed to bring payback periods to reasonable levels when allowances are included. When including cost sharing, the cost to the granting agency is between $206,400 and $230,700 per hectare.

Table 37: Required capital grants to meet landowner payback period requirements, with allowances included as a capital cost

Total capital costs*: $4,719,800			
Grant percentage (%)	85	90	95
Total grant amount ($)	4,011,800	4,247,800	4,483,800
Per hectare grant amount ($)	233,100	246,800	260,500
Property	**Payback period (years)**		
P-5	53	35	18
P-6	19	13	6
P-7	22	15	7
P-8	67	44	22
P-9	22	15	7
P-10	29	19	10
P-11	23	15	8
P-12	–	–	–
P-13	17	11	6
P-14	160	107	53

* Construction, engineering, administration, harmonized sales tax (HST), and allowances.

While paying allowances to landowners increases the capital costs for the works, they provide municipalities with an easement that does not require registration on the property's title and does not have an expiry date. This means that the municipality has the legal right (and corresponding obligation) to maintain any GSI facilities built on private property under the *Drainage Act*.

8.6 Conclusion

The comparison between GSI on private property and wet stormwater ponds on public property shows that GSI retrofits on private property are a cost-effective stormwater management solution. Water management modelling of the max credit scenario using PCSWMM software demonstrates that the design is technically feasible. For financial feasibility, the max credit design would cost significantly less than the public property design.

The project is ongoing. We are currently working on another design for the study area, called the one-water design scenario. The one-water scenario builds on the max credit scenario. The primary goal of the one-water scenario is to capture, infiltrate, or evaporate more of the total average annual rainfall than is captured by the max credit scenario, in order to further improve the area’s water balance. It will also add rainwater harvesting and disconnect direct connection to the sanitary sewer. This will be done through planting trees in open spaces, renaturalizing existing forested areas, converting the enhanced grass swales to linear bioretention, incorporating water conservation measures, and increasing the infiltration capabilities of the chamber systems.

After completing the one-water scenario, the next step will be to confirm the cost and performance estimates given in **Section 8.4** through a proof-of-concept implementation study for one of the two private property design scenarios.

The study area itself is representative of IC&I neighbourhoods in legacy developments across the country: high impervious land cover with no onsite water quality or quantity treatment. Our estimates give a reasonably accurate picture of the cost to retrofit similar IC&I neighbourhoods across the country.

Traditionally, municipalities provide stormwater services on public property. There they have direct control over these assets and do not need to rely on the private sector operating the stormwater facilities as designed. However, the cost-effectiveness of GSI retrofits on private property means that municipalities should investigate public–private partnerships as a feasible alternative for reducing CSOs and for improving stormwater management outcomes in legacy developments.

9.0 GLOSSARY

Bioretention: a **GSI** practice that uses soil and vegetation to capture, filter, **infiltrate**, and **evapotranspire** stormwater. Bioretention practices vary in complexity based on soil types, design objectives, and available resources, from simple landscaped depressions to complex systems with impermeable liners, gravel storage layers, special soil mixtures, and underdrains.

Business case: a financial, economic, or scientific justification for public investment in a project to realize "specific outcomes in support of a public policy objective" (Government of Canada, 2020).

Catchment: in **hydrology**, a catchment is an area of land that drains rainfall to a single point. Water leaves the catchment from this point. If an area of land drains to a single pipe or outlet, it can be defined as a catchment. **Subcatchments** are themselves catchments within other, larger catchments. Researchers apply these terms iteratively depending on the scale at which they are working. In urban areas, catchments and subcatchments are typically defined by the municipal storm sewer system. At the smallest scale, even small surface depressions—puddles, essentially—can be defined as subcatchments.

Chicago design storm or **Chicago method**: these modelling methods can be used in various regions. They use historical rainfall information to estimate rainfall intensity over time. An example of a Chicago design storm for the City of Mississauga is the three-hour storm, where about 74 millimetres of rain falls over a three-hour time period.

Co-benefits: positive effects of **GSI** that are not directly related to traditional stormwater management goals. Co-benefits include air pollution removal, **urban heat island** reduction, habitat creation, energy savings, and greenhouse gas reduction.

Combined sewer overflow (CSO): when **combined sewer systems** overflow or when wastewater treatment plants bypass incoming flows, untreated sewage is released into receiving water bodies.

Combined sewer system: a sewer system that collects and conveys both stormwater and wastewater.

Continuous simulations: these simulations model long-term observed rainfall data to determine how water and contaminants behave in a given area over an extended time period. These models are typically used for assessing water quality and **water balance**.

Detention: the temporary storage of stormwater to control discharge rates and to allow for sedimentation. Detained stormwater is slowly released as **runoff** or streamflow. The facilities that detain stormwater do not help re-establish a natural **water balance**. See **hydrologic cycle** and **water balance**.

Discount rate: the interest rate used to determine the present value of future cash flows.

Dry pond: an open area that can be used to detain stormwater during intense storm events. Dry ponds can have dual purposes; for example, they can be outdoor facilities such as soccer fields, baseball diamonds, public parks, urban forests, and outdoor cultural spaces.

Enhanced grass swales: Also referred to as enhanced vegetated swales, enhanced grass swales are open channels that are covered with plants and are designed to convey, treat, and attenuate stormwater **runoff**.

Evapotranspiration: the combined loss of water to the atmosphere from land and water surfaces by evaporation and from plants by transpiration.

Event simulations: these simulations model a given area's response to a single rainfall event (e.g. a 25 mm storm over four hours). Sometimes, event simulations are used to determine how a system responds to a design storm. A design storm is a significant rainfall event within a specified duration that engineers use to design or assess a stormwater management system. Event simulations are usually used to determine peak flows and flood risk.

Exfiltration system: a **GSI** practice in which surface **runoff** is collected by drainage inlets and delivered to a perforated pipe, usually surrounded by gravel, from where it **infiltrates** into the native soil.

Green infrastructure: "the natural vegetative systems and green technologies that collectively provide society with a multitude of economic, environmental and social benefits" (Green Infrastructure Ontario, 2020a).

Green rainwater infrastructure (GRI): a suite of rainwater management tools that use both engineered and nature-based solutions to protect, restore, and mimic the natural **water cycle**. This is the term the City of Vancouver uses for **GSI**.

Green roof: a thin layer of vegetation and growing medium installed on top of a conventional flat or sloped roof for capturing and treating stormwater. Also referred to as living roofs or rooftop gardens.

Green stormwater infrastructure (GSI): also known as low impact development (LID), green stormwater infrastructure is a stormwater management strategy that seeks to mitigate the impacts of increased **runoff** and stormwater pollution. GSI practices manage runoff as close as possible to the source in order to preserve or restore pre-development **hydrologic** and ecological functions. To preserve pre-development functions, GSI uses design to minimize runoff and to protect natural drainage patterns. To restore pre-development functions, GSI uses distributed structural practices that filter, **detain**, **retain**, **infiltrate**, **evapotranspire**, and **harvest stormwater**. GSI practices can effectively remove sediment, nutrients, pathogens, and metals from runoff, and they reduce the volume and intensity of stormwater flows.

Grey stormwater infrastructure: Grey stormwater infrastructure uses centralized facilities—typically stormwater ponds as well as curbs, catchbasins, and pipes—and does little to re-establish the natural **hydrologic cycle**. In **legacy developments**, grey stormwater systems typically discharge collected stormwater directly into waterways, without quality treatment or quantity control.

Hydraulics: the study of the flow of water through pipes and channels, such as rivers.

Hydrology: the study of water on the earth's surface, flowing either above ground or beneath it.

Hydrologic cycle: the circulation of water from the atmosphere to the earth and back, through precipitation, **runoff**, **infiltration**, groundwater flow and **evapotranspiration**. See **water balance**.

Infiltration: the passing (or penetration) of water through the ground surface.

Infiltration chambers: underground storage chambers that are designed to capture large volumes of stormwater. They reduce flood risk and allow precipitation, such as rainwater and snowmelt, to get under and **infiltrate** below hard surfaces, such as parking lots.

Inflow and infiltration: inflow and infiltration occur when stormwater enters the sanitary sewer system, either through maintenance access holes (inflow) or through cracked pipes underground (infiltration).

Legacy developments: urban areas that were built before quantity or quality controls became requirements for new development in Canada. Typically, legacy developments only have infrastructure to convey stormwater from built-up areas to receiving water bodies.

Major system, minor system: in urban areas, the **minor system** manages flows from frequent storm events using conveyance systems such as pipes and swales. Larger flood events surcharge the **minor system**, causing water to follow an overland flow route, which is called the **major system**. The boundaries for the major and minor system **catchments** can be the same or different.

Nutrient pollution: nutrient pollution occurs when too many nutrients, mainly nitrogen and phosphorus, are added to water bodies, causing excessive growth of algae. These blooms consume the excess nutrients and die quickly. Their decomposition causes low levels of dissolved oxygen in the water, which can kill aquatic animals.

Oil and grit separator: a type of stormwater management technology that treats stormwater primarily by using gravity to remove settleable particles and phase separation to remove buoyant materials (free oils and grease) from water.

One water: A "one water" approach looks at the full water cycle in all its forms: drinking water, wastewater, rainwater, surface water, and groundwater (City of Vancouver, 2019).

Opportunity costs: the foregone economic or financial gains from selecting one alternative from a set of mutually exclusive options.

Peak flow control: reduction of the maximum flow of **runoff** from a drainage area during a storm using stormwater management technologies (e.g. wet stormwater ponds, **GSI**).

Permeable pavements: a type of **GSI** practice that allows precipitation to **infiltrate** through surface pores (permeable asphalt and concrete) or through joints between pavers.

Ponding: unwanted collection of stormwater in surface depressions or roofs.

Pre-development conditions: the natural **hydrologic** conditions of the land before any human settlement or development takes place. Effective stormwater management requires that post-development **peak flows** match pre-development ones. When modelling pre-development conditions in the City of Mississauga, soil **infiltration** parameters and per cent imperviousness are set to achieve a volumetric **runoff** coefficient of 0.25 for the 1:100-year storm.

Rainwater harvesting: the use of captured rainwater for non-potable uses to offset potable water use.

Retention: the capture of stormwater for filtration, **infiltration**, and **evapotranspiration**. Retained stormwater does not become **runoff** or streamflow (unlike detained stormwater; see **detention**). Retaining of stormwater helps to restore a natural **water balance**.

Riverine flooding: also known as “fluvial flooding,” riverine flooding occurs when a river overflows its banks, causing water to flow across its flood plain.

Runoff: rainwater that flows over hard surfaces such as roofs and roads as runoff instead of **infiltrating** into the ground. Urban runoff carries heavy metals, nutrients, bacteria, and other pollutants into local streams, adversely affecting human, animal, and plant life.

Runoff volume control target (RVCT): a requirement that stormwater systems capture and retain the first portion of precipitation (rain) from a rainfall event. Retaining this pre-determined portion keeps it from entering the piped storm sewer network as **runoff**.

Sanitary sewer surcharging: sanitary sewer surcharging occurs when wastewater systems reach capacity or are obstructed, causing sewage to back up along the sewer line. This can result in sewage overflowing into buildings.

Separate sewer system: areas with a sewer system for wastewater and a separate sewer system for stormwater.

Stormwater charge: an annual fee charged to landowners by municipalities for stormwater services. Stormwater charges are separate from general property taxes and provide a dedicated revenue source for maintaining, operating, and revitalizing stormwater infrastructure.

Subbasin: an urban area that drains stormwater to a single trunk sewer or outlet. See also **catchment**.

Subcatchment: see **catchment**.

Surface flooding: surface flooding occurs when water reaches an opening (e.g. a basement window) in a building or inundates vehicles, destroys landscaping, etc.

Total suspended solids: the amount of particulate matter suspended in a water sample (Government of Canada, 2021).

Urban flooding: also known as "pluvial flooding," urban flooding includes **surface flooding** and **sanitary sewer surcharging**. Urban flooding results from intense or prolonged rainfall in urban areas, overwhelming the capacity of the stormwater management system and causing flooding in low-lying areas. This can cause damage in many ways, chiefly through sanitary sewer backups (from **inflow and infiltration**) and from stormwater directly entering buildings.

Urban heat island effect: because urban areas are covered with surfaces that retain heat—concrete, brick, and asphalt—their temperatures are higher than surrounding rural or natural areas. Also, because they have little vegetation, they do not benefit from the cooling effects of **evapotranspiration**.

Water balance: the accounting of inflow (precipitation) and outflow of water in a system according to the components of the **hydrologic cycle** (precipitation, **runoff**, **infiltration**, groundwater flow, and **evapotranspiration**). Precipitation over natural areas generates low amounts of runoff and high amounts of infiltration, while precipitation over highly impervious areas (e.g. urban areas) generates high amounts of runoff and low amounts of infiltration.

Water cycle: the continuous movement of water from the oceans to the atmosphere (by evaporation), from the atmosphere to the land (by condensation and precipitation), and from the land back to the sea (via groundwater and streamflow); also known as the **hydrologic cycle**.

10.0 ABBREVIATIONS

CSO	combined sewer overflow
CVC	Credit Valley Conservation
CWFM	City-Wide Flood Mitigation
DCL	development cost levy
GARP	Greened Acre Retrofit Program
GRI	green rainwater infrastructure
GSI	green stormwater infrastructure
GTA	Greater Toronto Area
IC&I	industrial, commercial, and institutional
ISWM-MP	Integrated Stormwater Management Master Plan
LCCT	life cycle costing tool
LID	low impact development
LSRCA	Lake Simcoe Region Conservation Authority
OGS	oil and grit separator
O&M	operations and maintenance
RVCT	runoff volume control target
SIRP	Stormwater Integrated Resource Plan
STEP	Sustainable Technologies Evaluation Program
SWM	stormwater management
TRCA	Toronto and Region Conservation Authority
TSS	total suspended solids
uDCL	utility development cost levy

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