GREEN STORMWATER INFRASTRUCTURE ON CITY STREETS

GREENEST CITY SCHOLARS PROGRAM

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AUGUST, 2016

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This report was produced as part of the Greenest City Scholars (GCS) Program, a partnership between the City of Vancouver and The University of British Columbia, in support of the Greenest City Action Plan.

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Image from greeninfrastructureontario.org

EXECUTIVE SUMMARY

With fast urbanization and population growth, there is an increasing percentage of impervious surfaces in cities, which have significantly altered natural hydrological processes. A growing amount of rainwater enters storm sewer pipes or combined sewer pipes, instead of infiltrating into the ground. Currently, many municipalities in North America are working on more innovative approaches for rainwater management, and Green Stormwater Infrastructure (GSI) is an emerging approach to address rainwater quantity and quality challenges. As much of urban street areas are covered by impervious surfaces, they present significant opportunities to reducing rainwater runoff and improving urban environment by utilizing GSI for rainwater management.

GSI on city streets can bring about a myriad of benefits to a city. This sustainable approach of rainwater management not only benefits urban environments, but also creates social and economic benefits as well. However, GSI is a relatively new technology and is currently in its development stage in many municipalities. Common barriers for implementing GSI include uncertainties about GSI performance and costs, lack of experience in GSI maintenance, requirements for site-specific design, etc.

The City of Vancouver is a highly urbanized area with a large amount of impervious surfaces. Arterial streets, local streets and laneways account for about 30% of total land use area, and they represent significant opportunities for utilizing GSI to reduce rainwater runoff and improve water quality. The city has completed the Citywide *Integrated Rainwater Management Plan* (IRMP), with a long-term Green Infrastructure Strategy to capture and treat Vancouver's rainfall.

Currently the City of Vancouver is in the development stage of a GSI program with several pilot projects completed. There are currently about 190 GSI installations on city streets,

including a wide range of GSI types. The biggest challenge related to GSI in Vancouver is the lack of dedicated funding for its construction and maintenance. There are also challenges regarding limited capacity for maintenance and limited tools to encourage future projects.

This research project investigates GSI on city streets in terms of its benefits and challenges, best practices, and lifecycle costs through a municipality survey, literature review, case studies, field studies, and personal interviews. The report summarizes the results of a North American peer municipality survey on GSI conducted by the City of Vancouver in June and July of 2016. The survey targeted American and Canadian municipalities with GSI or integrated rainwater/stormwater management programs, and was intended to collect lessons learned, best practices, and other technical information.

KEY FINDINGS FROM THE SURVEY

- GSI is a relatively new initiative, and many municipalities are in the early development stage of their GSI programs. American municipalities generally have more advanced GSI programs than Canadian municipalities.
- The most commonly used GSI tools are rain gardens & infiltration bulges, pervious paving, and infiltration trenches. Different GSI treatments implemented by municipalities vary significantly in terms of performance and challenges, and there are trade-offs for each treatment that need to be balanced.
- One common challenge shared by most surveyed municipalities for implementing GSI is the substantial capital and O&M costs associated with them. The limited available funding for GSI significantly restricts the opportunity for creating future projects and ensuring the performance/longevity of existing projects. Budgets for GSI are primarily allocated for its design and construction, while policy and planning, and operation and

> *"LIDs are becoming part of normal design. They are considered required items to address impacts of development."*
>
> CARRIE BARON
> FROM THE CITY OF SURREY

maintenance receive very limited amounts.

- Almost all surveyed municipalities plan to increase the budget, or at least keep the current budget for GSI projects in the next three years. Regarding funding sources for GSI, American municipalities commonly use stormwater utility charges and funding from other levels of government to fund their GSI projects. For Canadian municipalities, the primary funding sources are property tax and funding from private developers or through development.
- Another common challenge shared by most surveyed municipalities is insufficient maintenance for GSI assets, primarily due to limited funding for O&M. More than 40% of GSI assets in surveyed municipalities are inspected/maintained only on a complaint basis or receive almost no inspection/ maintenance. Only 34% of surveyed municipalities have a standard maintenance procedure/program.
- Many municipalities have identified the importance of multi-departmental collaboration on GSI projects, and suggested that all departments that are affected by GSI treatments should be involved in the early project planning/design stage. These may include multiple departments such as Engineering/Public Works, Planning, Environmental Services, Parks, etc.
- Over 90% of surveyed municipalities have some public engagement activities on GSI in a variety of formats, such as public meetings and workshops, info-sharing through websites, GSI guided tours, tree planting programs, etc. Many municipalities partner with local volunteering groups or engage with local property owners for GSI O&M.

In North America, many completed GSI and relevant research projects have demonstrated that utilizing GSI for rainwater management could be cost-effective if the project is well designed, facilitated and implemented. Lifecycle costs are estimated for rain gardens, bio-swales and permeable pavements based on cost and maintenance information collected from various GSI projects, as well as the WERF (Water Environment Research Foundation) tool.

RECOMMENDATIONS FOR IMPLEMENTING GSI IN THE CITY OF VANCOUVER

Based on findings from the peer municipality survey, literature review, case studies, and lifecycle cost estimation, the following recommendations are proposed for implementing GSI in the City of Vancouver:

- Create a citywide GSI plan/strategy to identify GSI opportunities, short-term and long-term actions, and processes to phase in GSI projects across the city;
- Incorporate GSI into other programs, policies and projects, such as future neighbourhood plans and ongoing development projects;
- Allocate dedicated funding for GSI projects on city streets both for construction and maintenance;

- Launch quick start projects for demonstration with monitoring programs;
- Develop a GSI maintenance program to ensure GSI long-term performance and longevity;
- Support increased collaboration between the city, communities and other organizations.

RECOMMENDATIONS FOR IMPLEMENTING GSI IN THE EAST FRASER LANDS

The East Fraser Lands (EFL) project is currently the largest development project in Metro Vancouver. The site is located in the southeast of the City of Vancouver, and the project features a strong policy emphasis on integrated rainwater management. The 2008 EFL Rainwater Management Plan (RMP) set up a framework for implementing GSI across the EFL, and proposed a series of GSI elements, including bio-swales, rain gardens, infiltration galleries, etc. Planned GSI elements and implemented GSI elements are compared in this report, along with an evaluation of the design objectives proposed in the RMP. The following recommendations are proposed for updating the RMP:

- Establish rainwater management targets with quantifiable metrics;
- Update information and plan elements to reflect actual site conditions;
- Include aesthetic/social value of GSI as part of the design objectives;
- Include more comprehensive plan elements with a diverse selection of GSI treatments;
- Establish maintenance and monitoring programs;
- Allocate secured funding for the O&M of GSI assets;
- Incorporate lessons learned and plan updating mechanisms.

Site-specific recommendations are provided for the planning, design and maintenance of GSI projects in the EFL, and are categorized based on areas within different development phases.

- For areas that have completed construction:
  - Engage with the public through outreach activities and public art;
  - Engage with the public for GSI maintenance and monitoring.
- For Areas in the Planning/Design Stage:
  - Utilize diverse types of GSI treatments;
  - Consider GSI maintenance in the early planning/design stage;
  - Utilize flexible design strategies that match site context.
- For areas that have not yet been rezoned:
  - Update the 2008 RMP.

INTRODUCTION

With fast urbanization and population growth, there is increasing demand for buildings, streets and other urban infrastructure. The rapid changes in land use have significantly altered the natural hydrological processes in a watershed. With an increasing percentage of impervious surfaces in a city, there is a growing amount of rainwater entering grey infrastructure such as storm sewer pipes or combined sewer pipes, instead of infiltrating into the ground. This significantly increases the burden to wastewater treatment plants. Additionally, storm runoff may carry trash, animal droppings, heavy metals and other pollutants from an urbanized area, and will contaminate receiving waterbodies, especially during extreme rain events.

Many municipalities in North America, with varied population and geological locations, are currently working on implementing Green Stormwater Infrastructure (GSI). GSI is an emerging approach used to address rainwater quantity and quality challenges, and it also provides environmental, social and economic benefits. According to the US EPA,

> *Green Infrastructure uses vegetation, soils, and other elements and practices to restore some of the natural processes required to manage water and create healthier urban environments. At the city or county scale, green infrastructure is a patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the neighborhood or site scale, stormwater management systems that mimic nature soak up and store water.*
>
> **US EPA, 2015**

Site-level GSI is also referred to as Low Impact Development (LID) and includes bio-swales, rain gardens, permeable

pavements, etc. For the purpose of this report, GSI is used interchangeably with LID.

> *LID comprises a set of approaches and practices that are designed to reduce runoff of water and pollutants from the site at which they are generated. By means of infiltration, evapotranspiration, and reuse of rainwater, LID techniques manage water and water pollutants at the source and thereby prevent or reduce the impact of development on rivers, streams, lakes, coastal waters, and ground water.*
>
> US EPA, 2007

Urban streets account for a large amount of impervious surfaces in a city, and represent significant opportunities of utilizing GSI for managing rainwater. Unlike conventional piped drainage systems that aim to remove rainwater from streets as soon as possible, GSI slows down, reduces and treats rainwater at its source. It not only reduces rainwater runoff from streets/sidewalks and improves water quality, but also increases ecological and aesthetic value of urban environments, and creates educational and recreational opportunities. However, despite the growing interests in utilizing GSI for rainwater management on city streets, it is a relatively new approach, and research and experience on the planning, design, and maintenance of GSI is crucial.

In the City of Vancouver, arterial streets, local streets and lanes account for about 30% of total land use area. Much of these streets/lanes are covered by impervious surfaces, which present significant opportunities to reduce rainwater runoff and improve urban environment by utilizing GSI for rainwater management. Although a few pilot projects have been completed to test the feasibility of GSI for managing rainwater on streets, it is currently in the development stage in the City of Vancouver.

This report investigates the benefits and challenges, best practices, and lifecycle costs of various types of GSI treatments through a municipality survey, literature review, case studies, field studies, and personal interviews. The report summarizes the results of a North American peer municipality survey on GSI conducted by the City of Vancouver in June and July of 2016. Recommendations are provided for implementing GSI projects on streets in the City of Vancouver. Site-specific recommendations for implementing GSI treatments are provided for the ongoing East Fraser Lands (EFL) project, which is currently the largest development project in Metro Vancouver. The EFL is located in the southeast of the City of Vancouver, and the project features a strong policy emphasis on utilizing GSI for rainwater management.

BENEFITS OF GSI

GSI can bring about a myriad of benefits to a city. This sustainable approach of rainwater management not only benefits urban environments, but also creates social and economic benefits.

Environmental Benefits

- GSI absorbs and slows down rainwater runoff, and reduces the volume of rainwater flowing into stormwater pipe systems. This can help to reduce the amount of combined sewer overflow and the risk of flooding;
- GSI absorbs pollutants in rainwater and thereby improves rainwater quality;
- GSI helps to infiltrate rainwater into the ground and thereby improves local groundwater recharge;
- Plants and vegetation as part of GSI treatments create ecological habitats for aquatic species and other wildlife, and improve the aquatic environment.

Social Benefits

- GSI provides plants and other types of landscaping in an urban environment, increasing aesthetic value and creating recreational opportunities;
- GSI creates educational opportunities for residents to learn about plantings, watershed health, and rainwater systems.
- Operation and maintenance of GSI creates volunteering opportunities, low barrier employment opportunities, and potential partnership programs.

Economic Benefits

- By reducing stormwater volume entering storm drains, GSI helps to reduce the need for expanding new storm sewer pipes. Depending on the type of system, this can help to reduce the construction and maintenance costs of grey infrastructure.
- By creating recreational opportunities and increasing aesthetic and social value of open spaces, GSI can help to increase land and property value of a neighbourhood and benefit local businesses.

CHALLENGES OF GSI

Although GSI offers significant benefits to an urban environment, it is a relatively new technology and is in its development stage. While grey infrastructure is generally well understood and has standard design and maintenance practices, many aspects of green infrastructure are still unknown, and are being developed on a trial-and-error basis.

UNCERTAINTIES ABOUT GSI PERFORMANCE AND COSTS

Many municipalities are uncertain about whether GSI will work in a local context, and how much it will cost for construction and maintenance. Cost-effectiveness is a primary consideration and the uncertainties about GSI performance and lifecycle costs are significant barriers for many municipalities. Material costs for rocks, gravel and sand layers may make green infrastructure more expensive than grey infrastructure, and plants for green infrastructure may need additional maintenance, especially in their establishment period. Additionally, requirements for close collaboration among engineers, planners, and landscape architects may add to planning and project management costs. These factors could make green infrastructure expensive, especially in the pilot stage when a municipality lacks both experience and economy of scale.

LACK OF EXPERIENCE IN GSI MAINTENANCE

Although GSI is intended to mimic natural processes, these installations need regular inspections and maintenance to function properly. For example, new plants need additional maintenance in the first few years for them to establish; trash and leaves need to be removed to prevent clogging and flooding. These maintenance tasks require materials and labor, which add to the lifecycle costs of GSI. Municipalities are also faced with issues such as uncertain maintenance responsibilities and limited capacity for GSI maintenance.

REQUIREMENTS FOR SITE-SPECIFIC DESIGN

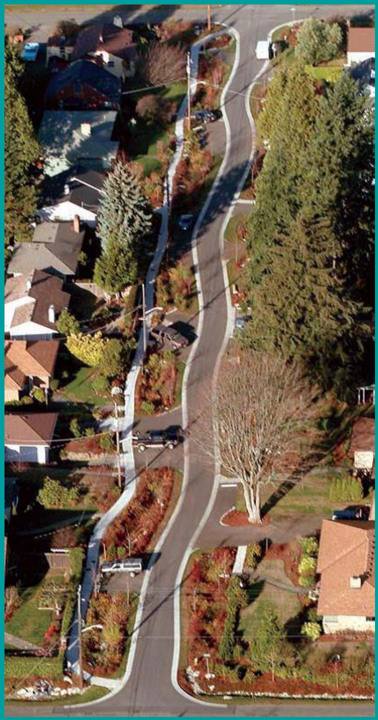
Many site-specific conditions may influence the design and construction of GSI, including topography, soil infiltration capability, vegetation types, and intended functions. Projects implemented in areas that are not suitable for GSI can result in inefficiencies or even flooding issues. This explains why GSI designs that work well in one location may not be applicable for another location, which adds more uncertainties about GSI performance. Additionally, GSI generally requires more available space on site, especially for city streets, which are traditionally paved by hard surfaces and restricted by intended functions such as traffic flow, pedestrian passage, etc.

The large knowledge gap of implementing GSI, along with the requirements for large space and flexible design techniques, has created significant challenges for implementing GSI in many municipalities. Some of these challenges may be significant barriers during the GSI development stage, and may be alleviated as technologies and experiences advance or develop.

GSI CASE STUDY

SEA STREETS, SEATTLE

SEA street - before



SEA street - after

The Street Edge Alternative (SEA) Street project was completed in the spring of 2001 in northwest Seattle (NW 117th and NW 120th Street on 2nd Avenue), which is a low-density residential area. It is one of the major pilot projects of Seattle Public Utility's Natural Drainage System strategy. The SEA Street project is designed to provide drainage that mimics natural landscaping, with vegetated swales and wetlands on both sides of the road serving to capture and infiltrate stormwater into the ground. The project successfully reduced the impervious surfaces of the street to 11% less than that of a traditional street. Granite boulders and washed river rocks of varied sizes were utilized to stabilize the swale and increase its aesthetic benefits. More than 100 evergreen trees and 1,100 shrubs were planted along the street (City of Seattle).

Image by Seattle Public Utilities

The drainage system of this project represents a combination of contoured infiltration swales and traditional drainage infrastructure (e.g. culverts, catch basins, flow control structures and slotted pipes). In order to maximize stormwater time of concentration and site detention volume, a long flow path was designed with high surface roughness. The project helps to reduce stormwater at its source, and according to a two-year monitoring program, SEA Street has reduced the total volume of stormwater leaving the street by 99% (City of Seattle). Stormwater quality is also improved, with plants and soils filtering out pollutants as stormwater moves through the swales.

With the narrower driving lane and meandering shape of the roadway, the design of SEA Street helps to slow down traffic, improve visual interest and create a pedestrian and cyclist-friendly environment. The street also helps to reduce the temperature in the area during the summer and improve air quality. It is very popular with local residents because of its natural and visually-appealing streetscape.

There were a few obstacles in the early years after the implementation of this project, such as skepticism among residents and from professionals, as well as debates about the benefits and challenges of a narrow roadway. Close collaboration among an interdepartmental project team has helped to change people's perceptions by engaging with local residents throughout the project.

SEA Street after completion in 2001
Image by Seattle Public Utilities

SEA Street in 2002
Image by Seattle Public Utilities

Image by NYV Water

PEER MUNICIPALITY SURVEY ON GSI

In order to learn about GSI implementation on city streets from the experience of other municipalities, and reduce the knowledge gap in the planning, design and maintenance of GSI assets, the City of Vancouver conducted a peer municipality survey on GSI on city streets/plazas in June and July of 2016. The survey targeted American and Canadian municipalities with GSI or integrated stormwater management programs, and was intended to collect lessons learned, best practices and other technical information. Most of the survey questions are about performance and challenges of GSI treatments, budgeting and personnel for GSI programs, and operation and maintenance practices. A survey questionnaire can be found in Appendix 1.

DATA COLLECTION METHODOLOGY

ASSEMBLING A LIST OF TARGET MUNICIPALITIES

The survey targeted North American municipalities that have been working on GSI or integrated rainwater/stormwater management programs. In order to identify municipalities with similar context to the City of Vancouver, several criteria were used to identify potential municipalities to be included in the survey.

1. Geographic Location

Both Canadian and American municipalities were included in the survey. It should be noted that although Canadian and American municipalities share similar planning and technological context, they are very different in terms of population size, provincial/federal regulations, and other socio-economic factors. Municipalities were categorized into three types based on geographic locations:

- Local municipalities in British Columbia (BC), Canada;
- Canadian municipalities (excluding BC municipalities);
- American municipalities.

2. Population

In order to identify municipalities with a more urbanized context, population data (obtained through US Census Bureau and Statistics Canada) was used. A list of municipalities was compiled based on the following benchmarks:

- Local municipalities in BC with populations of over 30,000;
- Canadian municipalities (excluding BC municipalities) with populations of over 150,000;
- American municipalities with populations of over 600,000.

3. Annual Precipitation

In order to include municipalities that have similar climatic conditions with the City of Vancouver, annual precipitation data (obtained through the US National Oceanic and Atmospheric Administration and Environment Canada) was used to screen potential municipalities for the survey. Municipalities with an annual precipitation of over 800 mm were retained in the list and municipalities with an annual precipitation of less than 800 mm were removed from the list.

4. GSI or Integrated Rainwater/Stormwater Management Programs

For a municipality that meets the geographic location, population, and precipitation criteria, its municipal website was searched for key words such as “Green (Stormwater) Infrastructure”, “Stormwater/Rainwater Management”, “Low Impact Development”, and “Integrated Stormwater/ Rainwater Management Plan”. If the municipality has a Green Stormwater Infrastructure or an Integrated Rainwater/ Stormwater Management program, or has completed/ been working on LID projects, it was retained in the list. Municipalities without such initiatives/strategies/projects were removed from the list.

Some municipalities did not meet both population and precipitation criteria, but may have made significant efforts/progress on GSI or Integrated Rainwater/Stormwater

Management programs (e.g. City of Portland, City of Los Angeles). Even though they have a smaller population or less precipitation than the baseline criteria, they were included in the list of target municipalities.

ASSEMBLING A LIST OF TARGET CONTACTS

For each target municipality identified, its municipal website was searched for appropriate department(s) responsible for rainwater/stormwater management. These were typically Public Works, Engineering, or Environmental Services. If a specific staff member was identified in the Green Stormwater Infrastructure or Integrated Stormwater Management program (e.g. Green Infrastructure program coordinator, Stormwater Manager), his/her name, position and contact information was recorded in the target contact list. If no specific staff contact information was found, the department inquiry contact information was recorded. If no specific department contact information was identified, the main phone number for the municipality was recorded in the target contact list.

Another source of contacts for the survey was the *Green Cities Clean Water* (GCCW) contact list that was obtained through the "*Green Cities, Clean Water: GSI Practitioner Exchange*" conference in September 2015. It includes GSI practitioners from municipalities across the US and Canada.

SURVEY FACILITATION AND ADMINISTRATION

Initial contacts to identify survey participants were made through phone calls in order to have a higher response rate. The target contact or department was given a brief introduction to the survey including its purpose and timeline, and was asked who would be best suited in the department to participate in this survey. After a contact agreed to participate in the survey, a follow-up introductory email was send to him/her with more details.

For municipalities without a phone number identified, or were not successfully reached by phone calls, emails were sent to target contacts/departments, with an introduction to the survey.

In the end, a list of 50 target municipalities from Canada and the US was compiled, including 25 Canadian municipalities (Vancouver included) and 25 American municipalities. A fillable PDF survey questionnaire was sent to them by email on June 13, 2016. Participants were given 3 weeks (June 30, 2016) to complete the survey. Some municipalities were given extended deadlines as they requested more time to complete the survey.

COMMUNICATION FLOWCHART OF THE SURVEY

Jun. 6-10 — **INITIAL PHONE CALL**

- Give a brief introduction to the survey
- Identify potential participants for the survey

INTRODUCTORY EMAIL

- Explain purpose, format, and timeline of the survey
- Explain that the focus of the survey is on performance and challenges, budgeting and personnel, and maintenance practices of GSI on city streets/plazas

Jun. 13 — **SURVEY EMAIL**

- Attach survey questionnaire
- Confirm the deadline for completing the survey

Jun. 27 — **REMINDER EMAIL**

- Send the email only to participants who had not completed the survey yet
- Re-attach survey questionnaire and remind participants of the deadline
- Ask participants if they need more time

Jul. 4 — **FOLLOW-UP EMAIL**

- Ask follow-up questions for their survey responses
- Thank survey respondents for their participation

End of Aug. — **SURVEY RESULTS**

- Share survey summary report with all respondents

SURVEY RESULTS

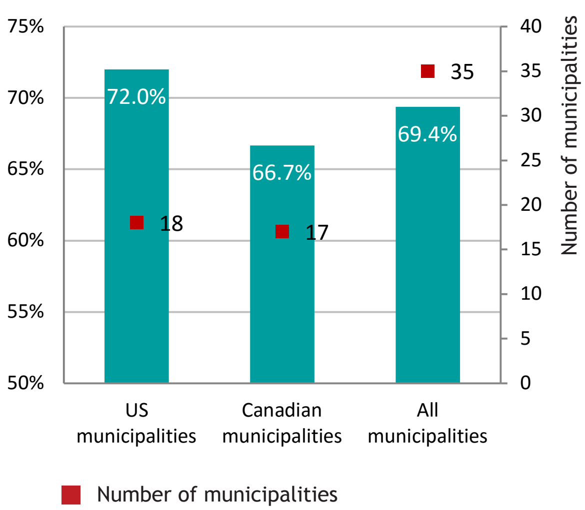
GENERAL INFORMATION

We have obtained responses from 35 municipalities, with a response rate of 69.4%. This includes 18 American municipalities and 17 Canadian municipalities. The response rates for American and Canadian municipalities are similar, with a 72.0% response rate for American municipalities, and a 66.7% response rate for Canadian municipalities.

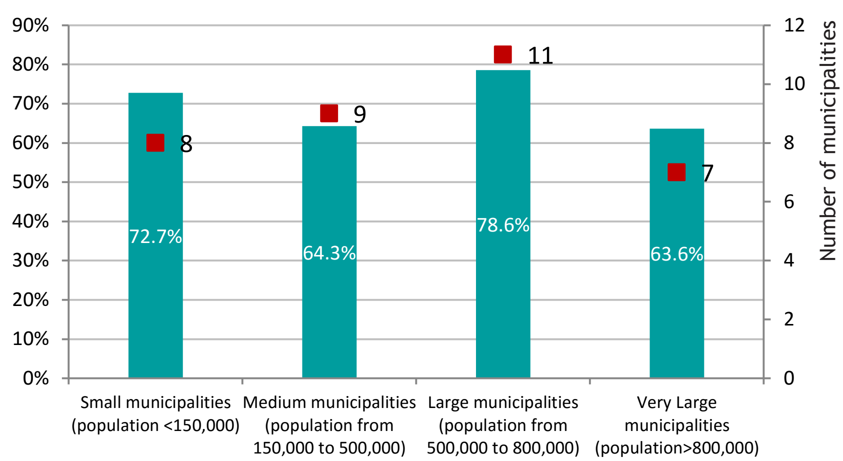
Among the 35 survey respondents, 8 respondents are small municipalities (72.7% response rate) with a population smaller than 150,000; 9 respondents are medium-sized municipalities (64.3% response rate) with a population between 150,000 to 500,000; 11 respondents are large municipalities (78.6% response rate) with a population between 500,000 to 800,000; 7 respondents are very large municipalities (63.6% response rate) with a population over 800,000. Respondents from municipalities ranging in size provided a good representative sample of GSI practices.

Note: the City of Vancouver is excluded in the calculation of response rate.

RESPONSE RATE BY COUNTRIES



RESPONSE RATE BY POPULATION

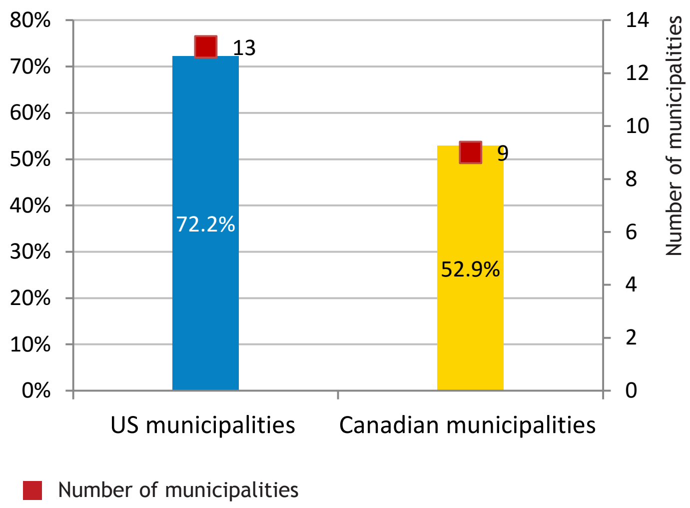


22 surveyed municipalities have clear commitments to implementing GSI on city streets/plazas through policies, bylaws, ordinances or agreements, representing about 2/3 of all surveyed municipalities. 72.2% of surveyed American municipalities have such commitments, as compared with 52.9% of surveyed Canadian municipalities. This is likely due to the more proactive regulatory requirements for stormwater quality in the US. In Canada, GSI is a relatively new initiative, and many Canadian municipalities are working on a trial-and-error basis without integrating GSI into policies, bylaws and other agreements.

SURVEY RESPONDENTS

AMERICAN MUNICIPALITIES	CANADIAN MUNICIPALITIES
City of Austin	City of Burlington
City of Berkeley	City of Calgary
City of Boston	City of Greater Sudbury
City of Charlotte	City of Hamilton
City of Chicago	City of Ottawa
City of Fort Lauderdale	City of Sherbrooke
City of Fort Worth	City of Toronto
City of Indianapolis	City of Vaughan
City of Los Angeles	City of Abbotsford
City of Memphis	City of Coquitlam
City of Nashville	Corporation of Delta
City of Pittsburgh	Township of Langley
City of Portland	District of North Vancouver
City and County of San Francisco	City of Port Coquitlam
City of Seattle	City of Surrey
City of St. Louis	City of Vancouver
City of Tacoma	City of Victoria
Washington, D.C.	

MUNICIPALITIES WITH A CLEAR COMMITMENT TO IMPLEMENTING GSI ON CITY STREETS/PLAZAS (THROUGH POLICIES, BYLAWS AND OTHER AGREEMENTS)



"The city is in the process of exploring and testing GSI. Most of the existing GSI throughout the city were constructed through development by developers. Over the years, the city has taken on small scale GSI projects whenever there was funding and space opportunity."

A SURVEY PARTICIPANT FROM THE CITY OF BURNABY

US REGULATORY CONTEXT

- **The Clean Water Act, 1972**

The *Clean Water Act* (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the US and regulating quality standards for surface waters. The objective of this act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by preventing point and non-point pollution sources.

- **NPDES Permit Program**

The National Pollutant Discharge Elimination System (NPDES) permit program was created by the CWA, and is intended to address water pollution by regulating point sources that discharge pollutants to US waters. The NPDES stormwater program regulates stormwater discharges from municipal separate storm sewer systems (MS4s). Operators of MS4s are required to obtain NPDES permits and develop stormwater management programs.

- **Total Maximum Daily Loads**

Under section 303(d) of the CWA, states, territories, and authorized tribes are required to develop lists of impaired waters, establish priority rankings for waters on the lists, and develop Total Maximum Daily Loads (TMDLs) for these waters. A TMDL is a pollution budget and includes a calculation of the maximum amount of a pollutant that can occur in a waterbody, and allocates the necessary reductions to one or more pollutant sources.

In terms of primary drivers for implementing GSI on cities streets/plazas, most survey respondents indicated stormwater volume control and water quality improvements as the primary drivers for implementing GSI in their municipalities. Regulatory/legislative requirements from higher levels of government, as well as aesthetic/urban design considerations, are also identified as major drivers for the implementation of GSI. Other drivers include combined sewer overflow reduction, ecological habitat improvement, and citizen group advocation. Some municipalities also have specified drivers for GSI projects in their municipalities, including local requirements, city department initiatives, and paradigm shifts.

PRIMARY DRIVERS FOR IMPLEMENTING GSI ON CITY STREETS/PLAZAS

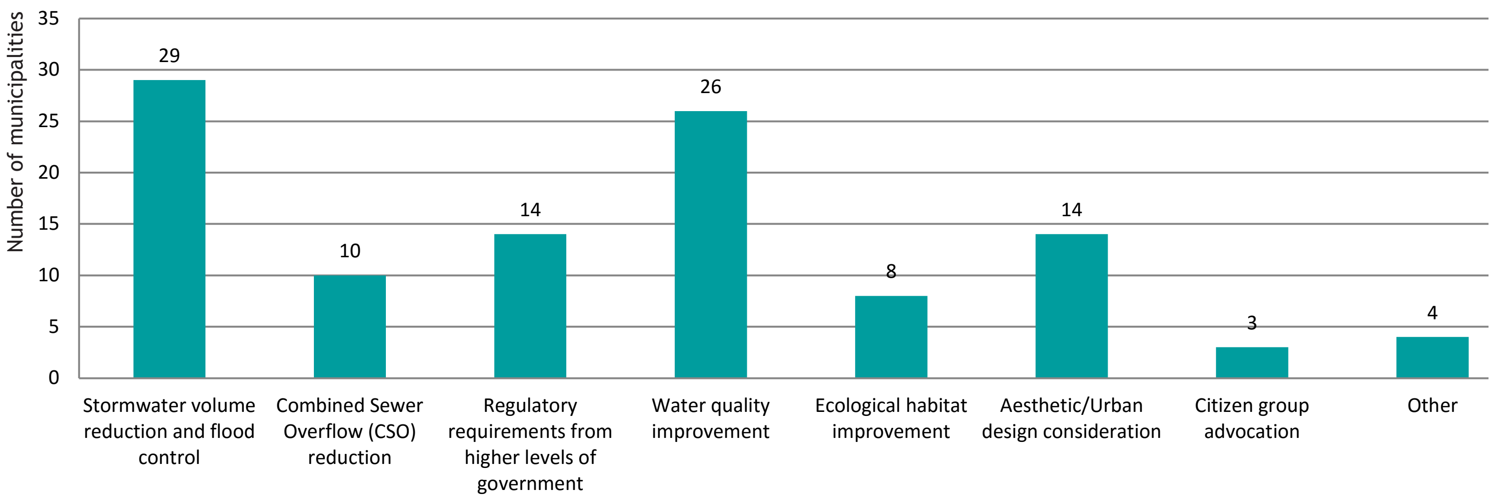
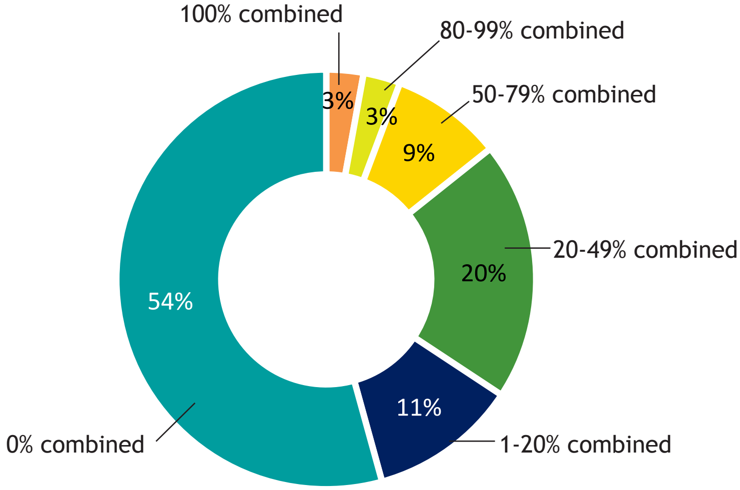


Image by NYV Water

The type of sewer system utilized by a municipality is an important factor for stormwater management choices. A combined sewer system imposes larger pressures to sewer treatment plants and may generate combined sewer overflows in times of large rain events. A separated sewer system does not have combined sewer overflow issues, but may discharge untreated, polluted rainwater into receiving waterbodies directly. 19 of 35 municipalities (54%) employ a completely separated sewer system, and another 11 municipalities (31%) have the majority of their land areas (51%-99%) served by separated sewer systems. The remaining 5 municipalities (15%) are primarily served by combined sewer systems.

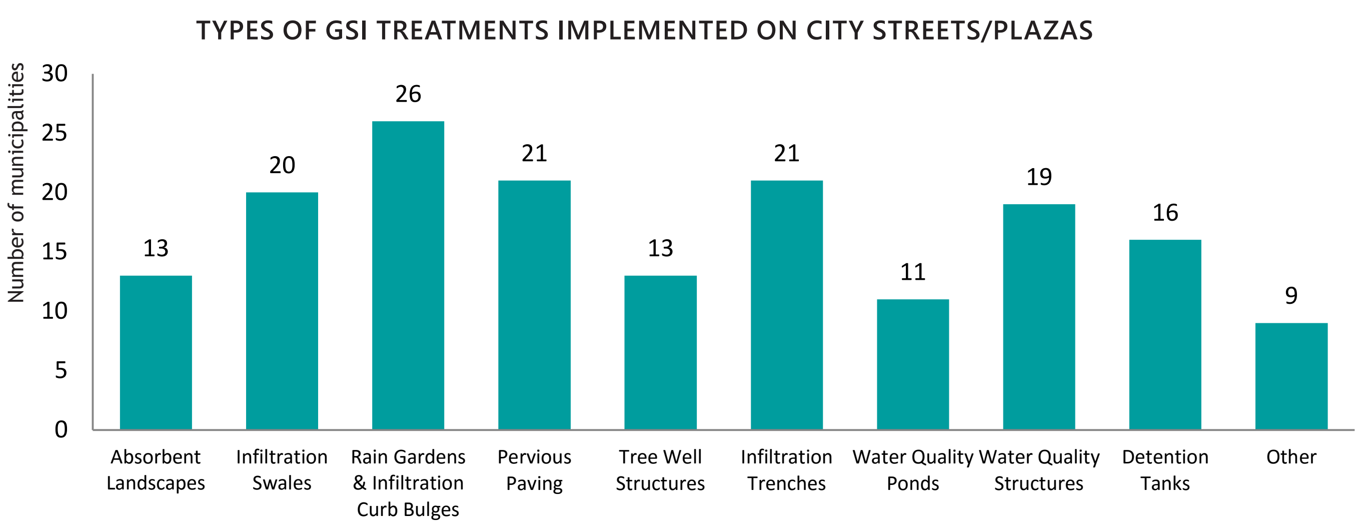
PERCENTAGE OF AREA SERVED BY COMBINED SEWER SYSTEMS



GSI CONSTRUCTION AND PERFORMANCE

GSI treatments include a wide variety of types, and in this survey, municipalities were asked about whether the following treatments were implemented on their city streets/plazas: absorbent landscapes, infiltration swales, rain gardens & infiltration curb bulges, pervious paving, tree well structures (e.g. designed tree trench infiltration systems, soil cells), infiltration trenches, and water quality ponds. Water quality structures (e.g. grit/oil/sediment separators or tanks) and detention tanks are two grey infrastructure treatments, and were also included in the survey for comparison. Although they are not green infrastructure, they are commonly used on streets to help to improve water quality and facilitate stormwater infiltration, and they are included in the best management practices toolkit in the Vancouver Citywide Integrated Rainwater Management Plan. According to the survey responses, municipalities are utilizing a variety of GSI treatments on their streets/plazas. The most commonly used GSI treatments are rain gardens & infiltration curb bulges. Other commonly used treatments include pervious paving, infiltration trenches, and infiltration swales. Absorbent landscape, tree well structures and water quality ponds are not as widely used as other GSI treatments. Water quality structures and detention tanks, which are included as grey infrastructure in the survey, are also utilized by many municipalities. Other GSI treatments specified by municipalities include sand filters, dry detention facilities, and daylit creeks.

Survey participants were asked about the number of projects for each treatment implemented in their municipalities, and the scale of these projects (e.g. by estimating total length/area of treatments) if data is available. Among the municipalities that have data on the number of projects and other metrics, the scale of their GSI programs varies significantly. Some municipalities consider GSI treatments as common planning and design components, and may have hundreds of treatments implemented. Some municipalities have just started their GSI initiatives, and may have just completed a few pilot projects.

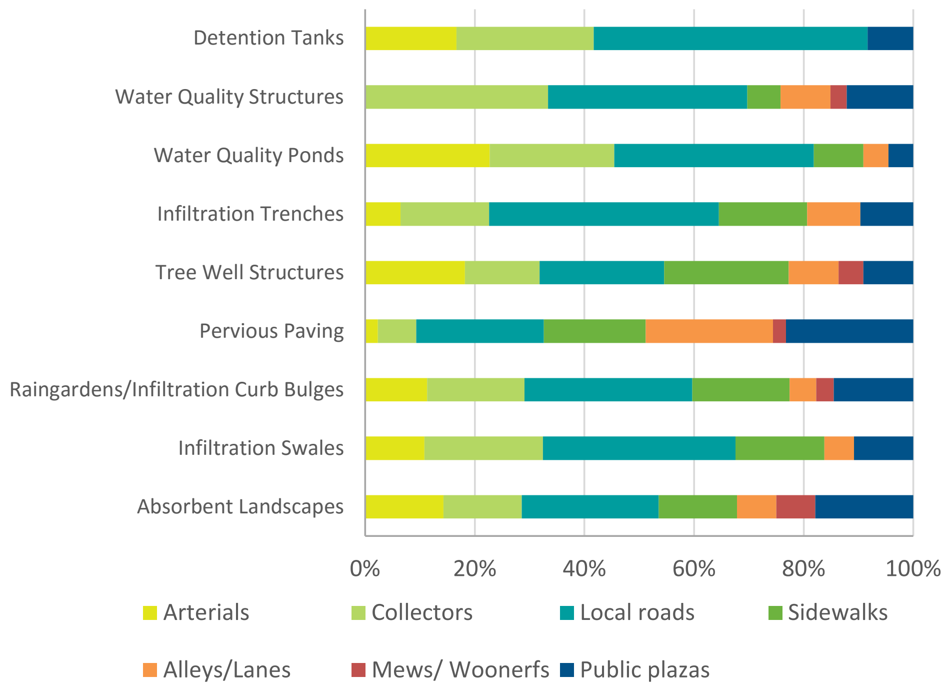


GSI TREATMENTS

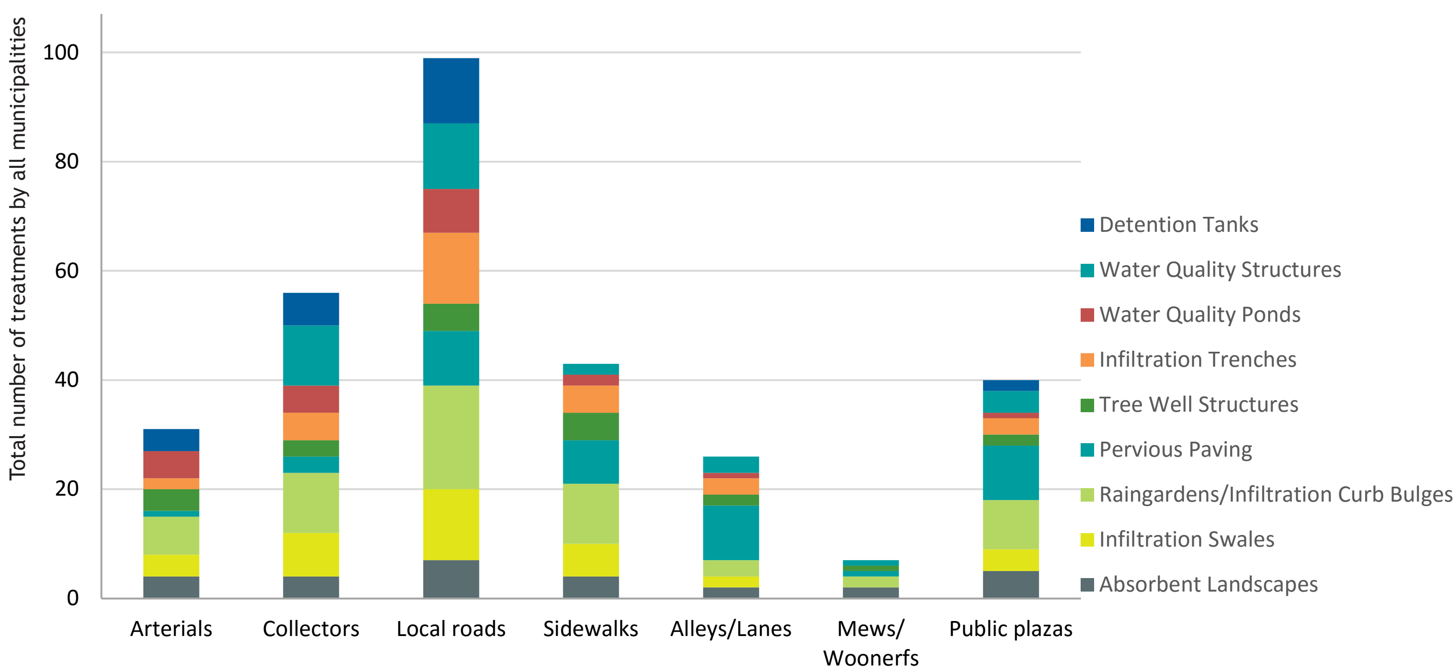
- **Absorbent Landscapes**: most landscape, such as trees, shrubs and grasses, acts like a sponge to absorb, store and slowly release rainwater. Native vegetation enhances both absorption of rainfall and evaporation of soil moisture due to extensive root systems.
- **Infiltration Swales**: an infiltration swale is a shallow vegetated channel designed to capture, detain and treat stormwater from small areas of adjacent paved surfaces such as roads and parking areas. Some swales include weirs to hold stormwater, allowing stormwater to infiltrate through a soil bed to an underlying drain rock reservoir system.
- **Rain Gardens & Infiltration Bulges**: a rain garden is a form of bio-retention facility that is commonly a concave landscaped area that captures and filters runoff from adjacent impervious surfaces such as roads, roofs, parking lots and driveways.
- **Pervious Paving**: pervious paving is a surface layer of permeable pavements that allow stormwater to percolate through the surface into the soil below where water is naturally infiltrated and pollutants are removed.
- **Tree Well Structures**: trees help to manage and reduce stormwater runoff by infiltration, evapotranspiration, and filtration. One example of a tree well structure with stormwater management function is a soil cell, which is a rigid frame structure that supports a large amount of soil to be installed, thereby optimizing tree growth and retaining excess stormwater.
- **Infiltration Trenches**: an infiltration trench is a below-grade infiltration facility with rocks to hold or infiltrate water into subsurface soils. As stormwater enters the trench through an inlet pipe or porous pavement, it fills the voids between rocks, and percolates through the bottom and sides of the trench into the subsurface soils.
- **Water Quality Ponds**: water quality ponds are constructed to treat and store stormwater runoff.

Local streets are the most common locations for GSI treatments. Collector roads, sidewalks, and public plazas are also identified by many municipalities as common locations. Arterial roads, alleys/lanes and mews/woonerfs are not as common as other types of streets/plazas. Different GSI treatments are utilized at different locations based on the nature of the treatment and the intended functions. For example, while pervious paving is widely used for public plazas, local roads and sidewalks, it is almost never used on arterial roads.

LOCATIONS WHERE VARIOUS GSI TREATMENTS ARE IMPLEMENTED



TYPES OF STREETS/PLAZAS WHERE GSI TREATMENTS ARE IMPLEMENTED

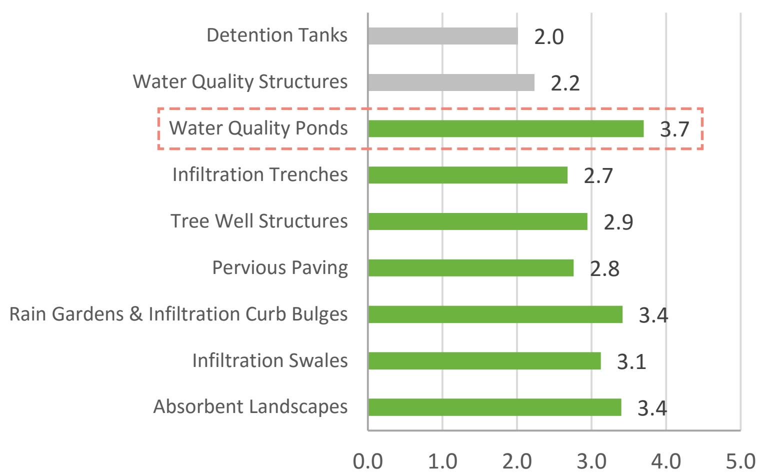


Municipalities were asked to evaluate the performance of different treatments in terms of the following aspects (with 5 = highly effective and 1= minimally effective):

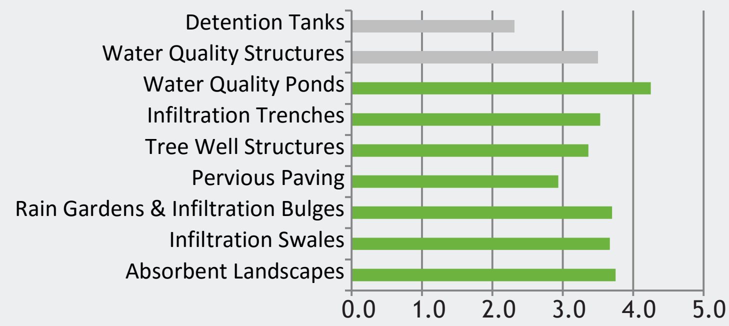
- Improve water quality;
- Reduce storm runoff;
- Increase aesthetic value of open space;
- Increase ecological value;
- Create educational opportunities.

An average score for each treatment is calculated. The treatment with the highest average performance score is water quality ponds, followed by rain gardens & infiltration bulges, and absorbent landscapes. A detailed performance score for each treatment is displayed on the side of this page. It demonstrates that green infrastructure can compete with the selected grey infrastructure (water quality structures and detention tanks) in terms of improving water quality and reducing stormwater runoff. As for increasing aesthetic/ecological value and creating educational opportunities, GSI performs much better than the selected grey infrastructure.

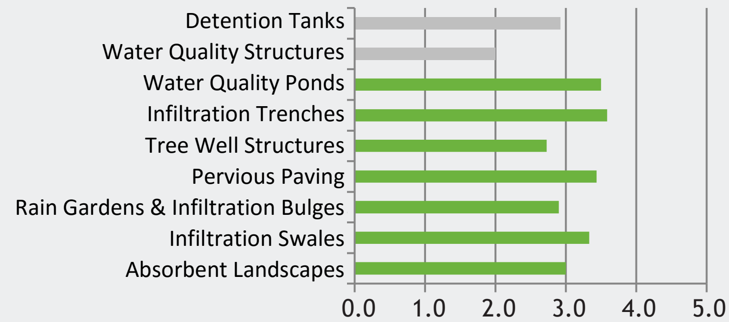
AVERAGE PERFORMANCE SCORE FOR EACH TREATMENT



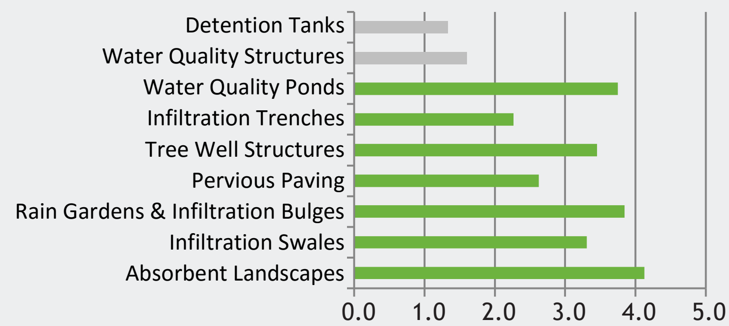
IMPROVE WATER QUALITY



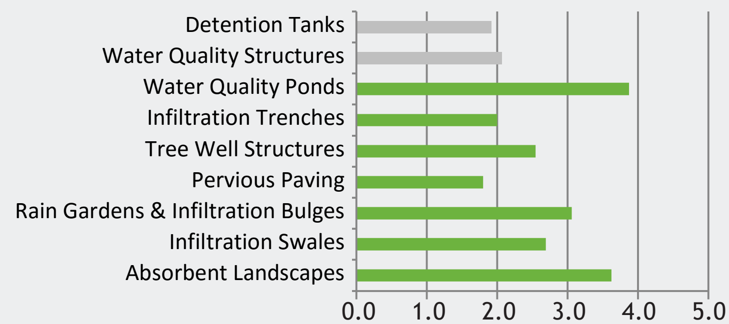
REDUCE STORM RUNOFF



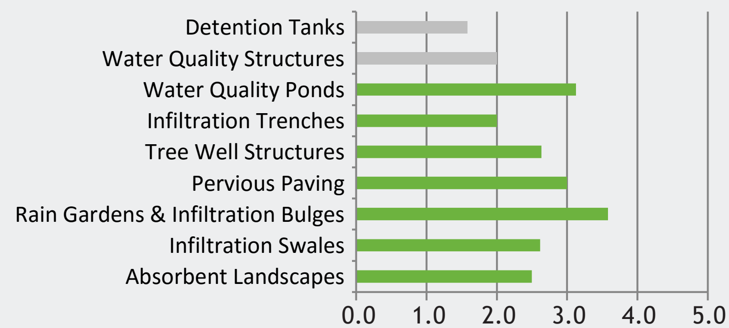
INCREASE AESTHETIC VALUE OF OPEN SPACE



INCREASE ECOLOGICAL VALUE



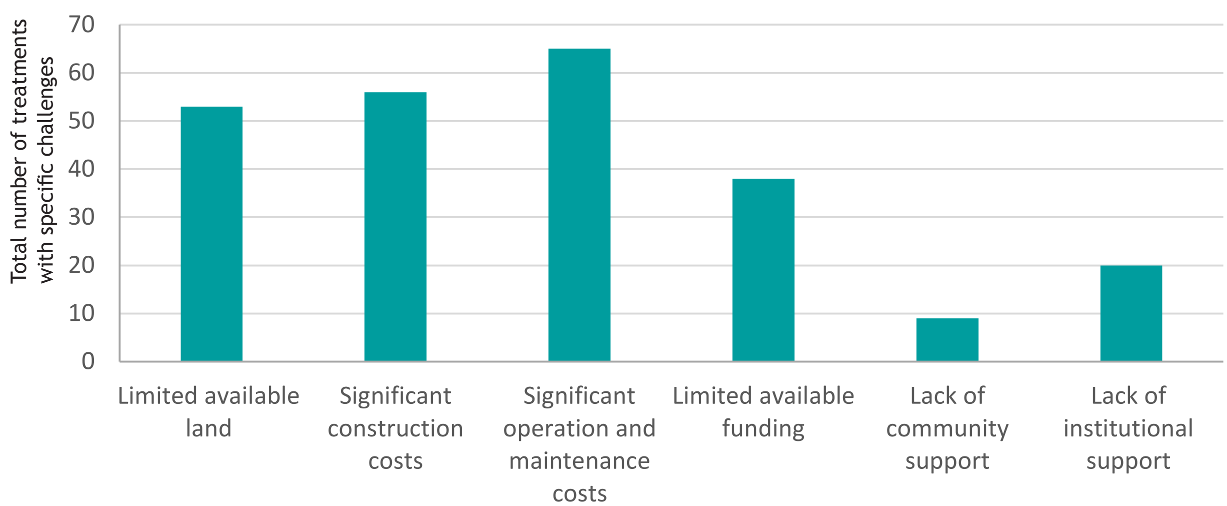
CREATE EDUCATIONAL OPPORTUNITIES



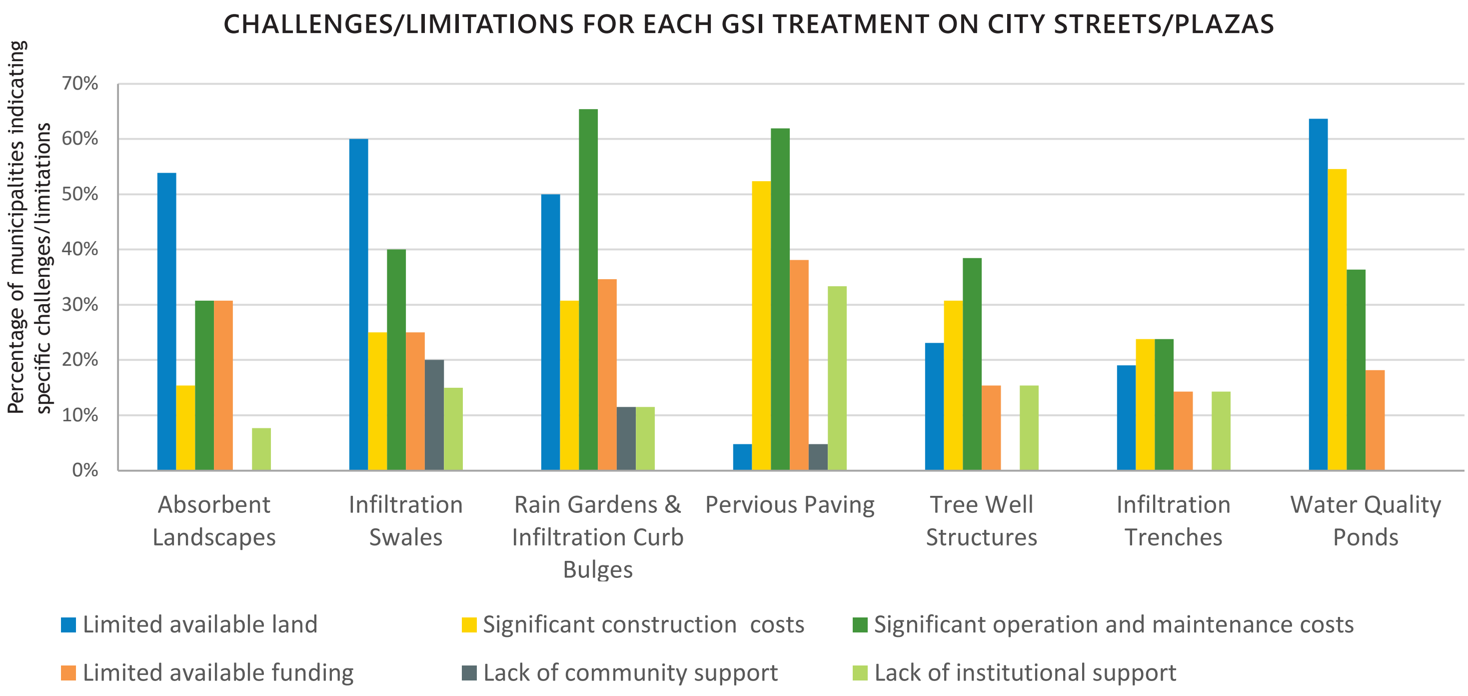
> "
> *Technologies are not implemented primarily due to a lack of buy-in from all departments. There are concerns regarding long-term operation, maintenance costs and doing things differently. There are also challenges in obtaining inter-departmental coordination and acceptance of conflicting values and needs.*
> "
>
> A SURVEY PARTICIPANT

As GSI is a relatively new initiative for many municipalities, there are currently many challenges associated with them. Several major challenges identified by municipalities for implementing GSI on streets/plazas include significant construction costs, operation and maintenance costs, limited available land and limited available funding. Other challenges specified by municipalities include a lack of interdepartmental collaboration, conflicting values and needs, a lack of experience in O&M, complex underground utilities, concerns about responsibilities for maintenance and land ownership, a lack of a formal green infrastructure policy/program, difficulties with paradigm changes, etc.

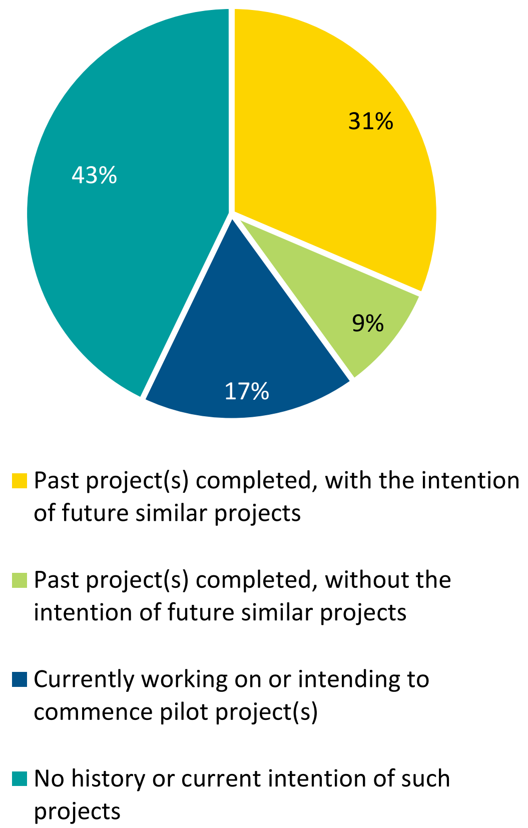
CHALLENGES/LIMITATIONS OF GSI TREATMENTS ON CITY STREETS/PLAZAS



The diagram below displays the percentage of municipalities indicating a challenge/limitation for a specific GSI treatment. This demonstrates trade-offs that need to be balanced when considering implementing a GSI treatment. For example, although water quality ponds have the highest average performance score, it is associated with many challenges such as limited available land, and significant construction and O&M costs. Different GSI treatments vary significantly in terms of specific challenges/limitations. For example, only 1 out of 21 municipalities utilizing pervious paving has identified “limited available land” as a challenge for this treatment. This is probably because pervious paving accommodates intended functions on streets. However, 13 out of these 21 municipalities have identified significant O&M cost as a challenge for pervious paving. Some participants indicated that pervious paving could be easily clogged and therefore needs frequent sweeping and vacuuming. Pervious pavers, as one type of pervious paving, also have accessibility challenges due to gaps between pavers and uneven settlement.



MUNICIPALITIES WITH A HISTORY OR AN INTENTION OF RECREATING HISTORIC STREAMS BY NEW NATURALIZED WATER COURSES

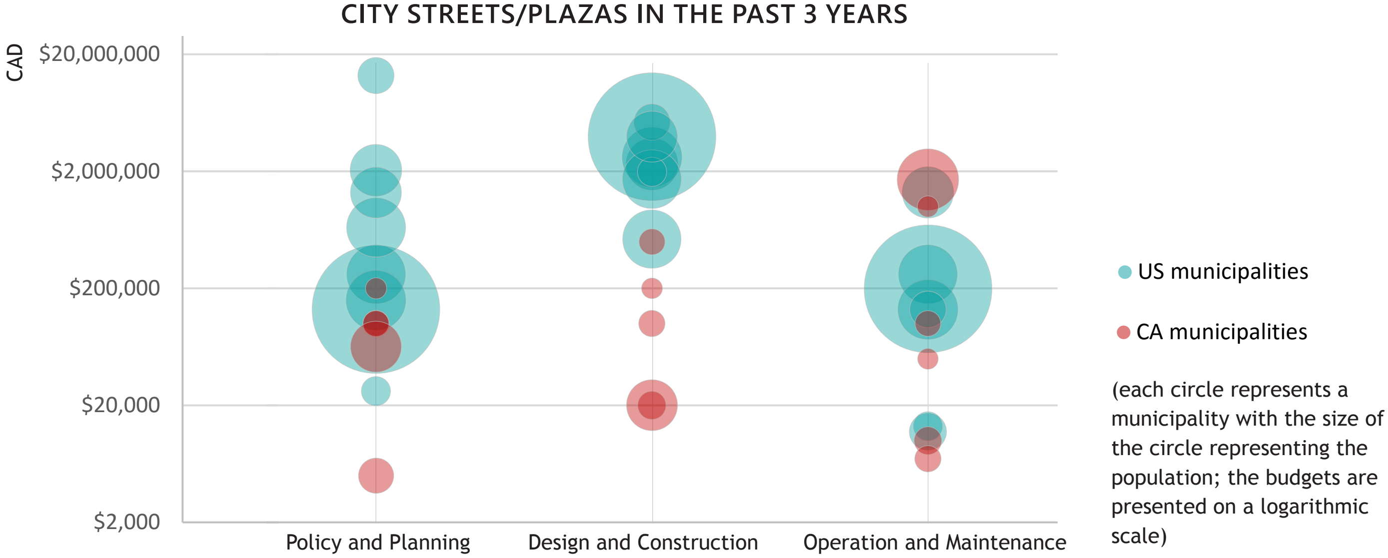


Municipalities were asked about their experience with creating open drainage channels or recreating historic streams by new naturalized water courses. 31% of surveyed municipalities have completed past project(s) with the intention of completing future similar projects, 9% have completed past project(s) without the intention of starting similar projects; 17% are currently working on or intending to commence pilot project(s). The rest of the municipalities (43%) have no history or current intention for such projects. Common challenges identified by municipalities include significant capital costs, significant costs for O&M, lack of community support, limited maintenance capacity, and lack of priority given.

GSI BUDGET AND PERSONNEL

Municipalities were asked about their average annual budgets for GSI projects on city streets/plazas for the past 3 years. Many municipalities indicated that they have no dedicated funding for GSI projects on city streets/plazas. Some respondents stated that the planning and construction of their GSI projects were integrated into

AVERAGE ANNUAL BUDGETS FOR GSI PROJECTS ON CITY STREETS/PLAZAS IN THE PAST 3 YEARS



broader basin planning projects, large scale drainage planning projects, or other developments. Other respondents suggested that funding for the O&M of their GSI comes from general O&M funds or from road & drainage O&M funds. Therefore, it is difficult for many survey respondents to estimate their budgets for GSI specifically.

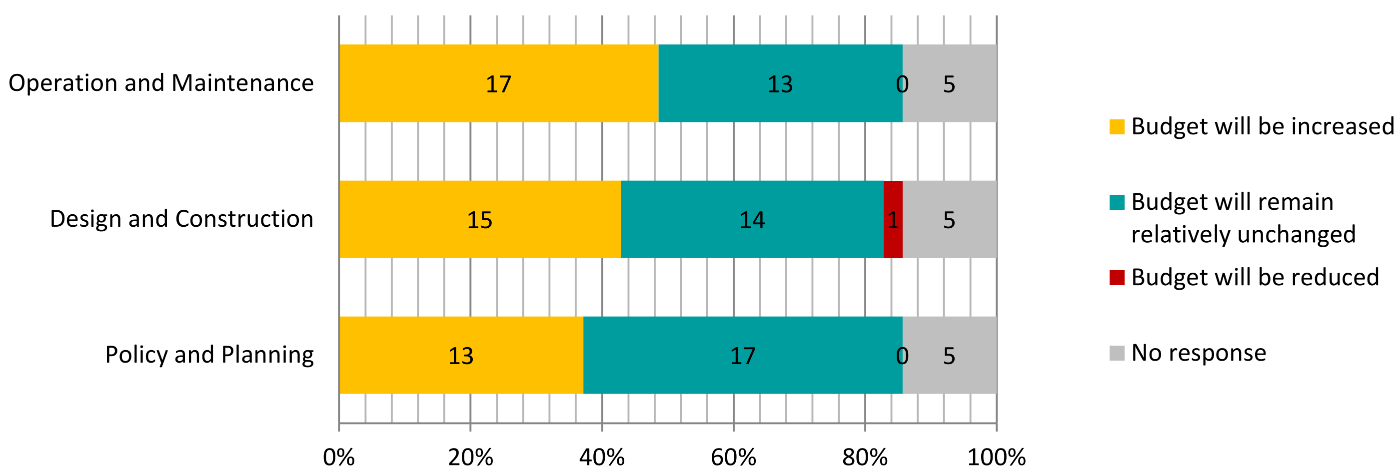
Some municipalities did provide us with data on annual budgets for policy and planning, design and construction, and operation and maintenance for GSI on city streets/plazas, and a detailed list of these budgets can be found in Appendix 2. Data on GSI budgets is presented in a scattered bubble graph on the previous page (data is represented in Canadian Dollars with 1 USD = 1.32 CAD), with the budgets presented on a logarithmic scale.

In general, the annual budgets for GSI in American municipalities are significantly higher than Canadian municipalities. Most of the GSI budgets are allocated for the design and construction of GSI, instead of policy and planning, or O&M. This indicates that municipalities may tend to implement GSI projects without overall comprehensive planning, and operation and maintenance is an area that is generally overlooked.

When asked about whether their budgets for GSI programs will be increased, reduced or remain unchanged for the next 3 years, very few municipalities indicated that they will reduce their budgets for GSI. Of the 30 municipalities that had responded to this question, 13 would like to increase their budgets for policy and planning, 15 would like to increase their budgets for design and construction, and 17 would like to increase their budgets for operation and maintenance.

Many municipalities suggested the reason why they wish to increase their GSI budgets is that their current GSI program is in the establishment phase, and will be expanded in the next few decades. Other reasons specified by municipalities include: new stormwater management requirements/ targets, agenda from the capital plan and other city initiatives (e.g. Green and Complete Street program), overall increased stormwater budget, anticipated stormwater charge, climate change impacts, emerging community visions, etc.

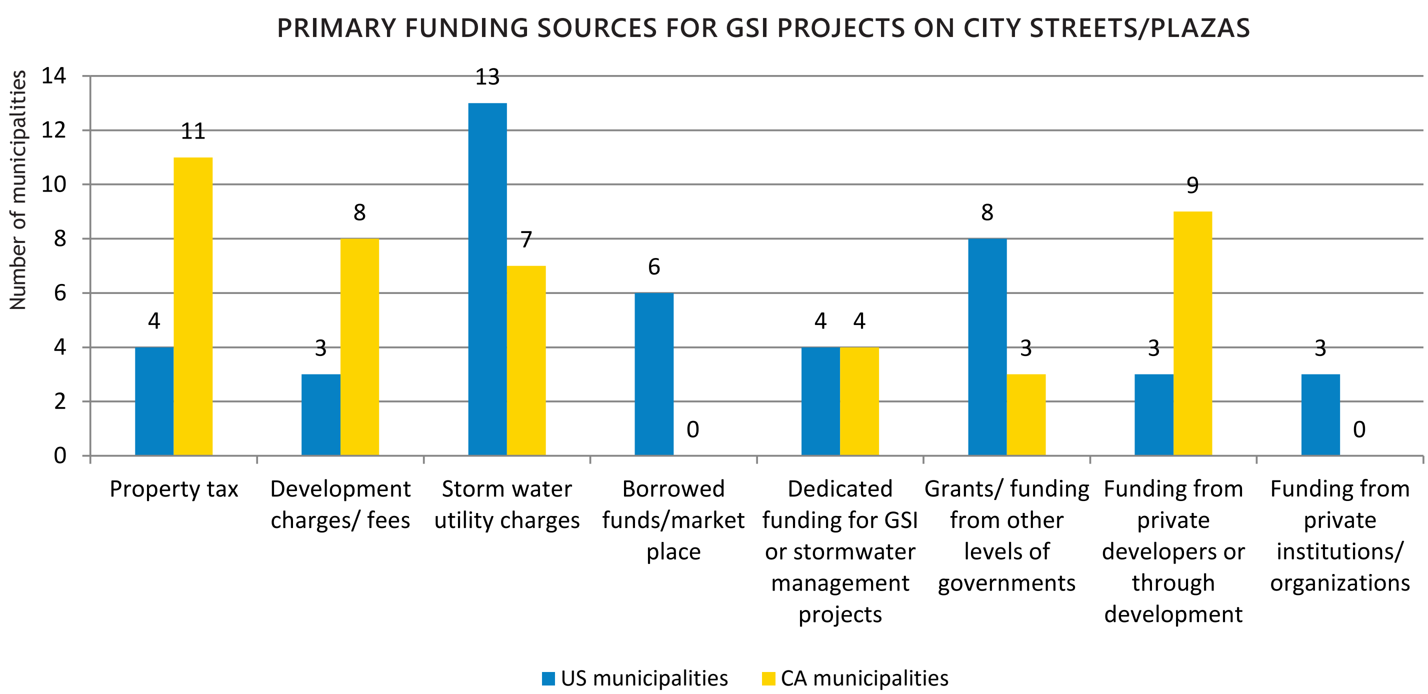
ANTICIPATED MUNICIPAL BUDGETS FOR GSI ON CITY STREETS/PLAZAS IN THE NEXT 3 YEARS



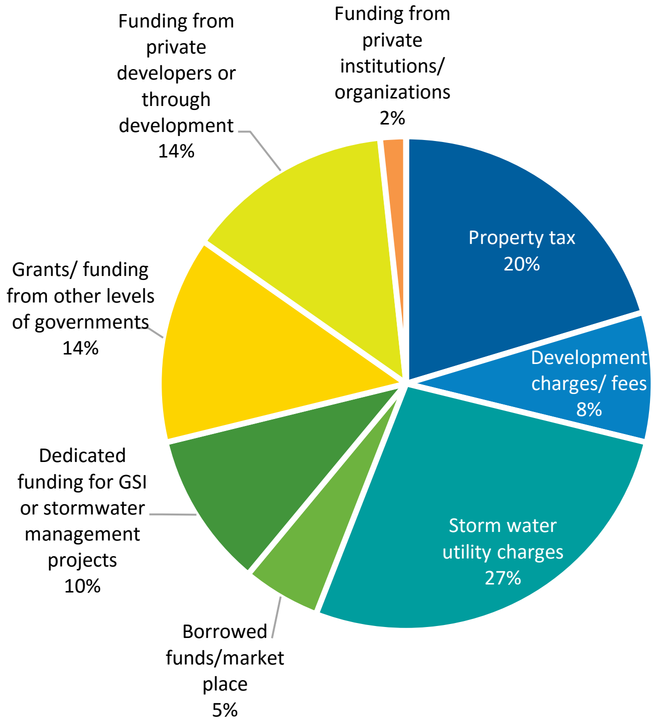
> "The biggest challenge has been to secure more funding and also more staff to do the O&M properly for these stormwater projects."
>
> A SURVEY PARTICIPANT

In terms of primary funding sources for GSI projects on streets/plazas, only 8 out of 35 surveyed municipalities have dedicated funding for GSI or stormwater management projects. Funding sources for GSI vary significantly among American and Canadian municipalities. For American municipalities, the most common funding sources are stormwater utility charges and grants/funding from other levels of governments. For Canadian municipalities, the most common funding sources are property tax, funding from private developers or through development, and development charges/fees.

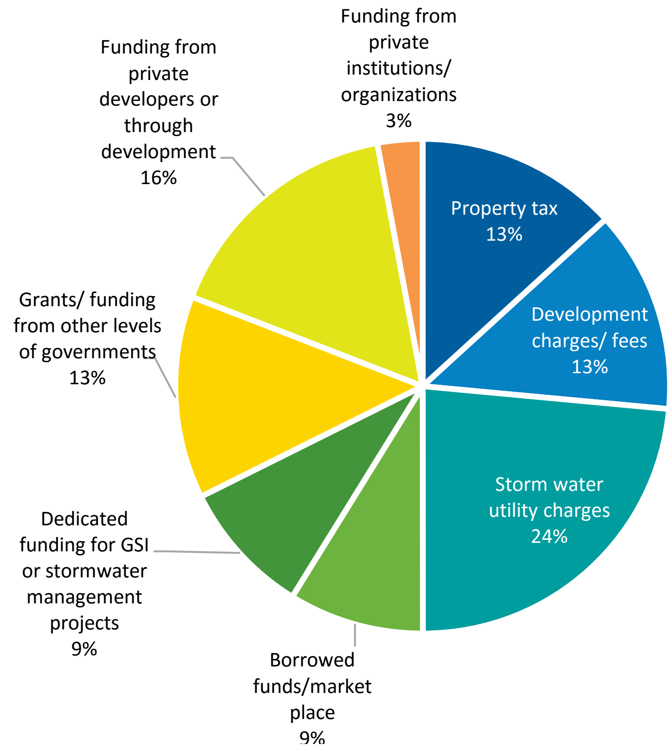
The pie charts on the next page display the breakdowns of funding sources for policy and planning, design and construction, and operation and maintenance of GSI projects on streets/plazas. The proportion of funding sources for these three aspects are generally similar. Property tax plays a less important role in the design and construction of GSI than the other two aspects, while development charges/fees are more frequently used for the design and construction of GSI. Stormwater utility charges play a very important role in O&M, with 37% of surveyed municipalities indicating it as a funding source for the O&M of GSI.



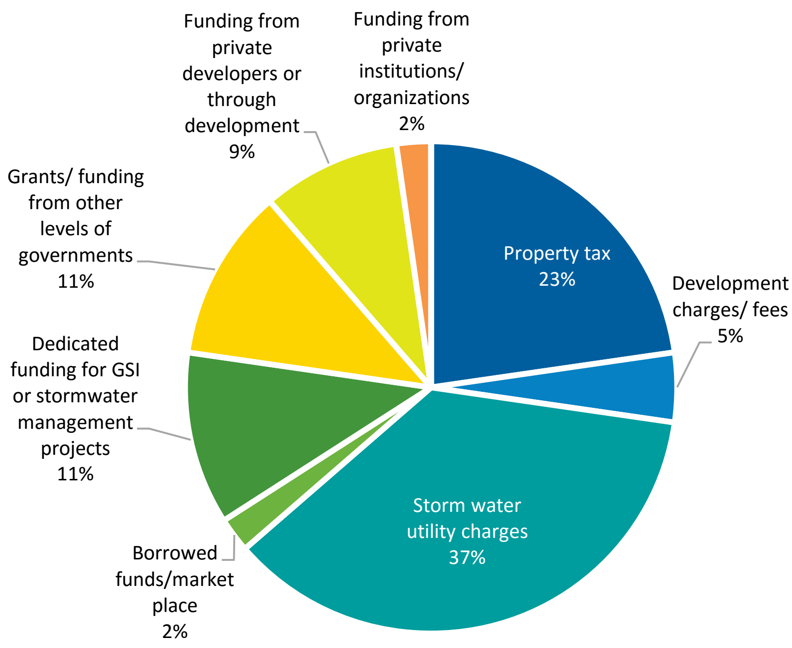
PRIMARY FUNDING SOURCES FOR GSI POLICY AND PLANNING



PRIMARY FUNDING SOURCES FOR GSI DESIGN AND CONSTRUCTION



PRIMARY FUNDING SOURCES FOR GSI OPERATION AND MAINTENANCE



"

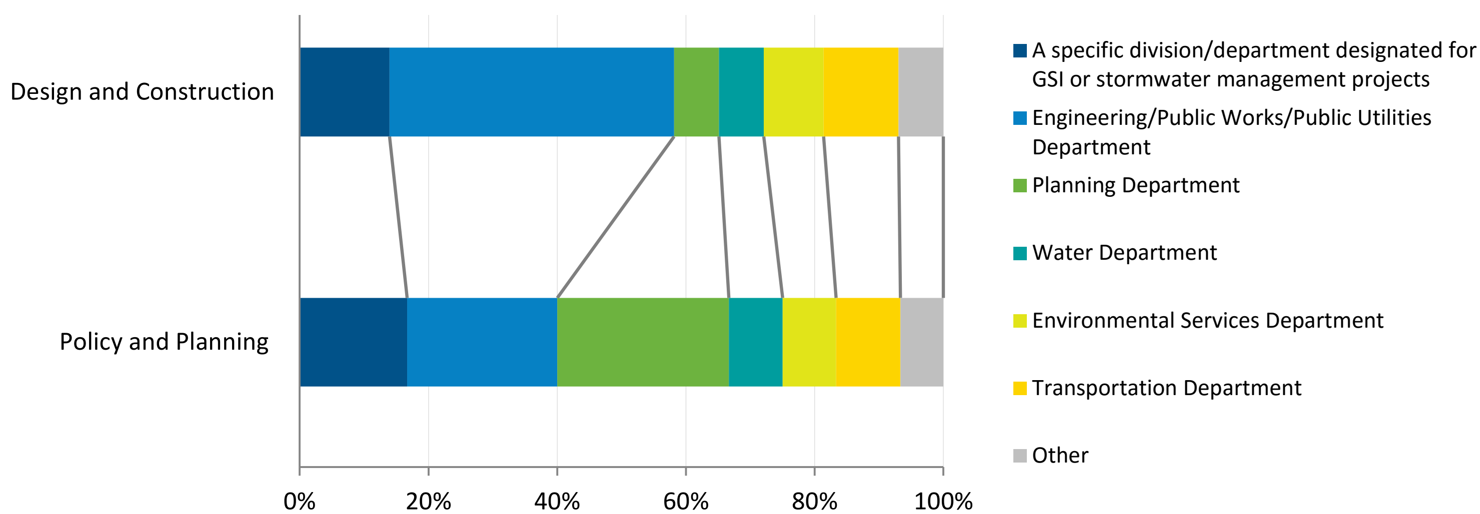
GSI maintenance depends on the collaboration amongst various Divisions/Sections within the Public Works Department. The owner of each project/asset may vary, i.e. Forestry & Horticulture, Parks Operations, Road Operations, Wastewater Collection, depending on the project location and complexity. The cost for each type of treatment may also vary greatly depending on locations.

"

A SURVEY PARTICIPANT
FROM THE CITY OF HAMILTON

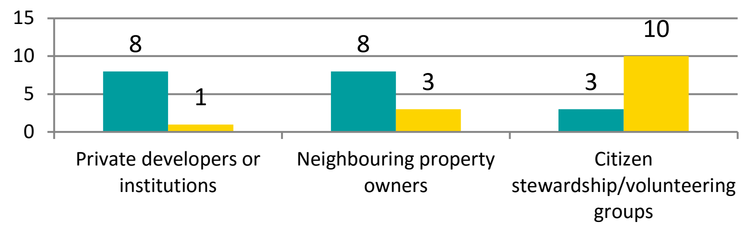
We asked surveyed municipalities to indicate which of their department(s) are primarily responsible for policy and planning, and design and construction of GSI projects on city streets/plazas. The Planning Department, Engineering/Public Works Department, and specific divisions/departments dedicated for GSI are the most common departments responsible for policy and planning for GSI projects/programs. For design and construction, the Engineering/Public Works Department is the most commonly responsible department. Other departments involved in GSI projects/programs include the Water Department, Environmental Services Department, Transportation Department and Parks Department.

DEPARTMENTS RESPONSIBLE FOR POLICY AND PLANNING, AND DESIGN AND CONSTRUCTION OF GSI ON CITY STREETS/PLAZAS

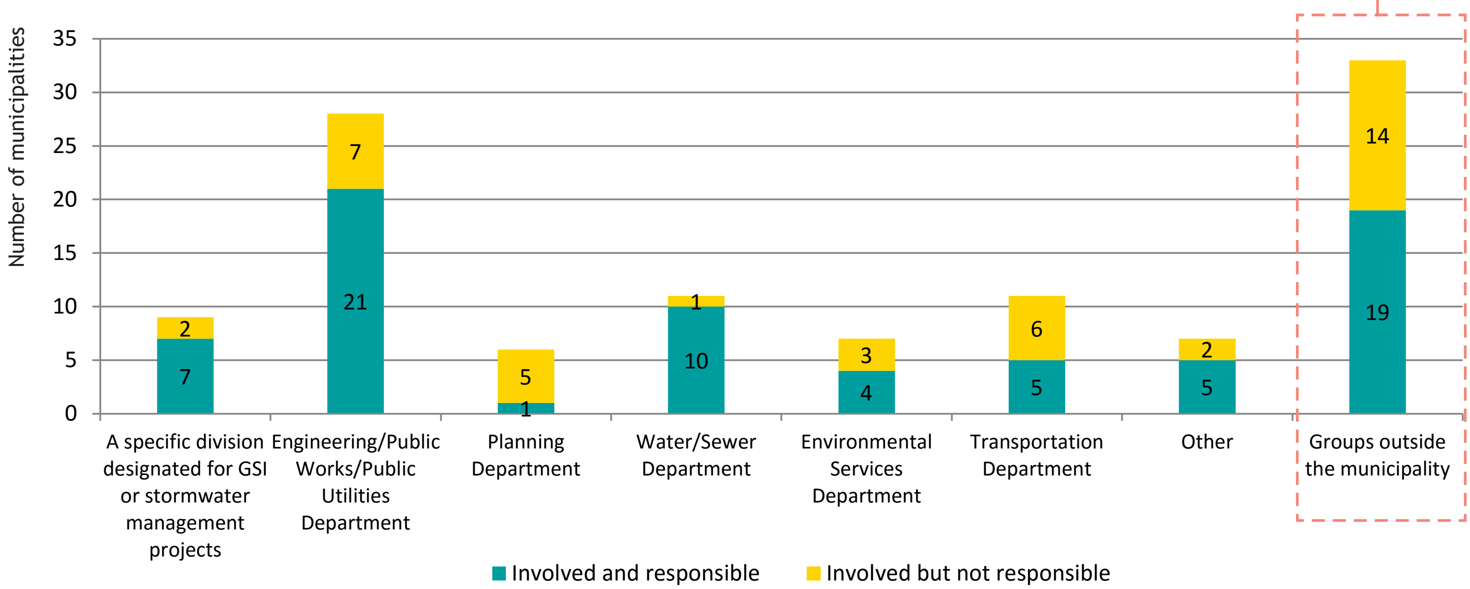


Municipalities were asked about the responsibility and involvement for the O&M of GSI by various municipal departments, as well as groups outside municipalities. For municipal departments, the Engineering/ Public Works Department appears to be the most common leading department for the O&M of GSI, followed by the Water/ Sewer Department and specific divisions/ departments dedicated for GSI. Groups outside municipalities also play important roles in the O&M of GSI (e.g. private developers or institutions, neighbouring property owners). Many municipalities engage citizen stewardship/volunteering groups for the O&M of GSI, although their roles are often voluntary.

GROUPS OUTSIDE MUNICIPALITIES THAT ARE INVOLVED IN OR RESPONSIBLE FOR THE O&M OF GSI ON CITY STREETS/PLAZAS



DEPARTMENTS/GROUPS INVOLVED IN OR RESPONSIBLE FOR THE O&M OF GSI ON CITY STREETS/PLAZAS

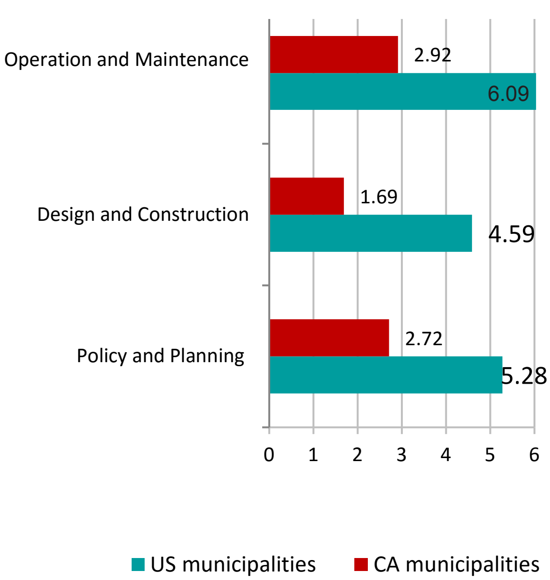


> "Our biggest suggestion to conduct the O&M properly and effectively for these stormwater projects is to be able to secure enough funding and enough personnel for O&M. Having adequate funding for O&M as well as enough personnel would be a tremendous benefit and would give the Green Stormwater projects the chance to be successful and meet the project goals."
>
> A SURVEY PARTICIPANT

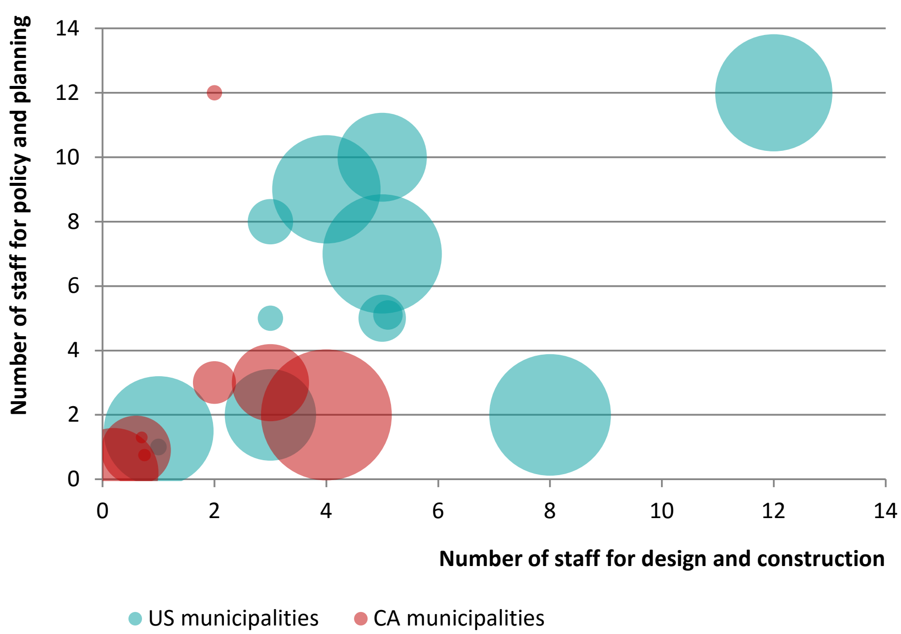
Municipalities were asked to estimate the equivalent number of full-time staff for GSI policy and planning, design and construction, and O&M. About two thirds of all surveyed municipalities have responded to this question. Again, American municipalities have a larger number of equivalent full-time staff for GSI projects, with an average of 5.28 full-time staff for policy and planning, 4.59 for design and construction, and 6.09 for O&M. For surveyed Canadian municipalities, the average number of equivalent full-time staff is 2.72 for policy and planning, 1.69 for design and construction, and 2.92 for O&M. Several surveyed municipalities also indicated that they have seasonal staff for O&M, with an average of 2.75 staff.

The graph below displays staffing information from municipalities that have provided data on the number of full-time staff for both policy and planning, as well

AVERAGE NUMBER OF EQUIVALENT FULL-TIME STAFF FOR GSI PROJECTS



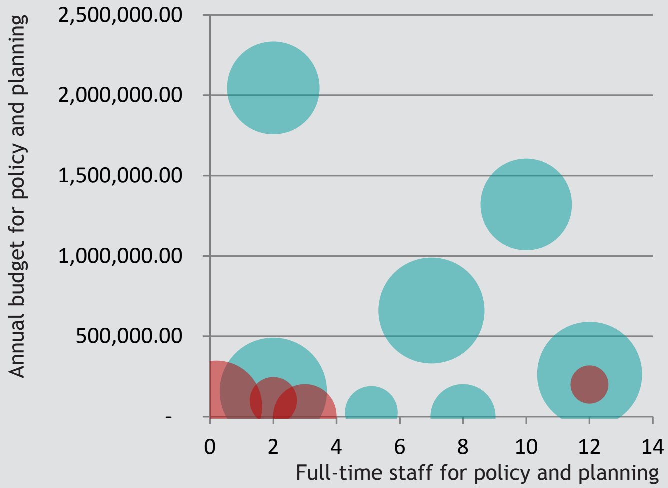
NUMBER OF EQUIVALENT FULL-TIME STAFF FOR GSI DESIGN AND CONSTRUCTION, IN RELATION TO POLICY AND PLANNING



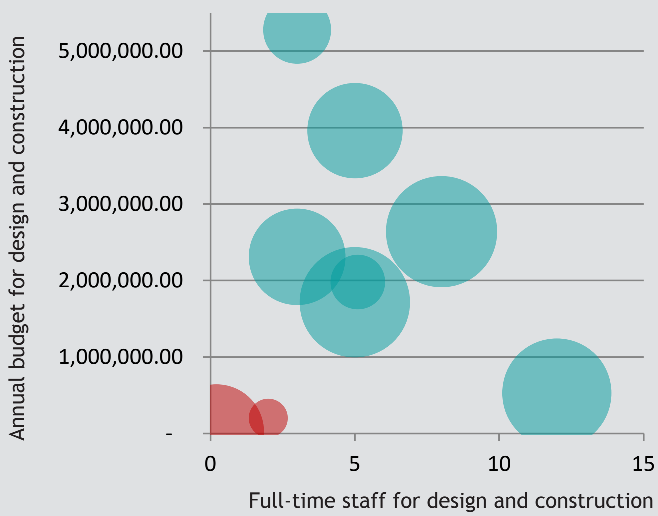
(each circle represents a municipality with size of the circle representing its population) as design and construction. The X axis represents the number of full-time staff for design and construction, the Y axis represents the number of full-time staff for policy and planning, and the size of a bubble represents the municipality's population. The graph shows that, in general, the larger a municipality is in terms of population, the more full-time staff they have for GSI projects/programs, and on average, American municipalities have significantly higher numbers of staff than Canadian municipalities. Additionally, American municipalities tend to have a higher proportion of staff in policy and planning compared to design and construction than Canadian municipalities, which may indicate a stronger focus on policy and planning.

The three graphs on the side of this page display the number of full-time staff in relation to a municipality's average annual budget, in terms of GSI policy and planning, design and construction, and operation and maintenance. Again, both annual budgets and numbers of staff of American municipalities are larger than that of Canadian municipalities, but the relationship between the number of staff and annual budget may be nonlinear, especially for operation and maintenance.

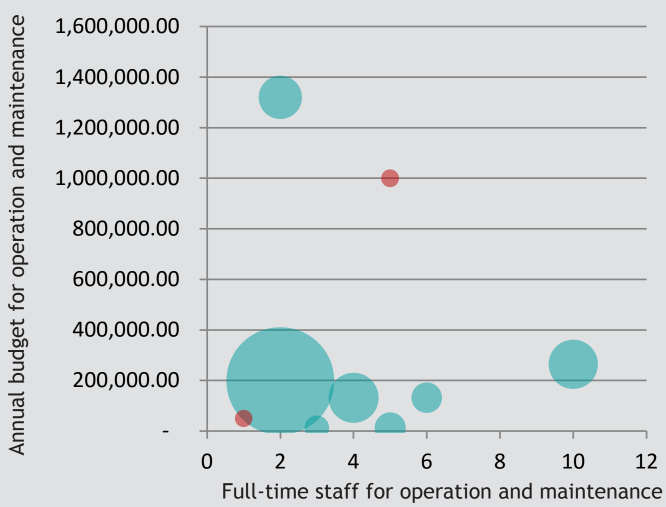
NUMBER OF FULL-TIME STAFF IN RELATION TO THE ANNUAL BUDGET FOR POLICY AND PLANNING



NUMBER OF FULL-TIME STAFF IN RELATION TO THE ANNUAL BUDGET FOR DESIGN AND CONSTRUCTION



NUMBER OF FULL-TIME STAFF IN RELATION TO THE ANNUAL BUDGET FOR OPERATION AND MAINTENANCE

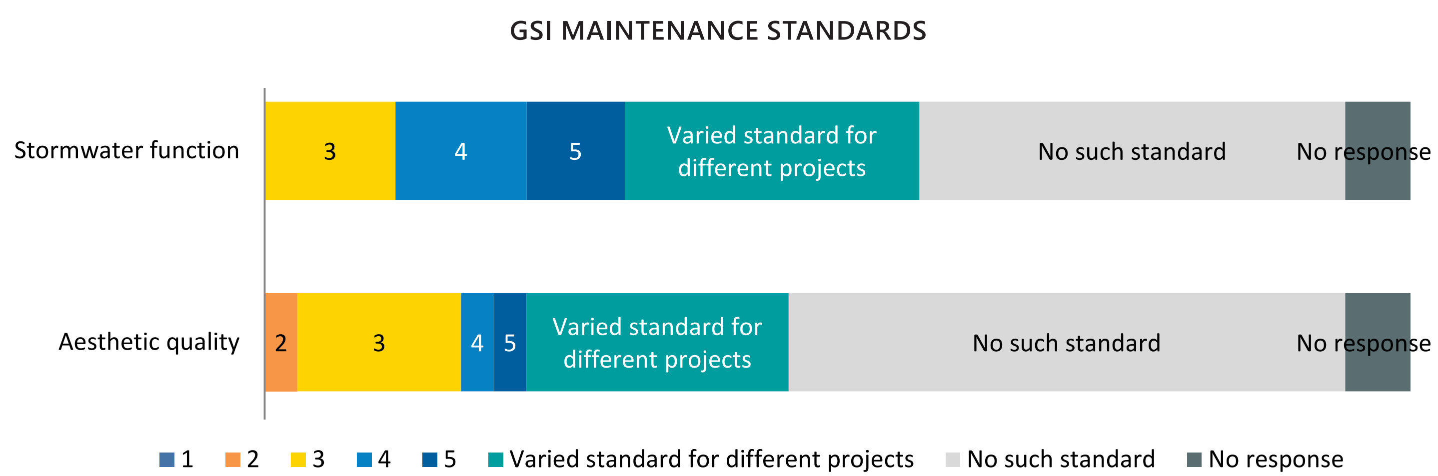


OPERATION AND MAINTENANCE PRACTICES

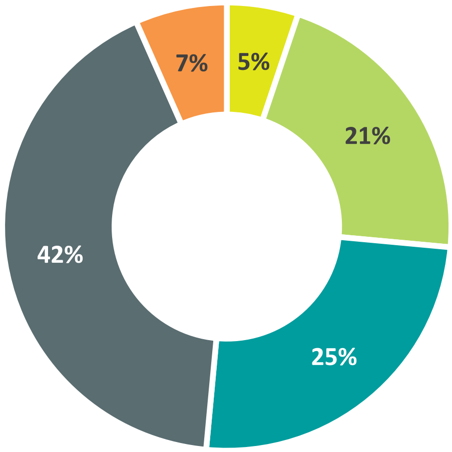
Some municipalities have maintenance standards to which they maintain their GSI treatments, such as standards for aesthetic quality and stormwater function. Municipalities were asked to rate their maintenance standards from 1=minimal quality or no function, to 5=excellent quality/function, or select a "varied standard for different projects" option. Among the 35 surveyed municipalities, almost half of them do not have a maintenance standard. 20 municipalities have stormwater function standards, as compared to 16 municipalities with aesthetic quality standards. Among municipalities with consistent standards across their GSI projects, the average score for stormwater quality standards (3.91) is higher than aesthetic quality standards (3.25).

Inspection and maintenance frequency is estimated by municipalities for each GSI treatment implemented on their city streets/plazas. Among various types of GSI treatments, more than 40% of them are inspected/maintained only on a complaint basis or receive almost no inspection/maintenance. About one quarter of them are inspected/maintained every 2-6 months, and about 20% of them are inspected/maintained every year. Some municipalities conduct seasonal inspection/maintenance, such as autumn leaf cleaning, summer irrigation, etc.

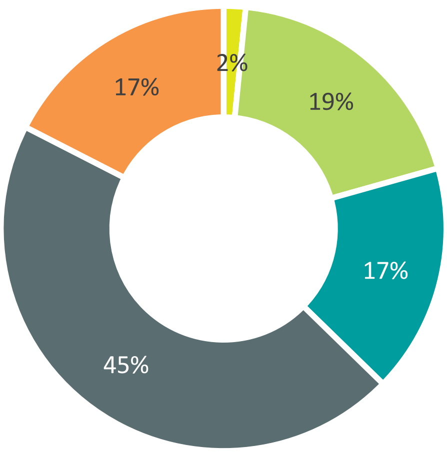
However, inspection/maintenance frequency varies significantly among different types of GSI treatments. For example, while most respondents indicated that their infiltration swales and trenches receive almost no inspection/maintenance, absorbent landscapes, rain gardens and water quality ponds are commonly inspected/maintained at least once every year. This is probably due to easy integration of these treatments with regular street landscaping maintenance.



INSPECTION FREQUENCY FOR GSI TREATMENTS

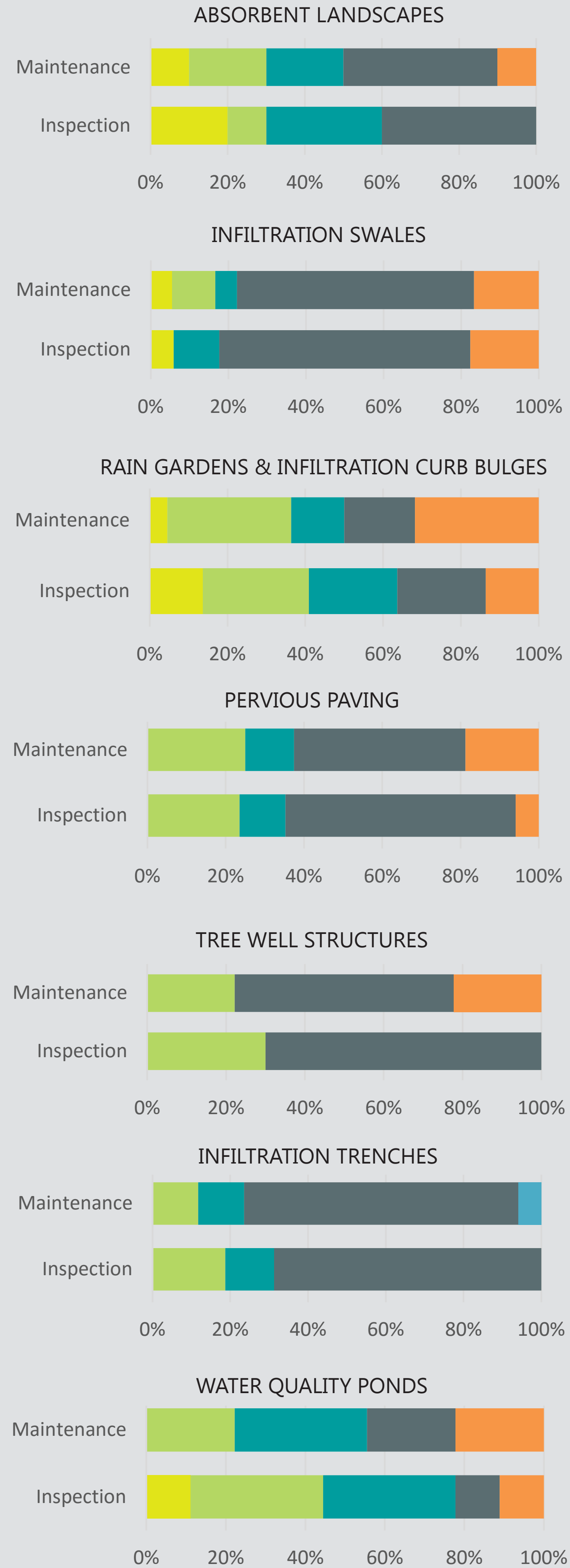


MAINTENANCE FREQUENCY FOR GSI TREATMENTS

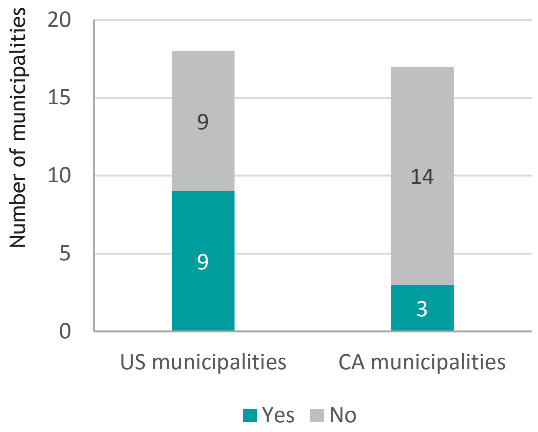


- Every month
- Every 2-6 months
- Every year
- Almost no inspection/maintenance or inspected/maintained on a complaint basis
- Seasonal or other

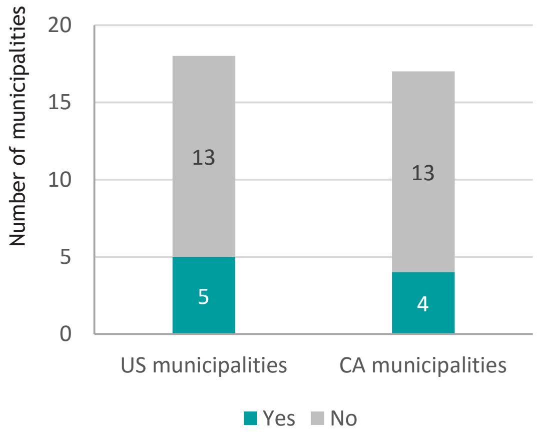
INSPECTION/MAINTENANCE FREQUENCY FOR VARIOUS GSI TREATMENTS



NUMBER OF MUNICIPALITIES WITH/WITHOUT A GSI STANDARD MAINTENANCE PROCEDURE/PROGRAM



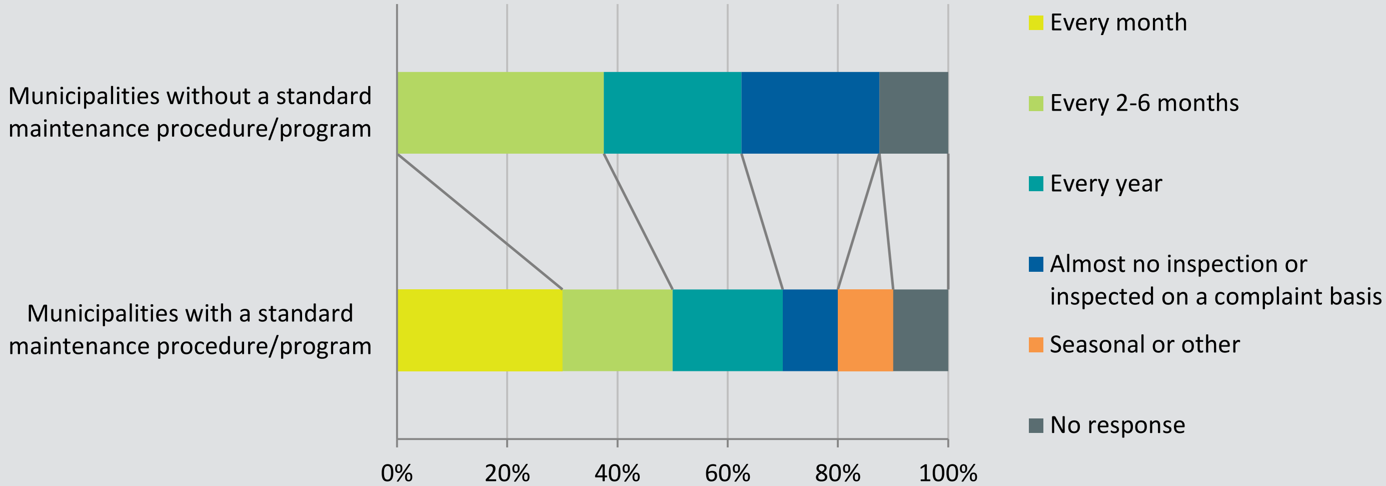
NUMBER OF MUNICIPALITIES WITH/WITHOUT A GSI PERFORMANCE MONITORING PLAN



Municipalities were asked whether they have documented standard maintenance procedures/programs for GSI on city streets/plazas. Currently only 12 out of 35 municipalities have such standard maintenance procedures/programs (9 American municipalities and 3 Canadian municipalities).

A documented maintenance procedure/ program will play an important role in assisting municipalities in establishing regular GSI maintenance practices. The inspection frequencies of 26 municipalities that utilize rain gardens and infiltration bulges on their city streets/plazas are analyzed. For municipalities without a maintenance procedure/program, approximately 40% of them inspect these assets once every 2-6 months, and 30% of them receive almost no inspection. For municipalities with a maintenance procedure/program, approximately 30% of them inspect their rain gardens/infiltration bulges once every month, and only 10% of them have almost no inspection of these treatments. Municipalities with a documented maintenance procedure/ program also tend to have more full-time

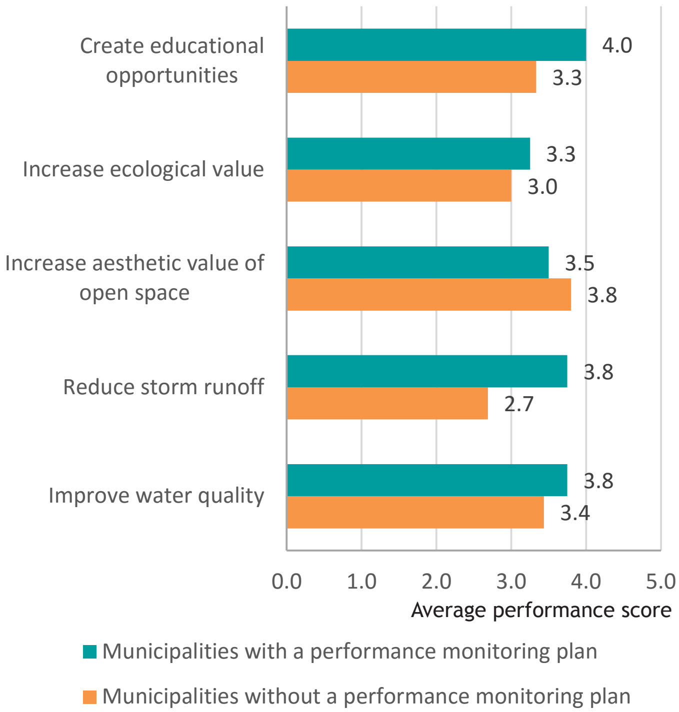
INSPECTION FREQENCY OF RAIN GARDENS/INFILTRATION BULGES BY MUNICIPALITIES WITH/ WITHOUT A GSI STANDARD MAINTENANCE PROCEDURE/PROGRAM



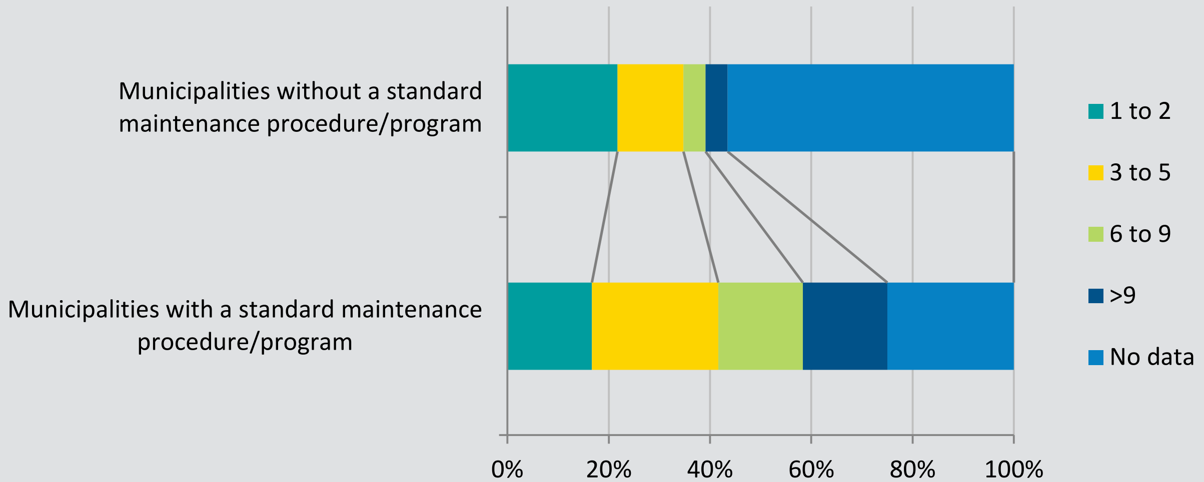
staff for the O&M of GSI treatments than those without a maintenance procedure/program. See the graph below comparing the number of full-time staff for O&M by municipalities with/without a maintenance procedure/program.

A performance monitoring plan could help municipalities to understand the performance, benefits and challenges of GSI in the long term. Only 9 out of 35 municipalities have a performance monitoring plan (5 American municipalities and 4 Canadian municipalities). This again demonstrates that GSI is a relatively new program for many municipalities and long-term maintenance and monitoring programs have not been established yet. The graph on the side of this page compares the performance of rain gardens and infiltration bulges among municipalities with and without a performance monitoring plan. With an exception of "increasing aesthetic value of open space", performance scores among municipalities with a performance monitoring plan are slightly higher than those without one for all of the other four aspects.

PERFORMANCE OF RAIN GARDENS/INFILTRATION BULGES BY MUNICIPALITIES WITH/WITHOUT A PERFORMANCE MONITORING PLAN

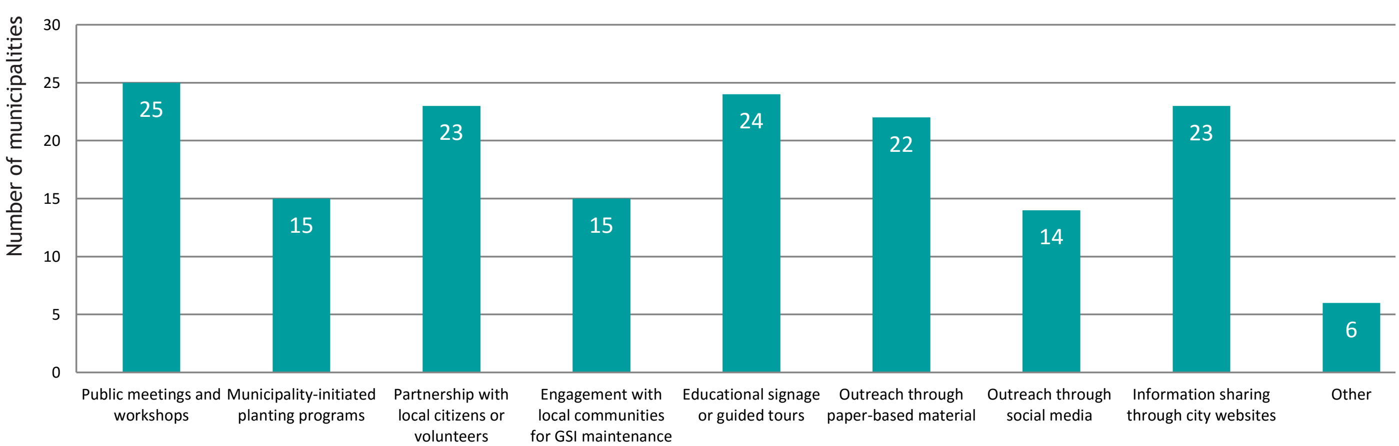


NUMBER OF FULL TIME STAFF FOR GSI O&M BY MUNICIPALITIES WITH/WITHOUT A GSI STANDARD MAINTENANCE PROCEDURE/PROGRAM



Public outreach is critical to GSI programs as public acceptance is very important for implementing GSI projects, and the public can play an important role for advocating for new projects and participating in GSI O&M. Over 90% of surveyed municipalities have some public engagement activities related to GSI. Municipalities employ a variety of public engagement activities in their GSI programs. Public meetings and workshops, educational signage or guided tours, partnerships with local citizen groups or volunteering programs, information sharing through city websites, and outreach through paper-based material are the most common tools/activities for public engagement. Engagement with local communities for GSI maintenance, municipality-initiated planting programs, and outreach through social media (e.g. Facebook and Twitter) are also used by many municipalities. Other activities specified by municipalities include door hanger brochures, EnviroScape Models, etc.

PUBLIC EDUCATION AND OUTREACH ACTIVITIES FOR GSI PROGRAMS



CONCLUSIONS AND LESSONS LEARNED

- According to the survey, GSI is a relatively new initiative, and many municipalities are in their early establishment stage of a GSI program, and plan to expand their projects/programs in the future. Overall, American municipalities have more advanced GSI programs than Canadian municipalities, likely due to regulatory requirements from the federal government to improve stormwater quality. More than 70% of surveyed American municipalities and 50% of surveyed Canadian municipalities have clear commitments to implementing GSI on streets/plazas, and many municipalities are working on GSI projects on a trial-and-error basis. The primary drivers for implementing GSI projects are stormwater volume control and water quality improvement.
- GSI includes a diverse range of treatments, and the most common GSI tools utilized by surveyed municipalities are rain gardens & infiltration bulges, pervious paving, infiltration trenches, and infiltration swales. GSI treatments vary significantly in terms of commonly implemented locations, performance, and challenges. There are trade-offs that need to be balanced for each treatment. For example, although water quality ponds perform better than many other treatments in terms of improving water quality, and increasing aesthetic/ecological value, they are associated with significant challenges as well (e.g. limited available land, significant construction and O&M costs).
- One common challenge shared by most surveyed municipalities for implementing GSI projects is the substantial capital and O&M costs associated with them. The limited available funding for GSI construction and O&M significantly restrains the opportunity for creating future projects and ensuring the performance/longevity of existing projects.

"We plan to continue identifying and utilizing opportunities to incorporate GSI into city projects, and for GSI in the public right-of-way as part of development agreements. We also plan to formalize policies and bylaws to require on-site stormwater management for developments, and for GSI on city projects. Supporting these initiatives, we have had citizen group advocacy and expect this to grow as a driver."

ADAM STEELE
FROM THE CITY OF VICTORIA

American municipalities have a much higher average annual budget for GSI than Canadian municipalities. Most of these budgets are allocated for the design and construction of GSI, while policy and planning, and operation and maintenance receive very limited budgets. This demonstrates that many municipalities are working on GSI projects on a trial-and-error basis without comprehensive planning, and O&M of GSI assets is an area that may be generally overlooked.

- Almost all surveyed municipalities plan to increase their budgets, or at least keep the current budgets, for GSI projects in the next 3 years. A variety of funding sources are currently employed by municipalities. American and Canadian municipalities have very different funding sources for GSI projects. While American municipalities commonly use stormwater utility charges and grants/funding from other levels of government, the primary funding sources for Canadian municipalities are property tax and funding from private developers or through development. Having secured funding sources for GSI projects will play a very important role in the construction and O&M of these projects.
- Another common challenge shared by most municipalities is the lack of maintenance for GSI assets. More than 40% of GSI assets in surveyed municipalities are inspected/maintained only on a complaint basis or receive almost no inspection/maintenance. Limited funding for O&M is a primary challenge and results in insufficient GSI maintenance. Additionally, a lack of experience with GSI O&M is another major barrier for municipalities to conduct GSI maintenance properly. Standardizing maintenance practices with maintenance programs/plans will be very helpful for the future O&M of GSI assets.
- Many municipalities have brought up the importance of multi-departmental collaboration on GSI projects. While most municipalities do not have a dedicated division/department for GSI programs, the Engineering/Public Works Department as well as the Planning Department are most commonly responsible for policy and planning of GSI projects, and the Engineering/Public Works Department

"Have dedicated staff and potentially specialized contract labor to perform O&M. Create tracking tools."

A SURVEY PARTICIPANT

Image from greeninfrastructureontario.org commonly plays a leading role in GSI design and construction. Many survey respondents suggested that all departments that are affected by GSI facilities should be involved in the early planning stages, and internal training of GSI among various departments is also very important.

- Public outreach with communities is critical to GSI programs/projects, as the public could play an important role for advocating for new projects, engaging with city initiatives/ projects, conducting GSI maintenance, etc. Over 90% of surveyed municipalities have some public engagement activities for GSI in a variety of formats, such as public meetings and workshops, info-sharing through websites, GSI guided tours, tree planting programs, etc. Many municipalities partner with local volunteering groups or engage with local property owners for GSI O&M.

> *"Involve all departments that may be affected by GSI facilities - streets and grounds, maintenance staff, planning staff, engineering staff, GIS staff. Provide plenty of internal training on what GSI means in your community."*
>
> **A SURVEY PARTICIPANT FROM THE CITY OF TACOMA**

Image by Seattle Public Utilities

LIFECYCLE COST ANALYSIS

Cost-effectiveness is one of the most important factors for municipalities in determining whether to adopt GSI in a local context. While there are case studies and models to estimate and compare capital costs and lifecycle costs of green and grey infrastructure, it is very important to note that cost-effectiveness will vary significantly based on a multitude of variables. These include scale of projects, costs of plant materials and survival rates, proximity to pollution sources, site preparation, necessary soil amendments, complexity of underdrain systems, and extent of maintenance (EPA, 2013). Understanding the local context, opportunities and constraints, developing and facilitating appropriate project design and implementation, and establishing effective maintenance programs will help to reduce lifecycle costs of GSI.

CAPITAL AND LIFECYCLE COST OVERVIEW

CAPITAL COSTS

Successfully implemented GSI projects around the world have demonstrated that utilizing GSI for rainwater management can be cost-effective if the project is well designed and implemented (American Rivers et al., 2012).

The US EPA conducted a cost analysis in 2007 of 17 LID projects across America. These projects include various types of LID practices, including bio-retention, swales, permeable pavement, vegetated landscaping, wetlands, etc. The research found that LID practices could be both fiscally and environmentally beneficial to communities, and the cost savings are primarily due to the reduced costs for site grading and preparation, stormwater infrastructure, site paving, etc. Total capital cost savings range from 15-80% when LID methods were used (EPA, 2007).

COST COMPARISON FOR THE SEA STREET PROJECT, SEATTLE

- Actual project cost: $651,548;
- Equivalent grey infrastructure cost: $868,803;

(Reduced costs largely due to avoided costs for stormwater infrastructure and reduced site paving)

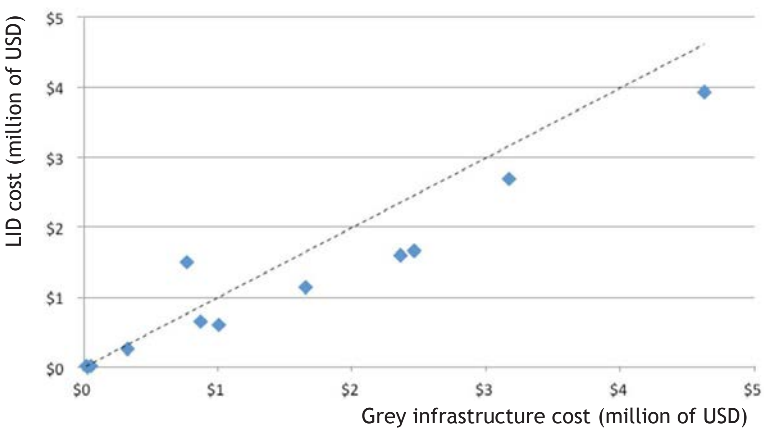
Data source: Seattle Public Utilities

However, capital costs for municipal GSI projects in their pilot phase may be higher than grey infrastructure projects. This could be explained by the lack of experience in GSI design and implementation, or economy of scale. For example, in 2006, when the Chicago Green Alley Program began, the city paid about $145 per cubic yard of permeable concrete. Just one year later, the cost of permeable concrete had dropped to only $45 per cubic yard, which is comparable to the cost of traditional concrete ($50 per cubic yard) (Lukes & Kloss, 2008).

Different types of GSI treatments vary significantly in terms of construction cost per square foot of treatment. Appendix 3 includes cost information of completed GSI projects by types of treatments. It includes area/length of GSI treatments completed, drainage area, project costs (e.g. costs for planning and design, project management, construction), and construction costs per unit area/length or drainage area.

COST COMPARISON BETWEEN CONVENTIONAL AND LID APPROACHES

Project	Conventional Development Cost	LID Cost	Cost Difference[b]	Percent Difference[b]
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington Estates	$765,700	$1,502,900	–$737,200	-96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[c]	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%



A comparison of costs for LID projects and their equivalent grey infrastructure counterparts. For projects below the dotted line, costs for LID are lower than their equivalent grey infrastructure counterparts. It shows that, with only one exception, most of these LID projects are more cost-effective than equivalent grey infrastructure (Image from: American Rivers et al., 2012; data source: US EPA. 2007)

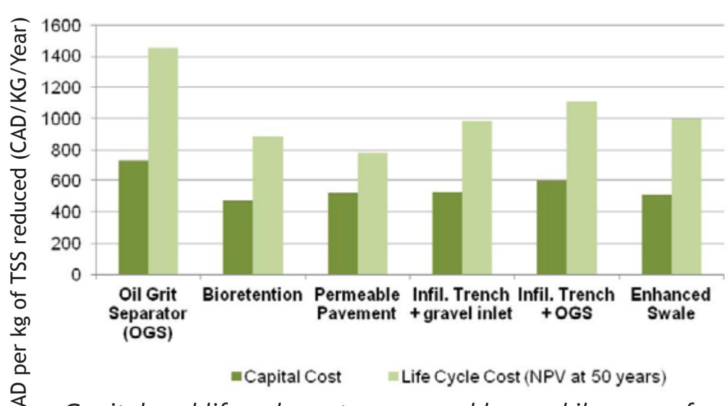
LIFECYCLE COSTS

Estimating lifecycle costs of GSI is very important for understanding the cost-effectiveness of these assets, and establishing an effective long-term maintenance program.

Although GSI projects continue to increase across North America, not much data on maintenance activities and costs across their lifecycle is available. This imposes a major barrier for municipalities to implement GSI projects due to the uncertainties about maintenance practices and costs.

Currently, some municipalities and organizations have started to estimate maintenance costs for GSI projects, and it was found that GSI practices could have lower long-term lifecycle costs, perform better, and provide more benefits than conventional grey infrastructure (EPA, 2012). Several models are currently available to estimate the costs of GSI treatments throughout their whole lifespan.

- In 2009, the Water Environment Research Foundation (WERF) collaborated with the US EPA to develop spreadsheet tools to estimate lifecycle costs of GSI. This tool enables users to estimate maintenance cost and the whole life cost of a GSI treatment through inputting basic information (e.g. drainage area, size of the treatment, design/maintenance options and discount rate). This tool estimates lifecycle costs for various treatments including permeable pavements, green roofs, cisterns, rain gardens, curb-contained bio-retention, and in-curb planter vaults. When estimating capital and maintenance costs, this tool gives users the flexibility to select different maintenance levels (high/medium/low), installation types (self/volunteer or professional) and other parameters. The model provides a quick reference for municipalities to estimate maintenance and lifecycle costs for potential GSI treatments.
- BMP-REALCOST is another spreadsheet-based tool, and it was developed by the Urban Drainage and Flood Control District in Denver, Colorado. This tool is designed to assist engineers, planners, developers, consultants and decision makers in determining lifecycle costs and effectiveness of structural stormwater runoff Best Management Practices (BMPs) (Olson et al., 2010). This tool allows for cost estimations for the construction, engineering, administration, and maintenance of potential BMPs.
- The Toronto and Region Conservation has developed a report on lifecycle costs for LID stormwater management practices (e.g. bio-retention cells, permeable pavement, infiltration trenches) over a 25-year and 50-year time horizon. Model designs were developed for up to 3 typical variations (full infiltration, partial infiltration and no infiltration) for each LID treatment, assuming a 2,000 m^2 paved and/or roof drainage area. Whole lifecycle costs were calculated for LID treatments. It demonstrated that capital costs of LID are between 24% and 44% lower than conventional oil grit separator



Capital and lifecycle costs expressed by per kilogram of total suspended solids (TSS) load reduced (Image from Toronto and Region Conservation, 2013)

(OGS) treatment, while lifecycle costs of LID practices are between 35% and 77% less than conventional OGS treatments (Toronto and Region Conservation, 2013).

- Some researchers and organizations have conducted research on lifecycle costs of GSI as compared to conventional grey infrastructure. For example, the Conservation Research Institute compared the costs for native landscaping for on-site stormwater management with those for conventional landscaping of turf grass lawns. They found that installation costs for natural landscaping can be between $4,400 and $8,850 cheaper per acre than for turf grass approaches. Maintenance costs for native landscaping range between $3,950 and $4,583 less annually per acre over the turf grass approach (Conservation Research Institute, 2005). Another study has found that green infrastructure is generally as effective as grey infrastructure in terms of removing pollutants and reducing peak flows, but costs about 5-30% less to construct and about 25% less over its full lifecycle compared with grey infrastructure (Jaffe et al., 2010).

COSTS PER SQUARE FOOT OF TREATMENT CONSTRUCTED USED IN THIS CALCULATION

Bio-swale: 50 CAD/sq. foot

Rain garden: 20 CAD/sq. foot

Permeable pavement: 15 CAD/sq. foot

LIFECYCLE COST ESTIMATION

In this report, lifecycle costs for three selected GSI treatments are estimated, including rain gardens, bio-swales and pervious pavements. Cost information and data is identified based on literature review, case studies and personal interviews.

Capital costs are calculated based on construction cost per square foot of GSI treatment constructed. A 15% soft cost is assumed for project management and other overhead costs.

Once capital costs are determined, annual regular maintenance costs and corrective maintenance costs can be determined based on the WERF tool. Corrective costs include infrequent maintenance activities that are not conducted every year. Lifecycle costs for rain gardens and bio-swales are estimated based on an evaluation period of 50 years, which is typical of the time span over which infrastructure decisions are made (Uda et al., 2013). The lifecycle costs for pervious pavements are estimated based on an evaluation period of 35 years, assuming the paving will have to be repaved/reinstalled by then. All the calculations are conducted in Canadian dollars, 2016 value with a discount rate of 3%.

$$PV = FC/(1 + r)^n$$

where,

PV = present value

FV = future value

r = discount rate

n = year of future cost

A rain garden along Blenheim St., Vancouver

In the City of Vancouver, the construction cost for a typical 200 sq. ft. rain garden is about $10,000-$20,000, which is $50-$100 per square foot. The estimated annual maintenance cost for a typical rain garden is $300-$500 ($1.50-$2.50 per square foot) depending on the extent of the maintenance. For comparison, the construction cost for normal landscaping is about $7.90 per square foot in the City of Vancouver.

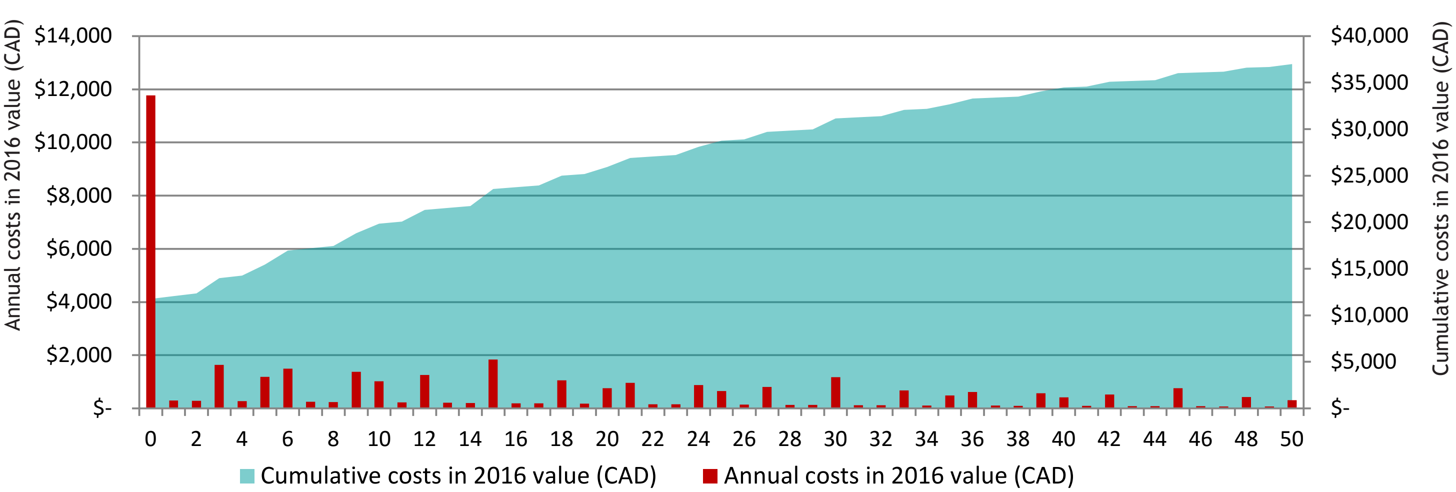
RAIN GARDENS

Assuming a construction cost per square foot of $20, the total construction cost for a 500 sq. feet rain garden will be $10,000. The capital cost will be $11,765, which includes a 15% soft cost. According to the WERF tool, the cost for annual routine maintenance is $309 for vegetation management. Corrective maintenance activities include replacing mulch every 3 years at a cost of $1,480, and tilling soil every 5 years at a cost of $1,066.

Based on these assumptions, a 50-year lifecycle cost can be calculated. Regular and corrective maintenance costs are calculated for each year, and are converted to 2016 value. The cumulative cost for the 50-year lifecycle of this rain garden is $36,992.

Capital Cost (CAD)	Cost for Annual Routine Maintenance (CAD)	Infrequent Maintenance Activity 1			Infrequent Maintenance Activity 2		
		Activity	Cost (CAD)	Frequency (Year)	Activity	Cost (CAD)	Frequency (Year)
11,765	309	Replace Mulch	1,480	3	Till Soil	1,066	5

LIFECYCLE COST OF A 500 SQ. FEET RAIN GARDEN



Year	Capital Cost (CAD)	Regular Maint. Costs (CAD)	Corrective Maint. Costs (CAD)	Total Costs (CAD)	Total Costs in 2016 Value (CAD)	Cumulative Costs in 2016 Value (CAD)
0	$ 11,765			$ 11,765	$ 11,765	**$ 11,765**
1	$ -	$ 309	$ -	$ 309	$ 300	**$ 12,065**
2	$ -	$ 309	$ -	$ 309	$ 292	**$ 12,357**
3	$ -	$ 309	$ 1,480	$ 1,790	$ 1,638	**$ 13,994**
4	$ -	$ 309	$ -	$ 309	$ 275	**$ 14,269**
5	$ -	$ 309	$ 1,066	$ 1,376	$ 1,187	**$ 15,456**
6	$ -	$ 309	$ 1,480	$ 1,790	$ 1,499	**$ 16,955**
7	$ -	$ 309	$ -	$ 309	$ 252	**$ 17,206**
8	$ -	$ 309	$ -	$ 309	$ 244	**$ 17,450**
9	$ -	$ 309	$ 1,480	$ 1,790	$ 1,372	**$ 18,822**
10	$ -	$ 309	$ 1,066	$ 1,376	$ 1,024	**$ 19,846**
11	$ -	$ 309	$ -	$ 309	$ 223	**$ 20,069**
12	$ -	$ 309	$ 1,480	$ 1,790	$ 1,255	**$ 21,324**
13	$ -	$ 309	$ -	$ 309	$ 211	**$ 21,535**
14	$ -	$ 309	$ -	$ 309	$ 205	**$ 21,739**
15	$ -	$ 309	$ 2,546	$ 2,856	$ 1,833	**$ 23,572**
16	$ -	$ 309	$ -	$ 309	$ 193	**$ 23,765**
17	$ -	$ 309	$ -	$ 309	$ 187	**$ 23,952**
18	$ -	$ 309	$ 1,480	$ 1,790	$ 1,051	**$ 25,004**
19	$ -	$ 309	$ -	$ 309	$ 176	**$ 25,180**
20	$ -	$ 309	$ 1,066	$ 1,376	$ 762	**$ 25,942**
21	$ -	$ 309	$ 1,480	$ 1,790	$ 962	**$ 26,904**
22	$ -	$ 309	$ -	$ 309	$ 161	**$ 27,065**
23	$ -	$ 309	$ -	$ 309	$ 157	**$ 27,222**
24	$ -	$ 309	$ 1,480	$ 1,790	$ 880	**$ 28,102**
25	$ -	$ 309	$ 1,066	$ 1,376	$ 657	**$ 28,759**
26	$ -	$ 309	$ -	$ 309	$ 143	**$ 28,903**
27	$ -	$ 309	$ 1,480	$ 1,790	$ 806	**$ 29,708**
28	$ -	$ 309	$ -	$ 309	$ 135	**$ 29,844**
29	$ -	$ 309	$ -	$ 309	$ 131	**$ 29,975**
30	$ -	$ 309	$ 2,546	$ 2,856	$ 1,177	**$ 31,151**
31	$ -	$ 309	$ -	$ 309	$ 124	**$ 31,275**
32	$ -	$ 309	$ -	$ 309	$ 120	**$ 31,395**
33	$ -	$ 309	$ 1,480	$ 1,790	$ 675	**$ 32,070**
34	$ -	$ 309	$ -	$ 309	$ 113	**$ 32,183**
35	$ -	$ 309	$ 1,066	$ 1,376	$ 489	**$ 32,672**
36	$ -	$ 309	$ 1,480	$ 1,790	$ 617	**$ 33,290**
37	$ -	$ 309	$ -	$ 309	$ 104	**$ 33,393**
38	$ -	$ 309	$ -	$ 309	$ 101	**$ 33,494**
39	$ -	$ 309	$ 1,480	$ 1,790	$ 565	**$ 34,059**
40	$ -	$ 309	$ 1,066	$ 1,376	$ 422	**$ 34,481**
41	$ -	$ 309	$ -	$ 309	$ 92	**$ 34,573**
42	$ -	$ 309	$ 1,480	$ 1,790	$ 517	**$ 35,090**
43	$ -	$ 309	$ -	$ 309	$ 87	**$ 35,177**
44	$ -	$ 309	$ -	$ 309	$ 84	**$ 35,261**
45	$ -	$ 309	$ 2,546	$ 2,856	$ 755	**$ 36,016**
46	$ -	$ 309	$ -	$ 309	$ 79	**$ 36,095**
47	$ -	$ 309	$ -	$ 309	$ 77	**$ 36,173**
48	$ -	$ 309	$ 1,480	$ 1,790	$ 433	**$ 36,606**
49	$ -	$ 309	$ -	$ 309	$ 73	**$ 36,678**
50	$ -	$ 309	$ 1,066	$ 1,376	$ 314	**$ 36,992**

In the City of Vancouver, the construction cost for bio-swales is about $3.25-$7.90 per square foot. The annual maintenance cost for the bio-swale along Ontario Street is about $0.58 per square foot. For comparison, the construction cost for a sod boulevard is about $4.77 per square foot in the City of Vancouver.

BIO-SWALES

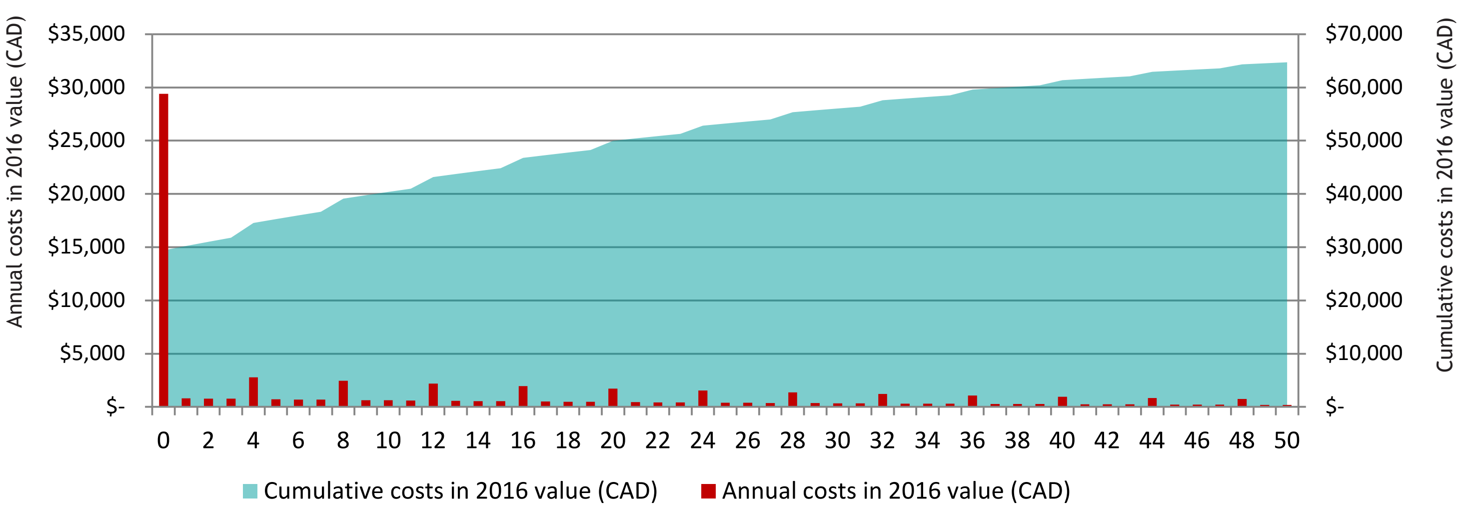
Assuming a construction cost per square foot of $50, the total construction cost for a 500 sq. feet bio-swale will be $25,000. The capital cost will be $29,412, which includes a 15% soft cost. According to the WERF tool, the cost for annual routine maintenance is $836 for vegetation management, trash/debris removal and inspection, and reporting and information management. Corrective maintenance activities are required every 4 years at a cost of $2,285.

Calculations are conducted based on these assumptions, and the cumulative cost for the 50-year lifecycle of this bio-swale is $64,720.

Bio-swales along Crown St. in Vancouver with a series of retention ponds for infiltration instead of a granular sub-base media.

Capital Cost (CAD)	Cost for Annual Routine Maintenance (CAD)	Infrequent Maintenance Activity	
		Cost (CAD)	Frequency (Year)
29,412	836	2,285	4

LIFECYCLE COST OF A 500 SQ. FEET BIO-SWALE



Year	Capital Cost (CAD)	Regular Maint. Costs (CAD)	Corrective Maint. Costs (CAD)	Total Costs (CAD)	Total Costs in 2016 Value (CAD)	Cumulative Costs in 2016 Value (CAD)
0	$ 29,412			$ 29,412	$ 29,412	**$ 29,412**
1	$ -	$ 836	$ -	$ 836	$ 812	**$ 30,223**
2	$ -	$ 836	$ -	$ 836	$ 788	**$ 31,011**
3	$ -	$ 836	$ -	$ 836	$ 765	**$ 31,776**
4	$ -	$ 836	$ 2,285	$ 3,121	$ 2,773	**$ 34,549**
5	$ -	$ 836	$ -	$ 836	$ 721	**$ 35,270**
6	$ -	$ 836	$ -	$ 836	$ 700	**$ 35,970**
7	$ -	$ 836	$ -	$ 836	$ 680	**$ 36,650**
8	$ -	$ 836	$ 2,285	$ 3,121	$ 2,463	**$ 39,114**
9	$ -	$ 836	$ -	$ 836	$ 641	**$ 39,754**
10	$ -	$ 836	$ -	$ 836	$ 622	**$ 40,376**
11	$ -	$ 836	$ -	$ 836	$ 604	**$ 40,980**
12	$ -	$ 836	$ 2,285	$ 3,121	$ 2,189	**$ 43,169**
13	$ -	$ 836	$ -	$ 836	$ 569	**$ 43,738**
14	$ -	$ 836	$ -	$ 836	$ 553	**$ 44,291**
15	$ -	$ 836	$ -	$ 836	$ 537	**$ 44,828**
16	$ -	$ 836	$ 2,285	$ 3,121	$ 1,945	**$ 46,772**
17	$ -	$ 836	$ -	$ 836	$ 506	**$ 47,278**
18	$ -	$ 836	$ -	$ 836	$ 491	**$ 47,769**
19	$ -	$ 836	$ -	$ 836	$ 477	**$ 48,246**
20	$ -	$ 836	$ 2,285	$ 3,121	$ 1,728	**$ 49,974**
21	$ -	$ 836	$ -	$ 836	$ 449	**$ 50,423**
22	$ -	$ 836	$ -	$ 836	$ 436	**$ 50,859**
23	$ -	$ 836	$ -	$ 836	$ 424	**$ 51,283**
24	$ -	$ 836	$ 2,285	$ 3,121	$ 1,535	**$ 52,818**
25	$ -	$ 836	$ -	$ 836	$ 399	**$ 53,217**
26	$ -	$ 836	$ -	$ 836	$ 388	**$ 53,605**
27	$ -	$ 836	$ -	$ 836	$ 376	**$ 53,981**
28	$ -	$ 836	$ 2,285	$ 3,121	$ 1,364	**$ 55,345**
29	$ -	$ 836	$ -	$ 836	$ 355	**$ 55,700**
30	$ -	$ 836	$ -	$ 836	$ 344	**$ 56,045**
31	$ -	$ 836	$ -	$ 836	$ 334	**$ 56,379**
32	$ -	$ 836	$ 2,285	$ 3,121	$ 1,212	**$ 57,591**
33	$ -	$ 836	$ -	$ 836	$ 315	**$ 57,906**
34	$ -	$ 836	$ -	$ 836	$ 306	**$ 58,212**
35	$ -	$ 836	$ -	$ 836	$ 297	**$ 58,509**
36	$ -	$ 836	$ 2,285	$ 3,121	$ 1,077	**$ 59,586**
37	$ -	$ 836	$ -	$ 836	$ 280	**$ 59,866**
38	$ -	$ 836	$ -	$ 836	$ 272	**$ 60,138**
39	$ -	$ 836	$ -	$ 836	$ 264	**$ 60,402**
40	$ -	$ 836	$ 2,285	$ 3,121	$ 957	**$ 61,358**
41	$ -	$ 836	$ -	$ 836	$ 249	**$ 61,607**
42	$ -	$ 836	$ -	$ 836	$ 242	**$ 61,849**
43	$ -	$ 836	$ -	$ 836	$ 235	**$ 62,083**
44	$ -	$ 836	$ 2,285	$ 3,121	$ 850	**$ 62,933**
45	$ -	$ 836	$ -	$ 836	$ 221	**$ 63,154**
46	$ -	$ 836	$ -	$ 836	$ 215	**$ 63,369**
47	$ -	$ 836	$ -	$ 836	$ 208	**$ 63,577**
48	$ -	$ 836	$ 2,285	$ 3,121	$ 755	**$ 64,332**
49	$ -	$ 836	$ -	$ 836	$ 196	**$ 64,529**
50	$ -	$ 836	$ -	$ 836	$ 191	**$ 64,720**

In the City of Vancouver, the construction cost for permeable asphalt is about $24.25 per square foot. The construction costs for permeable country lanes range from $18.03 to $47.58 per square foot. For comparison, the construction cost of a standard laneway with subbase is about $14.13 per square foot, and that of a standard laneway with grind & 2" overlay is about $2.52 per square foot.

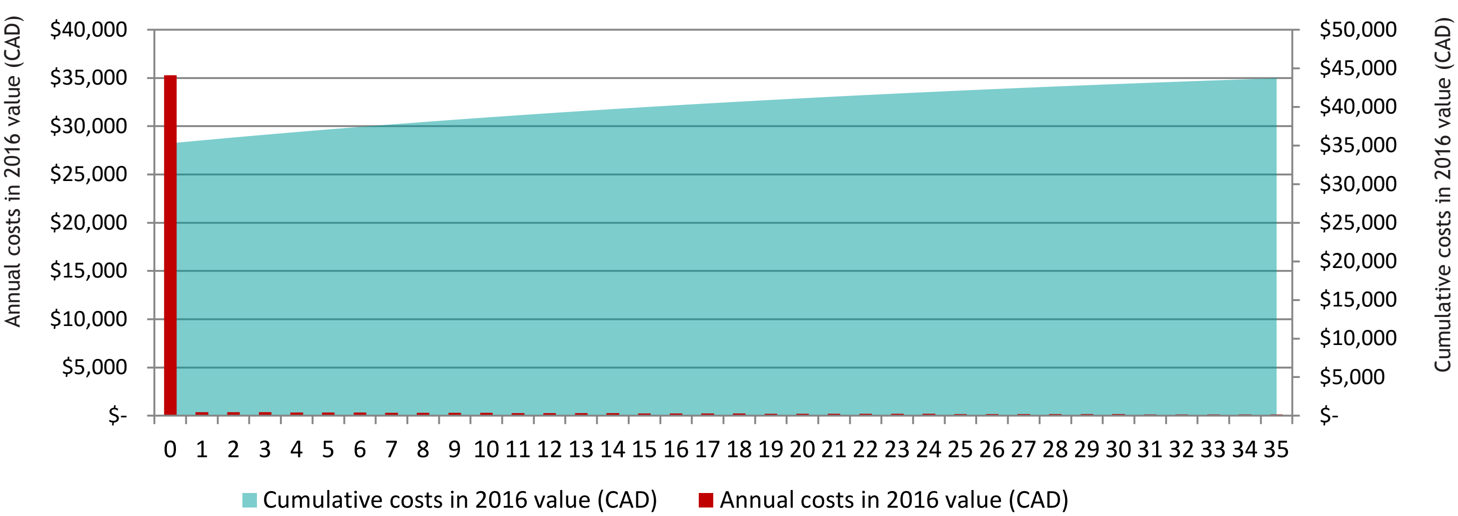
Permeable laneway, Vancouver

PERMEABLE PAVEMENTS

Assuming a construction cost per square foot of $15, the total construction cost for a 2,000 sq. feet permeable pavement area will be $30,000. The capital cost will be $35,294, which includes a 15% soft cost. According to the WERF tool, the cost for annual routine maintenance is $392, which includes sweeping, trash/debris removal, and inspection, reporting and information management.

Calculations are conducted based on these assumptions, and the cumulative cost for the 35-year lifecycle of this permeable pavement area is $43,717.

LIFECYCLE COST OF A 2,000 SQ. FEET PERMEABLE PAVEMENT AREA



Year	Capital Cost (CAD)	Regular Maint. Costs (CAD)	Corrective Maint. Costs (CAD)	Total Costs (CAD)	Total Costs in 2016 Value (CAD)	Cumulative Costs in 2016 Value (CAD)
0	$ 35,294			$ 35,294	$ 35,294	**$ 35,294**
1	$ -	$ 392	$ -	$ 392	$ 381	**$ 35,675**
2	$ -	$ 392	$ -	$ 392	$ 369	**$ 36,044**
3	$ -	$ 392	$ -	$ 392	$ 359	**$ 36,403**
4	$ -	$ 392	$ -	$ 392	$ 348	**$ 36,751**
5	$ -	$ 392	$ -	$ 392	$ 338	**$ 37,089**
6	$ -	$ 392	$ -	$ 392	$ 328	**$ 37,418**
7	$ -	$ 392	$ -	$ 392	$ 319	**$ 37,736**
8	$ -	$ 392	$ -	$ 392	$ 309	**$ 38,046**
9	$ -	$ 392	$ -	$ 392	$ 300	**$ 38,346**
10	$ -	$ 392	$ -	$ 392	$ 292	**$ 38,638**
11	$ -	$ 392	$ -	$ 392	$ 283	**$ 38,921**
12	$ -	$ 392	$ -	$ 392	$ 275	**$ 39,196**
13	$ -	$ 392	$ -	$ 392	$ 267	**$ 39,463**
14	$ -	$ 392	$ -	$ 392	$ 259	**$ 39,722**
15	$ -	$ 392	$ -	$ 392	$ 252	**$ 39,974**
16	$ -	$ 392	$ -	$ 392	$ 244	**$ 40,218**
17	$ -	$ 392	$ -	$ 392	$ 237	**$ 40,455**
18	$ -	$ 392	$ -	$ 392	$ 230	**$ 40,685**
19	$ -	$ 392	$ -	$ 392	$ 224	**$ 40,909**
20	$ -	$ 392	$ -	$ 392	$ 217	**$ 41,126**
21	$ -	$ 392	$ -	$ 392	$ 211	**$ 41,337**
22	$ -	$ 392	$ -	$ 392	$ 205	**$ 41,541**
23	$ -	$ 392	$ -	$ 392	$ 199	**$ 41,740**
24	$ -	$ 392	$ -	$ 392	$ 193	**$ 41,933**
25	$ -	$ 392	$ -	$ 392	$ 187	**$ 42,120**
26	$ -	$ 392	$ -	$ 392	$ 182	**$ 42,302**
27	$ -	$ 392	$ -	$ 392	$ 176	**$ 42,478**
28	$ -	$ 392	$ -	$ 392	$ 171	**$ 42,650**
29	$ -	$ 392	$ -	$ 392	$ 166	**$ 42,816**
30	$ -	$ 392	$ -	$ 392	$ 161	**$ 42,977**
31	$ -	$ 392	$ -	$ 392	$ 157	**$ 43,134**
32	$ -	$ 392	$ -	$ 392	$ 152	**$ 43,287**
33	$ -	$ 392	$ -	$ 392	$ 148	**$ 43,434**
34	$ -	$ 392	$ -	$ 392	$ 143	**$ 43,578**
35	$ -	$ 392		$ 392	$ 139	**$ 43,717**

It should be noted that capital and lifecycle costs will vary significantly based on multiple factors such as soil conditions, plant survival rates, design strategies, etc. The calculation above is a general estimate of project costs, with the actual costs being very dependent on site conditions and design/management strategies.

Additionally, the cost estimation above only includes construction and maintenance costs for GSI, but does not consider many of the benefits these treatments have over traditional grey infrastructure (e.g. improving water/air quality, increasing ecological/aesthetic value, providing educational opportunities). These factors are difficult to be quantified, but are very important and should be included in evaluating cost-effectiveness of GSI treatments. A more comprehensive cost-effectiveness estimation to compare costs and benefits of green and grey infrastructure would be very helpful in the future.

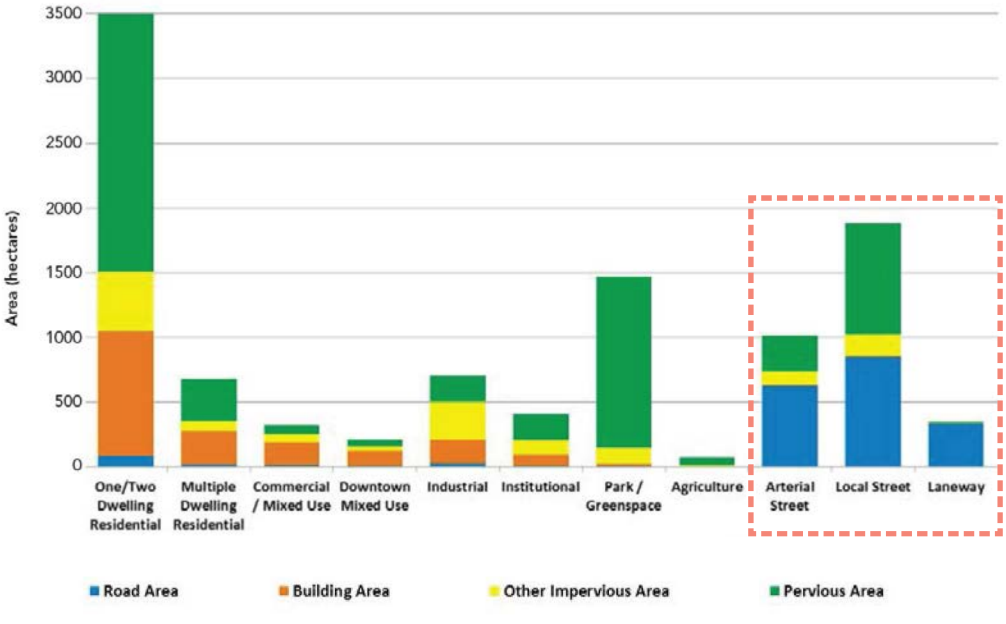
GSI IN THE CITY OF VANCOUVER

OVERVIEW

The City of Vancouver is a highly urbanized area with a large number of impervious surfaces. Implementing GSI will bring about significant environmental and social benefits, including reducing rainwater runoff, improving water quality, and creating recreational opportunities.

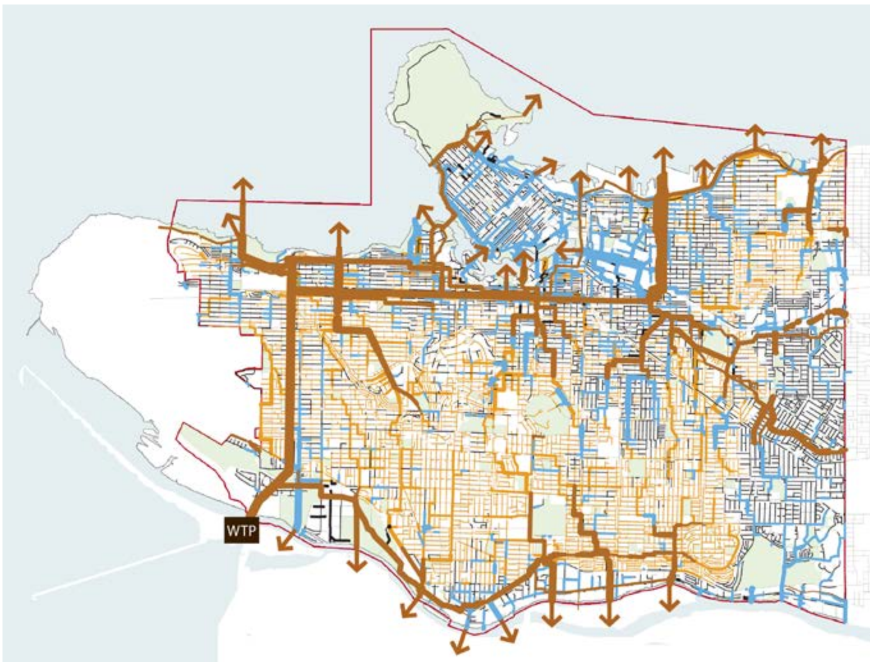
In the City of Vancouver, arterial streets, local streets and laneways account for about 30% of total land use area. The bar graph below displays a breakdown of each land use type including pervious and impervious areas, with most arterial/ local streets and laneways being impervious areas. Therefore, implementing green infrastructure on streets/lanes would play an important role in reducing rainwater runoff and protecting the nearby receiving waterbodies in the City of Vancouver.

AREAS OF LAND USE TYPOLOGIES IN THE CITY OF VANCOUVER

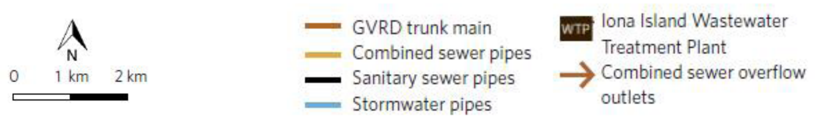


In some areas of the City of Vancouver, a combined sewer system carries both sanitary water and stormwater into wastewater treatment plants. This system may generate combined sewer overflow in times of extreme rain events and result in pollution of nearby waterbodies. Other areas of the city are served by separated sewer systems, with only sanitary water flowing into treatment plants, and stormwater flowing into a separate system to nearby waterbodies.

The City of Vancouver is working towards the Province of BC's environmental goal to eliminate sewage overflows by 2050. The combined sewer separation program is currently in progress. The city has so far completed sewer separation in multiple neighbourhoods accounting for approximately half of the total city area, including Downtown, the West End, Fairview, Hastings, Killarney, Mt. Pleasant, Renfrew, Burrard Inlet and Fraser River shorelines.



Sewer systems in the City of Vancouver



PLANNING CONTEXT

Environment Canada and Fisheries and Oceans Canada have developed guidelines for urban runoff. Green infrastructure, as a climate change adaptation measure, is also supported by Environment Canada's *Canadian Communities Guidebook for Adaptation to Climate Change*, which promotes adaptation measures that will generate co-benefits that contribute to climate change mitigation.

The Province of BC also sets requirements for the protection of the environment and public health, with the Minister of the Environment having approved a regional *Integrated Liquid Waste and Resource Management Plan* for Metro Vancouver. The Metro Vancouver *Stormwater Source Control Design Guidelines* was also developed for landscape-based solutions for managing stormwater, including design and sizing tools for absorbent landscapes, rain gardens, pervious pavers, infiltration swale systems, etc.

The City of Vancouver, along with other members of Metro Vancouver, is committed to creating and monitoring Integrated Stormwater Management Plans. The city has recently adopted the Citywide *Integrated Rainwater Management Plan* in April 2016. There are also other plans and policies to encourage sustainable rainwater management and the implementation of GSI.

INTEGRATED RAINWATER MANAGEMENT PLAN

The Citywide *Integrated Rainwater Management Plan* (IRMP) has a long-term Green Infrastructure Strategy to protect and improve water quality of receiving waterbodies surrounding Vancouver. This plan will treat Vancouver's abundant rainwater as a resource, reduce the demand for potable water, and restore the role of urban watersheds to support urban and natural ecosystems.

In Vancouver, about 70% of total rainfall volume in an average year comes from light showers to small storms, while about 20% comes from large storms. Only 10% of the total rainfall volume comes from extreme storms that may result in widespread flooding. IRMP includes targets to capture and treat Vancouver's rainfall by implementing GSI tools and design guidelines on public and private property throughout the city:

- The **Water Volume Reduction Target** is to soak up the first 24 mm of rainfall in a day (representing about 70% of the average annual rainfall volume), and the objective is to infiltrate this rainwater where it lands, providing both the benefits of water quality and reduced runoff.

- The **Water Quality Treatment Target** includes both the first and second 24 mm of rainfall in a day - to a total of 48 mm a day (representing about 90% of the average annual rainfall volume). The objective is to improve water quality of the rainwater near where it lands, as well as to maximize the time available for rainwater to soak into the subsoils.
- For rare extreme rain events, the objective is to safely convey rainwater runoff to outlets through pipes, gutters and other channels.

STRATEGIES FOR LANES, LOCAL STREETS, AND COLLECTOR/ARTERIAL STREETS IDENTIFIED IN THE CITYWIDE IRMP

Lanes

- Design new homes for no runoff from private parcel to lane.
- Implement regular lane vacuum sweeping and catch basin cleaning in sewer-separated areas.
- When resurfacing, meet water quality (but not necessarily water volume) targets by installing Green Infrastructure associated with resurfacing.

Local Streets

- Meet water quality and volume reduction targets.
- Provide flexibility to use several Green Infrastructure tools or combinations.
- Undertake neighbourhood consultation and involvement in design, as well as in operations and maintenance.

Collector/Arterial Streets

- Meet water quality targets. Due to space constraints, it may be necessary to consider gray infrastructure for limited water quality treatment.

GREENEST CITY 2020 ACTION PLAN

The *Greenest City 2020 Action Plan* was initiated in 2009 with the aim to make Vancouver the greenest city in the world by 2020. The plan sets a course towards realizing a healthy, prosperous, and resilient future for the City of Vancouver. The *Clean Water* goal in the plan encourages protecting local receiving waters as important habitats and providing recreational opportunities for residents. Actions include separating combined sewer systems, and administering municipal and regional liquid waste source control by-laws and programs. The *Access to Nature* goal of the plan aims to provide residents with more convenient access to green spaces. GSI will help to support both *Clean Water* and *Access to Nature* goals by improving rainwater quality, creating ecological habitats, increasing recreational opportunities, etc.

CLIMATE CHANGE ADAPTATION STRATEGY

In 2012, the *Climate Change Adaptation Strategy* was completed with a focus on understanding climate impacts and actions to adapt to the changing climate. In response to the potential increase in the intensity and frequency of extreme rain events, the plan proposes actions to reduce the proportion of rainwater entering the engineered infrastructure. It includes a series of rainwater management techniques such as limiting impermeable surfaces, creating runoff storage and conveyance, adopting infiltration and detention practices, etc. GSI on city streets will play a very important role to support these strategies by absorbing and reducing runoff from roads, sidewalks, and other impervious surfaces.

REZONING POLICY FOR SUSTAINABLE LARGE DEVELOPMENTS

A *Rezoning Policy for Sustainable Large Developments* was adopted in June 2008 for the rezoning of large developments (45,000 m^2 of new development floor area and/or a site size of 8,000 m^2 or more). The city will require a sustainable rainwater management plan for the rezoning application, along with several other sustainable development requirements (e.g. energy reduction, solid waste diversion). The required sustainable rainwater management plan will utilize sustainable strategies that allow for the infiltration, retention, treatment and utilization of rainwater where applicable and appropriate on site. According to the citywide IRMP, the target for these large scale developments is to reduce post-development rate and volume to at or below pre-development levels for 2-year/24-hour precipitation events.

GSI IN VANCOUVER

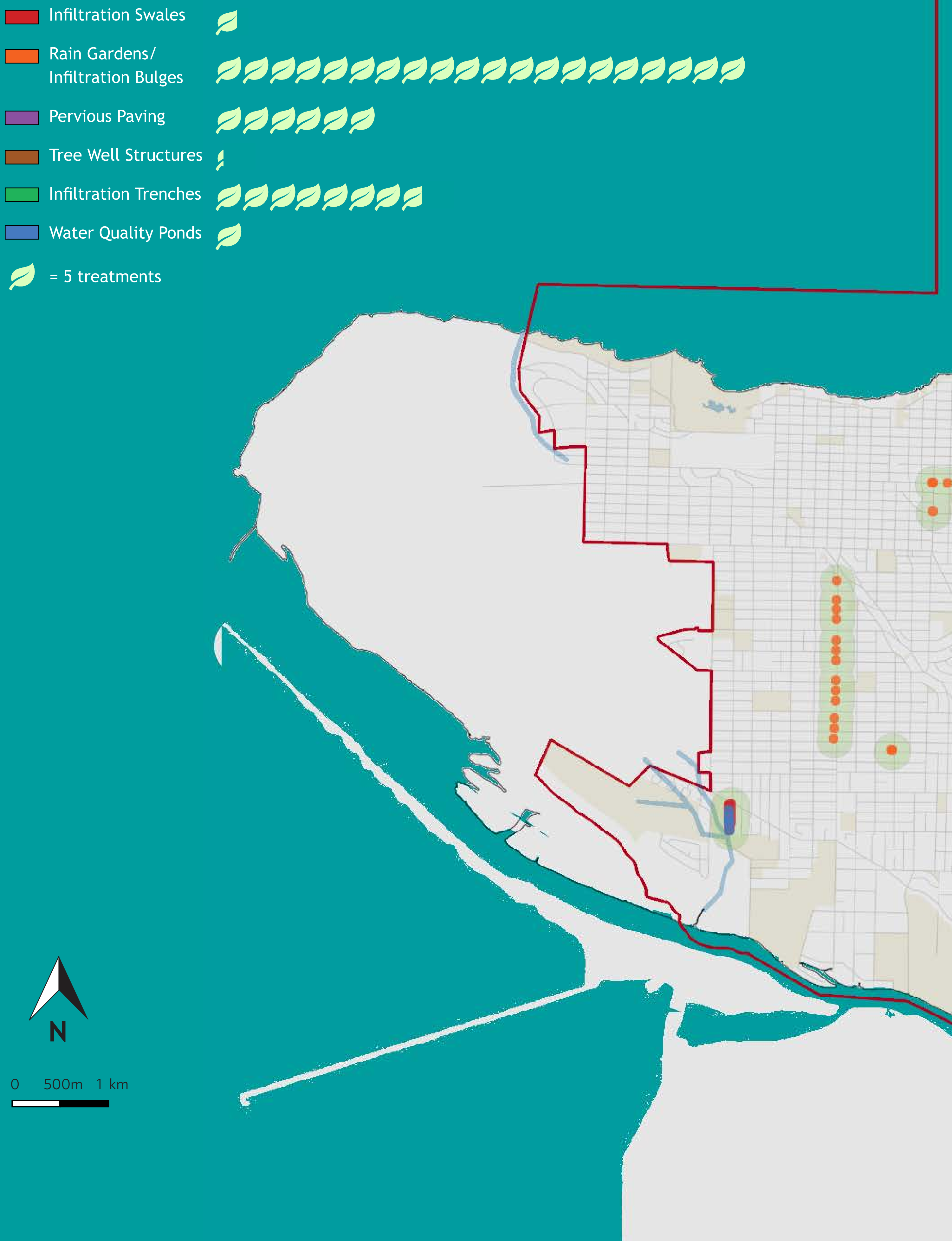
PROJECTS AND PERFORMANCE

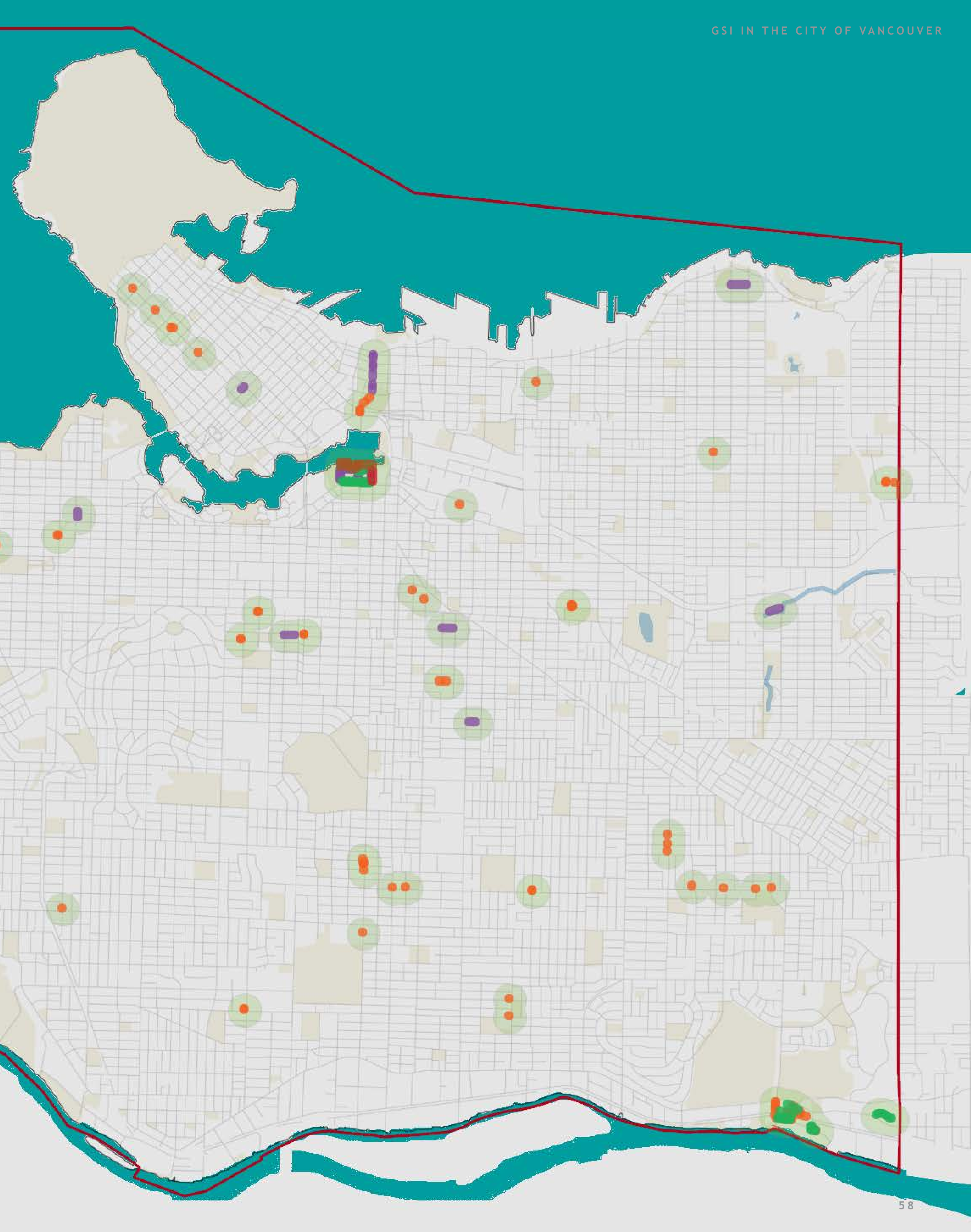
Currently the City of Vancouver is in the development stage of a GSI program, having completed several pilot projects. The primary drivers for implementing GSI on city streets/plazas include stormwater volume control, regulatory/legislative requirements from higher levels of government, and water quality improvement.

There are currently about 190 GSI installations on city streets/lanes in the City of Vancouver, including a wide range of GSI types (e.g. rain gardens, bio-swales, permeable pavement, soil cells, infiltration trenches). Many of these treatments were installed in large development sites such as the Olympic Village and the East Fraser Lands. Some GSI installations were constructed as pilot projects along streets (e.g. Crown Street and Carrall Street). These pilot projects helped to test how well GSI would work in a Vancouver context, and provided a baseline for how the design and implementation could be improved.

A rain garden along Blenheim St., Vancouver

GSI TREATMENTS IN THE CITY OF VANCOUVER (2016 DATA)





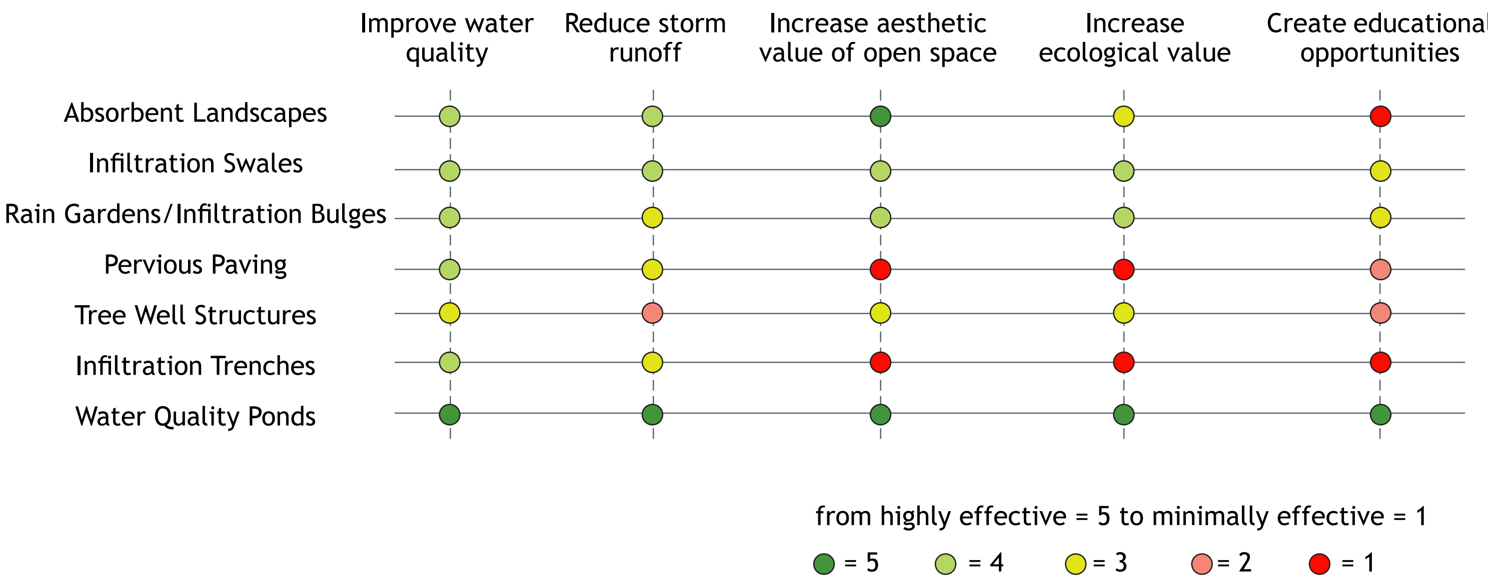
Local streets and sidewalks are areas with the most diverse types of GSI treatments implemented. For arterial/collector streets and alleys, only absorbent landscapes and rain gardens & infiltration curb bulges were implemented. Very few GSI treatments were implemented on mews/woonerfs/public plazas.

Overall, GSI treatments in the City of Vancouver have helped to locally improve water quality and reduce rainwater runoff. Some treatments, such as absorbent landscape, rain gardens and bio-swales, have also improved the aesthetic and ecological value of open spaces. However, very few educational opportunities are currently supported by GSI projects in Vancouver. The most common challenges associated with GSI projects are the limited available funding, and the significant costs for GSI construction and particularly for O&M. However, performance and challenges of GSI vary significantly across different types of treatments.

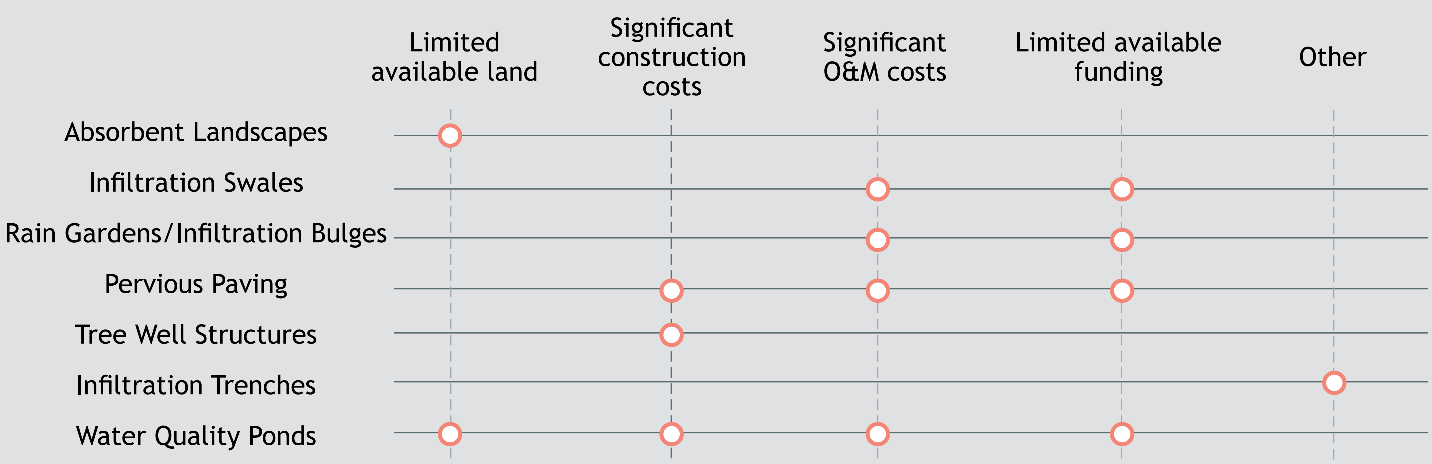
GSI TREATMENTS ON DIFFERENT TYPES OF STREETS/PLAZAS IN THE CITY OF VANCOUVER

	Arterials	Collectors	Local Roads	Sidewalks/ Walkways/ Multi-use paths	Alleys/ Lanes	Mews/ Woonerfs
Absorbent Landscapes	○	○	○	○	○	○
Infiltration Swales			○			
Rain Gardens/Infiltration Bulges	○	○	○			
Pervious Paving			○	○	○	
Tree Well Structures				○		
Infiltration Trenches			○			
Water Quality Ponds			○			

PERFORMANCE OF GSI TREATMENTS IN THE CITY OF VANCOUVER



CHALLENGES/LIMITATIONS OF GSI TREATMENTS IN THE CITY OF VANCOUVER



The following challenges on GSI implementation in Vancouver have been identified based on personal interviews, literature review, and field studies.

CHALLENGE 1: LIMITED AVAILABLE FUNDING

Currently there is no dedicated funding for the construction and O&M of GSI projects in the City of Vancouver. Most GSI on streets were constructed by capital funds through street renewal projects or through other development projects. The lack of funding opportunities limits the potential design and implementation of GSI projects, and also results in a lack of maintenance of existing assets. New funding sources should be investigated for future projects.

CHALLENGE 2: LIMITED GSI MAINTENANCE

While improvements have been made in the design and construction of GSI projects in the City of Vancouver, there is still a significant lack of capacity in terms of O&M of these assets. Many issues may arise a few years after construction due to a lack of maintenance. Various municipal departments, private groups and volunteering groups are involved in

landscaping maintenance on streets, and GSI maintenance is usually performed along with other street landscaping. However, most of these activities are complaint-based without a regular maintenance schedule.

- For most GSI installations on city streets, catch basins are cleaned every other year as part of regular street-cleaning activities. The streets/sewer maintenance team maintains GSI treatments on a complaint basis (i.e. when a resident detects and reports a clogging/flooding GSI treatment to the city). The maintenance team will ensure that the GSI treatments recover their stormwater function, but no standard currently exists in terms of aesthetic quality.
- The Park Board is also involved in the maintenance of GSI installations on streets, with a focus on landscaping along high-volume traffic streets (e.g. medians of major arterial streets).
- The Street Activities Branch inspects landscaping at traffic circles and corner bulges in residential areas through the Green Streets Program and the Street Horticulture Maintenance Program. Volunteering groups are engaged in the maintenance of street landscaping through these programs.
- Private developers may be responsible for the O&M of GSI on roadways (e.g. the first few years during construction), depending on their maintenance agreements with the city.
- Some local property owners are involved in and/or responsible for maintaining GSI treatments close to their properties.

GREEN STREETS PROGRAM IN VANCOUVER

Green Streets gardens are planted on traffic circles and corner bulges, and are maintained by Green Streets volunteers. There are currently about 600 registered volunteers in the program. Volunteer gardeners work with the city to help the gardens grow during the year by weeding and watering, or adding plants.

The Boulevard Gardening Design and Maintenance Guidelines was created to provide basic information and safety guidelines for landscape elements and program management.

Although various parties are involved in the maintenance of GSI on city streets, there is still a significant lack of GSI maintenance due to limited O&M funding, and a lack of experience and defined/programmed maintenance practices. Issues with street GSI are particularly common during the early fall, when street catch basins are easily clogged with falling leaves.

CHALLENGE 3: LIMITED TOOLS TO ENCOURAGE GSI IMPLEMENTATION

Currently, planning tools that encourage GSI implementation are limited, but the new citywide IRMP will play an important role in filling this gap. However, as this plan was just adopted in April 2016, many proposed actions and programs are still under development.

- The ongoing sewer separation program in the City of Vancouver will play an important role in reducing combined sewer overflow to receiving waterbodies, and thus help improve water quality. However, the current sewer separation strategy is to replace combined sewer pipes with separated pipes for storm/sanitary water, without utilizing GSI as a component to manage stormwater on streets.
- The *Rezoning Policy for Sustainable Large Developments* requires a sustainable rainwater management plan for rezoning applications on these sites. According to the citywide IRMP, the target for rainwater management on these sites is to reduce post-development rate and volume to at or below pre-development levels. However, in the City of Vancouver, there is a diverse array of land uses, and some re-development sites are already primarily impervious surfaces, making this target relatively easy to achieve. For other sites that are primarily pervious surfaces, this target could be a very challenging endeavour. Therefore, the application of this target can result in inconsistent outcomes in terms of managing rainwater flows in a Vancouver context.
- Aside from large development sites, IRMP also sets rainwater management targets for one/two family & lane housing, multi-family, and Industrial Commercial Institutional land uses. Planning tools and strategies to achieve these goals are still under development.
- The citywide IRMP has brought about many new actions for encouraging the utilization of GSI to meet rainwater volume and quality targets. These include updating engineering and building standards to include green infrastructure standards with typical design, sizing and specifications; updating maintenance standards and roles; updating development approval and inspection processes; creating awards and incentive programs, etc. These programs/actions will serve as important tools for encouraging GSI projects, but they are not yet developed.

A bio-swale at the Olympic Village, with the water inlet clogged due to a lack of maintenance.

NEW YORK CITY GREEN INFRASTRUCTURE PLAN

In September 2010, New York City released the NYC Green Infrastructure Plan, with green infrastructure alternative approaches established to improve water quality. The plan identified potential strategies and technologies for different types of land use, with a goal of capturing the first inch of rainfall on 10% of the impervious areas in combined sewer watersheds through detention or infiltration techniques (City of New York, 2010). From 2011 to 2015, a Green Infrastructure Annual Report was developed every year to summarize major accomplishments, completed pilot projects/ programs, budgets and personnel, and lessons learned.

> *"Strong policies are required to support the implementation of GSI and to maintain the required standards."*
>
> SHEILA BOUDREAU FROM THE CITY OF TORONTO

CITYWIDE RECOMMENDATIONS FOR GSI IN THE CITY OF VANCOUVER

A CITYWIDE GSI PLAN/STRATEGY

As the City of Vancouver aims to treat 90% of Vancouver's average annual rainfall by green infrastructure, a comprehensive citywide GSI Plan/Strategy would be very important for consolidating goals and coordinating resources. The plan/strategy should identify GSI opportunities, short-term and long-term actions, funding opportunities, and processes to phase in GSI projects across the city.

Currently many municipalities in North America have completed or have been working on citywide GSI plans/ strategies/programs. See the table on the next page for some examples of citywide plans/strategies/programs with goals and budgets for implementing GSI.

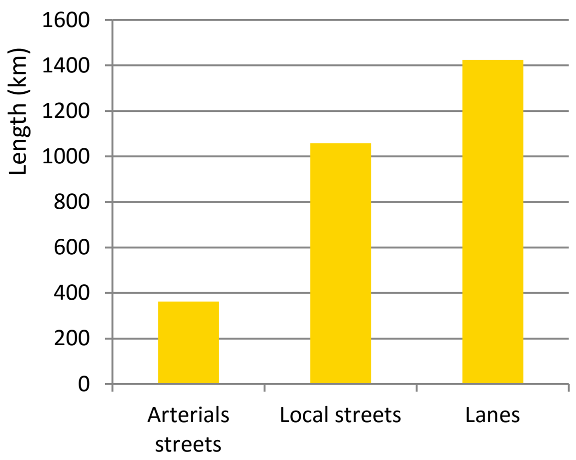
Land Use	% of Combined Sewer Watershed	Potential Strategies and Technologies
New development and redevelopment	5.0%	Stormwater performance standard for new and expanded development
		Rooftop detention; green roofs; subsurface detention and infiltration
Streets and sidewalks	26.6%	Integrate stormwater management into capital program in partnership with DOT, DDC, and DPR
		Enlist Business Improvement Districts and other community partners
		Create performance standard for sidewalk reconstruction
		Swales; street trees; Greenstreets; permeable pavement
Multi-family residential complexes	3.4%	Integrate stormwater management into capital program in partnership with NYCHA and HPD
		Rooftop detention; green roofs; subsurface detention and infiltration; rain barrels or cisterns; rain gardens; swales; street trees; Greenstreets; permeable pavement
Parking lots	0.5%	Sewer charge for stormwater
		DCP zoning amendments
		Continue demonstration projects in partnership with MTA and DOT
		Swales; permeable pavement; engineered wetlands
Parks	11.6%	Partner with DPR to integrate green infrastructure into capital program
		Continue demonstration projects in partnership with DPR
		Swales; permeable pavement; engineered wetlands
Schools	1.9%	Integrate stormwater management into capital program in partnership with DOE
		Rooftop detention; green roofs; subsurface detention and infiltration
Vacant lots	1.9%	Grant programs
		Potential sewer charge for stormwater
		Rain gardens; green gardens
Other public properties	1.1%	Integrate stormwater management into capital programs
		Rooftop detention; green roofs; subsurface detention and infiltration; rain barrels; permeable pavement
Other existing development	48.0%	Green roof tax credit
		Sewer charges for stormwater
		Continue demonstration projects and data collection
		Rooftop detention; green roofs; subsurface detention and infiltration; rain barrels or cisterns; rain gardens; swales; street trees; Greenstreets; permeable pavement

Green Infrastructure opportunities, strategies, and technologies
Image by the City of New York

CITYWIDE GREEN STORMWATER INFRASTRUCTURE PLAN/STRATEGY IN THE US WITH DEDICATED BUDGETS FOR GSI (NUMBERS IN US DOLLARS)

Plan/Strategy/ Program	Year	Goal	Budgets for GSI
New York City Green Infrastructure Plan	2010	• Reduce CSO volume by an additional 3.8 billion gallons per year (bgy), or approximately 2 bgy more than the all-grey strategy; • Capture rainfall from 10% of impervious surfaces in CSO areas through green infrastructure and other source controls techniques.	$1.5 billion from public funds over 20 years, and $187 million in capital funds over the next four years, for green infrastructure and other elements of the Green Infrastructure Plan.
City of Chicago Green Stormwater Infrastructure Strategy	2014	• Minimize basement flooding in Chicago's most impacted neighborhoods; • Reduce pollution to Chicago's rivers and Lake Michigan; • Enhance environmental quality through water infrastructure investments; • Increase the city's resilience to extreme rain events and climate change.	Increase the use of green stormwater infrastructure through an investment of $50 million over 5 years.
Green City, Clean Waters program: The City of Philadelphia's Program for Combined Sewer Overflow Control	2009	• Produce Greened Acres, achieving cumulative reductions in combined sewer overflows, and additional benefits.	$2.4 billion investment ($1.2 billion in 2009 dollars) for addressing water quality goals over a 25-year period, including $1.67 billion in Green Stormwater Infrastructure projects throughout the city.
Detroit Water and Sewage Department Green Infrastructure Plan for the Upper Rouge Tunnel Area	2014	• Reduce 1.2 million gallons (MG) of storm water flow (during the two-year design storm) to the combined sewer system.	The spending requirement for the GI Program is for a cumulative expenditure of $30 million by 2019.
Green Stormwater Infrastructure in Seattle: Implementation Strategy 2015-2020	2015	• Target: to manage 700 million gallons of runoff annually with GSI by the year 2025; • Interim goal: to manage 400 million gallons of runoff annually with GSI by 2020.	A total of about $155 million (6-year budget from 2015 to 2020) from Seattle Public Utilities, King County Wastewater Treatment Division and other departments for GSI projects.

ROAD ASSETS IN THE CITY OF VANCOUVER
(2014 DATA)



Streets account for a large amount of impervious surfaces in the City of Vancouver, and the citywide IRMP sets water quality targets for collector/arterial streets and lanes, and both water quality and volume reduction targets for local streets. To achieve these goals, specific GSI strategies should be developed to identify opportunities on city streets, and integrate GSI into existing street design/construction standards and guidelines.

Some municipalities in North America have developed plans/strategies for implementing GSI on streets, including Washington DC's *Greening DC Streets: A Guide to Green Infrastructure in the District of Columbia*, Philadelphia's *Green Streets Design Manual*, Portland's *Green Street Construction Guide*, etc.

GREENING DC STREETS: A GUIDE TO GREEN INFRASTRUCTURE IN THE DISTRICT OF COLUMBIA

Greening DC Streets: A Guide to Green Infrastructure in the District of Columbia was adopted in 2014 by the District Department of Transportation (DDOT) of Washington, D.C. The guide has identified opportunities and tools for implementing GSI on the District's streets and sidewalks, including permeable pavement, various types of bio-retention, and tree spaces (DDOT, 2014). The guide also provides guidelines for implementing GSI on different types of streets, including residential streets with detached/row houses, commercial streets with wide/narrow sidewalks, alleys, and traffic triangles. In each scenario, opportunities and limitations are identified with a design example.

Sandy Boulevard Rain Gardens in the City of Portland
Image by Kevin Robert Perry

PORTLAND'S GREEN STREETS POLICY

In April 2007, the City of Portland adopted the *Green Streets Policy* to promote and incorporate the use of green street facilities in public and private developments. The policy requires all city-funded developments, redevelopments, or enhancement projects to incorporate green street facilities for stormwater management. An off-site project or off-site management fee will be required if a green street facility is not incorporated into the infrastructure projects or only partial management is achieved (City of Portland, 2007). This policy takes advantage of transportation corridors to capture and treat stormwater runoff, and enhance streetscapes and pedestrian experiences.

> *"The city is in the process of developing a set of Town Centre Standards for our major town centres, which will provide standards for boulevard/curb bulge rain garden construction and define operation & maintenance needs."*
>
> **A SURVEY PARTICIPANT FROM THE CITY OF BURNABY**

INCORPORATING GSI INTO OTHER PROGRAMS, POLICIES AND PROJECTS

GSI policies and projects should be incorporated into other programs, policies, and neighbourhood planning initiatives. Integrating GSI into the earliest stages of community development projects would help to identify opportunities for GSI projects, and reduce the overall costs for planning, design and implementation. This could be achieved by including GSI on city streets in future neighbourhood plans, or integrating GSI installations into ongoing development projects such as the Cambie Corridor project, False Creek Flats project, etc.

The current *Rezoning Policy for Sustainable Large Developments* is a good opportunity to integrate GSI treatments onto large development sites. However, the current target for rainwater management on large development sites is to reduce post-development rate and volume to at or below pre-development levels, which may not be a very consistent or fair target. This policy should be updated with more specific and proactive rainwater management targets to encourage GSI treatments on large development sites.

A bio-swale along Crown St., Vancouver

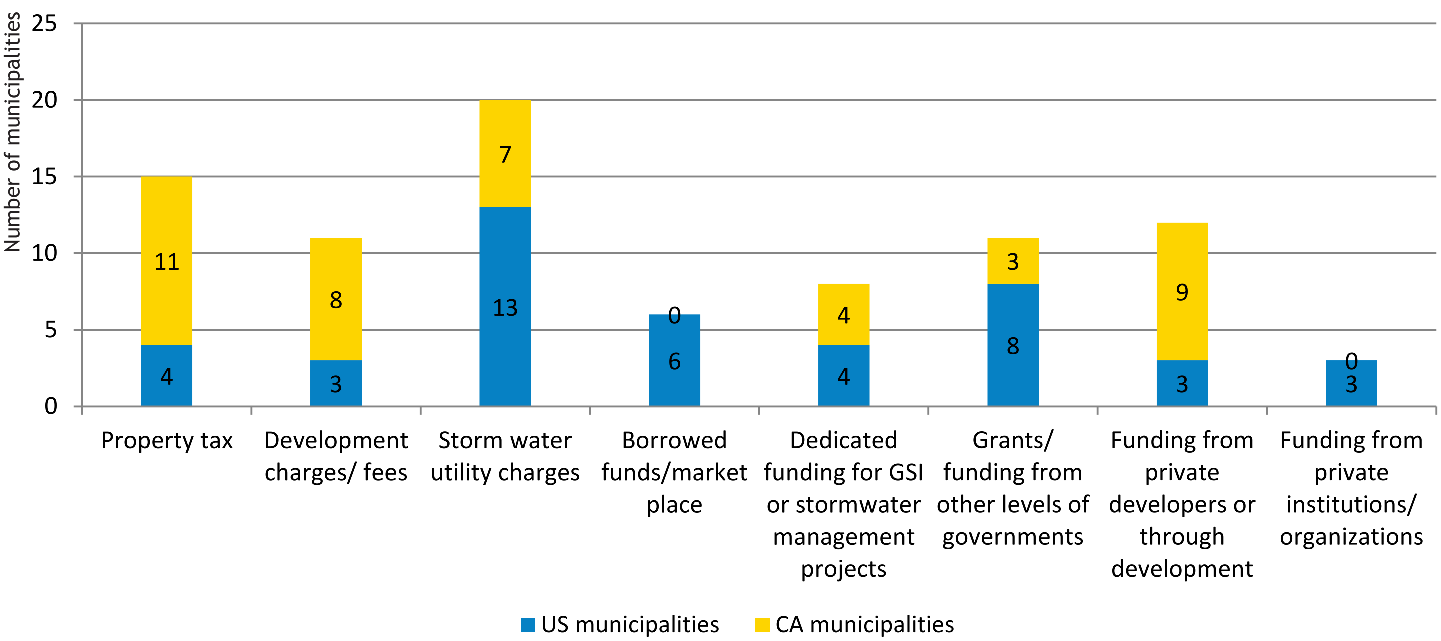
> *"LID is not seen as a separate effort because it needs to be incorporated into every design and maintained as part of our servicing infrastructure."*
>
> CARRIE BARON
> FROM THE CITY OF SURREY

ALLOCATING DEDICATED FUNDING FOR GSI PROJECTS

Allocating dedicated funding for GSI projects on city streets is critical for their successful implementation and long-term performance. Currently the City of Vancouver collects utility fees to fund water, sewer, and solid waste services. 25% of these utility fees are used for capital investments such as sewer separation and infrastructure renewal. However, the city has no dedicated funding for GSI programs, and most of the existing GSI installations on city streets were constructed along with other street projects through capital funds, or through private development projects. As for maintenance, funding is also the biggest challenge for effective GSI O&M in the long run. Therefore, allocating budgets or identifying dedicated funding sources for GSI implementation and maintenance is very important.

According to the peer municipality survey, property tax and funding from developers or through development are the primary funding sources for GSI projects among Canadian municipalities. Many American municipalities have stormwater utility fees as secured funding sources for implementing stormwater-related projects. A growing number of Canadian municipalities have adopted or are considering this structure. There are also a variety of other funding sources for GSI projects, including grants from higher levels of government, funding from private developers, etc.

PRIMARY FUNDING SOURCES FOR GSI PROJECTS



(Source: Vancouver peer municipality survey on GSI)

QUICK START THROUGH DEMONSTRATION PROJECTS

Pilot GSI projects are very critical for commencing a citywide GSI program. GSI programs in many municipalities started with well-documented demonstration projects, such as the Seattle SEA Street project, the Chicago Green Alley program, and the New York Neighborhood Demonstration Area Projects. For example, the City of Philadelphia has prioritized demonstration projects on public properties based on priority Combined Sewer Overflow (CSO) outfalls and their drainage areas. This was completed by mapping sewer-sheds in the city, with areas in greatest need of CSO reductions (EPA, 2010). This approach allows the city to prioritize new green infrastructure projects based on intended outcomes.

In the City of Vancouver, pilot GSI projects include various GSI treatments installed in the Olympic Village and the East Fraser Lands, bio-swales along Crown Street, etc. However, most of these projects do not have a monitoring mechanism to measure their performance or potential challenges. The only monitoring programs are water quality monitoring for Crown Street, and effective impervious area assessment for the Olympic Village. The city should phase in more demonstration projects across the city, as well as establish a comprehensive monitoring program for GSI projects to measure their performance and identify opportunities/challenges. A series of metrics should be developed and monitored in terms of the scale of GSI projects and their performance. Data and information collected from these projects could be used to generate best practices and lessons learned for the design, construction and maintenance of future similar projects.

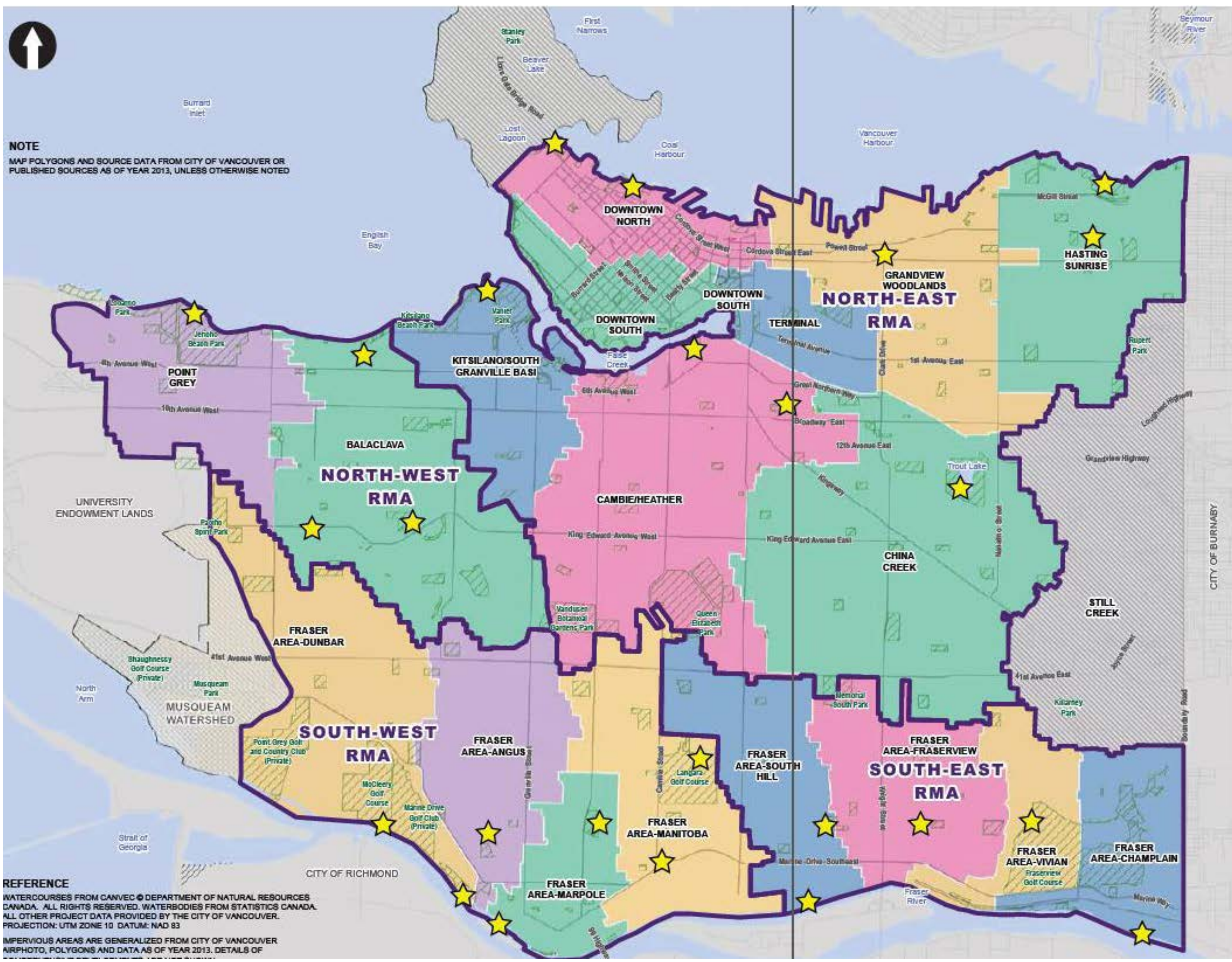
Effective monitoring would require comprehensive documentation of these projects, which should include GSI project design/construction strategies, treatment performance, capital and maintenance costs, and lessons learned. This will help reduce uncertainties and costs for similar projects in the future, as well as avoid or more effectively resolve similar design or implementation issues.

"Completing pilot projects is very important from many perspectives as they show: what is possible to generate support, and to help identify processes, procedures, materials and standard changes required. They can also be very useful training and educational tools."

SHEILA BOUDREAU
FROM THE CITY OF TORONTO

PRIORITIES IDENTIFIED BY THE VANCOUVER CITYWIDE IRMP

The Vancouver citywide IRMP has proposed that on-street GSI should be phased in according to the combined sewer separation pattern. Priority should be given to the oldest sewers and to sewers that output to confined waterbodies such as False Creek. It has also identified potential green infrastructure and biodiversity demonstration projects across the city.



Rainwater management areas and biodiversity demonstration projects identified by the Vancouver citywide IRMP

GSI CASE STUDY

GREEN ALLEY PROGRAM, CHICAGO

Alley with impermeable pavement and poor drainage
Image from CDOT, 2010

Alley incorporating green alley principles
Image from CDOT, 2010

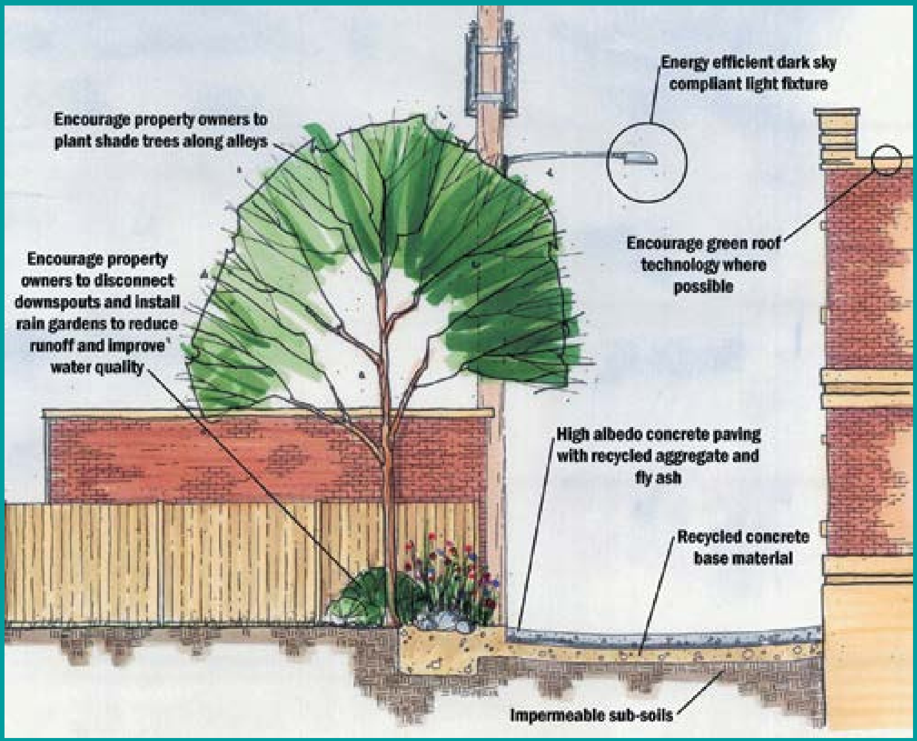
Alleys account for a significant portion of the City of Chicago's impervious surface coverage, and most of them were built without connections to sewers, resulting in rainwater puddles and increased risk of flooding.

Chicago's Department of Transportation (CDOT) started the Green Alley Program in 2006 with 6 pilot alley projects. The program promotes best management practices within public alleyways to address drainage issues by permeable pavement. A green alley features permeable pavement (asphalt, concrete, etc.) that allows stormwater to filter through the pavement and drain into the ground, instead of accumulating on hard surfaces or draining into the sewer systems. Open bottom catch basins are installed in alleys to capture water and funnel it into the ground. Light-colored pavement is used to reflect sunlight instead of absorbing it so as to reduce the urban heat island effect. Recycled materials are used in construction including concrete aggregate, slag and tire rubber (City of Chicago). Four pilot green alley techniques were employed to suit a variety of site conditions. These include green pavement materials with conventional drainage, full alley infiltration using permeable pavement, center alley infiltration using permeable pavement, and green pavement materials with subsoil filtration systems (City of Chicago, 2010).

A comprehensive monitoring program was developed to evaluate the prototype design and the effectiveness of permeable pavement materials. This monitoring program has played an important role in understanding a green alley's capacity to mitigate stormwater runoff and reduce flooding, and has helped to refine the maintenance and design protocols.

Construction costs for green alleys were found to be 150-200% more than conventional alley retrofits in the first pilot year (EPA, 2010). However, these costs have lowered significantly in later years as permeable paving materials have become more popular. In the second year of the pilot projects, the city paid about $45 per cubic yard for permeable concrete compared to conventional concrete at over $50 per cubic yard (Lukes & Kloss, 2008). Green alleys have also reduced the need for expanding the conventional sewer pipe system and water treatment facilities.

Since 2006, over 200 green alleys have been installed and CDOT has installed over 330,000 square feet of permeable pavement, which can detain approximately 17 million gallons of runoff each year (City of Chicago, 2014).



One of the four pilot green alley techniques
Image from CDOT, 2010

DEVELOPING A GSI MAINTENANCE PROGRAM

Planning and construction of a GSI project is just the first step towards establishing an effective rainwater management facility. It also requires a paradigm shift for providing increased support to O&M. Green infrastructure, just like grey infrastructure, requires regular inspection and maintenance, and this is critical to ensure its effectiveness and longevity. While grey infrastructure tends to require increased O&M over time as equipment and material wear out, green infrastructure is designed to increase in resilience/function as the vegetation matures and adapts to local environments until the end of its lifecycle (American Rivers et al., 2012). GSI may also require shifting priorities in O&M during and after the establishment period. Although currently there is no universal standard for the O&M of green infrastructure, it is an evolving issue, and its importance is being increasingly recognized by municipalities.

According to the peer municipality survey on GSI, developing an O&M plan/manual for municipal GSI maintenance can help to ensure the long-term effectiveness of GSI treatments. Currently there is only 0.12 equivalent full-time staff for the O&M of GSI projects on city streets in the City of Vancouver, which is much lower than the average of 4.75 equivalent full-time staff among municipalities responding to the GSI survey question. The City of Vancouver should consider allocating secured funding for O&M, and determine how many additional staff members are needed on a full-time or seasonal basis, or formally integrate GSI O&M into existing maintenance programs. A citywide maintenance and/or asset management program should be established, which specifies regular O&M activities and their frequencies, departments that are responsible, and secured budgets for O&M. Regular maintenance activities may include weeding, mulching, trimming of shrubs and trees, replanting, removing sediment and debris, and inlet/outlet cleaning (EPA, 2013).

Some routine maintenance activities, such as removing trash and weeds from rain gardens or bio-swales could be accomplished by local residents and volunteering groups. The city should continue partnering with them through the Green Streets program and the Street Horticulture Maintenance Program. A separate GSI maintenance guideline for local residents and volunteering groups will help to standardize and improve maintenance practices. The current *Boulevard Gardening Design and Maintenance Guidelines* was developed

SEATTLE GREEN STORMWATER OPERATIONS AND MAINTENANCE MANUAL

Seattle has a *Green Stormwater Operations and Maintenance Manual* as a summary of routine maintenance activities for the design of Natural Drainage System Projects. The manual features maintenance standards for GSI assets, including different service levels for maintaining vegetation, hardscape and infrastructure. For example, service level A refers to excellent maintenance effort, and Service D refers to low maintenance efforts (Seattle Public Utilities, 2009). Each service level includes images and descriptions to explain the desired maintenance level.

for landscaping maintenance practices for single/two family residential areas, and is currently in the process of being updated to include maintenance practices in other types of land uses. GSI assets should be differentiated from other landscaping in the maintenance guidelines, as they also serve stormwater functions and may require different inspection/maintenance activities. This should be reflected in the updated guidelines.

> "*O&M for green infrastructure should be scheduled, if needed, like other drainage infrastructure (i.e. creation of scheduled work order using the municipality's maintenance management system).*"
>
> **DANA SOONG FROM THE CITY OF COQUITLAM**

PLANS/MANUALS FOR THE OPERATION AND MAINTENANCE OF GSI

- City of Chicago, 2003: A Guide to Stormwater Best Management Practices
- Philadelphia Water, 2014: Green City, Clean Waters Green Infrastructure Maintenance Manual
- Seattle Public Utilities, 2009. Seattle Green Stormwater Operations and Maintenance Manual
- City of Indianapolis, 2015. Indianapolis Green Infrastructure Supplemental Document
- District Department of Transportation (DDOT), 2014: DDOT Green Infrastructure Standards
- City of Portland, 2016. Chapter 3: Operations and Maintenance, Stormwater Management Manual
- EPA, 2013: The Importance of Operation and Maintenance for the Long-Term Success of Green Infrastructure
- NOAA, 2015: Green Infrastructure Options to Reduce Flooding: Definitions, Tips, and Considerations

A New York City right-of-way bio-swale
Image by the NYC Department of Environmental Protection

"

Verify during planning/ design stage that there is adequate funding, trained staff and equipment available for long-term O&M of proposed GSI.

"

RACHEL WILSON
FROM THE CITY OF INDIANAPOLIS

INDIANAPOLIS GREEN INFRASTRUCTURE SUPPLEMENTAL DOCUMENT

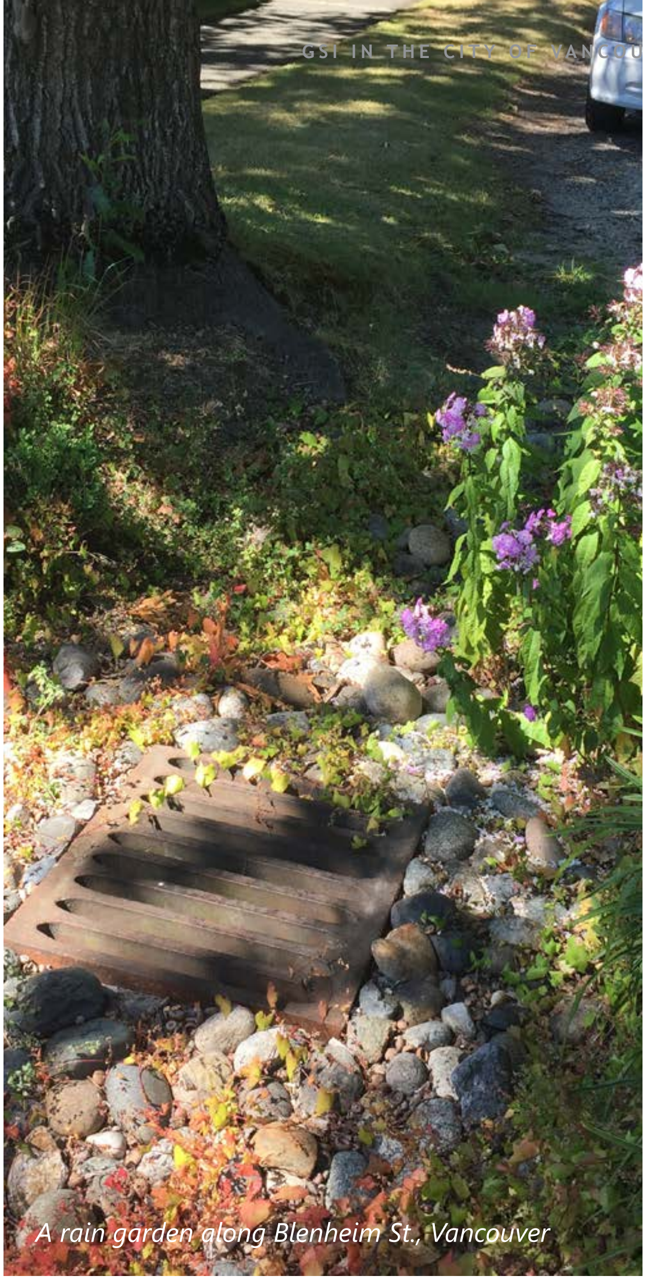
The Indianapolis Department of Public Works has compiled a *Green Infrastructure Supplemental Document* with maintenance practices for various types of LIDs. This document was compiled based on extensive review of the techniques of other cities/states on Green Infrastructure O&M, including Philadelphia, Milwaukee, Chicago, Portland, etc. This document has detailed maintenance guidelines based on a local context, and a recommended schedule of inspection and maintenance for each type of GSI.

Inspection Activities	**Minimum Frequency**
• Inspect to ensure that pavement was installed and working properly. • Inspect areas for potential erosion or damage to vegetation.	Post-construction
• Visibly inspect porous pavement surface after major storm event for evidence of sediment, debris (e.g., mulch, leaves, trash, etc.), ponding of water, oil-dripping accumulations, clogging of pores and other damage. • Inspect overflow devices (pipes and inlets) for obstructions or debris that would prevent proper drainage when filtration capacity is exceeded. • Ensure that the contributing area upstream of the porous pavement is free of sediment and debris.	Annually and after large storm events
• Verify that the porous pavement dewaters between storms.	Monthly
• Inspect the surface for structural integrity. Inspect for evidence of deterioration or spalling.	Annually
Maintenance Activities	**Minimum Frequency**
• Remove excess sediment from construction area and stabilize adjacent areas with vegetation.	Post-construction
• Prevent soil from being washed onto pavement by ensuring that adjacent areas are stabilized. Keep landscape areas well maintained with lawn clippings removed to prevent clogging pavement. • Rake and remove fallen leaves and debris from deciduous trees and shrubs to reduce the risk of clogging. • Remove debris and clear obstructions from overflow devices (pipes and inlets).	Annually, as needed
• Vacuum sweep porous concrete pavement (with proper disposal of removed material), followed by high pressure hosing (when needed) to free pores on the surface.	2-3 times per year or more frequent as needed.
• If ponding persists, clogged concrete pavement must be repaired or replaced.	If failure exists

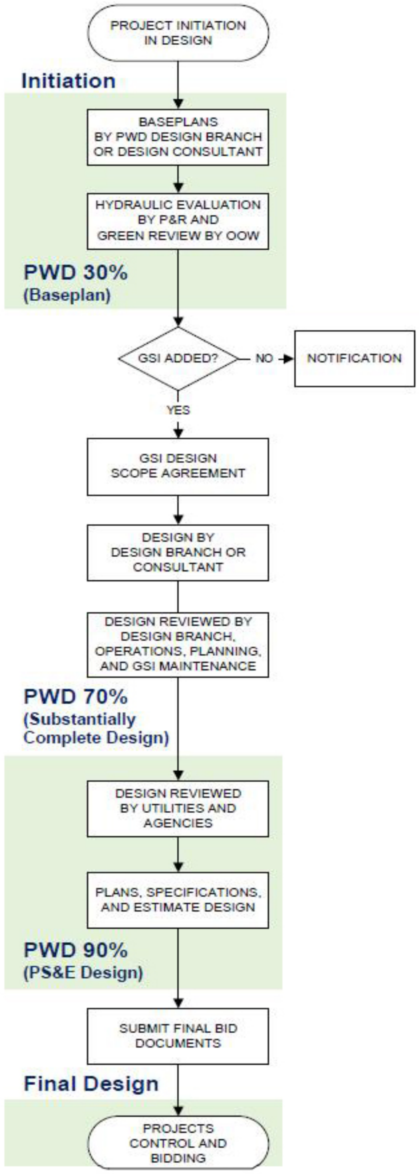
Porous pavement inspection and maintenance criteria
Table by the City of Indianapolis

STRONG COLLABORATION BETWEEN THE CITY, COMMUNITIES AND OTHER ORGANIZATIONS

A successful green infrastructure program requires the collaboration of multiple municipal departments, as green infrastructure has a wide range of impacts to street design and operation. These include impacts to storm/sanitary and other underground utilities, street public spaces, automobile/pedestrian transportation, and street O&M practices. The complexity of GSI programs requires collaboration among multiple departments such as Planning and Development, Engineering/Public Works, Transportation, Water/Sewer, etc. Coordination among these departments can help to effectively implement GSI projects, improve GSI performance, and reduce conflicts and construction/maintenance costs.

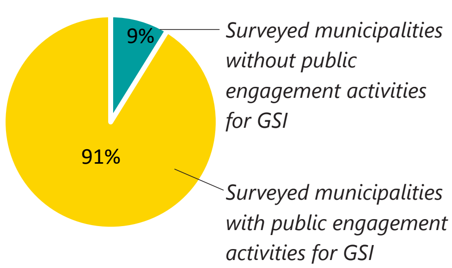

A rain garden along Blenheim St., Vancouver

> "Internal outreach and engagement is critical to identify opportunities and improve success."
>
> **SHEILA BOUDREAU FROM THE CITY OF TORONTO**



Workflow for GSI Design on Water/Sewer Projects. Image by PWD

MUNICIPALITIES WITH/WITHOUT PUBLIC ENGAGEMENT ACTIVITIES ON GSI



(Source: Vancouver peer municipality survey on GSI)

Public outreach with communities is also critical to the success of GSI programs/projects, as the public could play an important role for advocating new projects, assisting in city program/plan updates, and assisting with GSI maintenance. According to the municipality survey, more than 90% of surveyed municipalities have some kind of public engagement activities on green infrastructure in a variety of formats. While traditional outreach activities are widely used (e.g. information sharing through city websites, public meetings and workshops, and paper-based materials), other activities with a higher degree of engagement are also employed by municipalities (e.g. tree planting programs, GSI guided tours).

PHILADELPHIA'S GSI DESIGN PROCESS WORKFLOW PACKET

The Philadelphia Water Department (PWD) has developed a design process workflow package for GSI projects (PWD, 2015). This document defines the responsibilities of key roles in the GSI design process, including the Design Branch, Design Consultant, Office of Watersheds, etc. A detailed workflow is developed for the GSI design, review and submission procedure. This design process workflow helps to standardize and improve the efficiency of GSI design, and enhances the coordination among different departments and parties.

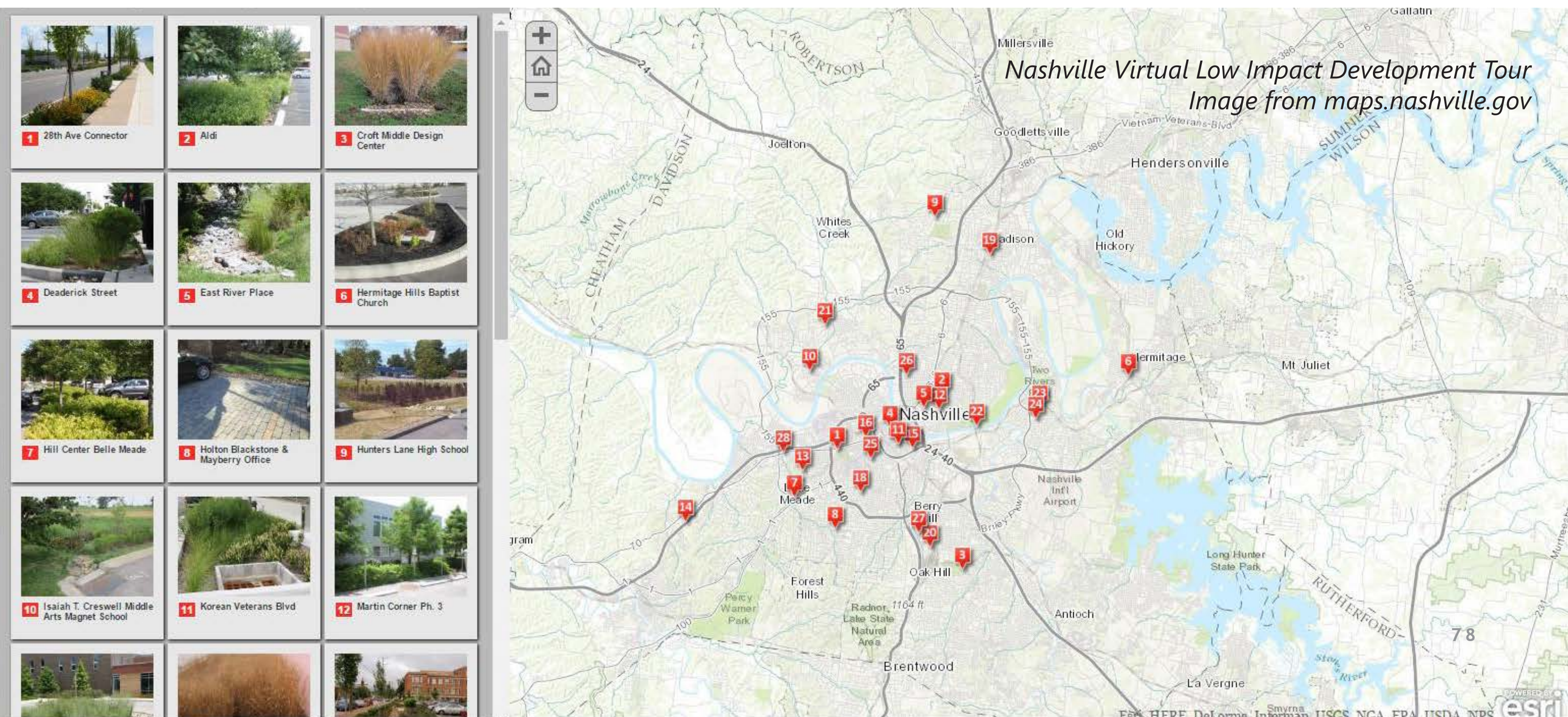
Stormwater tour at a Infiltration Trench in Villanova University Image from villanova.edu

In the City of Vancouver, there are many opportunities for integrating GSI public engagement activities into existing outreach programs or creating new opportunities for public outreach. These may include establishing educational signage close to GSI installations, integrating GSI into existing guided tours (e.g. green building tour at the Olympic Village), expanding partnerships with community/volunteering groups on GSI O&M, etc.

NASHVILLE LOW IMPACT DEVELOPMENT TOUR

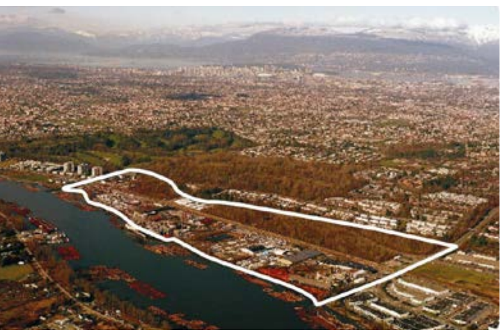
Nashville has developed a Virtual LID Tour on the city website. The interactive map includes LID projects in four categories including bio-retention, pervious pavements, green roofs and infiltration facilities. Each project has a short description with a thumbnail photo. This virtual tour serves as a public outreach tool, helping residents to understand where LID projects are located across the city, what they look like, and how they function.

> "*Involve all related departments... make sure those involved understand it from design to construction.*"
>
> A SURVEY PARTICIPANT



Nashville Virtual Low Impact Development Tour Image from maps.nashville.gov

GSI IN THE EAST FRASER LANDS



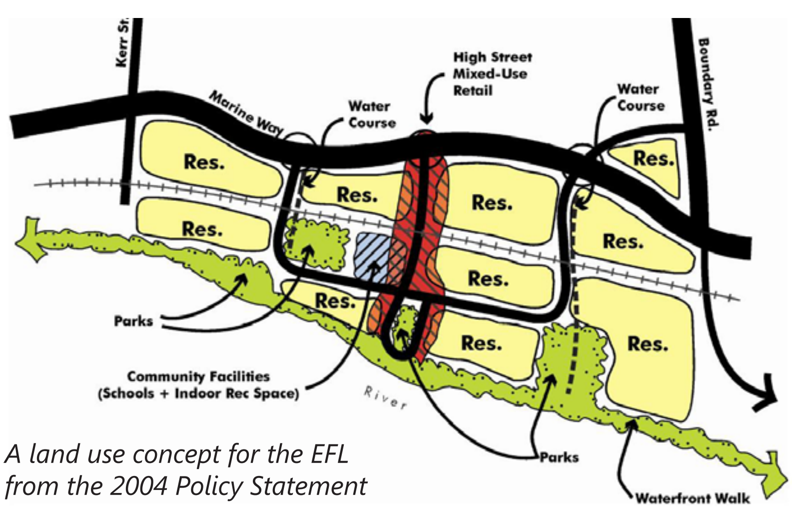
PLANNING CONTEXT

The East Fraser Lands (EFL) is an area located in the southeast corner of the City of Vancouver between Kerr Street and Boundary Road, and to the south of Marine Way. The site is 126 acres in area, with the Canadian Pacific Rail (CPR) corridor dividing it into north and south sections. This site used to be zoned for industrial use, with lumber manufacturing activities conducted throughout much of the 20th century.

Planning for the EFL started in May 2002 for the possibility of new residential development. Since then, policies and plans were completed at various levels with new visions and goals for the EFL.

POLICY STATEMENT

The 2004 *Policy Statement* provides a framework to create a complete and sustainable new community comprising of a variety of housing opportunities together with a range of supporting facilities and amenities. This statement establishes principles and objectives related to land use, transportation, urban design, and community amenities. It promotes utilizing innovative approaches to managing rainwater through green



A land use concept for the EFL from the 2004 Policy Statement

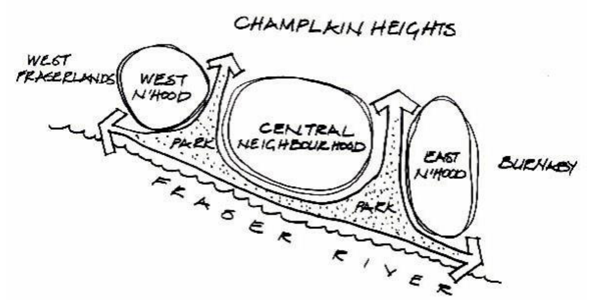
infrastructure, whenever possible, to restore natural systems and create wildlife habitats.

EFL OFFICIAL DEVELOPMENT PLAN

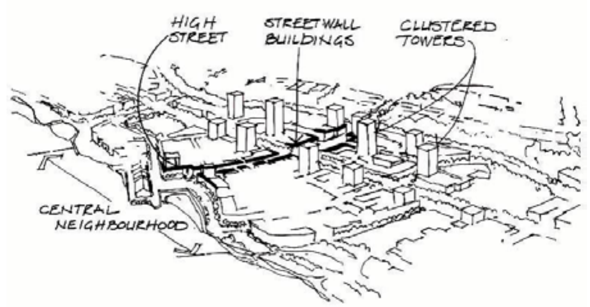
The *Official Development Plan* (ODP) in 2006 establishes a foundation of planning, urban design, development, and sustainability principles/strategies, and provides a framework for the creation of policies, zoning and other by-laws, etc. According to the ODP, the EFL is to consist of three distinct neighbourhoods:

- **The Central Neighbourhood** will serve as the heart of the EFL and provide opportunities for shopping, community services and transit. Development intensity will be highest here. A north-south high street with retail frontage, anchored by a town square and a waterfront plaza will act as the foundation of the central neighbourhood;
- **The Western Neighbourhood** is to be primarily residential in nature with a variety of housing forms such as row houses, townhouses, stacked townhouses, and low-rise apartments;
- **The Eastern Neighbourhood** is also to be primarily residential in nature but will include light industrial live-work uses.

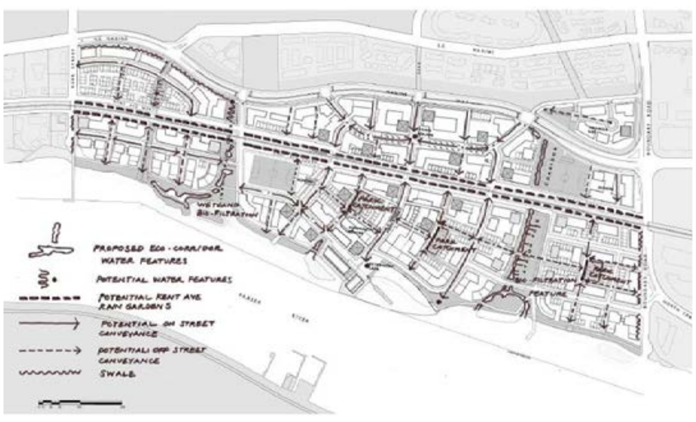
The ODP promotes rainwater management as one of its Sustainability Strategies.



Three distinct neighbourhoods defined by park corridors in the ODP



The Central Neighbourhood with clustered towers along the high street



Rainwater management strategies proposed in the ODP

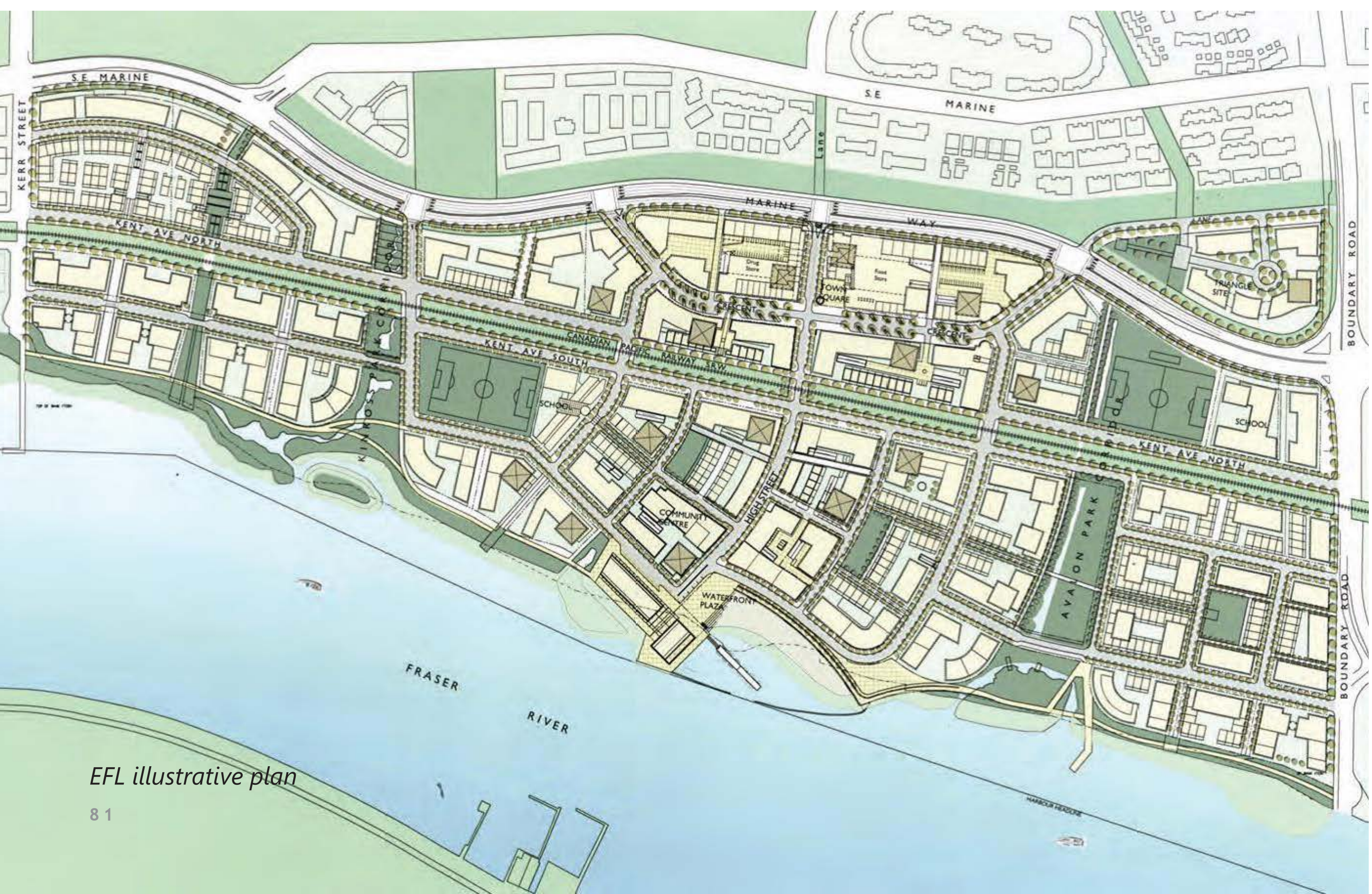
These include,

- Embracing Low Impact Development principles;
- Collecting rainwater from impervious surfaces, retaining rainwater on site, and cleaning rainwater before it enters the river;
- Directing rainwater to parks and public open spaces if possible;
- Cleaning water through rain gardens in the public street system;
- Requiring a rainwater management plan for each area during rezoning applications.

AREA 1 AND AREA 2 REZONING APPLICATIONS

EFL Area 1 was rezoned in 2008 from M1-B and M-2 (industrial), as well as CD-1 (Comprehensive Development) to three new CD-1 districts. The rezoning site comprises 52 acres to be developed with a range of residential forms from townhouses to 25-storey apartment towers as well as a neighbourhood commercial centre and high street, a public waterfront, parks, a community centre, and two child care facilities.

EFL Area 2 was rezoned from a single CD-1 district to two new CD-1 districts in 2009, along with Kerr Street Properties as well. The zoning application re-ordered the development of the EFL by starting construction in Area 2 first. The site is also to be developed with a range of residential forms from townhouses to 13-storey apartment towers as well as parks, a public waterfront, an elementary school, two child care facilities, and a small scale commercial building.



EFL illustrative plan

A rain garden in the EFL

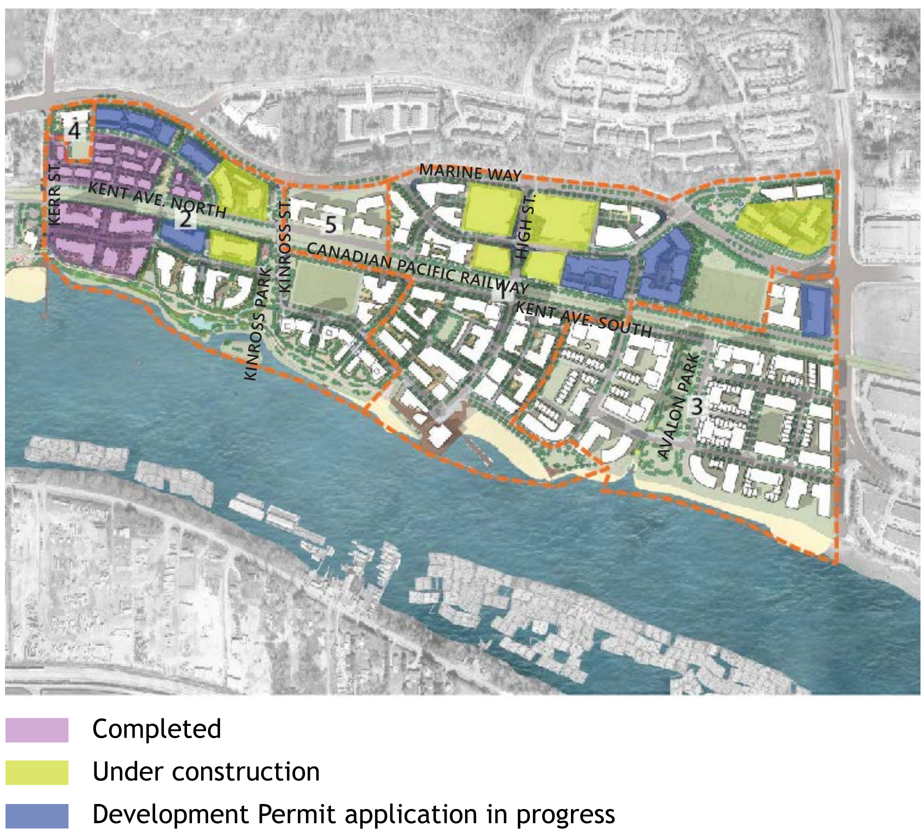
EFL DESIGN GUIDELINES

The *Design Guidelines for the EFL* was completed for Areas 1 and 2, including a public realm plan, built form, and parcelization of the areas. Rainwater management strategies are included in the design guidelines, with a focus on rainwater quality as the primary beneficial outcome. Other guiding principles include: emphasizing systems that achieve rainwater runoff capture within roadways; integrating rainwater management functions into landscape features; and incorporating rainwater management facilities as civic amenities where practical. Proposed landscape-based elements include vegetated swales, rain gardens, infiltration trenches, and permeable surface treatments.


Rainwater elements in public lands proposed in the EFL design guideline

CURRENT DEVELOPMENT PROGRESS

According to the ODP, the EFL site is divided into several areas. Currently Area 1 and 2 have completed rezoning processes. The map below displays the current development processes of the site, with some portions of Area 2 already completed. The northern part of Area 1 is either under construction or in the planning and design phase.



Current development progress

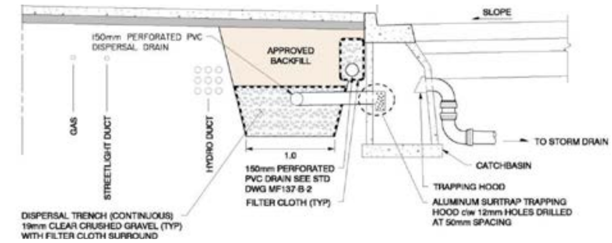
IMPLEMENTATION PROGRESS AND RECOMMENDATIONS FOR THE 2008 RMP

The *EFL Rainwater Management Plan* (RMP) was developed in 2008, with strategies for rainwater management through green infrastructure at the EFL. Similar to the EFL design guidelines, this plan has a focus on water quality as the primary beneficial outcome of integrated rainwater management, and the primary design objective targets "first flush" of a rain event. A Landscape-Based Rainwater System is proposed with two components: roadway systems on public lands, and open space rainwater features on development parcels of private lands. The guiding principles in the RMP are primarily in line with those specified in the design guidelines.

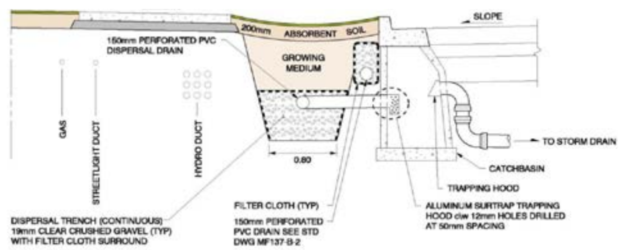
GSI TREATMENTS AND PLAN ELEMENTS

According to the 2008 RMP, rainwater management facilities will treat the first flush drainage captured on roads during rainfall events. Rainwater will be directed into these facilities where it can soak into the ground rather than flow into a storm drain. Rainwater management facilities are proposed in all roadways in the EFL, and are categorized into 4 types:

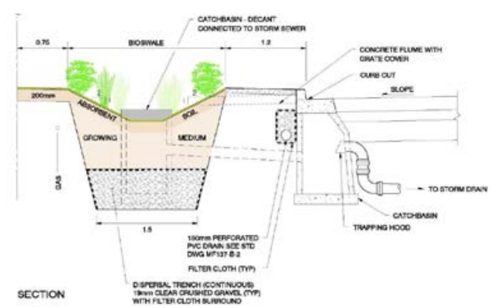
- **Closed dispersal drains** refer to hard surfaced boulevards constructed over the dispersal drain preventing rainwater from soaking into the ground from the surface;
- **Open dispersal drains** refer to grass landscaped portions of the boulevard beneath which the dispersal drain is located;
- **Bio-swales** are proposed on north and south Kent Avenue. Roadway runoff will be directed into the swales through curb cuts where it will be absorbed by soil;
- **Rain gardens** are proposed in both hard surfaced boulevards and at curb bump-outs.



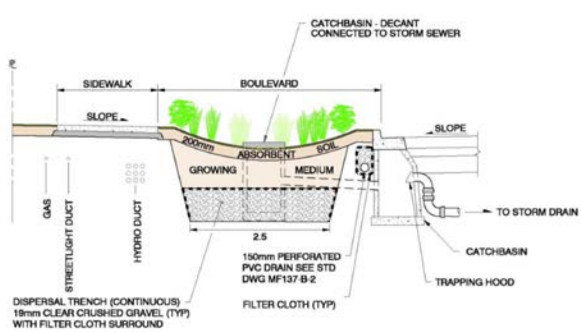
Closed dispersal drains



Open dispersal drains

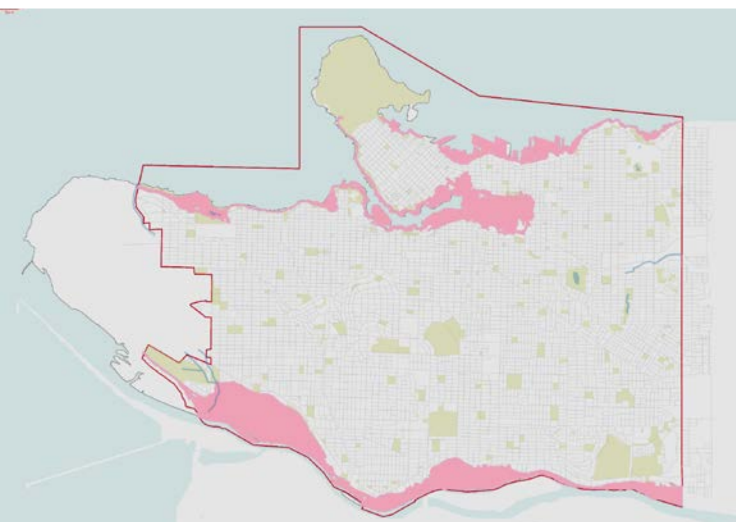


Bio-swales



Rain gardens

The 2008 RMP introduced a series of rainwater management elements. However, not all of the proposed elements have been implemented. The planned GSI elements and their actual implementation is compared and discussed below.



Designated floodplain areas in the City of Vancouver

PLAN ELEMENT 1: KENT AVENUE ROADSIDE BIO-SWALES

According to the RMP, areas north of the railway in the EFL site slopes to the south, and rainwater runoff from streets could be collected and directed to proposed bio-swales along both sides of Kent Avenue. The vegetated bio-swales with absorbent soil are supposed to collect and absorb rainwater and reduce the volume of rainwater into the storm sewer system.

The proposed bio-swales along Kent Avenue were not implemented due to changes in planning context and priorities, as well as technical difficulties on-site. In July 2014, Council adopted amendments to the building bylaw that raised flood construction levels in response to the impacts of climate change and the increased risk of flooding. It specifies that construction levels for buildings in designated floodplain areas cannot be lower than 4.6 m. As a result of this change in flood control levels, roads and buildings in the EFL are elevated and site grading is not the same as in the original RMP. There is also a shift in planning priorities with a growing interest in urban bike lane systems. With bike lanes planned and constructed along Kent Avenue in Area 2, there is even less space for green infrastructure. The originally proposed bio-swales along Kent Avenue in Area 2 were replaced by narrow grass boulevards with rainwater functions.

Narrow strips of grass boulevards with rainwater functions along Kent Ave.

PLAN ELEMENT 2: AVALON AND KINROSS PARK WATER COURSES

Engineered linear water courses are proposed in the two major park corridors in the RMP. According to the EFL Design Guidelines, Kinross Park will include a naturalistic water course that collects rainwater from the adjoining sites, meanders through the park, and terminates in a wetland. Avalon Park will feature a water course that conveys drainage from the Avalon Ponds supplemented by rainwater from storm sewers and surface drainage from the park and surrounding parcels.

The original idea for Kinross Park was to daylight historic streams by creating naturalized water courses through rainwater management. The City of Vancouver has completed past daylighting projects, such as the Creekway Park Project and the Still Creek Daylighting Project. Currently, the design for Avalon and Kinross Park water courses is in progress.

The Kinross Park water corridor is no longer considered feasible in collecting rainwater from adjoining sites due to raised flood construction levels, as well as other barriers along its water course, such as the CPR corridor and the bridge along Riverwalk Avenue. The park is currently in the detailed design phase, with the potential of being designed as a tidal marsh area.

The Avalon water corridor is currently in the concept design process, with the goal of directing rainwater from the Marine Way storm sewer, in order to create a water corridor with ecological habitats. However, it also faces similar challenges as the Kinross corridor, such as changes in site grading, barriers along the potential water course, bylaw restrictions against directing water across different properties, and additional funding requirements for directing rainwater through engineered structures.

According to the peer municipality survey on GSI, 14 municipalities have completed

DAYLIGHTING INITIATIVES IN THE CITY OF SURREY, BC

The City of Surrey adopted a Natural Drainage Policy in 1979, stating that the city will maintain the existing creeks/rivers in open states. The city has identified where to reopen historic creeks that were piped before 1979, and has been conducting enhancements and daylighting projects throughout the city. Some new naturalized water courses are aligned with historic routes. These initiatives are included in many city strategies and plans, including Integrated Stormwater Management Plans, the Biodiversity Conservation Strategy, the Parks Natural Area Management Plan, Neighbourhood concept plans and the new Streamside Bylaw. Some notable projects include: Robson Park ponds and channel daylighting, Robson daylighting at 103, Surrey Lake, Guildford Pond/Channel, Chantrell realignment, Bolivar obstruction removal, Newton Pond, and Latimer Creek realignment. The city has also been working on removing barriers in the streams to re-establish and enhance fish passage.

These daylighting projects provide a variety of benefits to the city, such as flood protection, water quality improvement, fisheries and wildlife enhancements, etc. Multiple city departments are involved in the planning and design process, including Engineering, Planning, Sustainability and Parks. This is to make sure these initiatives fit into long-term neighbourhood plans as well as recreational plans. The residents and students in the city are actively engaged in various phases of planning and design processes, and activities such as tree planting, riparian planting, invasive plant removal, instream fisheries enhancements, water quality monitoring, and fish releases (Baron, 2016).

Rain gardens in the EFL

past daylighting projects. 11 of them plan to conduct similar projects in the future, while the rest do not have the intention of conducting future daylighting projects. Some municipalities have completed pilot projects and are studying the performance and effectiveness of these projects, while other municipalities have carried out such projects as part of their combined sewer separation program. Common challenges for stream daylighting identified by municipalities include significant capital and O&M costs, limited maintenance capabilities, overlapping underground infrastructure, lack of community support, low priority, etc.

PLAN ELEMENT 3: BOULEVARD RAIN GARDENS/ PLANTERS AND INFILTRATION GALLERIES

Rain gardens/planters are proposed on boulevards to collect rainfall on streets in the RMP. Infiltration galleries are proposed for areas where it is not possible to construct rain gardens/planters or bio-swales.

Some of the rain gardens proposed in Area 2 by the RMP were implemented. However, due to raised roadways and changes in site grading, some areas are too flat to effectively utilize rain gardens to capture rainwater. There are also concerns about tall plants posing as possible safety hazards at road intersections and crosswalks. Therefore, some of the rain gardens in the plan have not been implemented.

PLAN ELEMENT 4: RAINWATER ABSORBING PAVED SURFACES

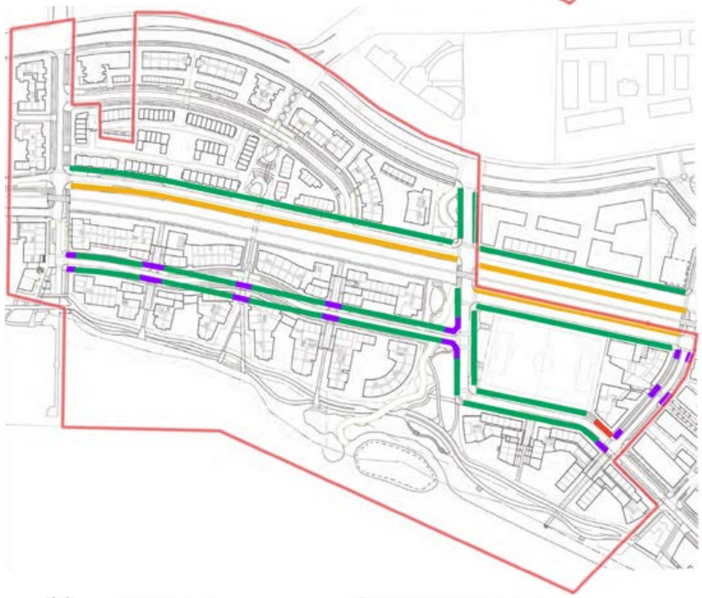
Permeable surface treatments are proposed in the RMP to reduce the amount of impervious surfaces on site (e.g. North Kent pedestrian/cycle path, and low-traffic volume roadways such as woonerfs and mews).

Currently no permeable surface treatments have been constructed, due to concerns about increased capital and O&M costs, treatment durability and longevity, etc.

A COMPARISON OF PROPOSED AND AS-BUILT RAINWATER ELEMENTS IN THE EFL AREA 2

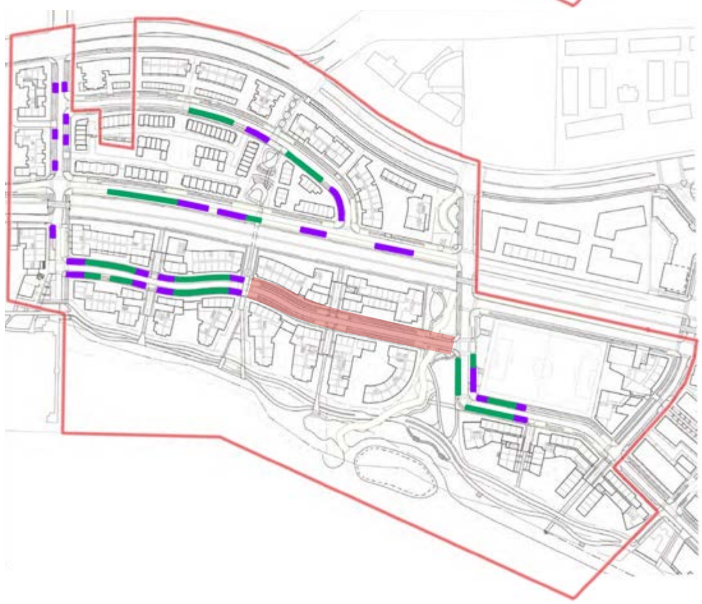
Rainwater elements in public lands proposed in the EFL design guideline

Proposed rainwater elements in the EFL design guideline



Bio-swales
Infiltration area - hardscape
Infiltration area - landscape
Rain gardens

Proposed rainwater elements in the 2008 RMP



Rain gardens
Infiltration areas
Areas not yet completed

Rainwater management facilities - as built

EVALUATION OF DESIGN OBJECTIVES

The 2008 EFL rainwater management plan (RMP) includes ten design objectives for rainwater management. These include eight objectives for GSI on city streets/roadways, and two objectives for GSI on private parcels. The eight objectives for GSI on city streets are evaluated based on the actual implementation of GSI treatments on site and their performance in completed areas.

"Target the 'first flush' as the primary objective for rainwater runoff capture"

Currently some of the rain gardens and infiltration trenches proposed in the RMP have been implemented. This helps to capture the initial surface runoff from streets, and reduce the volume of runoff entering the storm drains. However, "first flush" is a vague term, and is not clearly defined in the RMP. Therefore, it is not a specific target and is difficult to evaluate with certainty.

"Make roadways self-mitigating by managing rainwater runoff within road rights-of-way, to the extent feasible;

Capture rainwater runoff close to where it falls;

Prevent roadway runoff from flowing directly into the piped conveyance system, except during extreme events and extended wet periods;"

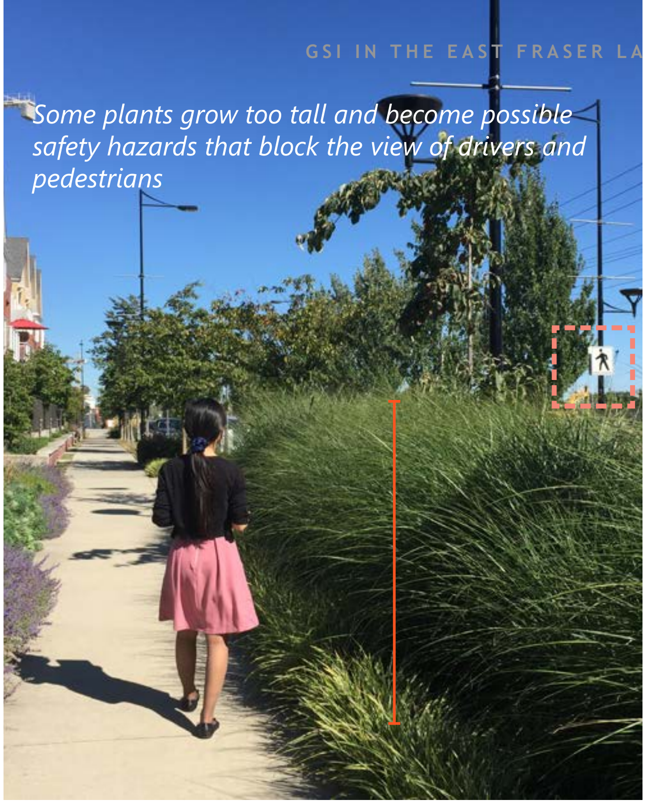
Although bio-swales are not constructed along Kent Avenue as originally planned, rainwater runoff from the Kent Avenue roadway in Area 2 is directed to grass boulevards and infiltration trenches along the avenue. With these rainwater facilities, rainwater is detained, slowed down and absorbed by soil or stored in trenches close to where it lands. This helps to reduce the volume of rainwater runoff entering the piped conveyance system.

However, the objective to "make roadways self-mitigating…to the extent feasible" is not a specific target for rainwater management. Additionally, there is currently no monitoring program to evaluate how effective the system actually is. For example, there is no data on the proportion of rainwater absorbed by green infrastructure, compared to how much enters stormwater pipes. Without specific targets or effective monitoring programs, it is very difficult to evaluate these goals effectively.

"Incorporate rain gardens and/or swales to maximize at-surface facilities for rainwater runoff capture and treatment;

Create a "pervious fingers network" to maximize

Grass boulevards along Kent Avenue


Some plants grow too tall and become possible safety hazards that block the view of drivers and pedestrians

infiltration of rainwater runoff into a capture zone, followed by exfiltration into the surrounding ground;"

Rain gardens were constructed on boulevards to collect rainfall on streets. For example, the southern portion of the site was graded into sewer-sheds, with rain gardens constructed as curb bump-outs to collect runoff from streets. Infiltration galleries were constructed in areas where rain gardens/planters are not feasible. Rainwater stored in these galleries is exfiltrated into surrounding soils over time. These rainwater treatments play important roles in improving rainwater quality and reducing runoff volume. However, there are a few challenges identified for rain gardens and infiltration galleries in the completed areas of the EFL.

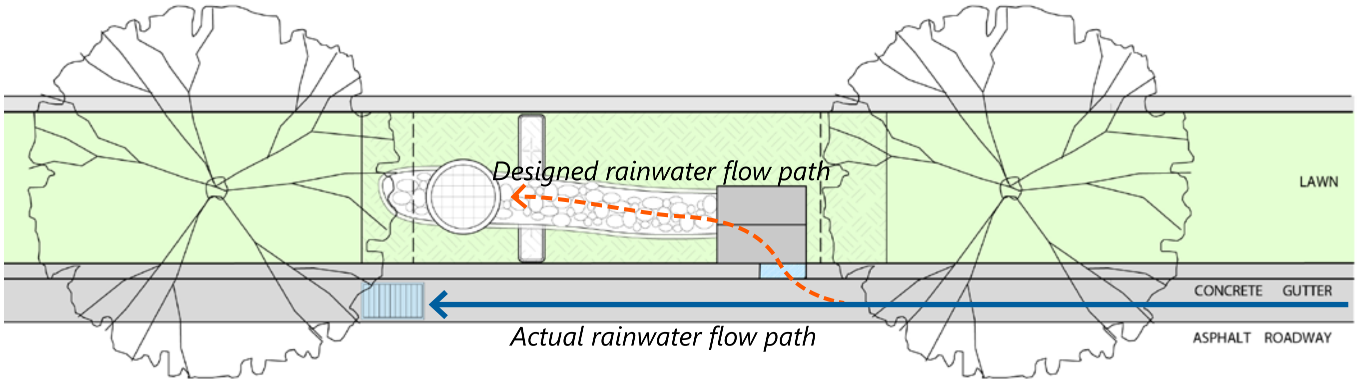
1. Planting Growth Condition in Rain Gardens

One challenge is the growing conditions of plants in rain gardens. For some native plants, they may grow well in a natural environment, but many of them do not grow well in an urbanized road environment, especially in their establishment phase. These plants had to be replaced with other species that are more adaptable to this context. For a few other fast growing species, they grew to significant heights in a short period of time. As rain gardens are often located in road intersections with pedestrian crosswalks, these excessively tall plants became possible safety hazards, and had to be trimmed more frequently to prevent them from blocking the view of pedestrians and drivers.

2. Performance of Rain Gardens

Based on site visits and personal interviews, most of the rain gardens


Rain gardens along Kerr Street with steep slope



As Kerr Street has very steep slope, very limited rainwater from streets flows into the water inlets of rain gardens

Grass boulevards with possible tripping risks

performed well in terms of reducing rainwater volume, improving rainwater quality, and improving streetscapes as public amenities. However, a few of them did not perform well due to site grading and a lack of site-specific design. For example, very limited rainwater flows into rain gardens along Kerr Street, primarily due to the steep slope of the road topography. The street slopes significantly to the south, and rainwater quickly travels down the slope to catch basins without flowing into the rain gardens.

3. Possible Tripping Hazard

In some rain gardens or grass boulevards, soil is sloped down to water overflow structures to provide drainage. However, this may cause the edge of the garden/ boulevard to be significantly lower than adjacent pedestrian sidewalks, thereby creating possible tripping hazards. This problem may also be caused or exacerbated by soil settlement over time, especially if the soil was not compacted properly during construction.

4. Limited Street Space

From an urban design perspective, a street with moderate width that matches the human scale is more effective in improving pedestrian experience and streetscape, as opposed to a wide street. However, rain gardens occupy a substantial amount of street space compared to underground grey infrastructure. The large open spaces

Various street elements within limited street space, including traffic lanes, boulevards, parking spaces, rain gardens, sidewalks, bike lanes, etc.

required by rain gardens and the limited street space available resulted in significant challenges for the planning and design of rain gardens. Oftentimes rain gardens compete for space with other street elements such as traffic lanes, parking spaces, sidewalks, bike lanes, street furniture, etc.

"Design the rainwater capture system to minimize maintenance;"

Currently rain gardens constructed in the EFL are maintained by Wesgroup (the project developer) in the establishment period, with major maintenance events taking place twice a year in the spring and fall. This includes removing sediment and trash, cleaning catch basins, weeding and trimming, etc. After a 2-year maintenance period, these assets will be handed over to the city. Some plants and grasses are maintained by local property owners if adjacent properties are developed and the property owners agree to take on maintenance responsibilities.

Proper design could help to reduce maintenance. For example, as mentioned before, some fast growing species grow very tall, and require more frequent trimming to ensure pedestrian safety. Future plant species selection could avoid using these fast growing species, which may reduce maintenance requirements.

However, same as grey infrastructure, green infrastructure needs regular inspections and maintenance, and this should be taken into consideration as early as possible in the GSI design phase. Incorporating GSI maintenance in the early phase of a project could help with the selection of proper plant species, improve street design, estimate lifecycle costs and allocate funding for long-term maintenance.

"Provide a piped system for conveyance of runoff overflows during periods of extreme wet weather;"

This objective was achieved by including overflow structures in rain gardens and infiltration galleries. The dispersal drains were designed so that when gravel zones become saturated during extreme rain events, rainwater runoff could overflow through standard catch basin outlets into storm drains. Similarly, catch basin decants were installed in rain gardens as overflow structures in case the gardens were inundated.

RECOMMENDATIONS FOR UPDATING THE 2008 RMP

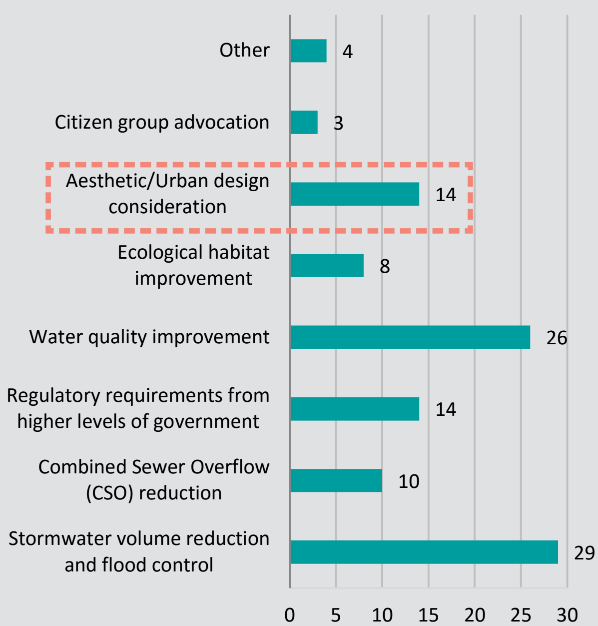
With updated planning policies and regulations, and improved understanding of site conditions and GSI design strategies, some information and plan elements in the 2008 RMP have become outdated and no longer applicable to the current conditions in the EFL. Therefore, recommendations for updating the 2008 RMP are proposed below:

1. Establishment of rainwater management targets with quantifiable metrics

According to the citywide IRMP, collector/arterial streets should meet water quality targets (treat and improve rainwater quality for the first 48 mm of rainfall in 24 hours), while local streets should meet both water quality and volume reduction targets (soak up the first 24 mm of rainfall in 24 hours). The updated rainwater management plan should include specific and proactive targets for rainwater management that are in line with or above the citywide targets. Quantifiable metrics should be utilized for monitoring programs to measure if these targets are met.

2. Updated information and plan elements to reflect actual site conditions

PRIMARY DRIVERS FOR IMPLEMENTING GSI ON CITY STREETS/PLAZAS



(Source: Vancouver peer municipality survey on GSI)

During the past few years, there were changes in planning context, with flood construction levels raised in response to climate change, as well as an increasing interest in urban bike lane systems. As a result of changes in planning context, and technical difficulties on-site, the proposed bio-swales and some rain gardens in Area 2 were not implemented. The RMP should be updated to reflect these changes, and propose new landscape-based rainwater plan elements that match site conditions and current development phases.

3. Aesthetic/social value of GSI as part of the design objectives

> *If possible, rain water is to run to parks and public open spaces where it can animate the public realm*
>
> THE EFL ODP

According to the municipality survey, although stormwater volume control and water quality improvements are the top two drivers for municipalities to implement GSI, aesthetic and urban design consideration also plays an important role. The citywide IRMP also includes aesthetic benefits and public education, as well as cultural and health value as major functional criteria for evaluating different types of best management practice tools.

The current RMP reflects the aesthetic/social value of GSI by incorporating “rainwater management facilities as civic amenities where practical” as one of the guiding principles. However, the focus of the plan is to improve rainwater runoff quality. While the implemented rain gardens on roadways have helped to improve streetscapes for pedestrians, other opportunities could be considered and integrated into the future design of GSI treatments, such as including them into neighbourhood parks and waterfront plazas, where they could serve as recreational and educational features.

4. More comprehensive plan elements with a diverse selection of GSI treatments

The current RMP includes plan elements such as rain gardens and trenches on roadways, and large parks (e.g. Avalon/ Kinross Park) for water courses. However, according to the EFL design guidelines, rain garden elements are also proposed in other neighbourhood parks (e.g. Promontory Park). In order to provide more diverse functions through green infrastructure, more comprehensive rainwater management facilities should be considered and included in the RMP, such as neighbourhood parks, plazas, mews and lanes, etc.

Additionally, the only GSI treatments implemented on site are rain gardens and infiltration galleries. According to the municipality survey and other case studies, there is a wide range of options for green infrastructure, including stormwater trees, absorbent landscapes, etc. Each of them is different in terms of functionality and street space required, and could be utilized on different types of streets.

5. Inclusion of maintenance and monitoring programs

The current plan states that the “rainwater management facilities located within road rights-of-way would be relatively maintenance free”. However, although proper design of these facilities could help to reduce maintenance, regular maintenance of these treatments is very important for stormwater functions, aesthetic quality, and public safety. O&M strategies with detailed maintenance activities and frequencies, monitoring programs with metrics to evaluate GSI performance, and lifecycle cost estimations should be included in the updated RMP. The plan should specify the responsibilities of different parties involved at different O&M stages of GSI treatments (e.g. establishment period and post-establishment period). Strategies should be developed for the city to work together

Construction processes documented in the Portland Siskiyou Green Street Report. Image by the City of Portland

PORTLAND GREEN STREETS CASE STUDY REPORTS

Between 2003 and 2007, Portland has developed a variety of Green Streets Pilot projects, and each pilot project was well documented with a consistent format. Documented information includes a concise project summary, background, site selection criteria, stormwater capacity and system configuration, project costs, and maintenance and monitoring practices. The information is presented with site photos, design drawings, tables of technical data, etc. Lessons learned from each case study are summarized at the end of each report, and play very important roles in the planning and design of future GSI projects.

Siskiyou Green Street Project in Portland Image by the City of Portland

with local residents and volunteering groups in the landscaping maintenance and GSI monitoring programs in the EFL.

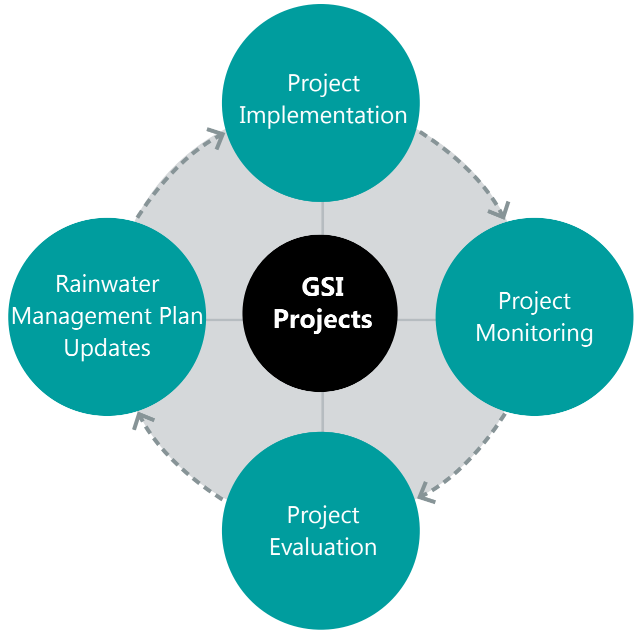
6. Allocation of secured funding for the O&M of GSI assets

Dedicated funding should be allocated for the O&M of GSI in the EFL as it is very important for the performance and longevity of these assets. According to the municipality survey, stormwater utility charge is a potential funding source for GSI O&M and is widely used by American municipalities.

7. Incorporation of lessons learned and plan updating mechanisms

Plan updating mechanisms should be included in the updated RMP (e.g. updating the plan every 5 years). This is not only to update GSI elements implemented on site and document their performance through the proposed monitoring program, but also to identify best practices, challenges and issues, as well as lessons learned. Incorporating knowledge/experience gained could create a cyclical process from project implementation and evaluation to plan updates, and this will benefit future GSI projects by incorporating lessons learned and avoiding similar design/implementation issues.

These proposed recommendations on the design and maintenance of GSI should be considered and reflected in the O&M of completed sections of Area 2 and in the future GSI planning and design of Area 1. Detailed recommendations for GSI planning, design and maintenance are proposed in the next section of this chapter based on different development phases.



PHILADELPHIA GSI MONITORING PLAN

In Philadelphia, monitoring and testing various GSI systems is an important component in the *Green City, Clean Water Plan*. The Philadelphia Water Department (PWD) has developed a Comprehensive monitoring plan that details GSI monitoring activities, and describes how the monitoring program should gather data to assess system performance. Elements for monitoring and assessment include surface water, groundwater, rainfall, Combined Sewer Overflow discharges, sewer flows, and green infrastructure performance (PWD, 2014).

RECOMMENDATIONS FOR GSI PROGRAMS/ PROJECTS IN THE EFL

Recommendations for the planning, design and maintenance of GSI projects in the EFL are proposed, and are categorized based on areas within different development phases.

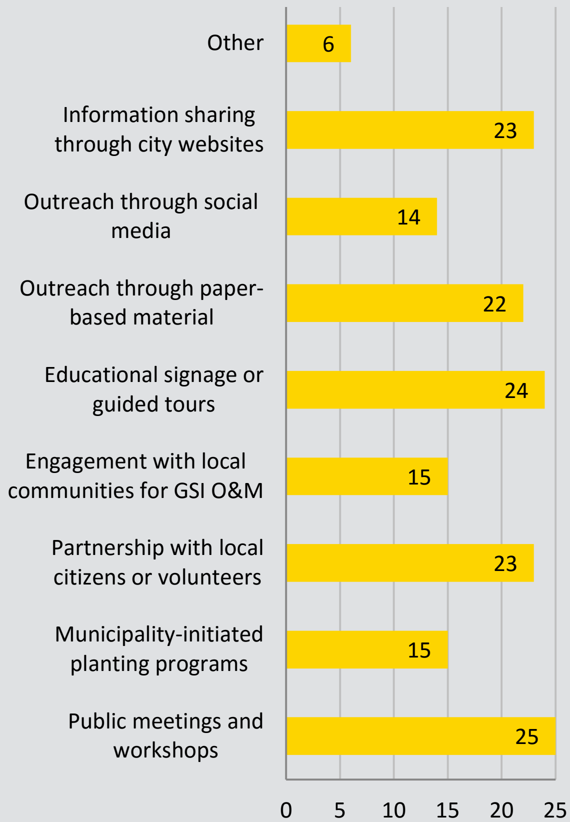
FOR AREAS THAT HAVE COMPLETED CONSTRUCTION

Strategies for future operation, maintenance and monitoring of GSI assets are proposed for areas that have been completed, primarily in Area 2.

• Public Engagement through Outreach Activities and Public Art

According to the municipality survey, there are a variety of activities and tools to engage with communities regarding green infrastructure. Public engagement is important for developing new opportunities for GSI projects and facilitating their implementation. As the EFL is a dense residential neighbourhood, there are significant opportunities to engage with local residents and other volunteering groups to increase public awareness of rainwater management strategies through GSI. For example, the current underground infiltration galleries in the EFL are not visible by the public, and creating GSI tours with educational signage by the completed rain gardens and infiltration galleries will help to explain and visualize the rainwater management processes. Additionally, according to the EFL Policy Statement, public art could be incorporated into sustainability measures. Future opportunities could be investigated in terms of utilizing public art installations to illustrate rainwater management features and processes.

PUBLIC EDUCATION AND OUTREACH ACTIVITIES FOR GSI PROGRAMS



(Source: Vancouver peer municipality survey on GSI)

A "City of Chicago Green Alley" concrete stamp marks the entrance of each reconstructed alleyway to increase public awareness of this initiative.

• Engagement with the Public for GSI Maintenance and Monitoring

As most of the landscaping in the EFL in Area 2 was installed more than 2 years ago, they are beyond the establishment period, and there will be a shifting focus in O&M from planting establishment (e.g. watering, fertilizing) to planting area maintenance (e.g. weeding, trash removing). A maintenance guideline/schedule should be developed with suggested maintenance frequencies and activities to ensure the rainwater management functions of GSI assets. The city could also engage local residents in the landscaping maintenance of these treatments in close proximity to their own properties, with a focus on improving the landscaping aesthetic quality.

A comprehensive, long-term monitoring program is also important for completed GSI projects. It would play a significant role in clearly identifying the effectiveness of GSI treatments in reducing rainwater runoff and improving water quality. Data and information collected from these projects would be beneficial for the design, construction and maintenance of future projects. The city could partner with volunteering or stewardship groups for the implementation of this monitoring program.

MAINTENANCE STANDARD IDENTIFIED IN THE CURRENT RMP

- Rain Gardens: Level 2 Groomed Maintenance defined by B.C. Landscape Standard
- Bioswales: Level 3 Moderate Maintenance defined by B.C. Landscape Standard
- Permeable Pavements: none
- Dispersal Trenches: none

MAINTENANCE OF THE SEATTLE STREET EDGE ALTERNATIVE PROJECT

For the Street Edge Alternative (SEA) project in Seattle, the bio-retention cells on the street are maintained by the Seattle Public Utilities Operations and Maintenance group to ensure stormwater functionality at a service level B. Street assets are also maintained by local residents on adjacent properties, who have taken responsibility for plants within their right-of-way, through weeding, mulching and mowing when necessary (City of Seattle, 2011).

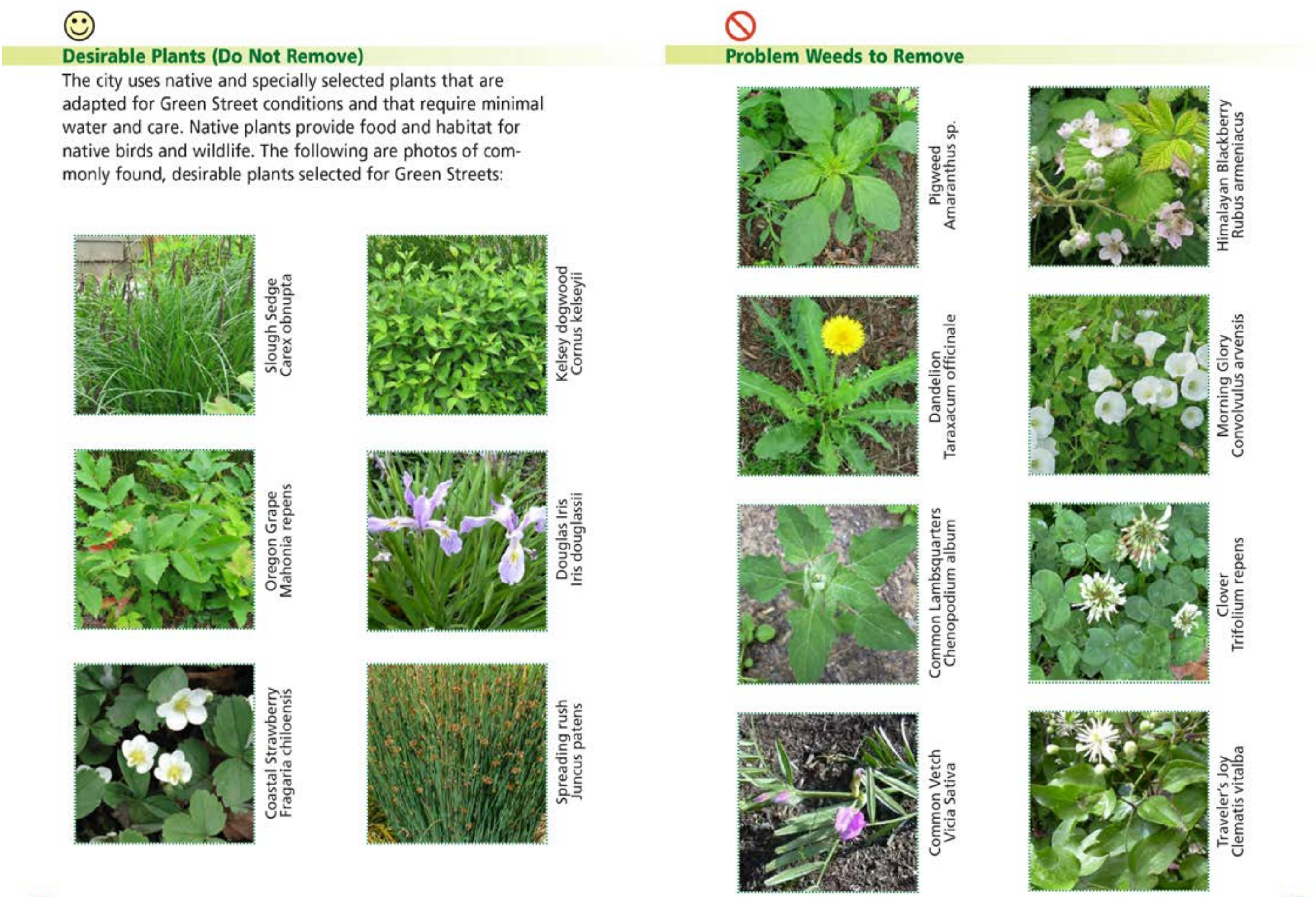
MAINTENANCE OF GSI ASSETS IN THE CITY OF PORTLAND

Portland's Bureau of Environmental Services (BES) routinely inspects Green Streets and maintains GSI treatments. Green Street maintenance includes a two-year establishment phase and a long-term stewardship phase. Maintenance includes removing sediment, leaves or trash that can impede water flow, replacing plants when needed, regular watering, etc.

Aside from maintenance of GSI assets by the city, a *Green Street Steward's Maintenance Guide* was developed for the Green Street Steward Program. The guide specifies maintenance activities, tools and other tips for both the 2-year establishment phase and the long-term stewardship phase. Photos are included in the guide to illustrate activities and plants species, which makes the guide much more easily understandable.

Anatomy of a Green Street

1. ***Capture and Treatment Area*** where stormwater flows and the water ponds
2. ***Overflow Drain*** Not all Green Streets have one
3. ***Curb Opening*** Also called an inlet or outlet where stormwater can enter and exit



Desirable Plants (Do Not Remove)

The city uses native and specially selected plants that are adapted for Green Street conditions and that require minimal water and care. Native plants provide food and habitat for native birds and wildlife. The following are photos of commonly found, desirable plants selected for Green Streets:

Slough Sedge *Carex obnupta*

Kelsey dogwood *Cornus kelseyii*

Oregon Grape *Mahonia repens*

Douglas Iris *Iris douglassii*

Coastal Strawberry *Fragaria chiloensis*

Spreading rush *Juncus patens*

Problem Weeds to Remove

Pigweed *Amaranthus sp.*

Himalayan Blackberry *Rubus armeniacus*

Dandelion *Taraxacum officinale*

Morning Glory *Convolvulus arvensis*

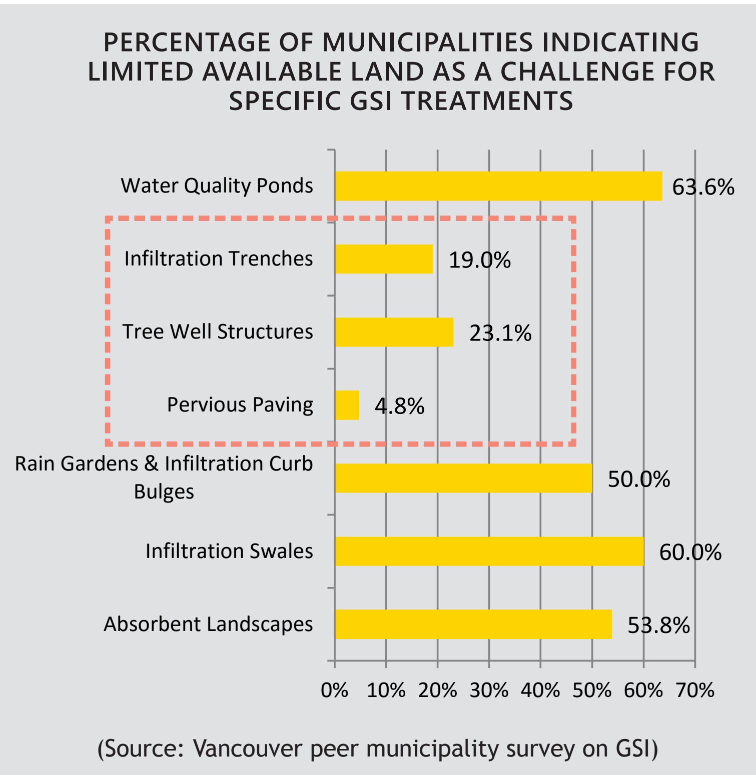
Common Lambsquarters *Chenopodium album*

Clover *Trifolium repens*

Common Vetch *Vicia Sativa*

Traveler's Joy *Clematis vitalba*

Guidelines and instructions for GSI maintenance included in the Green Street Steward's Maintenance Guide
Image by the City of Portland



City of Philadelphia Stormwater Management Practices Suitability Matrix
Table from the City of Philadelphia, 2014

FOR AREAS IN THE PLANNING/DESIGN STAGE

Strategies for future planning and design of GSI projects are proposed for areas that have completed rezoning and are currently in the planning and design stage, primarily in Area 1.

• *Diversity in Types of GSI Treatments*

One challenge in the rain garden design in the EFL was that although rain gardens provide stormwater functions and improve streetscape, they tend to occupy large amounts of street space, which may conflict with other street elements such as traffic lanes, parking spaces, sidewalks, and bike lanes. This is in line with findings from the peer municipality survey, which indicate that one of the biggest challenges for rain gardens is the limited land available. Also according to the survey, there are other GSI treatments that occupy less space or accommodate other street functions more effectively. For example, the GSI treatment with the least concern about limited available land is pervious paving, followed by infiltration trenches and tree well structures. It should be noted that pervious pavers have potential accessibility issues and may not be appropriate for sidewalks. However, pervious concrete and pervious asphalt can be utilized for sidewalks, bike lanes, etc.

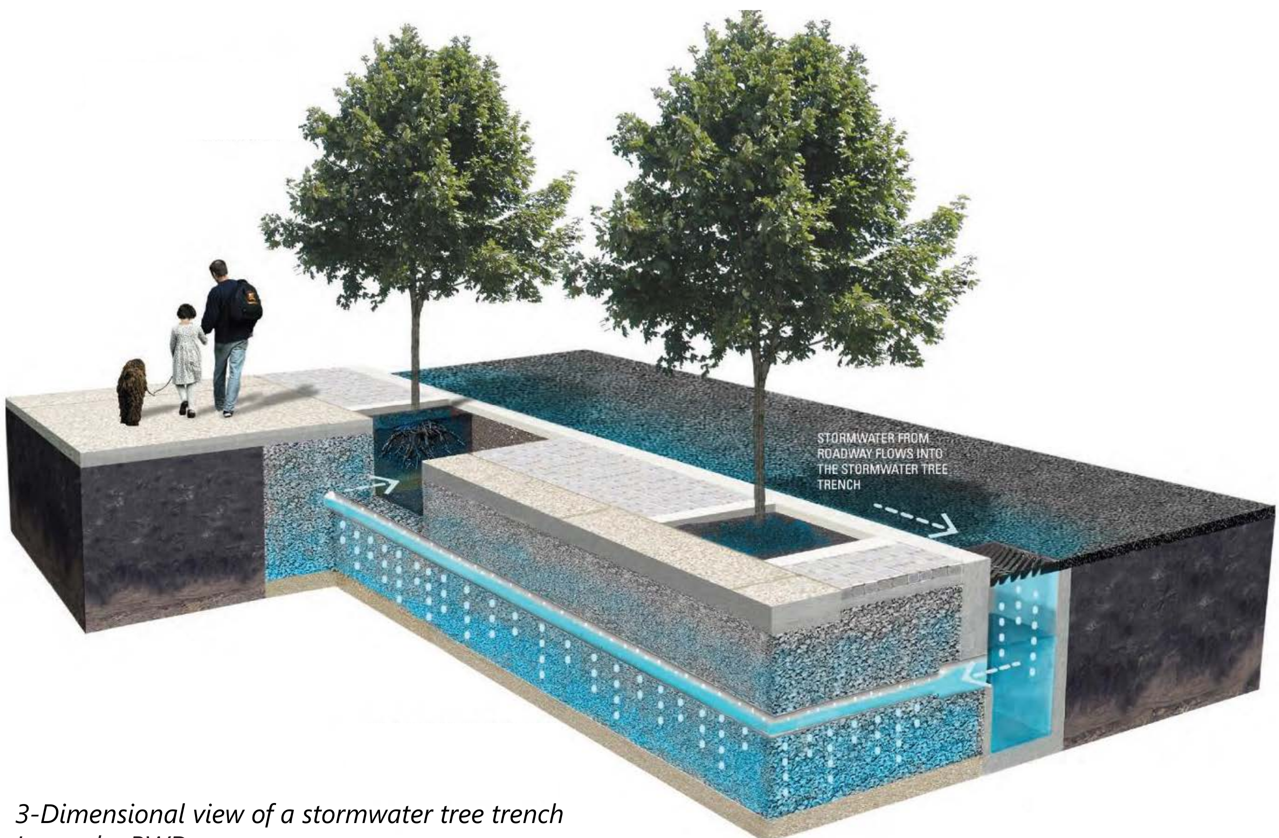
Many municipalities also conducted studies on what types of GSI treatments are most suitable for specific types of streets. For example, the City of Philadelphia, the City of Nashville and the City of Milwaukee have all developed suitability/selection matrices as a reference for the selection of GSI treatments on specific types of streets.

GSI CASE STUDY

STORMWATER TREE TRENCH, PHILADELPHIA

The Philadelphia Water Department (PWD) has been working on the Green Streets program as a key component of the *Green City, Clean Waters* plan. A Green Street captures and manages rain or melting snow using GSI such as stormwater tree trenches, planters, bump-outs, and pervious pavement.

A stormwater tree is a street tree planted in a specialized tree pit installed in the sidewalk area. It is designed to collect stormwater by placing the top of the planting media lower than the street gutter's elevation, and connecting the tree pit to an inlet. Fences are set up around the tree pit in order to protect pedestrians from stepping down into the planting media. A stormwater tree trench is a subsurface trench installed in the sidewalk area that includes a series of street trees along the subsurface trench. This system is composed of a trench along the sidewalk, lined with a permeable geotextile fabric, filled with stone or gravel, and topped off with soil and trees. Stormwater runoff flows into the tree trench and is stored in the empty spaces between the stones or other storage media in the trench, which waters the trees and slowly infiltrates through to the trench bottom (PWD, 2014). Both stormwater trees and stormwater tree trenches improve the streetscape and fit well with existing sidewalk widths, and surface features/functions.



3-Dimensional view of a stormwater tree trench
Image by PWD

Tree trenches along Ben Franklin Parkway
Image by PWD

3-Dimensional view of a stormwater tree
Image by PWD

Soil cells in the Olympic Village, Vancouver

The City of Vancouver has completed soil cell pilot projects in the Olympic Village. They are more suitable for industrial sites without native soils, or above parkades. Potential challenges for soil cells include significant capital and O&M costs, conflicts with other underground utilities, and higher O&M costs for other utilities.

• Considerations of GSI Maintenance in Early Planning/Design Stage

According to the US EPA, several factors should be considered in terms of GSI O&M in the early planning/design stage. These include types of maintenance to be performed, maintenance frequency, available personnel to perform maintenance, cost of material replacement, and funding for O&M activities (EPA, 2013). Considering O&M practices, costs and funding opportunities is very helpful for determining what types of GSI treatments and plant species should be used, and ensuring secured funding to meet design objectives.

The first one to three years are very critical for ensuring the health of vegetation, and are known as the establishment period. The required maintenance in a plant's establishment period is more intensive than the rest of its lifecycle. According to the US EPA, best maintenance practices during this period include (EPA, 2013):

- **General maintenance:** activities such as weed removal, watering, and some fertilization may be necessary as young plants take root.
- **Erosion control:** additional erosion control may be necessary during this period, as roots may not be deep enough yet to limit erosion.
- **Minimize shock to plants:** where an inflow control mechanism exists, wastewater or stormwater entering the system should be minimized to reduce shock to the newly planted vegetation.
- **Compensate for short growing seasons:** in cold climates, the planting of larger, more matured plants may help to accelerate establishment.

> *"Operation and maintenance of GSI facilities should not be considered differently than operation and maintenance of any other assets. GSI structures are just another assets that need inspection and maintenance."*
>
> A SURVEY PARTICIPANT FROM THE CITY OF TACOMA

GSI maintenance activities
Image by the City of Portland

After the establishment period, the intensity of maintenance can be reduced, but regular inspection is still necessary, especially after heavy rain events. In general, inspections should include both routine maintenance activities and monitoring activities to ensure the success of the system.

For proposed GSI treatments in the EFL, a specific maintenance schedule should be developed prior to construction approval. Inspection and maintenance activities should be performed during the establishment period and afterwards. As green infrastructure encompasses a broad variety of project types, their maintenance activities/intensities vary considerably. Literature regarding operation and maintenance of different types of GSI treatments was reviewed, and maintenance activities and frequencies identified by municipalities and other organizations are summarized in Appendix 4.

• Flexible Design Strategies that Match Site Context

GSI projects in the completed areas of EFL provide good learning opportunities throughout their planning, design and construction phases. Unlike grey infrastructure, GSI has no universal design standard, and a successful project requires flexible design to match site topography, soil conditions, and intended functions. As several limitations have been observed for GSI implemented in Area 2 of the EFL, the design of future GSI projects should be based on experience and lessoned learned, and be flexible enough to match site context.

- Proper plant selection is very important for GSI projects. They should be suitable for site soil and climatic conditions so that they can grow well. Additionally, plants with very

Rain gardens in the EFL getting clogged by sediment, leaves, and litter

The NW 110th Street Cascade project
Image by Seattle Public Utilities

tall maximum heights should be avoided, to maintain visibility between pedestrians and drivers at street intersections.

- Site topography should be carefully evaluated to determine whether to implement a GSI treatment, and the design of water inlets/outlets. For rain gardens along Kerr Street, most rainwater flows quickly downhill without entering the rain gardens due to the steep slope present. Future design should consider other design options such as designing water inlet alternatives that help direct runoff into the rain gardens, constructing tiered rain gardens that match site topography, and utilizing other GSI treatments that better fit site context.
- Some completed grass boulevards were lower than adjacent pedestrian sidewalks, and may pose as possible tripping hazards. Innovative design strategies can help to reduce these risks and even provide more functions for pedestrians. For example, in the City of Victoria, rain gardens are designed with concrete parapets. These both protect pedestrians from stepping down into planting media, and serve as public seating areas.

FOR AREAS THAT HAVE NOT YET BEEN REZONED

Strategies for future planning of GSI are proposed for areas that have not been rezoned yet, primarily in Areas 3 to 5. The 2008 RMP should be fully updated during the rezoning process of these areas based on recommendations from the previous section "*Recommendations for Updating the 2008 RMP*".

Rain gardens with parapets as public seating areas in the City of Victoria

Rain gardens in the City of Vancouver with curbs on both sides to reduce tripping risk

Image from google.ca

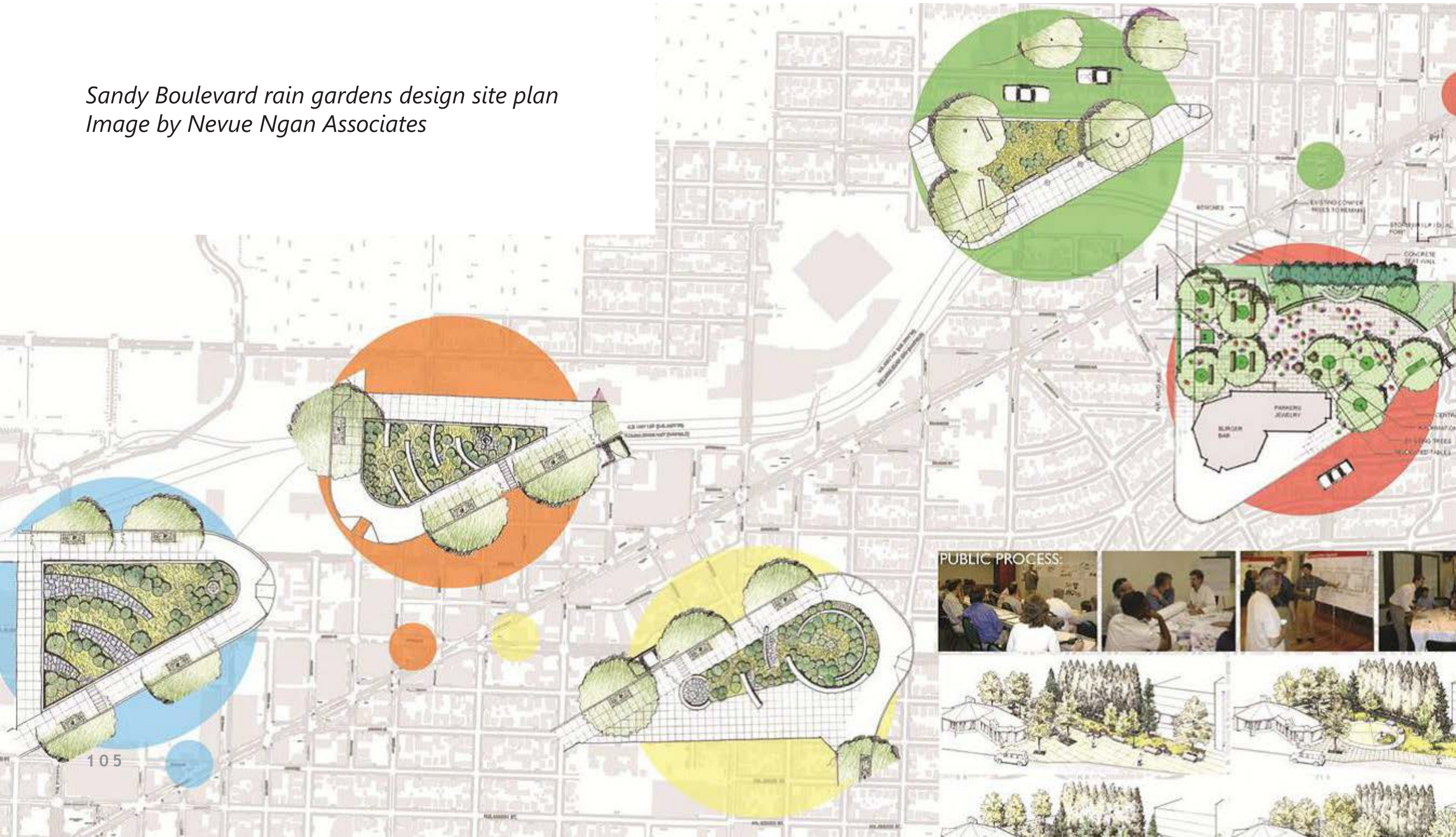
GSI CASE STUDY

NE SANDY BOULEVARD RAIN GARDENS, PORTLAND

Sandy Boulevard rain gardens
Image by Kevin Robert Perry

In 2007, a series of GSI treatments were installed along a 30-block stretch of NE Sandy Boulevard, one of Portland's busiest corridors. As Sandy Boulevard runs at an angle to the block grid, there is a series of "asphalt triangles" at many intersections with large areas of undefined street-level pavement (City of Portland, 2005). These triangular spaces at street intersections opened up a significant number of open spaces with GSI opportunities. This project took advantage of these triangular spaces, and installed 4 rain gardens and 1 stormwater plaza along the boulevard utilizing flexible design. The previous paved spaces were replaced by green open spaces and reconfigured to serve stormwater management functions.

Sandy Boulevard rain gardens design site plan
Image by Nevue Ngan Associates



The purpose of the rain gardens and the plaza is to reduce stormwater runoff and combined sewer overflow, provide wildlife habitats, and improve water and air quality and neighbourhood livability. Currently the rain gardens are populated by rushes and sedges, with drought-tolerant shrubs on the side slopes (Mayer-Reed). Storm runnels in the sidewalk and curb cuts surrounding the rain gardens help to direct storm runoff from streets/sidewalks into the rain gardens. Concrete slabs from site demolition were reused for pavement and benches. The design of the rain gardens also takes into account the historic character of this area. For example, the wall along the edge of a rain garden is designed to reflect the Art Deco-era architecture that remains along the historic strip.

Two of the rain gardens are monitored by the city to track their performance, and the rain garden at NE Sandy Boulevard and NE 13th Ave has captured and infiltrated 100% of the collected runoff (Mayer-Reed). This project has also significantly improved the pedestrian environment along NE Sandy Boulevard by providing safer pedestrian crossings and creating additional public open spaces along the boulevard.

The project was funded by a grant awarded to the City of Portland by the Oregon Department of Transportation (ODOT) to resurface the roadway and implement transportation improvements to Sandy Boulevard (City of Portland, 2005).

Sandy Boulevard Rain Gardens
Image by Kevin Robert Perry

Image by Carol Mayer Reed

CONCLUSION

Green Stormwater Infrastructure is an emerging trend for rainwater management. Although relatively new to many municipalities, worldwide research and pilot projects have tested its feasibility, its significant environmental, social and aesthetic value, and its cost-effectiveness compared to traditional grey infrastructure systems. It not only improves water quality and reduce stormwater runoff, but also creates valuable environmental, recreational and educational opportunities. Initiating and implementing more GSI projects becomes increasingly important, as climate change results in more extreme weather events.

Although GSI offers many opportunities and benefits, many municipalities may be uncertain about their cost-effectiveness, especially during the pilot stage. According to the peer municipality survey, municipalities planning to commence or expand their GSI programs are faced with many challenges, which include: limited available funding, limited experience and capacity for O&M, lack of inter-departmental collaboration, uncertainties about GSI performance and maintenance responsibilities, etc. These issues could be significant barriers for some municipalities in implementing GSI projects. However, as more municipalities adopt GSI, its design and performance is likely to improve as more experience and lessons learned are generated, and costs will likely reduce due to the increased economy of scale. Surveyed municipalities have identified various strategies for GSI programs, such as allocating dedicated funding for GSI, developing maintenance schedules/standards, internal outreach within municipalities, and engaging with local residents/volunteering groups for O&M.

GSI is currently in the development stage and is becoming a valuable and flexible tool for many municipalities to manage rainwater. Municipalities should take an iterative approach with incremental steps to phase in GSI projects. By accumulating experience and incorporating lessons learned into future projects, GSI could be successfully integrated into the fabric of our built environment.

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APPENDIX

APPENDIX 1 SURVEY QUESTIONNAIRE

CITY OF VANCOUVER

Peer Municipality Survey on Green Stormwater Infrastructure

Thank you very much for participating in this peer municipality survey conducted by the City of Vancouver, BC, Canada.

The City of Vancouver recently adopted a citywide Integrated Rainwater Management Plan with a target to capture and treat 90% of Vancouver's average annual rainfall by implementing green infrastructure tools and design guidelines. The purpose of this survey is to support infrastructure planning policy, budgeting, and processes for implementing Green Stormwater Infrastructure in the City of Vancouver.

This survey is in regards to Green Stormwater Infrastructure (GSI) that is operated and maintained by your municipality. The focus of the survey is on GSI that is implemented on city streets or plazas, including sidewalks. Most of the survey questions are about performance, operation and maintenance, as well as lifecycle costs of GSI in your municipality.

Please consult with staff in your municipality who have relevant experience and knowledge of GSI, and answer as many questions as you can. Please send the completed survey to Jessica Jin at jessica.jin@vancouver.ca before **June 30, 2016**. If you have any questions or suggestions, or would like further clarification, please feel free to contact Jessica Jin at the above email or 604-673-8378.

We would be happy to share our survey results with you following our receipt and processing of the survey data. Your participation is greatly appreciated!

GENERAL INFORMATION

Municipality: _______________ **State/Province:** _______________ **Country:** Select country

1. Does your municipality have a clear commitment to implementing GSI on city streets/plazas (e.g. through policy, bylaws, ordinances, or agreements)?

- ○ Yes
- ○ No

2. What are the primary drivers for implementing GSI on city streets/plazas in your municipality (please check the top 3 reasons)?

- ☐ Stormwater volume reduction and flood control
- ☐ Combined Sewer Overflow (CSO) reduction
- ☐ Regulatory/Legislative requirements from higher levels of government
- ☐ Water quality improvement
- ☐ Ecological habitat improvement
- ☐ Aesthetic/Urban design consideration
- ☐ Citizen group advocation
- ☐ Other, please specify ______________________________

3. What percentage of your municipality (by area) is served by combined sewer systems (as opposed to separated sewer systems)?

- ○ 100 %
- ○ 80 -99 %
- ○ 50 - 79 %
- ○ 20 - 49 %
- ○ 1 - 20 %
- ○ 0 %

CONSTRUCTION AND PERFORMANCE

4. Which of the following GSI treatment(s) have been implemented on city streets/plazas in your municipality (check all that apply)?

GSI Treatments	Yes	No	If yes, please estimate the number of projects	and with other metrics (e.g. total length or total area of GSI treatments)
Absorbent Landscapes	O	O		
Infiltration Swales	O	O		
Rain Gardens & Infiltration Curb Bulges	O	O		
Pervious Paving	O	O		
Tree Well Structures (e.g. designed tree trench infiltration systems)	O	O		
Infiltration Trenches	O	O		
Water Quality Ponds	O	O		
Water Quality Structures (e.g. grit/oil/sediment separators or tanks)	O	O		
Detention Tanks	O	O		
Other, please specify: ____________	O	O		

5. For the GSI treatment(s) indicated, on what type(s) of streets/plazas are they implemented in your municipality (check all that apply)?

GSI Treatments	Yes	No	If yes, please select the type(s) of streets/plaza: Arterials	Collectors	Local roads	Sidewalks/ Walkways /Multi-use paths	Alleys/ Lanes	Mews/ Woonerfs	Public plazas
Absorbent Landscapes	O	O	☐	☐	☐	☐	☐	☐	☐
Infiltration Swales	O	O	☐	☐	☐	☐	☐	☐	☐
Rain Gardens & Infiltration Curb Bulges	O	O	☐	☐	☐	☐	☐	☐	☐
Pervious Paving	O	O	☐	☐	☐	☐	☐	☐	☐
Tree Well Structures	O	O	☐	☐	☐	☐	☐	☐	☐
Infiltration Trenches	O	O	☐	☐	☐	☐	☐	☐	☐
Water Quality Ponds	O	O	☐	☐	☐	☐	☐	☐	☐
Water Quality Structures	O	O	☐	☐	☐	☐	☐	☐	☐
Detention Tanks	O	O	☐	☐	☐	☐	☐	☐	☐
Other,	O	O	☐	☐	☐	☐	☐	☐	☐

6. Does your municipality have a history or intention of creating open drainage channels or recreating historic streams by new naturalized water courses?

- O Past project(s) completed, with the intention of future similar projects
- O Past project(s) completed, without the intention of future similar projects
- O Currently working on or intending to commence pilot project(s)
- O No history or current intention of such projects

7. For the GSI treatments implemented on city streets/plazas in your municipality, how do they perform in terms of the following aspects? (from *Highly effective* = 5 to *Minimally effective* = 1)

GSI Treatments	Yes	No	If yes, please rate with the following performance criteria: Improve water quality	Reduce storm runoff	Increase aesthetic value of open space	Increase ecological value	Create educational opportunities
Absorbent Landscapes	O	O	Select	Select	Select	Select	Select
Infiltration Swales	O	O	Select	Select	Select	Select	Select
Rain Gardens & Infiltration Curb Bulges	O	O	Select	Select	Select	Select	Select
Pervious Paving	O	O	Select	Select	Select	Select	Select
Tree Well Structures	O	O	Select	Select	Select	Select	Select
Infiltration Trenches	O	O	Select	Select	Select	Select	Select
Water Quality Ponds	O	O	Select	Select	Select	Select	Select
Water Quality Structures	O	O	Select	Select	Select	Select	Select
Detention Tanks	O	O	Select	Select	Select	Select	Select
Other,	O	O	Select	Select	Select	Select	Select

8. For the GSI treatments implemented on city streets/plazas in your municipality, what are the primary challenge(s)/limitation(s) associated with them (check all that apply)?

GSI Treatments	Yes	No	If yes, please select challenge(s)/limitation(s)							
			Limited available land	Significant construction costs	Significant operation and maintenance costs	Limited available funding	Lack of community support	Lack of institutional support	Other, please specify	None
Absorbent Landscapes	○	○	☐	☐	☐	☐	☐	☐		☐
Infiltration Swales	○	○	☐	☐	☐	☐	☐	☐		☐
Rain Gardens & Infiltration Curb Bulges	○	○	☐	☐	☐	☐	☐	☐		☐
Pervious Paving	○	○	☐	☐	☐	☐	☐	☐		☐
Tree Well Structures	○	○	☐	☐	☐	☐	☐	☐		☐
Infiltration Trenches	○	○	☐	☐	☐	☐	☐	☐		☐
Water Quality Ponds	○	○	☐	☐	☐	☐	☐	☐		☐
Water Quality Structures	○	○	☐	☐	☐	☐	☐	☐		☐
Detention Tanks	○	○	☐	☐	☐	☐	☐	☐		☐
Other,	○	○	☐	☐	☐	☐	☐	☐		☐

Additional comments on challenges/limitations of GSI on city streets/plazas

____

BUDGET AND PERSONNEL

9. How much does your municipality spend on policy and planning, design and construction, and operation and maintenance of GSI on city streets/plazas every year (on average for the past 3 years)?

- Policy and Planning ____________
- Design and Construction ____________
- Operation and Maintenance ____________

10. Does your municipality plan to increase or reduce the budget for policy and planning, design and construction, and operation and maintenance of GSI on city streets/plazas in the next 3 years?

Budget Type	Budget will be increased	Budget will be reduced	Budget will remain relatively unchanged
Policy and Planning	○	○	○
Design and Construction	○	○	○
Operation and Maintenance	○	○	○

Please explain the reason(s) for the increased/reduced budget

____

11. Which of the following are the primary funding sources for policy and planning, design and construction, and operation and maintenance of GSI on city streets/plazas in your municipality (check all that apply)?

Budget Type	Funding Sources							
	Property tax	Development charges or fees	Stormwater utility charges	Borrowed funds/market place	Dedicated funding for GSI or stormwater management projects	Grants/Funding from other levels of government	Funding from private developers or through development	Funding from private institutions/ organizations
Policy and Planning	☐	☐	☐	☐	☐	☐	☐	☐
Design and Construction	☐	☐	☐	☐	☐	☐	☐	☐
Operation and Maintenance	☐	☐	☐	☐	☐	☐	☐	☐

Other, please specify____

12. Which departments in your municipality are primarily responsible for policy and planning, and design and construction of GSI on city streets/plazas (check all that apply)? Please estimate the number of full time employees dedicated specifically to GSI in each department.

Departments	Policy and Planning		Design and Construction	
	Yes	If yes, please estimate the approximate number of staff	Yes	If yes, please estimate the approximate number of staff
A specific division/department designated for GSI or stormwater management projects	☐		☐	
Engineering/Public Works/Public Utilities Department	☐		☐	
Planning Department	☐		☐	
Water/Sewer Department	☐		☐	
Environmental Services Department	☐		☐	
Transportation Department	☐		☐	
Other, please specify ____________	☐		☐	

13. Which of the following department(s) or group(s) are involved in the operation and maintenance of GSI on city streets/plazas (check all that apply)?

Departments	Involved and responsible	Involved but not responsible	Not Applicable
A specific division/department designated for GSI or stormwater management projects			
Engineering/Public Works/Public Utilities Department			
Planning Department			
Water/Sewer Department			
Environmental Services Department			
Transportation Department			
Private developers or institutions			
Neighbouring property owners (e.g. requirements for residents to maintain boulevards)			
Citizen stewardship/volunteering groups			
Other, ______			

14. Approximately how many city staff members are involved in the operation and maintenance of GSI on city streets/plazas?

Type	Approximate number of staff
Full time employees	
Seasonal employees	

OPERATION AND MAINTENANCE PRACTICE

15. Does your municipality have a GSI maintenance standard in terms of aesthetic quality and stormwater function? If so, to what standard are most GSI treatments maintained?

GSI Quality and Function	If yes, please rate from *Minimal quality or no function* = 1 to *Excellent quality/function* = 5						No such standard
	1	2	3	4	5	Varied standard for different projects	
Aesthetic quality							
Stormwater function							
Other, ______							

16. For typical GSI treatments implemented on city streets/plazas in your municipality, (1) how often are they inspected?

GSI Treatments	Yes	No	If yes, please indicate the inspection frequency								N/A
			Every week	Every month	Every 2-3 months	Every 6 months	Every year	Almost no inspection	Inspected on a complaint basis	Seasonal or other, please specify	
Absorbent Landscapes											
Infiltration Swales											
Rain Gardens & Infiltration Curb Bulges											
Pervious Paving											
Tree Well Structures											
Infiltration Trenches											
Water Quality Ponds											
Water Quality Structures											
Detention Tanks											
Others,											

(2) how often are they maintained?

GSI Treatments	Yes	No	If yes, please indicate the maintenance frequency								N/A
			Every week	Every month	Every 2-3 months	Every 6 months	Every year	Almost no maintainance	Maintained on a complaint basis	Seasonal or other, please specify	
Absorbent Landscapes											
Infiltration Swales											
Rain Gardens & Infiltration Curb Bulges											
Pervious Paving											
Tree Well Structures											
Infiltration Trenches											
Water Quality Ponds											

17. Does your municipality have documented standard maintenance procedures and programs for GSI on city streets/plazas?

- ○ Yes
- ○ No

18. Does your municipality have a performance monitoring plan for GSI on city streets/plazas?

- ○ Yes
- ○ No

19. Which of the following public education and outreach activities has your municipality implemented in regards to your GSI programs (check all that apply)?

- ☐ Public meetings and workshops
- ☐ Municipality-initiated planting programs
- ☐ Partnership with local citizen groups or volunteering programs
- ☐ Engagement with local communities for GSI maintenance
- ☐ Educational signage or guided tours
- ☐ Outreach through brochures and other paper-based material
- ☐ Outreach through social media (e.g. Facebook and Twitter)
- ☐ Information sharing through city websites
- ☐ Other, please specify ______________________________
- ☐ None

ADDITIONAL COMMENTS

20. Do you have any comments/suggestions on policy and planning, as well as design and construction of GSI on city streets/plazas?

21. Do you have any comments/suggestions on the operation and maintenance of GSI on city streets/plazas?

22. Do you have any additional information/documents on GSI in your municipality that you can share with us (e.g. standard operation and maintenance procedures, GSI plans or policies, GSI asset management plans)?

PRIMARY RESPONDENT

Name: ______________________
Position: ______________________
Department: ______________________
Email: ______________________

OTHER RESPONDENT(s) (if applicable)

Name: ______________________
Position: ______________________
Department: ______________________
Email: ______________________

Name: ______________________
Position: ______________________
Department: ______________________
Email: ______________________

Thank you very much for completing the survey. Your input will be very helpful.
Please email your completed survey to Jessica Jin at jessica.jin@vancouver.ca before June 30, 2016.

APPENDIX 2 GSI BUDGETS AND PERSONNEL OF SURVEYED MUNICIPALITIES

Municipalities	Population	Average Annual Budget for the Past 3 years (CAD)			Equivalent Number of Full-time Staff		
		Policy & Planning	Design & Construction	Operation & Maintenance	Policy & Planning	Design & Construction	Operation & Maintenance
City of Austin	790,390	$264,000	$528,000	$264,000	12	12	10
City of Berkeley	112,580	-	-	-	1	1	-
City of Boston	617,594	$2,046,000	$2,310,000	-	2	3	-
City of Charlotte	731,424	-	-	-	9	4	5
City of Fort Lauderdale	172,389	-	-	-	5	3	10
City of Fort Worth	741,206	-	-	-	1.5	1	4
City of Indianapolis	820,445	$158,400	$2,640,000	$132,000	2	8	4
City of Los Angeles	3,792,621	$132,000	$3,960,000	$198,000	-	-	2
City of Memphis	646,889	-	-	-	1	-	-
City of Pittsburgh	305,704	$13,200,000	$5,280,000	$132,000	8	3	6
City of Portland	583,776	-	-	-	-	-	16
City and County of San Francisco	805,235	$660,000	$1,716,000	-	7	5	-
City of Seattle	608,660	-	-	$1,320,000	-	-	2
City of St. Louis	319,294	-	-	$11,880	5	5	5
City of Tacoma	198,397	$26,400	$1,980,000	$13,200	5.1	5.1	3
Washington, D.C.	601,723	$1,320,000	$3,960,000	-	10	5	-
City of Burlington	175,779	-	$20,000	$10,000	-	-	-
City of Greater Sudbury	160,274	$100,000	$100,000	$7,000	2	-	-
City of Hamilton	519,949	-	-	-	3	3	5
City of Ottawa	883,391	-	-	$1,700,000	2	4	8
City of Sherbrooke	154,601	$100,000	$500,000	$100,000	-	-	-
City of Toronto	2,615,060	-	-	-	2	-	-
City of Vaughan	288,301	$5,000	-	-	3	2	-
Corporation of Delta	99,863		$200,000	$50,000		2	1
Township of Langley	104,177	$200,000		$1,000,000	12	2	5
District of North Vancouver	84,412	-	-	-	0.75	0.75	2
City of Port Coquitlam	56,342	-	-	-	-	-	0.2
City of Surrey	468,251	-	-	-	0.9	0.6	-
City of Vancouver	603,502	$63,300	$20,000		0.2	0.2	0.12
City of Victoria	80,017	-	-	-	1.3	0.7	2

Note: this table only includes municipalities that have provided budgets and personnel data for their GSI projects on city streets/plazas.

APPENDIX 3 COSTS FOR COMPLETED GSI PROJECTS

Municipalities	State	Project/Data Source	Year	Area (sq. feet)	Length (feet)	Drainage Area (sq. feet)	Planning & Design
Native Landscaping							
Chicago	IL	(City of Chicago, 2010)	2010	1			
Oakland County	MI	Oakland County Campus project (SEMCOG, 2013)	2011	696,960			
Conservation Design Forum	-	(Conservation Design Forum, 2001)	2001	435,600			
Bio-swales							
Toledo	OH	Maywood Avenue (City of Toledo, 2011)	2011		1		
Chicago	IL	(City of Chicago, 2010)	2010	1			
Milwaukee	WI	West Grange Avenue from South Howell Avenue to I-94 (SEMCOG, 2013)	2012	8,700		93,000	
Milwaukee	WI	South 6th St.: W. Howard Ave. to W. Layton Ave. (SEMCOG, 2013)	2011	8,400		92,000	
Seattle	WA	2nd Ave. SEA Streets (Seattle Public Utilities)	2000		660	100,188	
Coquitlam	BC	(City of Coquitlam, 2008)	2008		3.28		
Water Environment Research Federation	-	(Water Environment Research Federation, 2009)	2009			435,600	2,516
Ohio EPA	OH	(Tetra Tech, 2012)	2012	1			
Vancouver	BC	Bio-swales	2016	1			
Rain Gardens & Curb Extensions							
Portland	OR	NE Fremont Street Green Street Project (City of Portland)	2005	300		4,500	
Portland	OR	SE Ankeny Green Street Project (City of Portland)	2004	495		7,300	
Portland	OR	NE Siskiyou Green Street Project (City of Portland)	2003	550		9,300	included in management
Merrillville	IN	54th Court Rain Garden Bioremediation (SEMCOG, 2013)	2012	8,739			
Grand Rapids	MI	Plainfield Ave. (City of Grand Rapids, 2012)	2012	52,800	5,280	143,748	
Lancaster	PA	(City of Lancaster)	2011	1			
Water Environment Research Federation	-	(Water Environment Research Federation, 2009)	2009	1			
Ohio EPA	OH	(Tetra Tech, 2012)	2012	1			
Vancouver	BC	Typical rain gardens	2016	1			
Permeable Pavement							
Portland	OR	Pervious Pavement Projects (City of Portland)	2004		1,000		
Chicago	IL	(City of Chicago, 2010)	2010	1			
Toledo	OH	Maywood Avenue (City of Toledo, 2011)	2011	1			
Portland	OR	North Gay Avenue (City of Portland)	2005	32,000		50,000	125,130
Portland	OR	Westmoreland Pervious Pavers (City of Portland)	2004	28,000		60,984	149,124
Portland	OR	East Holladay Park NE 130th and Holladay Street (City of Portland)	2006	5,225		5,225	included in management
Ann Arbor	MI	Willard Street Permeable Asphalt Pavement (City of Ann Arbor, 2012)	2012	14,850	675		64,113
Low Impact Development Center	-	(Low Impact Development Center)	2002	1			
Water Environment Research Federation	-	(Water Environment Research Federation, 2009)	2009	1			
Ohio EPA	OH	(Tetra Tech, 2012)	2012	1			
Vancouver	BC	Permeable Asphalt Lane	2016	1			
Vancouver	BC	Permeable Country Lane	2016	1			

Project Cost Information in Past Value (CAD)			Project Construction Cost in 2016 Value with 3% discount rate			
Project Management	Construction	Total	Construction Cost (CAD)	Construction Cost Per Unit Area (CAD/sq. m)	Construction Cost Per Unit Length (CAD/m)	Construction Cost Per Unit Drainage Area (CAD/sq. m)
	0.13-0.65		0.15-0.77	**1.29-6.46**		
	229,620		266,192.51	**3.19**		
	181,890		283,378.69	**5.43**		
	194		224		**570.36**	
	3.87-38.7		4.62-46.21	**102.76-385.42**		
	516,000		580,763	**556.80**		**52.09**
	554,700		643,049	**638.54**		**58.30**
	840,497		1,348,751			**112.29**
	31.0-95.46		39.27 - 120.93		**30.41-93.74**	**0.00**
Included in Planning	10,062		12,375			**0.24**
	34		37.75	**314.87**		
	36-85		36-85	**36-85**		
4,470	16,685	21,156	23,096	**642.15**		**42.81**
	13,099	15,410	18,676	**314.70**		**21.34**
5,805	16,125	21,930	23,680	**359.12**		**21.24**
	69,080	81,270	77,750	**74.21**		
	340,560		383,303	**60.55**		**22.24**
	14.19-21.93		14.95-25.42	**124.71-212.08**		
	20.70		25.46	**212.40**		
	10.06		11.32	**94.46**		
	538-1,076		538-1,076	**538-1,076**		
	531,480		757,763		**1926.72**	
	3.87-19.35		4.62-23.10	**35.82-192.71**		
	7.74		8.97	**74.84**		
	330,240	455,370	457,129	**119.15**		**76.26**
included in plannign	436,020	585,144	621,660	**185.19**		**85.03**
28380.00	129,516	212,850 (including consultant, permits, etc.)	174,059	**277.86**		**277.86**
	312,954		352,232	**197.85**		
	2.58-8.39		3.90-12.68	**32.6-105.77**		
	8.39		10.31	**86.02**		
	15.97		17.97	**149.93**		
	261		261	**261**		
	194-512		194-512	**194-512**		

APPENDIX 4 GSI MAINTENANCE PRACTICES

GSI Treatments	Establishment Period (1-3 years)	Maintenance Inspection	Weeding, Mowing, &
Rain Gardens & Infiltration Bulges	Within 6 months following construction, the practice and drainage area should be inspected after storm events that exceed 1/2 inch of rainfall; Remove stakes, wires, and tags; Water plants weekly during first 2-3 months after installation, and when rainfall is less than 1 inch per week; Conduct spot fertilization once as needed in first to second year of installation (DDOT, 2014);	Conduct a maintenance inspection quarterly (DDOT, 2014); Regular monitoring and inspection to ensure adequate infiltration rate (EPA 2013); Bioinfiltration maintenance includes periodic inspection to ensure the system is operating properly, along with management of the vegetation (City of Chicago, 2003);	Necessary on a regular basis; m manicured cells, in urban areas, roads/walkways (EPA 2013); Mow turf areas monthly from M mow naturalized meadow areas and October, and water trees a (Philadelphia Water, 2014); Spot weed quarterly; water pla droughts consisting of more th (DDOT, 2014);
Infiltration Trench		Regular inspections (City of Coquitlam, 2008); Inlets should be inspected regularly to detect any clogging of the system (State of California);	
Pervious Paving	In the first year following construction, inspect the practice and contributing drainage area twice, within 24 hours after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization. (DDOT, 2014);	Annually (DDOT, 2014); One to two times a year (EPA 2013);	Controlled herbicide as necessa disturb pavement (EPA 2013); Vegetated paving blocks may re mowing (City of Chicago, 2003) Mow grass in grid paver applica weeks during the growing seaso
Tree Well Structures	Water trees 25 gallons weekly via slow release device in the first year, and 25 gallons bi-monthly via slow release device in the second and third years. Remove stakes and wires one year after planting (DDOT, 2014);	Inspect annually for erosion, sediment buildup, and proper vegetative conditions; and inspect inlets, outlets, and cleanouts twice annually (NOAA, 2015); Inspect trees for health and establishment three times during establishment period, and every five years for the life of the tree (DDOT, 2014);	Routine landscape maintenance (Philadelphia Water, 2014); Remove trash quarterly (DDOT,
Infiltration Swales	Within 6 months following construction, the practice and drainage area should be inspected after storm events that exceed 1/2 inch of rainfall; Remove stakes, wires, and tags; Water plants weekly during first 2-3 months after installation, and when rainfall is less than 1 inch per week; Conduct spot fertilization once as needed in first to second year of installation (DDOT, 2014);	Conduct a maintenance inspection quarterly (DDOT, 2014); Inspect regularly to ensure water is not pooling and channel is not eroded or damaged (EPA 2013);	Necessary on an occasional bas swales (EPA 2013); Mow turf areas monthly from M mow naturalized meadow areas and October, and water trees a (Philadelphia Water, 2014); Spot weed quarterly; water pla droughts consisting of more th (DDOT, 2014);

& Watering	Trash & Debris Removal	Sediment Removal, Cleaning, Draining, & Flushing	Plant & Component Replacement
ore frequent for , or near May to October, and s twice a year in June nd shrubs nts weekly during n 2 weeks of no rain	Necessary on a regular basis, particularly in urban settings (EPA 2013); Remove trash, sediment, and organic debris monthly (Philadelphia Water, 2014); Remove trash and animal waste, and any dead or diseased plants (DDOT, 2014);	As-needed; if water is standing for long periods of time (EPA 2013); Periodically removing sediment may be required to ensure the proper functioning of these systems (City of Chicago, 2003); Clean filter (NOAA, 2015); Remove sediment in pre-treatment cells and inflow points quarterly (DDOT, 2014); Subsurface maintenance (vacuum clean structures, jet-rod pipes) annually (Philadelphia Water, 2014);	Plant replacement as necessary; regular mulching to minimize weed growth (EPA 2013); Control invasive species, rake mulch annually (NOAA, 2015); Apply mulch annually in March, prune trees and shrubs annually, and remove invasive vegetation monthly from March to November (Philadelphia Water, 2014); Prune trees and shrubs, remove invasive plants, and add planting to maintain desired vegetation density as needed; Mulch with 3 inches shredded hardwood mulch annually (DDOT, 2014);
	Remove trash, sediment, and organic debris monthly (Philadelphia Water, 2014); Remove sediment and debris from all accessible components (City of Portland, 2016);	Cleaning of inlets to prevent clogging, mowing and inspection of observation wells (City of Coquitlam, 2008); Subsurface maintenance (vacuum clean structures, jet-rod pipes) annually (Philadelphia Water, 2014); Clean gutters, rain drains, catch basins, or silt traps at least twice a year (City of Portland, 2016);	
ry so as not to equire occasional ; tions once every 6 n (DDOT, 2014);	Necessary on a regular basis (EPA 2013); Remove trash, sediment, and organic debris 3 times a year (Philadelphia Water, 2014);	Vacuuming at a minimum of one to two times per year and, where present, flushing of drainage system (EPA 2013); Subsurface maintenance (vacuum clean structures, remove fine sediment and debris, jet-rod pipes) annually (Philadelphia Water, 2014); It is important to sweep or vacuum and reduce the application of sand and salt in cold climates. (NOAA, 2015); Mechanically sweep pavement with a regenerative street sweeper, or a vacuum sweeper to remove sediment 4 times per year in potential high sediment load areas, 2 times per year otherwise (DDOT, 2014);	Replace damaged pavers with spares; small areas can also be repaired with traditional pavement. Infill can be replaced with a broom (EPA 2013);
e of street trees 2014);	Collect garbage, removing litter as needed (NOAA, 2015); Remove weed quarterly (DDOT, 2014); Remove trash, sediment, and organic debris monthly (Philadelphia Water, 2014);	Subsurface maintenance (vacuum clean structures, jet-rod pipes) annually (Philadelphia Water, 2014); Remove sediment and trash from any inlets and slot drains (DDOT, 2014);	Ensure plant survival and density, and control invasive species; (NOAA, 2015); Tree pruning is needed; mulch with 3 inches of double ground shredded hardwood mulch. Place much in a ring to capture rain water (DDOT, 2014); Apply mulch and prune trees annually (Philadelphia Water, 2014);
is for vegetated May to October, and s twice a year in June nd shrubs nts weekly during n 2 weeks of no rain	Remove trash, sediment, and organic debris monthly (Philadelphia Water, 2014); Remove trash and animal waste, and any dead or diseased plants (DDOT, 2014);	Not necessary unless swale is damaged (EPA 2013); Drainage swales may require periodic cleaning but this cost should be minimized if upstream sources of sediment, particularly from construction activities, are well controlled (City of Chicago, 2003); Remove sediment in pre-treatment cells and inflow points quarterly (DDOT, 2014);	Plant replacement as necessary if the channel is damaged by erosion (EPA 2013); Prune trees and shrubs, remove invasive plants, and add planting to maintain desired vegetation density as needed; Mulch with 3 inches of shredded hardwood mulch annually (DDOT, 2014); Remove invasive vegetation monthly from March to November, prune trees and shrubs annually (Philadelphia Water, 2014);

GREENEST CITY SCHOLARS PROGRAM

AUGUST, 2016