Green Stormwater Infrastructure Asset Management Resources Toolkit

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Green Infrastructure Ontario Coalition

the green infrastructure leadership exchange

Southwest Environmental Finance Center

Contents

Cover image: A bioretention asset in Vancouver, British Columbia – the Sunset Bioswale.
Photo credit: Shannon Mendes

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How to Use this Toolkit

This toolkit should be read in conjunction with Southwest Environmental Finance Centre's Integrated Asset Management Framework. The Framework provides detailed theoretical guidance on asset management for gray and green infrastructure as well as examples and resources, while the Toolkit is focused entirely on green assets and provides more practical challenges and lessons learned, as well as case studies and examples developed or obtained through this Green Infrastructure Leadership Exchange funded Toolkit project.

The Toolkit is organized into the major components of asset management: Levels of Service, Current State of the Assets, Criticality, Life Cycle Costing, and Long-Term Funding. In each section, a brief overview of that component is provided, as well as challenges and lessons learned. Further information is included in **case studies**, **snapshots**, and **stories**. The reader can use the following graphic elements and style markers to help navigate to their content of interest:

Snapshots are short examples or descriptions of what a municipality or agency has done, is doing, or will do with respect to a particular asset management component. These are summarized in boxes, separate from the body text.

Case studies and stories always start on a new page and are indicated by different coloured bars on the right edge of each page.

Case studies are more detailed than snapshots, providing specific details about the reasoning and process of developing that asset management component used by agencies, as well as extracts from asset management programs or plans.

Colour side bars are used to indicate case studies and different colours indicate each asset type:

- Permeable pavement: **yellow**
- Bioretention and stormwater trenches: **green**
- Streams: **blue**

Stories provide a narrative overview of the challenges, lessons learned, process, and/or progress made by participating municipalities in developing their asset management plan. These pages are indicated by a grey bar.

It is recommended that the reader review the opening sections of this Toolkit which provide an overview of asset management and the featured green stormwater infrastructure asset types, before moving to specific components and relevant snapshots, case studies, and stories.

Introduction

While many municipalities are implementing and advancing components of asset management for green stormwater infrastructure (GSI) assets, for example, developing asset inventories and maintenance protocols, few have made the leap from *managing assets* to *asset management*, in other words, creating and implementing an asset management plan. This GSI Asset Management Resources Toolkit (the Toolkit) was born out of the need to provide more specific guidance and case studies on how to incorporate GSI into asset management.

The development of Toolkit was funded by Green Infrastructure Leadership Exchange (GILE) and involved a collaborative effort among six GILE members: the City of Toronto, Ontario; City of Vancouver, British Columbia; City of Atlanta, Georgia; City of Portland, Oregon; Metropolitan Sewer District of Greater Cincinnati, Ohio; and City of Palo Alto, California, as well as two subject matter experts: the Southwest Environmental Finance Center (SWEFC) and the Green Infrastructure Ontario Coalition (GIO).

SWEFC developed a free, online Integrated Asset Management Framework for combining green and gray assets into asset management which was released in 2021. The GSI Asset Management Resources Toolkit project aimed to build upon this work by beta testing SWEFC's Framework and applying it to GSI assets that are commonly used within the right-of-way: **pervious pavement**, **bioretention planters**, and **stormwater trenches**, as well as **streams**, which provide essential stormwater services. These asset types represent a cross section of assets ranging from entirely engineered/built (permeable pavement) to natural (streams), with bioretention planters in the middle.

The major goal of this project was to develop a toolkit that includes guidance on establishing a GSI asset management program and case studies sharing outcomes, tools, progress, challenges, and lessons learned from participating agencies developing their asset management plans for GSI.

Overview of Asset Management

Asset management is a strategic business process designed to help agencies manage their assets in a cost-efficient manner to ensure sustainable service delivery and keep risks to an acceptable level. Asset data are analyzed within a systematic framework to support decision-making on how, where, and when to spend limited resources on acquiring, maintaining, repairing, and replacing assets. Asset management involves five core components: levels of service, current state of the assets, criticality, life cycle costing, and long-term funding.

- The **level of service** component allows a municipality or utility to define the *level* (e.g., quantity, quality, and reliability) of services that the assets should provide to its customers, which in turn enables it to determine how the system must be operated and maintained to provide these desired service levels;
- The **current state of the assets** summarizes what assets are owned and/or managed by the agency and identifies the current condition of the asset; it is informed by an asset inventory;
- **Criticality** is an analysis of the risk associated with each asset should it fail; Criticality supports prioritizing where, when, and how money is spent to repair, rehabilitate, or replace assets;
- **Life cycle costing** refers to understanding the costs associated with each stage of an asset's life cycle to identify cost-effective interventions to make throughout its life; and
- **Long-term funding** is the process of developing a sustainable funding strategy to support day-to-day operations and longer term needs such as repair and replacement.

More information on each stage of asset management can be found in the SWEFC's online Integrated Asset Management Framework.

Green Stormwater Infrastructure Assets

This toolkit features four broad types of green stormwater infrastructure assets: **permeable pavement**, **bioretention assets**, **stormwater trench assets**, and **streams**. The first three are commonly used in the right-of-way (ROW), i.e., typically municipal or government land reserved for transportation or movement such as roads, bike trails, and sidewalks. The benefits of building GSI in the ROW is that it allows roads and sidewalks to have multiple ecological and hydrological functions in addition to being a surface for walking, driving, or parking. Streams also provide stormwater services and a host of other services and co-benefits.

Permeable Pavement

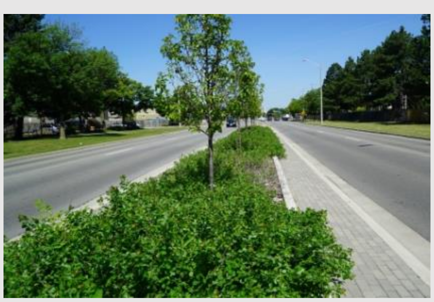
Permeable pavement serves the purpose of conventional pavement—a hard surface which allows, vehicles, bikes and/or pedestrians to move over, park, and sit on—and it has the additional functionality of allowing rainfall to permeate the surface to reduce runoff volume and improve water quality.

Rain or stormwater received directly on the surface, and sometimes also directed there from surrounding impervious surfaces, soaks through the surface layer into an underground reservoir where it infiltrates into the ground or is routed by an underdrain into the storm drainage system. Different aggregate layers and the underlying subsoil layer help to filter and clean rainwater received.

Bioretention Facilities

Bioretention assets are stormwater infiltration systems that are designed and engineered to use plants and layers of soil and crushed rocks to capture, treat, and infiltrate some or all of the stormwater that is directed into them from impervious areas. Some may include gravel under-drains and/or impermeable liners which support the conveyance of water to the stormwater system. A variety of bioretention asset types and terms are used including bioretention planters, rainwater gardens, and bioswales.

Stormwater Trenches



Stormwater trenches are similar to bioretention assets—they infiltrate stormwater received from surrounding paved areas. In addition, they have the capacity to store water and are particularly useful in locations where space is limited.

Stormwater *tree* trenches are trenches specifically designed to support the growth of trees using the collected and stored stormwater and additional soil volume. In turn, trees contribute to the asset’s stormwater function by increasing infiltration capacity and removing water requiring conveyance through evapotranspiration. Not all stormwater trenches include trees.

Streams*

Because streams are naturally occurring features, they are not often considered assets in decision making. However, streams, riparian areas, and floodplains are essential infrastructure that support and provide multiple ecological, economic, and social services such as stormwater conveyance, sources of drinking, improved water quality, flood risk mitigation, habitat provision, and recreational services.

A note on Streams:

Streams within urban and metropolitan areas face many stressors including channelization, increased stormwater runoff from paving and loss of natural vegetation, erosion, and point and nonpoint source pollution. If streams are not proactively managed and invested in, communities risk losing many of the vital services they provide, as well as experiencing dangerous and costly failures such as flooding and bank collapses.

Only recently have asset management plans started to include streams and watercourses as infrastructure assets. Municipalities have started to grapple with the challenges of including natural assets, such as streams, into asset management programs which were originally developed for built infrastructure. To date only a limited number of municipalities such as the City of Blue Mountains, Australia, and the City of Adelaide, Australia, have included watercourse assets into their asset management plans. This is an exciting area of development which will continue to expand and challenge the use of tools and concepts available in asset management.

Story: Ohio, Cincinnati's Evolving Approach to Asset Management

The Metropolitan Sewer District of Greater Cincinnati's green infrastructure assets are currently organized by project. For example, if a construction project included green infrastructure, those assets would be entered into CityWorks under that project name. All of the different assets and their components would then be attached to that site.

Through the work of this GSI Asset Management Resources Toolkit project, the Cincinnati team learned that although organizing assets by site makes inspection and maintenance easy for internal and external customers, it does little to produce valuable, usable information for the efficient management of their assets. Organizing assets by site allows internal employees to assign all labor, materials, and equipment costs to that site for whatever work is completed to obtain an overall cost for the site. However, it does not enable staff to do more detailed investigations, for example, to look at granular information related to how assets fail or to use maintenance information to determine potential failures.

Cincinnati also discovered that it has all the pieces needed to create a successful green infrastructure asset management program, including the technology and internal knowledge. Additionally, Cincinnati learned it has already been collecting good information related to condition assessments for their bioretention assets.

To shift towards an asset centered approach, Cincinnati staff revisited identifying their assets. The City realized that in order to make good decisions about green infrastructure assets, it needed to get a little uncomfortable. Rather than being about making it easier for the inspector or the contractor, it is important to do the process properly. The existing processes provide a good foundation but will need to be revised in order to collect all the necessary information for asset management.

The biggest challenge to date to making these changes has been time. Personnel already have full workdays and overall resources are scarce. Unfortunately, these revisions are currently not a top priority. Another challenge is consistency between processes for green and gray assets; Cincinnati wants to be able to use the same methodology for vegetated systems as they do for hardscape systems, but this has proven to be very challenging.

Levels of Service

Introduction

A foundational component of asset management is the specification of levels of service (LoS). There are two types of LoS—external LoS that focus on how the customer and community receive services, and internal LoS which specify how staff will deliver services. External LoS should focus on topics that customers care about the most and should be easily understood by them. Well-defined internal LoS are linked to the external LoS and define how an agency will provide and meet the external LoS. Internal LoS often require technical expertise to understand. The SWEFC Integrated Asset Management Framework provides more information on the concepts and steps involved in setting up LoS goals and performance indicators.

- Unlike most gray infrastructure, GSI can provide multiple services and co-benefits. Therefore, defining LoS for GSI can take upfront planning and revision over time. It can be useful to divide services into two categories: core and secondary. Core services are the primary reason(s) an asset is built, and failure to deliver these services can result in a levels of service failure (see section on Criticality). Secondary services should cover those co-benefits that are important to an agency. The core services, rather than the secondary services, drive implementation or maintenance work. For GSI, core services are related to stormwater functions such as infiltration, reduced stormwater runoff, filtration, and conveyance. Secondary services may be related to aesthetics, recreation, and habitat provision.

Table 1, Table 2, and Table 3 provide examples of LoS performance indicators that can be set for permeable pavement, bioretention, and stream assets, respectively. The tables are intended to provide ideas for setting LoS goals and indicators or metrics. Typically, an agency would choose a few indicators that are particularly important and add more goals and indicators over time. The tables below include a long list of options, and agencies should not necessarily use all the indicators provided. A wide range of goals and indicators are included here for readers to help them brainstorm, select, and adapt goals and indicators for their own use.

The performance indicators shown in the table can easily be translated into goals or specific targets. An example is shown below for permeable pavement:

- **Performance indicator:** percent of residents satisfied with the condition of permeable pavement sidewalks
- **External goal:** residents are satisfied with condition of permeable pavement sidewalks
- **Target:** 90 percent of residents are satisfied with the condition permeable pavement sidewalks.

Targets can be changed over time as the agency’s capacity and knowledge increases.

Table 1 Examples of Level of Service for Permeable Pavement Assets

Core Services – Permeable Pavement		
Service Attributes that Matter to Customers or Elected Leaders	**External LoS Performance Indicator**	**Internal LoS Performance Indicator**
The public has **safe** places to walk/bike/drive/park	Percent of residents satisfied with condition of parking lots, sidewalks and/or streets with permeable pavement	Number of education sessions hosted to train engineers on permeable pavement design
		Percent of permeable pavements in good or very good condition.
		Percent of pavements maintained according to standard roadway winter maintenance standards
		Number of reports on surface ponding on permeable pavement
	Percent of permeable pavement locations that are fully accessible to wheelchair users	Percent of new projects meeting internal guideline requirements for sidewalk widths
		Percent of existing sidewalks that meet minimum sidewalk width requirement based on internal guidelines
		Precent of new permeable pavement that meet accessibility requirements for gap width
Right-of-ways provide **stormwater management**	Percent of residents satisfied with permeable pavement installations	Square meters/foot of impervious area that has permeable pavement
		Percent of target pollutants removed by permeable pavement
		Percent of permeable pavement that infiltrates to help recharge groundwater
Permeable pavement is managed in a **cost-effective** way	Average maintenance cost per square meter/yard of permeable pavement	Percent of permeable pavement projects that meet lifecycle cost targets
		Percent permeable pavement maintenance completed on schedule
		Number of new permeable materials or construction techniques tested every 5 years
Paved areas are **aesthetically** pleasing	Number of complaints about weeds/vegetation in permeable pavement installations	Number of permeable pavement assets rated as good or very good condition
Green infrastructure is distributed **equitably** across the jurisdiction	Number of applicants to workforce development programs	Number of participants in workforce development program
		Number of contracts (or total $ amount) awarded to companies on social procurement list
	Number of attendants at community consultations or community outreach events in underserved areas	Number of instillations in underserved areas
Watercourses are protected from pollutants	Percent of residents satisfied with pollution levels in waterways	Cubic meters of suspended solids and concentration of chemical contaminants removed before entering watercourses

Table 2 Examples of Level of Service for Bioretention Assets

<table>
<tr><th colspan="3">Core Services – Bioretention</th></tr>
<tr><th>Service Attributes that Matter to Customers or Elected Leaders</th><th>External LOS Performance Indicator</th><th>Internal LOS Performance Indicator</th></tr>
<tr><td rowspan="6">An effective green infrastructure stormwater system in the ROW</td><td rowspan="4">Percent of residents satisfied with performance of stormwater infrastructure</td><td>Volume of runoff diverted from the gray system per square meter or yard (or neighborhood or drainage area)</td></tr>
<tr><td>Percent of bioretention systems operating at their design criteria rate</td></tr>
<tr><td>Percent of features with ponding beyond 24 hours after a rain event.</td></tr>
<tr><td>Percent of bioretention features in good or very good condition</td></tr>
<tr><td rowspan="2">Response time to customer complaints</td><td>Annual operating expenditures on bioretention features</td></tr>
<tr><td>Percent of assets inspected every 5 years</td></tr>
<tr><td rowspan="2">Clean receiving waters</td><td>Percent of days beaches are open</td><td>Number of combined sewer overflow (CSO) events</td></tr>
<tr><td>Number of key fish species present</td><td>Percent of community with sufficient stormwater quality control
(Sufficient could mean the target level of total suspended solids (TSS) or other pollutants, e.g., phosphorus to achieve)</td></tr>
<tr><td rowspan="7">GSI contribute to aesthetically pleasing neighborhoods</td><td rowspan="2">Percent of residents satisfied with bioretention features</td><td>Percent of road reconstruction projects (by project length) using bioretention practices</td></tr>
<tr><td>Percent of bioretention feature with adequate sight lines (plants below a maximum height).</td></tr>
<tr><td>Average number of pieces of trash in feature</td><td>Frequency of trash removal based on asset location</td></tr>
<tr><td>Response time to removing invasive species</td><td>Frequency of weed removal (or % of weed cover below a target amount)</td></tr>
<tr><td rowspan="3">Percent of residents satisfied with the plant health and aesthetics in bioretention features</td><td>Percent irrigation system inspections completed on schedule</td></tr>
<tr><td>Percent plants that are appropriate for climate and operations (e.g., salt tolerant)</td></tr>
<tr><td>Percent of successfully established plants at the end of the warranty period (or replacement frequency during establishment)</td></tr>
<tr><td rowspan="2">Trees are used to manage stormwater runoff</td><td rowspan="2">Percent of trees in bioretention assets surviving annually</td><td>Percent of street trees that have at least 30 cubic meters of soil volume</td></tr>
<tr><td>Tree canopy percentage in the ROW</td></tr>
</table>

Secondary Services – Bioretention		
Service Attributes that Matter to Customers or Elected Leaders	**External LOS Performance Indicator**	**Internal LOS Performance Indicator**
There are **shaded** places to stop along sidewalks	Percent of sidewalk shaded by street trees	Number of trees per linear meter/foot of sidewalk
Planted areas contribute to improved **biodiversity**		Percent of features with 2 or more native plant species

Table 3 Examples of Level of Service for Streams

Core Services – Streams		
Service Attributes that Matter to Customers or Elected Leaders	**External LoS Performance Indicator**	**Internal LoS Performance Indicator**
Properties are **protected** from riverine flooding	Number of residential properties not flooded by nearby adjacent streams.	A floodplain capacity for 100-year return period storm
		Percent of the floodplain that is developed OR For small streams without floodplain mapping: Percent of development within 25 ft of riparian area on either side of the stream centreline
		Number of buildings prone to riverine flooding during a 100-year return period storm
It is **safe** to be in and around streams and trail/path/road infrastructure is **minimally damaged** during storm events	Percent of customers satisfied with how well streams are maintained	Percent of streams in good or very good condition
		Total spent on erosion damages and repairing stream degradation ($)
	Number of signs communicating risk to public	Percent of riparian area developed
		Date of urbanization surrounding stream
		Cost of repairs to damaged trails in the flood plain during storm ($)
		Cost of repairs to damaged sewer and water infrastructure within the stream valley ($)
	Number of visits to combined sewer overflow or warning websites	Percent effective impervious area of the watershed
	Percentage of length of trails closed due to erosion or flooding impacts	Number of indicators of erosion, e.g., number of uncontrolled outfalls
	Number of trail or road service requests relating to safety of watercourses	Number of bank stability projects undertaken to help prevent erosion
		Percent of bank stability projects that use natural approaches
Streams are **clean**	Percent of time stream water quality meets minimum standard for recreational use	Percent of community with stormwater quality control in place

Core Services – Streams		
Service Attributes that Matter to Customers or Elected Leaders	**External LoS Performance Indicator**	**Internal LoS Performance Indicator**
	Percent of public users satisfied with cleanliness of streams	Number of CSO events
Accessibility and Connectivity – streams are accessible to the public and there are stretches of uninterrupted natural stream landscapes	Percent of stream that is natural landscape	Number of road crossings
		Total length of stream piped or length of each piped section of stream
		Total length of stream channelized
		Number of aquatic migration barriers in the steam
		Stream connectivity to the floodplain (measure of entrenchment or incision – entrenchment and/or incision ratio)
	Kilometers (or miles) of trails along streams	Number of stream trail access points

Secondary Services – Streams		
Service Attributes that Matter to Customers or Elected Leaders	**External LOS Goal**	**Internal LOS Goal**
Streams are **aesthetically** appealing	Kilometers/miles of stream that are naturalized	Total length of stream restoration projects
		Median age of stream restoration projects
		Number of streams with restoration projects in the last x years
Streams provide **healthy habitat**	Number of streams where ecologically sensitive species are found	Number of bank and bed barriers to fish and amphibians
		Aquatic biodiversity index (fish, plants, benthic)
		Type of bank material (ranking scale)
	Number of educational signs along the watercourse	Number of residents reached by watershed/aquatic education programs
		Number of participants in “Adopt a stream” program
	Average grade of watershed report card	Riparian vegetation biodiversity
		Aquatic biology diversity
		Percent of vegetation planted that is native
		Land area impacted with invasive plant species

Lessons Learned and Challenges

- When developing LoS goals, agencies should focus on services and values most important to them and their customers. As a result, different municipalities will likely have different LoS goals for the same asset types.

- It is important to set LoS goals at a level that will help the municipality or agency assess whether they are under- *or* overperforming relative to community expectations and its current capacity.

- The LoS goals need to be measurable. The necessary data should be readily available or possible to collect through a reasonable effort given the agency's capacity and resources. When setting LoS, it is important to consider who will be collecting the data (e.g., operations and maintenance staff), their level of expertise, and the time/resources available for data collection.

- In some contexts, it can be important to set LoS goals around regulatory requirements or mandates for that utility, municipality, or department to avoid potential fines or litigation.

- There is no standard or minimum number of LoS goals to set. At the beginning of the asset management process, an entity can begin with as few as two to three goals to learn how to collect data and measure progress towards goals. As experience is gained, more goals can be added. The correct number of goals is the number that allows the entity to achieve its stated purpose and properly serve its customers.

- It is helpful to identify core and secondary services for green infrastructure and set goals for both. Recognizing the co-benefits provided by green infrastructure will help to inform other aspects of asset management. For GSI, core services would likely relate to water quantity and quality, while secondary services might relate to public health, the environment, climate change, and aesthetics.

- It can be helpful to think of LoS goals as results-based or effort-based (effort-based are usually internal goals) and set goals and targets for both. For example, a results-based LoS goal might be, "*x* percent of vegetation remains below *y* height," while an effort-based level of service goal could be "95 percent of sites are subjected to bi-annual pruning during fall and winter".

  For example, Portland Bureau of Environmental Services will be revising their Levels of Service goals to be more condition and outcome-based rather than action and output-based. For example, their current LoS describes the number of inspection and maintenance visits per year. Instead, LOS goals will be more focused on the desired outcomes of regular inspections, e.g., better condition.

- LoS goals may be set for resident or public satisfaction. While dis/satisfaction is often measured by number of complaints (since the data may be readily available), it is important to recognize that this does not always provide an accurate reflection of overall satisfaction across neighborhoods, e.g., complaints can be more frequent in more affluent neighborhoods relative to less affluent. To obtain a better understanding of community satisfaction, it can be better to use a survey process instead of relying on complaints alone. For example, every five years the City of Toronto hires summer students to knock on residents' doors to ask questions about customer experience.

Case Study 1: Toronto, Ontario – Levels of Service for Green Street GSI Assets

The City of Toronto is investing in Green Streets—roads and streets that incorporate green infrastructure to provide ecological and hydrological functions and contribute towards Toronto's Resilience and Climate Change goals. While the current number of managed assets in the city are low (fewer than 50), policy changes are expected to increase the number of GSI assets exponentially in the next few years, making the scalability of asset management a high priority.

An asset management framework is being developed to support the management of GSI. Since 2019, the City's Division of Transportation Services has been responsible for GSI assets on behalf of all divisions. Working together with Road Operations, it has been working on drafting basic LoS for GSI which will form the basis of a new operations program.

Figure 1 Example of Green Street at Fairford Parkette, Toronto (Source: City of Toronto)

Toronto has identified several draft key themes for LoS, but it is still figuring out which and how many metrics are needed to reflect the values provided by GSI while remaining feasible to measure, track, and quantify as the number of GSI assets increase. In addition, LoS developed for traditional road and pavement assets as part of the City's core asset management plan (still to be published) will also inform GSI LoS, for example, LoS related to winter clearance and pothole response times.

Table 4 shows an extract of some of the draft LoS themes that Toronto has identified. Conversations are still being held with operations and maintenance (O&M) teams due to the implications of LoS on monitoring and maintenance. The condition assessment framework for GSI assets (still in development) will also be an important input for setting LoS for GSI.

Table 4 Draft Level of Service Themes for Toronto Green Street Assets (Source: City of Toronto)

Level of Service(s)	Considerations	Key Checklist Item(s)	Questions and Discussion Topics with O&M
Core functionality: • Structure and safety of hard surfaces are maintained as required for a typical ROW • 95% at "good" condition	• Meet Accessibility for Ontarians with Disabilities Act requirements for pedestrians using the sidewalk • Set LoS around winter maintenance, street sweeping, trip/fall hazard identification and removal, and structural integrity	• surface damage • slip/fall hazards • traffic sightlines	• Should a permeable hard surface have a different LoS than traditional surfaces, e.g., less salt and more frequent inspections? • Field experience is required to validate current recommendations
Stormwater management: • Ensure proper functionality of inlets, outlets, overflows, underdrains, etc., so that water flows through the system as designed • 80% of sites at "good" condition	• Runoff enters system as per design storm • Overflow/outlet system cleared and functional • Ponding duration (24, 36, or 48 hours). • Sedimentation & erosion	• inlet and outlet clearance • ponding duration • underdrain inspections • over-sedimentation • signs of erosion	• How should "good" be defined? • How should "redundant" storm systems be ranked? • Should targets be standardized or vary site to site? • Should infiltration results be used as key performance indicators? • Would it be possible to scale up as the number of assets increase? • Should inspections be required after storms to verify LoS? • Condition assessment parameters & processes still need to be determined • Is 80% of sites in good a feasible/acceptable LOS? • Field testing is required
Vegetation / Aesthetics: • Proper maintenance of vegetation treatment (i.e. sod and horticulture) • Sod cut as per existing LoS for Toronto • Horticulture health/condition • Aesthetic health/ considerations • Free of invasive species • Trees to be in condition to meet	• Vegetation health (cover, wilting) • Grass height • Tree health/pest problems • Sightlines, slip/trip hazards from shrub/ trees • Invasive species • Aesthetics • 311 requests/complaints • For permeable hard surfaces: vegetation growth from sediment/gaps/aggregate.	• vegetation health • vegetation cover • invasive species presence • mulching • irrigation • sightline obstruction • trip hazards	• No existing horticulture LoS for Toronto • Current practices are bi-weekly inspection and maintenance OR complaint based • Condition assessment parameters and process TBD • Is 80% of sites in "good" condition feasible? • Is there a native plant/ biodiversity index that should be considered? • Does the City have the capacity to address weed issues in permeable paver aggregate?

Level of Service(s)	Considerations	Key Checklist Item(s)	Questions and Discussion Topics with O&M
urban forest canopy standards • 80% of sites in "good" condition			
Other Options: • 311 (Toronto assistance line) response time • Equity lens • Financial/budgetary lens • Community value • Co-benefit scores	Possible program-based LoS linked to: • Customer satisfaction • Equitable distribution of maintenance effort • Justifiable use of resources • Measuring and quantifying co-benefits	TBD	• Besides 311 response time, what other methods can be used to gauge customer satisfaction? • Does the benefit of establishing, tracking, and reporting co-benefit LoS to justify the resources dedicated to them?

Lessons Learned and Challenges

- While setting LoS, the scalability of tracking LoS must be kept in mind. Staff cautioned against formalizing too many or too complicated LoS which would need to be tracked (e.g., infiltration rates) as these exercises may be prohibitively time consuming as the number of assets increases city-wide. It is important to keep in mind the capacity of the staff who will be collecting data on assets, Road Operations, in this case. For example, a LoS goal may require a 24-hour drawdown time but measuring performance might require operations to visit sites after each storm, which may be impossible to sustain as the number of green street assets increases.

- Some bioretention components (e.g., trees and catch basins) have LoS that are maintained and tracked by other divisions, i.e., not Transportation Services. In a bioretention asset, it will be important to determine if these components warrant the development of a higher LoS that applies to the whole bioretention facility rather than just the individual components.

- Toronto has had to consider how to translate results-based LoS into how much maintenance effort is needed to meet them. Work still needs to be done to determine the appropriate maintenance effort required to meet LoS.

- Toronto faces challenges with existing definitions of LoS. For operations staff, LoS commonly pertain to a frequency-based activity (i.e., effort-based LoS), but the discussion is shifting towards a focus on results-based LoS. Clarification of what is meant by LoS is often required during communication between operations and asset management teams.

Current State of the Assets

Introduction

Understanding the current state of the assets is foundational to all asset management components. At the most basic level, it is necessary to understand what assets are owned or managed by the municipality or agency. Additional attribute data can be collected depending on the resources available for updating the asset inventory. Some key attributes to include are a unique asset ID, location, year installed, owner, manager, expected useful life, and condition (see Table 5). Detailed information on setting up an asset inventory can be found in the SWEFC Integrated Asset Management Framework.

Table 5 Important Attributes to include within an Asset Inventory

Field	Description
Asset ID	Unique identifier for the assets
Location	The physical location of the asset. (e.g., coordinates, intersection, or street address)
Quantity	The amount of the asset (e.g., length, volume, size, area)
Year Installed	The year the asset was installed or acquired
Ownership	Who owns the asset
Management Responsibility	Who is responsible for maintaining the assets
Age	The current year minus the date of installation
Unit Replacement Cost	Cost per unit to replace, in the same unit as the quantity
Replacement Value	The cost of replacing the asset with a new asset today
Expected Useful Life	Theoretical service life of the asset
Remaining Useful life	Estimated number of years until the asset fails. May be based on expected useful life, or based on actual performance/condition data
Condition Rating	A rating of the condition of the asset

Lessons Learned and Challenges

- An integrated asset database representing spatial and attribute data where each asset has its own unique ID forms an essential foundation of asset management.

- It can be helpful to separate surface and subsurface components of GSI assets (e.g., vegetation and underdrain) into parent-child relationships, where each parent asset, component, and/or child asset has its own unique identifier. This allows costs to be tracked precisely and supports the sharing of information and coordination of maintenance across departments responsible for different components of GSI assets.

- Developing an asset inventory requires ongoing discussions with key stakeholders to define an asset and its key components, and identify core and secondary services, modes of failure, and data needed to assess these. Sufficient time should be allocated to this task early in the process, and flexibility is required to meet diverse stakeholder needs.

- It is important to find the balance between trying to collect too much data (costly, time consuming) and not collecting enough (not enough information is available to inform optimal decisions). It is essential to consult with staff who will be collecting the data when developing the inventory specifications and data protocols to ensure that data collection can be implemented successfully.

Snapshot: Palo Alto, California – Bioretention Asset Inventory

Palo Alto has developed a three-level asset hierarchy for its GSI assets. The GSI assets fall within stormwater assets which are considered part of the right-of-way assets. Currently, all bioretention assets are in the same category, i.e., bioretention assets are not further subdivided within the hierarchy. The components of bioretention assets are, however, separated into surface and subsurface assets, each with its own unique ID. Data can be rolled up in different ways depending on the city's needs. For example, asset costs can be rolled up based on location or asset type. Condition assessments for all assets are currently based on an Asset Condition Index which is used for building assets, e.g., office blocks. Assets are currently stored as points but the City plans to switch to polygons.

Palo Alto is also working on creating a single set of unique IDs that is the same across systems. Currently, the unique asset IDs in the GIS spatial database do not match the asset IDs in the asset management system.

Snapshot: Vancouver, British Columbia – Permeable Pavement Asset Inventory

The City of Vancouver is working on updating and improving its inventory for permeable pavement assets. They have created a standard description of permeable pavement and identified several different subtypes of permeable assets which are represented in their class hierarchy including grid pavers, permeable concrete pavers, pervious concrete, porous asphalt, porous asphalt overlay, and porous rubber. Vancouver's definition of permeable pavement is provided below:

> *Permeable pavement comes in a variety of forms similar to the various types of conventional paving materials. All permeable pavement types allow rainfall to soak into an underlying reservoir base where it is either infiltrated to the ground or stored and conveyed by a subsurface drain. Rainwater is filtered and cleaned through the different aggregate layers and the underlying subsoil layer. Permeable pavement provides a hard, usable surface, whether by cars, bikes, or pedestrians, while reducing runoff volume and improving water quality.*
>
> —City of Vancouver

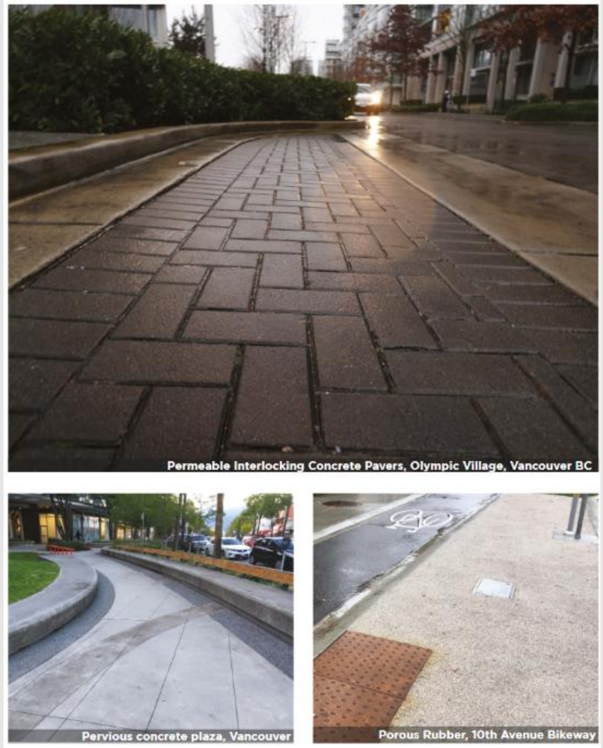


Figure 2 Types of Permeable Pavement (Source: City of Vancouver)

Vancouver has also identified the types of applications where permeable pavement might be used such as bike lanes, laneways[1], plazas, sidewalks, parking lots, parking lanes, and low parking streets.

[1] A laneway is a narrow, low traffic road often occurring between rows of dense residential and commercial buildings.

Case Study 2: Toronto, Ontario – Asset Inventory for Green Street GSI Assets

Overview

Since 2019, the City of Toronto's Transportation Services has been tasked with managing all GSI assets occurring on Green Streets on behalf of all divisions. Toronto is in the early phases of implementing GSI, and it currently expects fewer than 200 assets to be created by 2023. One key management task underway includes the establishment of a centralized Enterprise Work Management System (EWMS) that will act as an asset inventory and a work management system that supports asset management, operations and maintenance, and coordination across divisions. As of 2021, the City has been working on transitioning from the current work management systems to the EWMS.

In support of this goal, Transportation Services has made progress in understanding the City's GSI asset types and databases currently used as well as defining asset classes and hierarchies. Green infrastructure is defined within the context of Green Streets as follows:

> *In alignment with the Toronto's Official Plan, Green Infrastructure (GI) means natural and human-made elements that provide ecological and hydrological functions and processes while also delivering multiple co-benefits. Green Streets, refers to roads or streets incorporating green infrastructure, systems include bioswales and bioretention planters, stormwater tree trenches, and permeable surfaces such as permeable pavers.*
>
> — City of Toronto

In 2019, three asset classes, bioretention systems, stormwater tree pits, and permeable hard surfaces, were proposed for Green Street GSI assets, as well as descriptions, components, maintenance requirements for each (summarized in Table 6).

Asset types were organized into the class hierarchy shown in Figure 3 below.

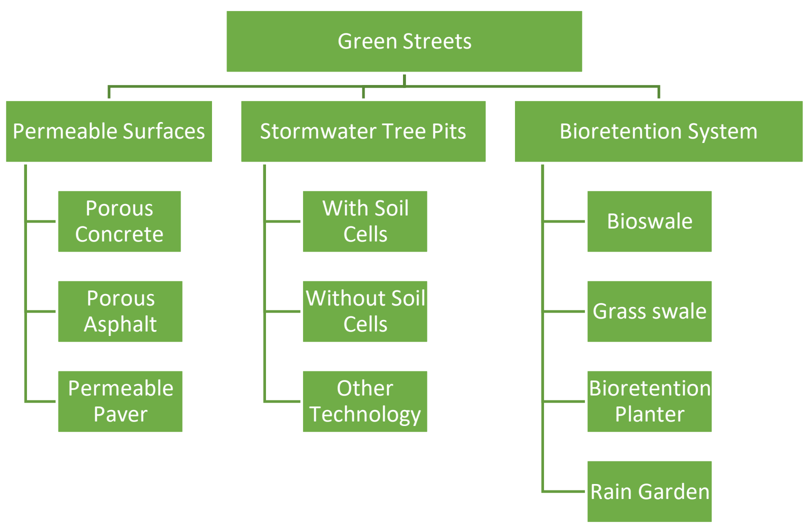


Figure 3 City of Toronto Green Streets GSI Asset Hierarchy (Source: City of Toronto)

Table 6 Toronto's Proposed Asset Classes for GSI (Source: City of Toronto)*

Key Assets	Description	Asset Components/ Features	Major Maintenance Requirements
Bioretention	A swale/pit/planter/garden that is filled with engineered biofiltrative soil and covered with vegetation (sod, hort, and/or tree). Typically has pretreatment rocks near inlet to reduce erosion and filter road debris. Under biofiltrative soil (biomedia) is a granular layer, and potentially impervious liner if soils are contaminated. Underdrain systems may be incorporated to prevent pooling.	trees, horticulture, sod, inlet pretreatment (if any), soil medium, granular subbase, curb (if any), weirds (if any), overflow pipe (if any)	Maintain tree health (UF) Maintain sod/horticulture (TS) Maintain supporting hard infrastructure (TS) Maintain drainage infrastructure (TW)
Stormwater Tree Pits	Tree pits designed to (a) meet uncompact soil volume requirements of the Toronto Green Standard and (b) PF and R requirements to provide tree canopy in the ROW, and (c) receive and treat stormwater runoff up to a designated volume. Such technologies mainly include soil cells and engineered soil.	tree, surrounding hard infrastructure, growing medium, soil cell (if applicable), inlet, pretreatment (if any), distribution pipes (if any), underdrain (if any, trench drains (if any)	Maintain tree health (UF) Maintain supporting hard infrastructure (TS) Maintain drainage infrastructure (TW)
Permeable Hard Surfaces	Road, sidewalk, or other hard surface within right-of-way designed to receive runoff and provide infiltrative functions. Permeable hard surfaces could include pervious pavers, pervious interlocking pavers, porous concrete, porous asphalt, and other similar technologies.	subbase specifications, underdrain specifications, permeable matrix specification, receiving area.	Maintain hard infrastructure (TS) Maintain drainage infrastructure (TW)

*Adapted from City of Toronto Green Streets Asset Management Framework Recommendations, Table C2

Toronto's Asset Databases

The EWMS is expected to be completed in late 2023. In the interim, Toronto uses a variety of software tools to manage GSI data including Microsoft (MS) Access and ESRI's ArcGIS. This flexible approach is feasible because of the small number of staff whose work is currently impacted by the Green Streets inventory. MS Access is used to track green infrastructure projects, location, type, components, dimensions, costs, year installed, ownership, maintenance responsibility, and more. It was chosen because it is highly accessible to City staff and has a wide range of functionality such as forms and saved queries. The MS Access Green Streets Database Landing Page is shown in Figure 5. Switching between Access/GIS to EWMS is an intensive process that involves many staff and departments across the City. The following functions illustrated in Figure 5 are still under development: Search Project, Maintenance Log Related, As-built Database and KPI Tracker.

Figure 4 Screenshot of MS Access Landing Page for Green Streets Assets (Source: City of Toronto)

Figure 5 displays an extract of the current attribute data collected for different asset types, while Figure 6 shows the list of attributes and their data type collected for GSI assets.

Landing Page | Capital Projects | Constructed Projects

GS_Identif	Common_Name	Ward	End_Ye	Supertype	Type	Inlet_Type	Pretreatment	Suface_Treatr	Trees	Subgrade	Distributio
T08-1	Queensway Sustainable Sidewalk	03	2008	Trees (SWM)	T.Covered Soil Cel	Catchbasin		Concrete Panels	4	Top Soil	Dist. Pipe S
B13-2	Fairford Parkette	14	2013	Bioretention	B.Parkette	Curb Cut, Trench Dra	River Rock/Rift R	Horticulture, Mu	11	Biomedia #1	-none-
B13-4	South Station Street (BR Planter)	05	2013	Bioretention	B.Planter	Curb Cut, Trench Dra	Concrete Foreba	Horticulture, Mu	3	Biomedia #1	-none-
B13-3	South Station Street (Grass Swale)	05	2013	Bioretention	B.Enhanced Grass	Curb Cut, Trench Dra		Sod/Grass	0	Biomedia #2	-none-
P18-45	Cupolex Laneway	16	2018	Permeable Hard Sur	P.Others	Sheet Flow, Trench D		Concrete	0	Cupolex Cell	-none-
B18-41	Stanley Greene Bioswale (George Buchart Dr)	06	2018	Bioretention	B.Swale	Sheet Flow	Concrete Foreba	Horticulture, Mu	0	Biomedia #1	-none-
B18-42	Stanley Greene Bioswale (S. G. Blvd)	06	2018	Bioretention	B.Swale	Sheet Flow		Horticulture, Mu	0	Biomedia #1	-none-
B18-43	Stanley Greene Bioswale (Downsview Park)	06	2018	Bioretention	B.Swale	Sheet Flow		Horticulture	0	Biomedia #1	-none-
P19-6	Byng Avenue LID Demo (Prm. Sidewalk)	01	2019	Permeable Hard Sur	P.Concrete (Cast-i	Sheet Flow		Cast-in-place #1	0	Granular #1	-none-
B19-5	Byng Avenue LID Demo (BR cell)	01	2019	Bioretention	B.Cell	Sheet Flow		Horticulture, Mu	0	Biomedia #1	-none-
B19-39	Ryerson Avenue Passe Mural Theatre (BR Cell)	10	2019	Bioretention	B.Cell	Sheet Flow		Horticulture, Soc	0	Biomedia #1	NA
T19-40	Ryerson Avenue Passe Mural Theatre (ST Planters)	10	2019	Trees (SWM)	T.Open Planter So	Trench Drain (Narrov		Sod/Grass, Trees	0	Top Soil	NA
P20-9	Riverside Drive	04	2020	Permeable Hard Sur	P.Pavers (perm. A				0		-none-
B20-24	Lawrence Heights NED Phase 1 Bioswale		2020	Bioretention	B.Swale				0		
B2020-21	Lakeshore & Bonniecastle		2020	Bioretention	B.Swale				0		
?2120-11	Lawrence Avenue & Weston Road		2021	? To be confirmed					0		
T2120-20	Six Points	03	2021	Trees (SWM)					0		Dist. Pipe S
B2121-14	Hanna Avenue	10	2021	Bioretention					0		

Figure 5 Example of Green Streets MS Access Data for Constructed Projects (Source: City of Toronto)

Landing Page | Capital Projects | Constructed Projects | GI_AssetTypes | GI_Components_n_LOS | 00_ASSET_MAINFRAME

Field Name	Data Type	Description (Optional)
OID	AutoNumber	
GS_Identifier	Calculated	
Common_Name	Short Text	
Sorting_ID	Calculated	Status_Year_CommonName (Used for sorting)
End_Year	Number	
Plan_Year	Short Text	
Delivery_Stream	Short Text	
Status	Short Text	
Ward	Short Text	
Supertype	Short Text	
Type	Number	
Asset_Area	Number	Physical Footprint
Asset_Depth	Number	Avg Depth of Facility
Drainage_Area	Number	Area that drains into GI
Inlet_Type	Short Text	Component details
Pretreatment	Short Text	Component details
Suface_Treatment	Short Text	Component details
Trees	Number	Component details
Subgrade	Short Text	Component details
Distribution_Pipe	Short Text	Component details
Underdrain	Short Text	Component details
Subdrain_AccessPoint	Short Text	Component details
Trench_Drain	Short Text	Component details
Lining_Type	Short Text	Component details
Monitoring_Comps	Short Text	Component details
As_Builts	Attachment	
Last_Updated	Date/Time	
Add_Description	Long Text	
Cost_Delta	Currency	
KPI_SWM	Short Text	
KPI_GreenAcreage	Short Text	
KPI_TreeRelated	Short Text	
KPI_MaintenanceTrips	Short Text	
Plan_DStatus	Short Text	
Plan_DContractNumber	Short Text	
Plan_DPM	Short Text	
Plan_DeliveryScope	Long Text	
Plan_DeliveryAdditionalInfo	Long Text	

Figure 6 Screenshot of MS Access Database: Attributes of GSI Assets (Source: City of Toronto)

The MS Access Database also provides the opportunity to store data on each component type and subtype including maintenance requirements, costs, and estimated lifespan as shown in Figure 7.

Landing Page | Capital Projects | Constructed Projects | GI_AssetTypes | GI_Components_n_LOS

Category	Component Type	Regular Maintenan	Inspection Points	Task	Frequency/Schedule
Inlet	Concrete Curb Cut	☑	Sedimentation	Clear Debris	6mo or as required
Inlet	Catchbasin	☑	Sedimentation	Hydrovac	12mo or as required.
Inlet	Trench Drain (Narrow)	☑	Sedimentation, structi	Power wash or manual cleanc	6mo or as required
Inlet	Trench Drain (Wide)	☑	Sedimentation, structi	Power wash	12mo or as required.
Inlet	Sheet Flow	☐	Sedimentation, erosio	Clear debris	12mo or as required.
Inlet	-none-	☐			
Pretreatment	Concrete Forebay	☑			
Pretreatment	River Rock/Rift Raft	☑			
Pretreatment	Wood Disperser	☑			
Pretreatment	Catchbasin - Jellyfish	☑			
Pretreatment	Catchbasin - CB Shield	☑			
Pretreatment	Oil Grid Separator (OGS)	☑			
Pretreatment	-none-	☐			
Surface Treatment	Trees	☑			
Surface Treatment	Shrubs	☑			
Surface Treatment	Horticulture	☑			
Surface Treatment	Sod/Grass	☑			
Surface Treatment	Mulch	☑			
Surface Treatment	Base Soil	☑	Erosion	Inspect for erosion	
Surface Treatment	Metal Grate	☐			
Surface Treatment	Concrete	☐			
Subgrade	Top Soil	☐			
Subgrade	Biomedia #1	☐			
Subgrade	Biomedia #2	☐			
Subgrade	Biomedia #3	☐			
Subgrade	Biomedia #4	☐			
Subgrade	Soil Cell #1	☐			
Subgrade	Soil Cell #2	☐			
Subgrade	Soil Cell #3	☐			
Subgrade	Cupolex Cell	☐			
Subgrade	Choker #1	☐			
Subgrade	Choker #2	☐			
Subgrade	Granular #1	☐			
Subgrade	Granular #2	☐			
Lining	Geotextile #1	☐			
Lining	Impervious Liner #1	☐			
Lining	Concrete Tank	☐			
Distribution Pipe	Dist. Pipe Spec #1	☑			
Distribution Pipe	Dist. Pipe Spec #2	☑			
Distribution Pipe	-none-	☑			
Underdrain	Perforated Pipe Spec #1	☑			
Underdrain	Perforated Pipe Spec #2	☑			
Underdrain	Perforated Pipe Spec #3	☑			
Underdrain	Perforated Pipe Spec #4	☑			
Monitoring Well	WL Well (Basic)	☐			
Monitoring Well	Flowmeter (Basic)	☐			

Figure 7 Component Types and Their Associated Maintenance Requirements, Cost, and Estimated Lifespan Recorded within Toronto's MS Access Database (Source: City of Toronto).

The spatial component of GSI is managed, manipulated, queried, and visualized through ArcMap. Unfortunately, ArcGIS is not widely available among staff and requires specialized knowledge. Some GSI assets, such as permeable surfaces are represented as points, while others are represented as polygons (Figure 8). The goal is to transfer all data stored within MS Access and the shapefiles into the EWMS so that the EWMS can provide a single access point to view, query, and manage all data.

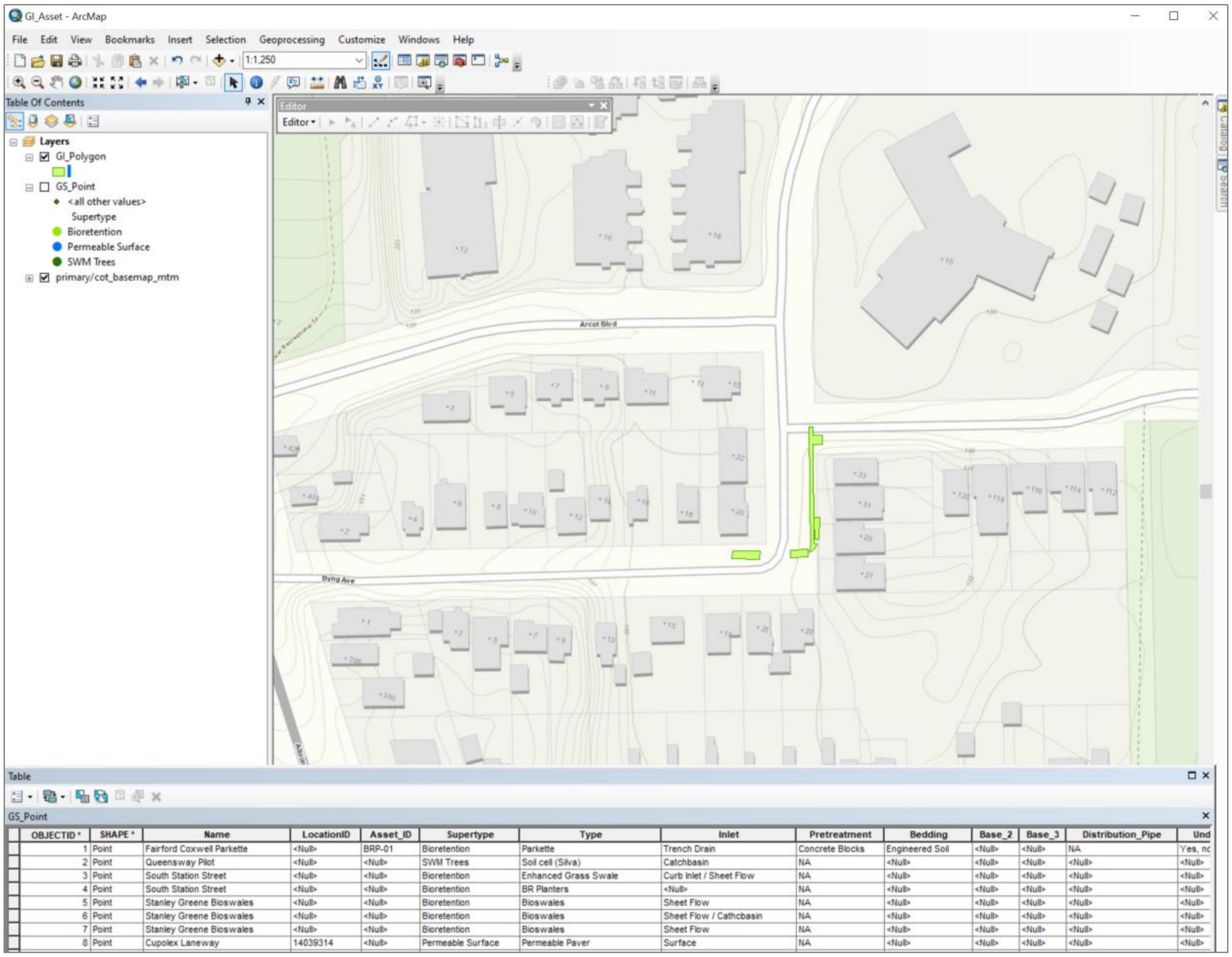


Figure 8 Screenshot of ArcMap Displaying the Footprint of a GSI asset and Attribute Data (Source: City of Toronto)

Lessons Learned and Challenges

- Defining boundaries for interconnected projects: Staff struggled to find a simple and concise method to spatially represent interconnected systems (e.g., permeable pavement feeding into bioretention via a perforated pipe, or two stormwater management tree planters connected via a soil trench), that reflects the discrete nature of these systems on the ground level while maintaining their interconnectivity underground.

  To display these assets purely as the appear on the surface undermines the system's network effect, while representing them purely as a subsurface system creates problems for surface operations staff. In the interim, characteristics like these are noted in the "Description" field. The intention for the EWMS is to build relationship links between interconnected assets.

- Developing an (automated) asset intake process: For most transportation infrastructure in Toronto, different software systems are used to manage planning layers (ArcGIS), manage built assets (consultant-developed asset management computer software), and maintain work orders and maintenance logs (the City's legacy custom work management system). An asset intake process will have to account for the limitations of these three systems. To further complicate matters, the Green Streets program is often unaware of the numerous other divisions within the City building GSIs within the ROW. Therefore, an asset intake process will need to ensure all built GSI assets in Toronto are registered.

- Shifting timelines for new asset management software: EWMS was originally planned to be developed in phases between 2021 to 2023 but was delayed due to the COVID pandemic. During the planning stages of the GSI inventory, the lack of certainty around whether the EWMS would be used as a repository for GSI assets or whether independent asset management databases or systems for GSI would be implemented resulted in delays. As a result, an interim system of MS Access and ArcGIS is being used.

Next Steps

The next steps for the City of Toronto's Green Streets asset management program are to:

- finalize asset attributes for the asset inventory.
- perform city-wide condition assessment for all assets.
- integrate assets into the Enterprise-Wide Management System.
- create an in-house mobile software for Road Operation's on-site workflow.

Asset Condition

Asset condition is a key attribute to collect as part of the asset inventory. It defines the physical state of the asset at a particular moment in time and helps to inform the assessment of remaining useful life, maintenance interventions, replacements, and other asset management decisions. Condition is also used in metrics to determine whether service levels are being met or if the asset is underperforming. Tracking condition supports more accurate estimates of remaining useful life than an asset's age, although asset age can be used when condition information is not available. Assessing asset condition often requires collecting new data or modifying existing inspection or operations and maintenance protocols to ensure useful information is collected which can also be updated regularly.

Case Study 3: Vancouver, British Columbia – Condition Assessment of Permeable Pavement

Overview

The City of Vancouver has developed a condition scoring system (Figure 9) for permeable pavement assets as well as a pilot inspection program. Data collected from the inspection program is used to assign assets a score ranging from very good (1) to very poor (5). Each level in the grading scale is paired with a description of its condition and recommended management actions.

1 VERY GOOD	New or nearly new. No noticeable issues. No Action Required. Continue routine maintenance.
2 GOOD	Minor noticeable issues; no longer a new asset. Continue routine maintenance.
3 MODERATE	Noticeable issues which may impact functionality in the next 3-5 years. Monitor progress of issue during next inspection. Continue routine maintenance. No additional immediate inspections or tests required.
4 POOR	Noticeable issues which may impact functionality in the next few years (1-2 years). Need a more detailed inspection or infiltration tests.
5 VERY POOR	Functionality of the asset is questionable. Immediate action required. A more detailed inspection or infiltration tests required within 30 days.

Figure 9 Vancouver's Condition Grade Scale for Pilot Permeable Pavement Inspection Program (Source: City of Vancouver)

The condition grade scale and pilot inspection program were designed to identify issues which might impact the ability of pavements to carry out their primary function, namely, to provide drainage services. If the drainage service is non-functional, immediate action must be taken to restore function such as additional site investigations and performance tests. Figure 10 shows an example of permeable pavement in overall good condition, but it has vegetation growth which indicates the accumulation of sediment. In response, an infiltration test would be conducted to test functionality.

The pilot inspection program involves collecting condition data at the asset component level. Component level data is combined to generate an overall condition score for each asset. It also helps to identify if non-routine maintenance is needed. Although an asset may appear structurally sound, its drainage performance may become suboptimal due to a variety of factors such as a lack of regular maintenance. By inspecting components, it is possible to better identify potential or actual problems with function.

Figure 10 Example of Permeable Pavement in Good Condition but with Potential Infiltration Issues (Source: City of Vancouver)

Inspection data is collected via an app and includes basic asset attributes such as typology and street name, asset components including contributing drainage area, pavement surface, control structure, monitoring well, clean out, outlet, and functionality. Figure 11 shows an example of the condition data collected in the inspection app.

Lessons Learned and Challenges

- The pilot inspection protocol requires that inspectors have knowledge of GSI and understand the functionality of the system and its design. Since operations staff do not always have the required knowledge, design staff have had to conduct some of the site inspections. However, this will make it challenging to implement the protocol on a wide scale as the number of assets increases. To increase the number of inspections, other staff would need to be trained on the functionality of GSI.

- Next year, the City of Vancouver plans to develop a detailed training program for inspectors based on lessons learned during the pilot program. Piloting is a very important part of refining the condition assessment protocol.

ASSET ATTRIBUTES

Unique ID	230001
Typology	Permeable Pavement
Sub-Typology	Porous Asphalt
Street	Tupper St
Street Description	Lane south of 18th Ave between Ash St and Tupper St
Location Type	Alley
As-Built Drawing Present?	No
Accessible by Maintenance Vehicle?	Yes
General Comments	The lane faces backyards and garages of homes on 18th and 19th avenue

CONTRIBUTING DRAINAGE AREA (CDA)

Is discharge only from Pavement Surface?	Not Sure
CDA Type	Downspout, Impervious
Is there construction activity within CDA or materials staged on it?	No
Practice Size	0-Unknown
Sediment Accumulation	0-Unknown
Trash / Debris	0-Unknown
Surface Damage	0-Unknown
Obstruction / Foreign Object	3-Fair
General Comments	No as-built drawings present to confirm practice size or to confirm CDA. Not all downspouts discharged to pavement. Only 3 discharged on area between pavement and property boundary. Some of this area have gardens established. Mulch from the garden can be seen accumulated on pavement surface. Need to confirm the intended discharge area from drawings.

PAVEMENT SURFACE

Pavement Surface Type	Porous Asphalt
Practice Size	0-Unknown
Sediment Accumulation	4-Poor
Trash / Debris	3-Fair
Obstruction / Foreign Object	1-Very Good
Standing Water / Stains?	1-Very Good
Surface Damage Type	Ravelling & Loss of Surface Aggregate, Wheel Track Rutting
Surface Condition	3-Fair
Paver Joint Filling Missing or Low	NA
Weeds / Unwanted Vegetation	2-Good
General Comments	Sediment is suspected to be clogging the porous Asphalt. Asset suspected to be not functional. Requires additional investigation. Surface damage such as rutting and deterioration observed. However, extent of damage is only moderate in context of assumed practice size (the complete lane). Some weeds, unwanted vegetation. Along with debris noticed.

Figure 11 Extract of Condition Data Collected for Permeable Pavement Assets from Vancouver (Source: City of Vancouver)

Example of Condition Rating System for Permeable Pavements

As part of the GSI Asset Management Resources Toolkit project, a series of workshops were held between June and August 2021, in which municipal participants workshopped components of asset management for each asset type featured in this Toolkit. Table 7, an output from these workshops, provides an example of what a condition scoring system for permeable pavement might look like that is based on physical conditions which would impact its ability to support infiltration and driving/walking functions. Standard management actions for each condition score have also been assigned.

Table 7 can be used to spark ideas and discussion about developing a condition scoring system for permeable pavements, but it is not intended to be used directly as is. When developing a condition assessment scoring system, it is usually easiest to start by defining the extreme conditions (very good and very poor), then the middle, and finally filling in the remainder. Adding quantitative measurements for qualitative descriptors will improve the consistency of ratings across assets.

Table 7 Example of Condition Score Components for Permeable Pavement

Condition Rating	Factor 1: Infiltration function	Factor 2: Driving/walking function	Management Action
Description	Rating based on components that impact infiltration function	Rating based on the type and severity of distresses observed on the surface: damage, deformation (e.g., ruts)	Recommended management action for condition score
Very Good	Free of sediment accumulation on surface; joint aggregate compound between pavers is clear (e.g., >95% of parking lot area); no visible surface ponding (timed after rainfall); free of clogging in the structure/surface of pavement	No cracks, spalling or raveling; no missing or damaged pavers; pavement is even	Routine maintenance (e.g., remove trash and sediment, top-up joint fill, remove undesirable vegetation)
Good	Very low sediment accumulation on surface; joint aggregate compound between pavers is clear (e.g., >90% of parking lot area); minimal clogging in the structure/surface of pavement	One or two surface issues observed, but low severity, and affects a very small proportion of surface	Routine maintenance (as above)
Fair/Average	Some sediment accumulation on the surface; joint aggregate compound between pavers is mostly clear; some clogging	A few surface issues observed, medium severity or quantity increasing	Repair: fill small potholes or cracks with patching mixes, replace missing or damaged pavers, vacuum
Poor	Sediment accumulation on surface; joint aggregate compound between pavers clogged	Major surface issues observed over a large proportion of surface, such as large cracks, potholes, spalling or raveling of the porous asphalt or pervious concrete surface; large number of pavers or grid units are missing, damaged or displaced	Rehabilitation: large potholes or cracks may require cutting and replacement of a section of the surface layer. Replace with the same permeable material where possible. Replace or reset unit by hand and restore joint or grid cell fill material. Vacuum

Condition Rating	Factor 1: Infiltration function	Factor 2: Driving/walking function	Management Action
Very Poor	Significant proportion of surface is covered in sediment or leaf debris; blocked/sedimentation in subsurface storage unit that reduces subsurface storage capacity; joint aggregate compound between pavers is clogged (e.g., >75% of parking lot area is clogged); significant surface ponding; clogging in the structure/surface of pavement	Significant surface issues across most or entire surface area (x %), e.g., major cracks, settlement, spalling or raveling over a large area; a large proportion of paver or grid units missing, damaged or displaced; Aggregate not replaced or missing in large parts.	Powerwashing to remove surface clogging (may be required twice) followed by infiltration testing. Replacement: It can sometimes be more cost effective to lift up pavers and replace when there is significant settlement. The pavers may not need to be replaced, however, and could just be re-laid.

Case Study 4: Portland, Oregon – Condition Assessment of Bioretention Assets

Overview

City of Portland Bureau of Environmental Services (the Bureau), Oregon, has developed a condition assessment scheme for green street facilities. Green streets (bioretention planters or swales located in roadway right-of-ways), are assigned a condition score ranging from 1 (excellent) to 5 (failed), and each value is associated with a description and suggested management actions (Figure 12). Overall condition scores are based on two components of bioretention: structure and vegetation. Structure (Figure 13 and Figure 14) and Vegetation (Figure 14 and Figure 16) are each scored separately, and the sum of their scores is used to allocate an overall condition value for each asset.

In the field, inspectors assess each asset based on several indicators of Structure and Vegetation. Each indicator, e.g., *sediment intrusion* under Structure and *weed cover* under Vegetation, is given a rating from excellent to very poor condition, and each rating is assigned a numerical value indicating the *relative* severity of that rating for that component. For example, the *soil* category under Structure (Figure 15), can be assigned a rating of none, minor, and major, with severity values of 1, 180, and 2,500, respectively. A high value of 2,500 indicates an asset has major soil problems that have a severely negative impact on condition. Structure and Vegetation scores are obtained by summing the severity ratings for each subcategory.

Overall Combined Scores				
Range	**Action**	**Condition Score**		**Description of Condition**
<=10	No Needs	Excellent	1	Green street is in the best possible condition.
11 - 64	Routine Maintenance	Good	2	Green street is in good condition and will be maintained as part of regular routine.
65 - 270	Prioritize Maintenance	Fair	3	Green street is in fair condition and will be maintained with priority.
271 - 1999	Intervene	Poor	4	Green street components may need repair. Facility may need replant. Function is not affected. No safety risks.
>=2000	Repair	Failed	5	Green street needs repair. Function is affected. Possible safety risk.

Figure 12 Portland BES overall combined condition score for bioretention assets

Structural Score		
Range	**Description**	**Action Required**
<=6	Structural components are in best possible condition. Fully functional.	Nothing
7 - 49	Structural components can wait for routine maintenance. Fully functional.	Routine Maintenance
50 - 169	Structural components require priority maintenance. Fully functional.	Priority Maintenance
170 - 724	Minor structural problems need intervention but do not affect safety or function.	Intervention
>=725	Major structural problems that affect safety and / or function.	Repair

Figure 13 Scoring System for Structure of Bioretention Assets in Green Streets, Portland Oregon

Vegetation Score		
Range	**Description**	**Action Required**
<=4	Vegetation and trees are in best possible condition.	Nothing
5 - 19	Vegetation and trees can wait for routine maintenance and / or pruning.	Routine Maintenance
20 - 149	Vegetation and trees require priority maintenance, pruning, irrigation, and / or weeding.	Priority Maintenance
150 - 849	Vegetation and trees require high priority weeding, irrigation and / or lower priority replanting.	Intervention
>=850	Vegetation and / or trees require replacement with high priority.	Replant

Figure 14 Scoring System for Vegetation of Bioretention Assets in Green Streets, Portland Oregon

Green Street Inspection / Condition Assessment Codes			
Observation, Severity	**Score**	**Description**	**Explanation / Action**
STRUCTURAL COMPONENTS			
Damage - Overall	**Score**	**Overall Damage / Vandalism / Components or Veg**	**Damage or Deterioration beyond normal wear and tear**
NONE	1	No Damage	None
MINOR	170	Minor Damage	Repair as needed - Damage does not impair function / No safety risk
MAJOR	2000	Major Damage	Repair required - Damage impairs function / Poses safety risk
Debris		**Debris / Trash**	**Leaves, Litter, Trash, Branches or other debris in facility**
NONE	1	No Debris / Trash	None
LIGHT	10	Light Debris / Trash	Routine maintenance - Minor amount
HEAVY	50	Heavy Debris / Trash	Priority maintenance - Significant amount
Inlets		**Inlets / Outlets Status**	**Obstruction of Inlet / Outlets**
OPEN	1	Inlets / Outlets Open	No Obstruction
PARTIAL	15	Inlets / Outlets Partially Blocked	Routine maintenance - Partial Obstruction / Resolved at time of inspection
FULL	55	Inlets / Outlets Fully Blocked	Priority maintenance - Complete Obstruction
Sediment		**Sediment Intrusion**	**Sediment Intrusion within facility**
NONE	1	No Sediment Present	None
LIGHT	20	Light Sediment / Confined	Routine maintenance - Does not impair function / Confined to forebay
HEAVY	60	Heavy Sediment	Priority maintenance - Impairs function / Forebay full
Soil		**Soil Problems**	**Soil Subsidence, Grading or Quallity**
NONE	1	No soil problems	Soil hosts plants and is at plan elevations
MINOR	180	Minor soil problems - Subsidence / Grade / Compaction / Quality	Subsidence / Grade < 4" deviation from plan elevation / Soil quality below average, vegetation may be affected / Intervention - Medium Priority
MAJOR	2500	Major soil problems - Subsidence / Grade / Compaction / Quality	Subsidence / Grade > 4" deviation from plan elevation / Soil quality poor, does not sustain vegetation / Requires repair / High priority
Structure		**Facility Structural Problems**	**Defects in Structural Elements / Walls, Checkdam, Inlets**
NONE	1	No Structural Problems	None
MINOR	190	Minor Structural Problems	Report as needed - Does not impair function
MAJOR	3000	Major Structural Problems	Report and repair required - Impairs function / Poses safety risk

Figure 15 Indicators of Structure for Bioretention Assets in Green Streets, Portland Oregon

Observation, Severity		Description	Explanation / Action
VEGETATION			
Trees		Tree Condition	Condition of trees within facility / 1 inspection for each tree
EXCELLENT	1	Excellent Vigor / No Pests, Disease, Damage / Symmetrical Form	No action needed
GOOD	10	Average Vigor / No Pests, Disease, Damage / Minor Asymmetry	Routine maintenance - Pruning for clearance or structure
FAIR	60	Fair Vigor / Minor Pest, Disease, Damage / Minor Defects	Priority maintenance - Pruning / Intervention with expectation of survival
POOR	160	Poor Vigor/ Significant Pest, Disease / Significant Defects	Priority intervention - Survival in question / Specify intervention
FAILED	260	Dead or Nearly Dead / Not able to be saved	Requires removal / Replacement
Veg Cover		Desirable Vegetation Cover	Areal extent of desirable vegetation, not including weeds
> 90%	1	Desirable vegetation > 90% of soil area	No action needed
75%-89%	2	Desirable vegetation covers 75% - 89% of soil area	Observe for signs of decline, may require intervention to improve
50%-74%	150	Desirable vegetation covers 50% - 74% of soil area	Replant required - priority low
25%-49%	850	Desirable vegetation covers 25% - 49% of soil area	Replant required - priority medium
< 25%	900	Desirable vegetation covers < 25% of soil area	Replant required - priority high, may require additional intervention for success
Veg Health		Overall Vegetation Health	Overall health of all installed vegetation
EXCELLENT	1	Excellent Vigor	No action needed
GOOD	2	Average Vigor	Routine maintenance - Recovering from stress
FAIR	25	Fair Vigor	Priority maintenance - Stressed / Declining
POOR	125	Poor Vigor	Priority intervention - Survival in question / Specify intervention
FAILED	225	Dead or Nearly Dead / Not able to be saved	Requires removal / Replacement
Weed Cover		Overall weed cover	Areal extent of weed cover (independent of desirable vegetation cover)
< 25%	1	Weeds cover < 25% of soil area	No action needed
25%-49%	5	Weeds cover 25% - 49% of soil area	Routine maintenance
50%-74%	20	Weeds cover 50% - 74% of soil area	Priority maintenance - low
75%-89%	100	Weeds cover 75% - 89% of soil area	Priority maintenance - medium
> 90%	200	Weeds cover > 90% of soil area	Priority maintenance - high / May require additional intervention / Specify intervention

Figure 16 Indicators Vegetation for Bioretention Assets in Green Streets, Portland Oregon

Lessons Learned and Challenges

Many factors were considered by the Bureau when designing the inspection protocol for the bioretention condition assessment and rating scheme. An essential component was thinking about and engaging with the inspectors who would be doing the condition assessment. Efforts were made to:

- ensure that the inspection provided data that was relevant to operations and maintenance teams while also describing the condition of each asset.
- obtain perspectives from inspectors so that the protocol would be supported and useable.
- minimize subjectivity by describing in detail what good, fair, and poor ratings mean, particularly for vegetation health. Each rating was mapped onto clear parameters that could be easily observed and judged by the inspectors in the field, as well as clear maintenance actions.
- collect enough relevant data for asset management, but not so much that it would be burdensome to inspectors. It was important to consider how much time the inspectors have available to do the inspections and develop a protocol that was efficient. As a result, some categories are broad, for example, “Structure” includes walls, check dams, and beehives. Scoring was designed to be concise, but inspectors can provide additional details in comments.

Another important component was developing the weighted scoring metrics so that:

- scores and ratings did not over- or underrepresent the severity of the asset condition. For example, since a bioretention asset can contain multiple trees, the tree with the worst condition is used to assign the condition rating for the *tree* characteristic. This was done to prevent a single parameter from causing bioretention to shift into a “Failed” condition when it might otherwise be functional.
- numerical scores associated with ratings for each component accurately reflected relative risk of that component, with the highest scores being given to categories that have the highest risk. For example, the rating, *major structural problems*, has a higher risk than a *full inlet* (see Figure 15). Even though a full inlet means that it is currently non-functional, it can be easily opened with small maintenance effort, while structural damage requires more significant repair. Therefore, *major structural problems* was assigned a score of 3,000 while *full inlet* was associated with a maximum score of 55.

Next Steps

- Currently, it is only possible to conduct one condition assessment inspection per year. However, the Bureau hopes to increase staffing and expand to at least at least 2 to 4 inspections per year so that inspections drive subsequent maintenance visits more directly.
- The Bureau aims to increase the use of condition assessment scores by site managers to inform or even drive maintenance decisions.
- The Bureau plans to develop a manual with photos of examples for each category for training purposes and to ensure consistencies.

Case Study 5: Atlanta, Georgia – Condition Assessment of Stream Assets

Overview

Figure 17 Proctor Creek: Natural Stream and Riparian Area (Source: City of Atlanta)

The City of Atlanta Department of Watershed Management (COA DWM) stream assessments were implemented in the early to mid-2000s, and the methodology was created by a consultant team hired by the City. Initially, DWM employees volunteered for the work until a designated team was created.

Since the assessment's inception, several changes have been made including altering the assessment to be rapid. In doing so, variables such as Bank Erosion Hazard Index (BEHI) ratings and macroinvertebrate sampling were removed due to time constraints. Although macroinvertebrate sampling was omitted from stream condition assessments, DWM does conduct biennial biological monitoring of their streams, including macroinvertebrates, IBI (fish), and habitat assessments.

The COA DWM is required to walk 20% (roughly 250 miles) of blue-line perennial streams yearly, which results in all ten of its watersheds being walked every five years. Each watershed is given its own ID and each main stem and tributary within the watershed is also given its own unique ID (e.g., in the Peachtree Creek watershed, the mainstem is labeled 4000, and the most downstream tributary to the mainstem is labeled 4000.1, the next is labeled 4000.2, and so on). The stream lengths are divided into 500-foot reaches, although some are shortened to end at culverts and bridges. The assessment team performs a rapid assessment along each reach.

The rapid assessment is primarily geomorphic, but it does include other variables. The assessment looks at grain sizes, erosion extent, canopy cover percent, buffer extent, presence of incision, widening, aggradation, invasive species, and more. Each category has its own ranking system. Figure 18 shows the survey form used by the assessment teams.

Lessons Learned and Challenges

- Rapid condition assessments do not need to be very in-depth and measurement heavy. Once a reach has been identified as an area for further study, the organization can perform more labor-intensive measurements, tasks, and studies to gather additional data.

- A large challenge with the data collection is fitting large streams and small tributaries into the same assessment, as they can be very different.

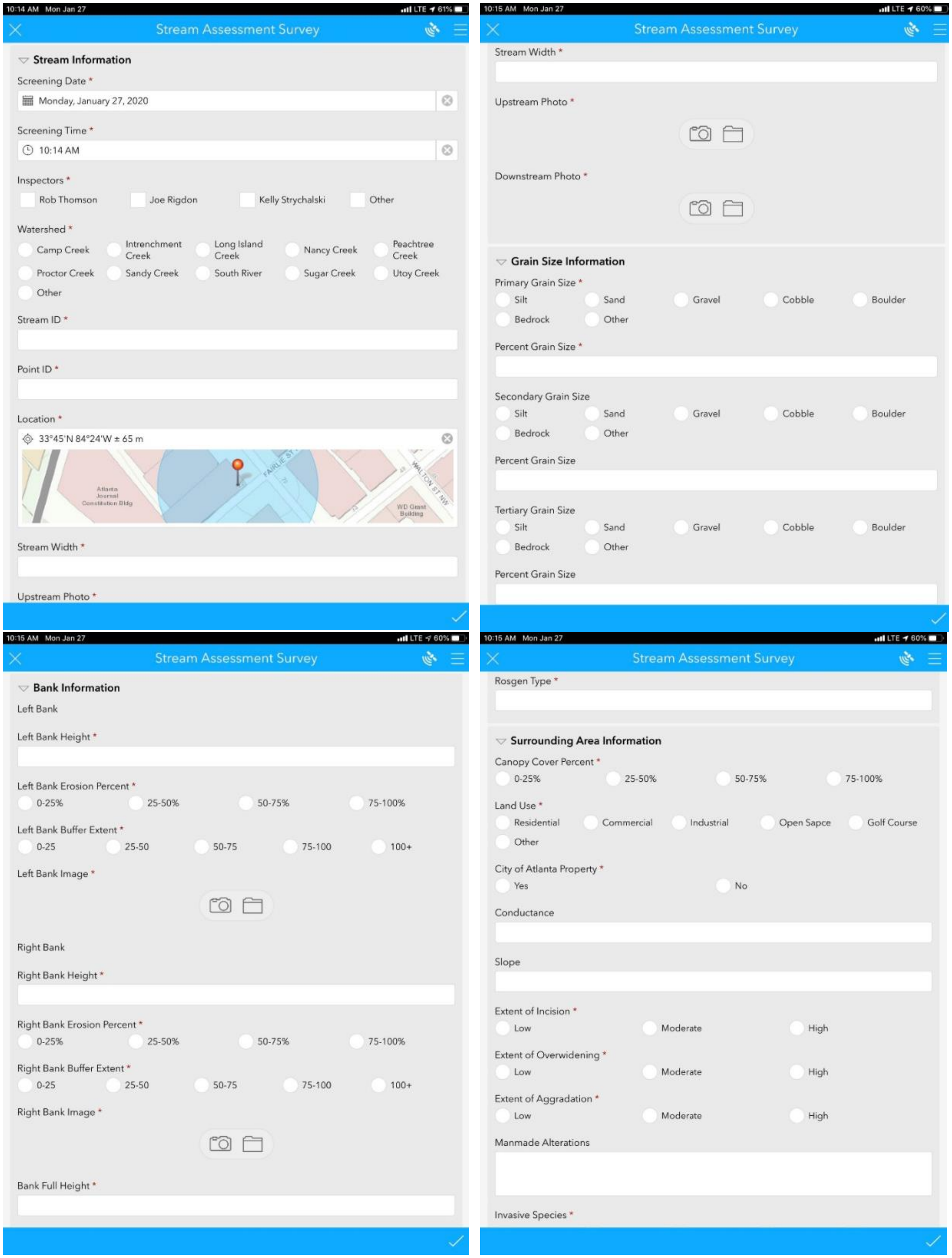


Figure 18 City of Atlanta Stream Condition Survey Sheet (Source: City of Atlanta)

Story: Portland, Oregon – Incorporating Streams into Asset Management

Overview

The City of Portland Bureau of Environmental Services (the Bureau) is responsible for both sanitary sewer and stormwater systems. In recent years, the Bureau has been restructured to better support asset management, including the creation of Risk Assessment and Integrated Planning Teams. This reorientation has included the recognition of GSI, including streams, as vital infrastructure assets.

Streams play an essential role in conveying stormwater, and stormwater management impacts natural stream functions. Therefore, streams are also being incorporated within the Bureau's larger asset management system. The Bureau has started with identifying the core services provided by streams as well as key indicators of condition that affect the ability of streams to provide those services.

Next steps for the Bureau include developing stream condition scores reflecting the stream's ability to deliver the core services and incorporating condition scores into an asset management framework to inform criticality. In the process of developing an asset management framework for streams, the Bureau has gained several insights into the challenges of and best approaches for streams.

Lessons Learned and Challenges

- It is essential to think of the stormwater system holistically. Therefore, it is necessary to include all assets that play a vital role in the stormwater system in asset management, whether they are natural or built, or owned by the Bureau or not. By incorporating streams as assets, an improved understanding of the stormwater system can be obtained which supports better asset management.
- It is important to recognize that unlike traditional stormwater assets, streams provide many environmental, social, and economic services. Services that are relevant to the Bureau must be included within the asset management framework. Therefore, when developing an asset management system, agencies should consider the key services that they expect streams to provide based on their organizational goals and community's expectations, as well as regulatory requirements.
- Identifying the core services provided by streams is a foundational step which supports all the other components of asset management. For example, the core services inform which physical condition indicators should be monitored to assess how well a stream can deliver those services.
- Developing an asset management plan for streams is a challenging process for several reasons. Overall, natural systems and the multiple services they provide are very difficult to compartmentalize and categorize, and they resist a narrow, siloed approach.
- Ownership of streams and their riparian areas is complex. Only some streams and their riparian areas fall on Bureau land, which can complicate the assessment and understanding of the complete stormwater system.
- Silos between departments with an interest in the services provided by streams create challenges to thinking about and managing streams in an integrated manner.
- To deal with these challenges, it is important to develop an asset management framework that includes the complexities of multiple owners, managers, and services, and to work together with other departments and landowners to share information and manage assets in a coordinated manner. The Bureau is focused on developing an integrated approach that engages and elevates the various stakeholders in this work to help inform likelihood and consequence of failure for these complex natural systems.

Criticality

Introduction

Analysis of criticality is conducted to understand the risks associated with each asset and to inform the prioritization of projects and management activities so that limited resources can be used wisely. Each asset is given a criticality score which reflects the combined probability and consequence of its failure. Assets can fail in multiple ways (modes of failure) known as mortality, capacity, level of service, and financial inefficiency failures. Level of service failures are likely to be very relevant for green stormwater infrastructure assets which provide multiple services. The SWEFC Integrated Asset Management Framework provides detailed steps on how criticality scores can be determined.

Lessons Learned and Challenges

- Very few agencies have developed risk scores for their GSI assets as they have been focusing on inventorying their assets, developing condition assessments, and setting levels of service, which are essential inputs into criticality analysis.

  However, while it may be difficult to develop risk scores while these other components are in development, it is recommended to at least begin planning for the criticality analysis early in the process. Agencies can start with using what they already know about assets combined with a few basic assumptions to identify potential risks and indicators to set up a risk assessment framework.

> **Stormwater Tree Trenches - Failure**
>
> It is important to consider the designed purpose of an asset and LoS goals when conducting criticality assessments. For example, although the death of a tree in a bioretention asset would be unlikely to indicate overall asset failure, it would indicate failure in the stormwater tree trench, which is *designed* to support healthy trees.

- GSI assets are vulnerable to level of service failures caused by the growth of weeds, overgrowth of plants, or declining vegetation quality. Although the asset may still be functioning in terms of stormwater treatment, it may fail to provide expected services for aesthetics, for example.

- A particular challenge for GSI is how to compare different types of consequences/risks, for example, risk to human safety or biodiversity. In addition, it can be difficult to assign monetary values to some of the consequences associated with GSI asset failure.

- Another challenge is how to factor in multi-asset failure. While the failure of a single asset might not have significant consequences, the consequences of multiple asset failures could be severe. More advanced asset management plans can use asset redundancy to adjust criticality scores. When assets have low redundancy, consequences of failure tend to be higher.

Failure in GSI Assets

On July 27, 2021, three workshop were held as part of this Toolkit project in which participating agencies identified the ways in which bioretention, permeable pavement, and stream assets can fail, consequences of failure, and factors influencing the probability of failure. Some key results of those workshop are summarized below.

Criticality of Permeable Pavement

Ways that permeable pavements can fail

- Pavement joints or pores are clogged (sediment accumulation)
- Ponding
- Underdrain has deteriorated and is damaged or collapsing (end of life)
    - Damage to surface makes it unusable for walking/biking/parking/etc.
    - Heaving or settlement that becomes a safety hazard
    - Construction, falling tree, or other external force destroys the pavement
    - Improper material installation (unravelling of the stones)
    - Lack of winter maintenance
- Vegetation growing through cracks

Consequences of failure for permeable pavements

- Clogged pavements (without overflow) causing overland flow into private property, potentially causing damages
- Financial impacts for required repairs
- Warmer stream temperatures
- Tripping hazards for users causing injuries
- Consequences of failure vary by location

Factors influencing the probability of failure for permeable pavements

- Low levels of preventative maintenance
- Construction
- Weather (rain/freeze-thaw cycle)
- Traffic load/type
- Location

Criticality of Bioretention Assets

Ways that bioretention assets can fail

- Vegetation death or invasive species infestation
    - Could result in aesthetics LoS failure
- Broken curbs, walls, compacted soils, concrete washout, and soil subsidence create safety issues.
- Water failing to exit the feature due to:
    - sediment accumulation
    - debris going into the overflow pipe causing the underdrain to clog
- Water unable to reach the feature due to:
    - inlet blocked (debris: trash, leaves)
    - poor design of construction
- Changes to contributing drainage area leading to capacity failure
- For stormwater management tree trench/soil cells: tree mortality

Consequences of failure for bioretention assets

- Water ponding contributing to breeding mosquitos and vegetation mortality
- Roadway closure (due to flooding because water could not reach the feature)
- Increased runoff to pipe system (combined sewer overflow event, residential basement sewer back up)
- Street flooding that includes private property
- Residential complaints about aesthetics

Factors influencing the probability of failure for bioretention assets

- Improper design for the location and/or micro-environment
- Improper installation
- Future construction around the feature
- Improper erosion sediment control causing more sediment
- Long term staging of materials for construction projects in GSI assets
- Lack of active maintenance during warrantee period and/or during the asset's life

Criticality of Streams

Ways that streams can fail

- Trails and access points are inaccessible for community members (overuse, stream meandering, bank erosion, flooding, or realignment)
- Streams do not provide healthy habitat (migration barriers, invasive species, habitat degradation, erosion, water quality, quantity, and temperature)
- A stream becomes disconnected from its flood plain (through bank erosion or bank hardening).
- Stream erosion impacts private property
- Impacts of flood (more than financial cost of damage, human injury, contaminated water).
- Lack of proper vegetated buffer (riparian zone)
- Piped sections (these sections can fail to provide other services such as aquatic habitat and recreational)

Consequences of failure for streams

- Erosion
- Lack of habitat (reduced or limited aquatic refugia and stream cover, and poor stream bed substrate, loss of or limited vegetation diversity – aquatic and terrestrial)
- Degraded habitat (buried or displaced)
- Property loss and damage
- Increased stream temperature
- Poor water quality (sediments and suspended solids)
- Increase non-point source pollution
- Less aesthetically pleasing
- Resulting failure or damage to sewer and/or trail infrastructure

Factors influencing the probability of failure for streams

- Climate change increasing precipitation intensity (changes in frequency and intensity).
- Development and increased paved area.
- Sewer presence and condition and existence of antiquated combine sewers with combined sewer overflow discharges.

Snapshot: Toronto, Ontario – Criticality of Permeable Pavement

In Toronto, permeable pavers in the right-of-way only reach the end of their life when they fail to function as a paved surface (e.g., sinkhole, paver buckling, and poor rating in pavement quality index).

As of 2021, right-of-way permeable pavers are built to be redundant with grey stormwater management (SWM) infrastructure. Therefore, if permeable pavers fail to provide their SWM function they would experience a level of service failure that would warrant a rehab/repair but would not have reached the end of their life.

The most significant factors that lead to failure for permeable pavement assets are structural damage and severe defects on the pavement surface, severe clogging, and significant loss of SWM function. SWM function can be significantly impacted when other utilities patch and replace the surface with impermeable materials. There is still a gap in developing a suitable protocol for coordinating utility access and repairs which affect permeable pavers to minimize damage.

Life Cycle Costing

Introduction

The goal of life cycle costing is to manage assets across their entire life cycle to keep costs to a minimum by making the right management interventions at the right time. Life cycle costing involves establishing the phases of an asset's life and the costs associated with an asset in each phase, starting from initial design and planning all the way to decommission/disposal and replacement. Life cycle costing is an essential input for the development of long-term financial plans. The SWEFC Integrated Asset Management Framework provides detailed information on this important component of asset management.

Lessons Learned and Challenges

- Agencies seldom have much data available on the life cycle costs of GSI assets as these assets are often very new. The initial design, construction, and installation costs may be available, but operations, maintenance, repair, and replacement costs are less likely to be well understood. The development of a good asset database and inventory which allows agencies to track costs is invaluable for developing accurate life cycle costs. It can be helpful to set up the database so that costs can be tracked to the component level.

- It can be challenging to develop standard costs for green stormwater infrastructure because costs are context and site-specific.

  To deal with this challenge, the Philadelphia Water Department (PWD) has developed metrics which allowed it to statistically model the relationship between those metrics and costs. They recommend that agencies think about the variables that drive the costs of their program so that these can be analyzed.

  In their experience, statistically significant variables were related to system attributes as opposed to external site-level factors (e.g., in right-of-way versus off right-of-way setting), design parameters (i.e., loading ratio and drainage area) or system type (e.g., stormwater planter, rain garden, and stormwater bump-out). Variables to consider include cost by number of inlets, costs per square foot/meter of vegetated area or footprint, and subsurface cost per linear foot/meter of pipe.

  PWD has also found it useful to divide analyses into subsurface (e.g., inlet cleaning and pipe jetting) and surface costs (e.g., landscaping tasks, litter, and sediment removal) and to look at maintenance effort across different asset types.

  Data on the amount of effort required to maintain GSI asset types (e.g., hours per square foot or meter) would be more useful to share across agencies than actual costs to minimize the local factors that affect costs, such as the impact of unions on labor rates. Ultimately, these analyses assisted PWD in arriving at appropriate ranges of unit costs for all routine surface and subsurface maintenance tasks which has played a considerable role in facilitating cost control measures, especially when compared to costing methods based on a time and materials approach.

Portland, Oregon – Life Cycle Costing

Portland Bureau of Environmental Services recently launched a capital rehabilitation/repair shell project to address soil subsidence in green street facilities. Condition assessment data collected at the asset level through annual inspections were critical to scoping the problem and developing the capital budget request. Lessons learned from this project will factor into life cycle costing and inform future capital construction as well as operating budgets.

- In addition to identifying costs, another challenge is specifying the end of life for GSI assets. For bioretention, end of life might occur when it is clogged beyond what could be reasonably fixed by rehabilitation. It might also occur if there is significant surface damage or deterioration.

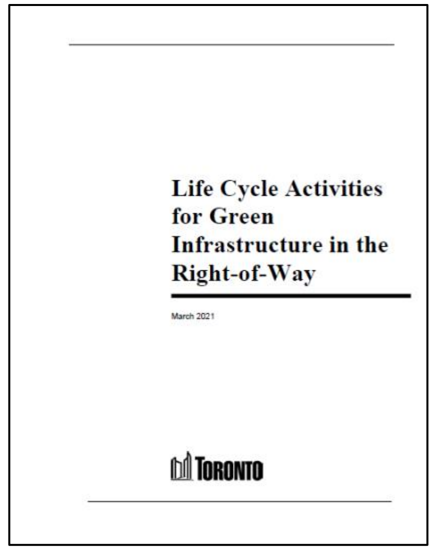
- For streams it is more challenging to envisage what a complete life cycle might look like. While engineered components of streams such as buttressing could be assigned a life span, it is less clear what to assign to natural parts of the stream. These portions are essentially unlimited in terms of life span. However, the natural parts of streams and riparian zones often require interventions such as erosion control, planting, and invasive plant removal. The average interval between doing major works or rehabilitation could be used as the life span for natural assets such as streams.

- Although full life cycle costing is challenging for most agencies at the early stages of asset management, a good starting place is examining the current operating and maintenance costs to evaluate whether they are being optimized and to identify opportunities to increase cost-effectiveness across the entire asset life cycle.

Case Study 6: Toronto, Ontario – Life Cycle Costing of GSI in the Right-of-Way

Life Cycle Activities

In March 2021, the City of Toronto finalized the report, *Life Cycle Activities for Green Infrastructure in the Right-of-Way*. It is a guide created to help in-house operations and consulting engineers consistently maintain green infrastructure assets. The guide links design standards to standard life cycle activities such as inspections and maintenance and helps to ensure assets that are built can be maintained and continue to deliver their intended services.


Life Cycle Activities for Green Infrastructure in the Right-of-Way

March 2021

TORONTO

The guide covers maintenance (preventative, corrective, and predictive) and monitoring (performance and long-term) activities required to support green infrastructure.

Maintenance topics include:

- Types of Maintenance: Covers the different types of inspections and accompanying maintenance that are recommended to be performed throughout the life cycle.
- Maintenance Indicators: Covers the general visual and testing indicators pertaining to GSI that warrant specific maintenance tasks.
- Green Infrastructure Specific Maintenance Practices: Covers the routine maintenance, specific indicators, life cycle operations and maintenance, failure conditions, and mitigation strategies for each respective GSI asset type.
- Resident Engagement Protocol: offers a high-level overview of the Community Engagement Protocol for GSI in the Right-of-Way manual.

Monitoring topics include:

- Performance Monitoring: covers the different types of monitoring activities, frequency, and associated inspections from Part 1.
- Water Quantity Parameters: covers an overview and expansion on water quantity monitoring.
- Water Quality Parameters: covers an overview and expansion on water quality monitoring.
- Tree Health and Tree Growth: covers tree structural integrity, tree health, and tree growth, pests and disease monitoring, and associated frequency, equipment, and targets.
- Soil Health: covers physical, chemical, and biological soil health monitoring parameters and associated frequency, equipment, and targets.
- Vegetation Health: covers vegetation health monitoring, pest and disease monitoring, irrigation, and drainage system monitoring parameters and associated frequency, equipment, and targets.
- Monitoring FAQs: covers frequently asked questions about monitoring of green infrastructure systems.

- Health and Safety: covers important health and safety related guidelines, procedures, and requirements necessary to conduct maintenance and monitoring practices.

The guide also includes field inspection forms for asset condition assessments. The next step for Toronto is to incorporate recommendations of these guidelines into regular operations and start tracking cost pertaining to each life cycle activity.

Life Cycle Stages and Costs for Permeable Pavers

Toronto has created definitions for repair and rehabilitation for permeable pavers to support management.

- Repair: Spot treatment to restore structural damage, e.g., patching potholes with asphalt and relaying pavers in a small area to address settlement.

- Rehabilitation: Treatments that pertain to the majority of the paver area OR anything that requires excavation/construction procedure, e.g., non-routine vacuum and excavation to replace collapsed underdrain.

- End of Life: an expected useful life of 25 years based on Sustainable Technology Evaluation Program's guidelines for permeable surface assets.

Toronto is currently tracking construction costs and design costs of permeable pavements but is lacking costs for other stages of the life cycle. Their next steps for developing life cycle costs are to:

- deploy the maintenance program (above) and track key cost metrics (e.g., human end equipment hours, materials).

- establish an asset intake process to ensure city-wide metrics are accurate.

- track utility companies' repair costs of permeable pavements and traditional pavements to allow for comparison.

- explore new equipment requirements for clogged pavements and other new applications, such as sidewalks and boulevards, that can affect life cycle costs.

Lessons Learned and Challenges

- In large transportation construction projects, it can be challenging to isolate the costs of GSI such as permeable pavement from the costs of other project components (e.g., bike lane, traffic safety, and bump outs); a formalized process of doing this up front would be helpful.

- GSI products (especially for permeable pavements) and implementation methods are still very dynamic/in development, making it difficult to assign a standard cost.

- Very little or no experience in all life cycle activities makes it difficult to determine costs.

- It is challenging to extrapolate costs from a small asset inventory of several unique products to generalized asset types.

Case Study 7: Vancouver, British Columbia – Life Cycle Costing for Green Rainwater Infrastructure

Overview

Vancouver's asset management planning initiatives started in earnest in 2021. This included hiring an asset manager, establishing an asset management team, piloting operations and maintenance (O&M) and rehabilitation programs, and hiring an external consultant. The municipality has made significant progress in understanding the current state of their assets including GSI.

Vancouver has started to develop life cycle costs for bioretention assets. The first step was developing a framework for bioretention life cycle activities that could be used to determine their operating expenditure (Figure 19). The expected service life for bioretention facilities is 25 years.

Vancouver has also developed a detailed Table 8 of O&M activities and frequencies for bioretention assets informed by the Sustainable Technologies Evaluation Program's (STEP) Low Impact Development Stormwater Inspection and Maintenance Guide. Table 8 lists maintenance frequencies proposed by STEP as well as Vancouver's existing and desired frequencies. Their goal is to eventually develop unit rate costs for each activity.

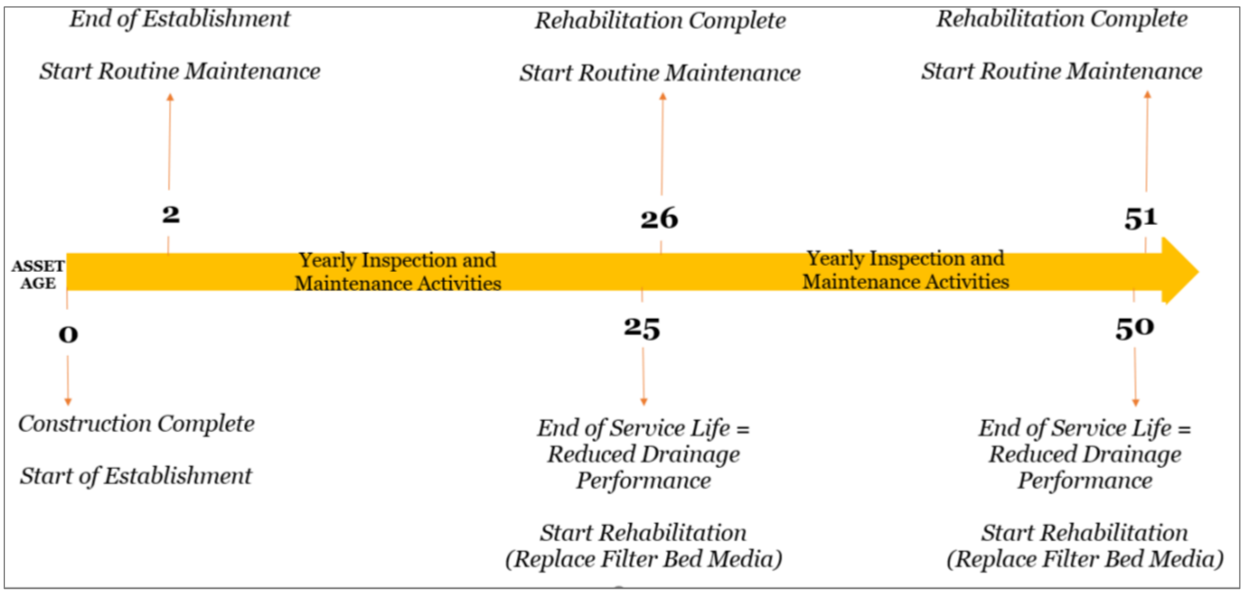


Figure 19 Vancouver's Life Cycle Model for Bioretention Assets (Source: City of Vancouver)

Lessons Learned and Challenges

- In 2021, Vancouver initiated their first formal O&M and rehabilitation program. Because no formal maintenance or inspections had been performed in the past, historical cost information was not available for developing life cycle costs. Therefore, the municipality decided to take the approach of estimating costs based on information from other municipalities or from contractors.

- An important factor to consider when developing life cycle costs is the location of the asset as it has a significant impact on the frequency of O&M activities needed and expected service life. To better understand the impacts of location, Vancouver has been focusing on finalizing the asset inventory including the collection of location attributes.

Next Steps

Vancouver's next steps will be to:

- develop levels of service and define key performance indicators to track performance of assets.
- determine criticality of assets and establish risk scores.
- develop life cycle costs of assets.
- establish an integrated Computerized Maintenance Management System (CMMS) and conduct process mapping for data standardization and management.
- develop service delivery models and governance structures.

Table 8 Life Cycle Operations and Maintenance Activities and Frequencies for Bioretention Assets (Source: City of Vancouver)

Maintenance Activity	Activity Type and Description	Min. Freq. (Source: STEP)	High Freq. (Source: STEP)	Existing Freq. (Vancou -ver)	Proposed Freq. (Vancou-ver)	Program Implementation Notes/ Assumptions	Unit Cost ($) (per Asset)	Assump-tions
Inspection	Visual Inspection	Com-plaint Driven	1x - 2x per Year	1x / Year	Once Every 2 Years	Assess the condition of each asset component and determine asset functionality. To be performed by staff trained on functionality of green rainwater infrastructure assets, and on using electronic form. Effort will also require detailed pre- and post-inspection steps. Data will be used to determine non-routine maintenance requirements. On average, inspector will spend an hour at each site.		
Routine Maintenance	***Part of Community Stewardship Program*** Remove sediment, trash, and debris from pre-treatment devices, the filter bed surface and inlet and outlets.	2x per Year	4x per year	1x / Year	1x / Year	Scope is limited to a quick 30 min visit per site. Assuming 20% of assets are part of community stewardship program. Assumption based on current state of 30 assets of 152 assets being part of community stewardship program.		
Routine Maintenance	***Not Part of Community Stewardship Program*** Remove sediment, trash, and debris from pre-treatment devices, the filter bed surface and inlet and outlets.	2x per Year	4x per year	1x / Year	3x / Year	One visit will be combined with the routine maintenance contract for vegetation (listed below). Scope is limited to a quick 30 min visit. This frequency will apply to the remaining 80% of assets.		

Maintenance Activity	Activity Type and Description	Min. Freq. (Source: STEP)	High Freq. (Source: STEP)	Existing Freq. (Vancou -ver)	Proposed Freq. (Vancou-ver)	Program Implementation Notes/ Assumptions	Unit Cost ($) (per Asset)	Assump-tions
Routine Maintenance	• Trim trees and shrubs • Replace dead vegetation, remove invasive growth • Repair eroded or sparsely vegetated areas • If gullies are observed along the surface, regrading and re-vegetating may be required • Remove sediment, trash, and debris from pre-treatment devices, the filter bed surface and inlet and outlets.	1x - 2x per year	4x per year	2x / Year	2x / Year	Scope similar to the ongoing contract.	$80	Unit cost assumed based on landscaping and mainte-nance contract of 2021. Assuming contract price of $115,000 for 145 assets.
Routine Maintenance	Remove sediment buildup (if more than 5 cm depth) or Sediment raking	As Needed	As Needed	2x / Year	2x / Year	Combined with the routine vegetation maintenance contract.		
Routine Maintenance	Composted Mulch Top-up	Once Every 2 years	Once Every 2 years	NP	Once Every 2 years	Combined with the routine vegetation maintenance contract. Assume 20% of assets will require replacement every year.		
Routine Maintenance	Replace Displaced / Missing Round River Rock	Once Every 2 years	Once Every 2 years	1x / Year	1x / 2 years	Combined with the routine vegetation maintenance contract. Assume 20% of assets will require replacement every year.		

Maintenance Activity	Activity Type and Description	Min. Freq. (Source: STEP)	High Freq. (Source: STEP)	Existing Freq. (Vancou -ver)	Proposed Freq. (Vancou-ver)	Program Implementation Notes/ Assumptions	Unit Cost ($) (per Asset)	Assump-tions
Routine Maintenance	Catch Basin Flushing	NA	NA	NP	1x / 3 Years	Contract will only be limited to CB flushing.		
Routine Maintenance	Invasive Species Management	NA	NA	NP	1x / Year	Combined with the routine vegetation maintenance contract.		
Non-Routine Maintenance	Structural Repairs	NA	NA	NP	1x / 5 Years	Will be performed on an as-needed basis. However, assume 20% of assets need some form of basic repair every year. Common examples include parging concrete curbs, catch basin (external), replacing or repairing grate, and repairs to inlet/pre-treatment device.		
Non-Routine Maintenance	Underdrain Flushing	1x per year	1x per year	NP	1x / 10 Years	Contracted. Performed on an as-needed basis.		
Performance Testing	Post Storm Inspections	NA	NA	NP	1x / 3 Years			
	Infiltration Tests	NA	NA	NP	1x / 15 Years			
Rehabilitation	• Perennial Plant Replacement • Replace top 15 cms of bioretention filter media / soil • Replace mulch & river rock	Once Every 25 Years	25 Years	NP	1x / 25 Years	Assuming most above grade assets will be replaced during this process.		

Case Study 8: Credit Valley Conservation, Ontario – Life Cycle Costing for Streams

Overview

Credit Valley Conservation (CVC) Authority[2] in Ontario, produced a report, *Life Cycle Costing of Restoration and Environmental Management Actions: Costing Natural Assets in Peel Region* (2020), to support the incorporation of natural assets into asset management. Their goal was to develop defensible life cycle cost estimates for natural assets, including streams.

They identified four types of stream corridor assets for this purpose:

- Stream Corridor – Small System Rehabilitation
- Stream Corridor – Large System Rehabilitation
- Stream Corridor Erosion Control - Small System
- Stream Corridor Erosion Control - Large System

Small systems were defined as up to 5 m bankfull width and large systems between 5 m and 20 m bankfull width.

CVC defined the life cycle of stream corridors as made up of iterative phases involving long-term monitoring and management occurring over a 50-year time span. The life cycle stages are shown in Figure 20. Each phase of the life cycle was assigned a duration:

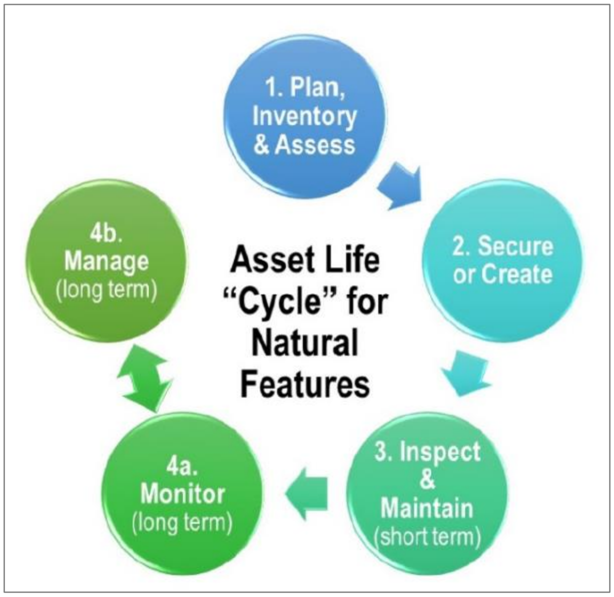


Figure 20 Life Cycle of Natural Features (Source: CVC 2020)

- Phase 1 – Plan, Inventory, and Asses: 2 years
- Phase 2 – Secure or Create (or Establish): 3 years
- Phase 3 – Inspect and Maintain: 6 years
- Phase 4 – Monitor and Manage: 39 years.

To develop life cycle costs, specific activities were identified for each life cycle phase and assumptions were made about the scope and frequency of activities. Activities were assumed to be taken to such a degree to produce assets that were in good or acceptable condition.

Low, moderate, and high costs were then established for each phase based on projects completed in the region between 2017 and 2020, and the input of local experts. The results are summarized in Table 9.

[2] CVC was not a part of the GILE-funded project to develop this Toolkit, however, they are one of the few agencies within North America that has developed a method for estimating life cycle costs of streams. Therefore, the methods and results of their report are included within this Toolkit.

The difference between low and high-cost estimates reflect differences in the complexity, time commitment, and materials needed across different projects.

Table 9 Estimated Standard Life Cycle Costs (in Canadian Dollars) for Stream Corridors (Source: CVC 2020)

Asset Sub-Type	Initial Site Conditions	Low Cost	Moderate Cost	High Cost
Stream Corridor – Small System Rehabilitation (500m)	Watercourse with bankfull width up to 5m for a 500m long reach and within a 20m wide corridor in need of rehabilitation	$ 764,388	$1,114,600	$1,368,842
Stream Corridor – Large System Rehabilitation (500m)	Watercourse with bankfull width of 5m to 20m for a 500m long reach and within a 30m wide corridor in need of rehabilitation	$962,350	$1,585,050	$1,929,090
Stream Corridor Erosion Control - Small System (100m)	Approx. 500m of established small watercourse corridor (up to 5m bankfull width) with a naturalized channel requiring erosion protection works for about 20% of the reach.	$338,410	$514,022	$750,457
Stream Corridor Erosion Control - Large System (100 m)	Approx. 500m of established small watercourse corridor (5m to 20m bankfull width) with a naturalized channel requiring erosion protection works for about 20% of the reach.	$457,995	$813,620	$933,713

The report notes that there is a large variability in cost sources and estimates. Some activities were completely omitted from life cycle costing due to significant inconsistencies in scope and the nature of the activity included. Costs excluded from the results above included planning for asset acquisition, coordination of access and permissions, actual asset acquisition, and monitoring wildlife. In addition, costs reported in Table 9 do not account for inflation or discounting, opportunity costs, possible cost savings due to taking activities at larger scale, and contingencies due to catastrophic events or risk of failure.

Long-Term Funding

The long-term funding component of asset management helps to develop a sustainable, long-term funding plan for managing assets so that they continue to provide the expected levels of service into the future. Funding plans need to consider the long-term future as most stormwater assets have long lives; Long-term funding plans can project as far as 50 to 100 years into the future. Without sufficient funding, some of the activities needed to maintain levels of service may not be completed which could result in levels of service failure. Also, insufficient funding can make it impossible to carry out the management activities at the ideal schedule which can result in an increase in life cycle costs in the long term. The SWEFC Integrated Asset Management Framework is an important resource for learning more about this important component of asset management.

City of Vancouver: Next Steps

The service delivery model and governance structure of municipalities inform life cycle costing and long-term funding of green infrastructure. Vancouver has hired an external consultant to assist them with life cycle costing and long-term funding. A challenge for long-term funding of GSI is finding a dedicated and/or reliable funding source, such as a stormwater fee. Currently Vancouver uses funds from existing funding streams.

City of Toronto: Next Steps

Toronto will be leading an exercise to establish a life cycle cost sharing model for green infrastructure assets between three divisions that 'benefit' from/are stakeholders in GSI assets in the right-of way: Transportation Services, Toronto Water and Parks, Forestry and Recreation. The intent is to acknowledge the full life cycle of GSI and adapt a funding model that incorporates not just design and capital costs but ongoing maintenance and rehabilitation costs, using a 'benefiting agency' model.

Conclusions

The aim of this Green Stormwater Infrastructure Asset Management Resources Toolkit is to contribute to the relatively new endeavor of incorporating green stormwater infrastructure into asset management on equal footing with gray infrastructure. Including GSI into asset management provides an opportunity to formally recognize the vital services and co-benefits that green and natural assets provide as well as support the allocation of resources to ensure that they are managed wisely. This is an exciting area of growth and innovation that is likely to benefit asset management as well as green infrastructure management. The resources, case studies, and examples provided in this Toolkit will hopefully support municipalities, agencies, and utilities as they begin or continue to advance their own GSI asset management programs.