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

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TORONTO

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Introduction

The *Life Cycle Activities for Green Infrastructure in the Right-of-Way* manual provides the recommended maintenance and monitoring activities to ensure the longevity of the City's Green Infrastructure assets. It is intended to be used in conjunction with the City's standard drawings and specifications for Green Infrastructure in the right-of-way, *Design Criteria for Green Infrastructure in the Right-of-Way* manual, and *Community Engagement for Green Infrastructure in the Right-of-Way* manual. This manual was written for City of Toronto staff and consulting professionals with the purpose of ensuring that consistency between all operations. This manual will also help ensure that consistent information is provided by staff regardless of City Division or office location.

What is Green Infrastructure (GI)?

According to Toronto's Official Plan, "Green Infrastructure means natural and human-made elements that provide ecological and hydrological functions and processes. Green infrastructure may include components such as natural heritage features and systems, parklands, stormwater management systems, street trees, urban forests, natural channels, permeable surfaces, and green roofs."

Within the context of this manual, Green Infrastructure ,referred to herein by the abbreviation 'GI' are intended to be systems located within the Toronto's right-of-way. This manual will also focus on the lifecycle activities required to maintain the stormwater management function of constructed, engineered GI systems. This manual will not apply to all street trees, green spaces or naturalized areas in the right-of-way, but only to engineered GI systems specifically designed and constructed to support stormwater management.

What are GI Lifecycle Activities?

Similar to other types of infrastructure, GI systems are designed to have a certain lifespan during which they require inspection, maintenance, and monitoring to continue to perform as intended.

Lifecycle activities discussed in this manual include maintenance – preventative, corrective, and predictive – and monitoring – performance and long-term – activities required to support the GI system over its service life.

What This Manual Contains

Part 1 – Maintenance of Green Infrastructure

Chapter 1 – Types of Maintenance – covers the different types of inspections and accompanying maintenance that are recommended to be performed throughout the life cycle of a Green Infrastructure system.

Chapter 2 – Maintenance Indicators – covers the general visual and testing indicators pertaining to Green Infrastructure systems that warrant specific maintenance tasks.

Chapter 3 – Green Infrastructure Specific Maintenance Practices – covers the routine maintenance, specific indicators, life cycle operations and maintenance, failure conditions, and mitigation strategies for each respective Green Infrastructure system.

Chapter 4 – Resident Engagement Protocol – offers a high-level overview of the *Community Engagement Protocol for Green Infrastructure in the Right-of-Way* manual.

Part 2 – Monitoring of Green Infrastructure

Chapter 5 – Performance Monitoring – covers the different types of monitoring activities, frequency, and associated inspections from Part 1.

Chapter 6 – Water Quantity Parameters – covers an overview and expansion on water quantity monitoring.

Chapter 7 – Water Quality Parameters – covers an overview and expansion on water quality monitoring.

Chapter 8 – Tree Health and Tree Growth – covers tree structural integrity, tree health, and tree growth, pests and disease monitoring, and associated frequency, equipment, and targets.

Chapter 9 – Soil Health – covers physical, chemical, and biological soil health monitoring parameters and associated frequency, equipment, and targets.

Chapter 10 – Vegetation Health – covers vegetation health monitoring, pest and disease monitoring, irrigation, and drainage system monitoring parameters and associated frequency, equipment, and targets.

Chapter 11 – Monitoring FAQs – covers frequently asked questions about monitoring of green infrastructure systems.

Chapter 12 – Health and Safety – covers important health and safety related guidelines, procedures, and requirements necessary to conduct maintenance and monitoring practices.

Glossary – an alphabetical list of technical terms and their definitions relating to the contents of this manual.

Index – an alphabetical list of topics, keywords and synonyms used in this manual.

Appendix A – Field Inspection Forms

Part 1 – Maintenance of Green Infrastructure

The maintenance framework for Green Infrastructure (GI) is strategically developed to ensure that the function, aesthetics, investment, safety and mobility of the systems are preserved throughout the system's service life. As part of the City's asset management program, it is important for an effective framework to be enforced to maintain the function of the GI systems, mitigate system failures and accommodate the legal requirements set forth within the asset management policies. Continuous improvement of operations and maintenance (O&M) activities is a key component of the asset management process considering O&M practices can significantly impact asset life cycle costs, management of risk, and performance levels. Maintenance plans should allow for feedback mechanisms from various stakeholders and a framework to embed lessons learned into continuous improvement of O&M practices.

Unlike other City infrastructure, GI systems are often at grade and are visible within streetscapes. They can play a role as an aesthetic amenity and shape the appearance of a Green or Complete street; however, they must be maintained properly. Due to their visibility, maintenance often focuses on a visual level of service rather than maintaining fundamental GI performance levels. The goal of satisfying resident expectations who live adjacent to GI facilities through cosmetic maintenance, such as grass mowing, has heavily outweighed the performance consideration of these systems. The absence of controlling critical issues such as sediment accumulation has led to system failures which are easily avoidable. Historically, this has presented challenges with effective implementation of GI maintenance practices across jurisdictions. Other contributing factors to maintenance implementation challenges for GI include the lack of enforcement authority, difficulty to assign and track responsible parties, unawareness of responsibilities, absence of inspections, and insufficient funding.

Therefore, this manual is intended to provide a comprehensive guide to address maintenance challenges through the design of a strategic and systematic O&M framework that is easily adaptable and enforces consistency throughout all operations. Types of maintenance, indicators prompting the need for maintenance, detailed recommendations of life cycle maintenance practices, acknowledgement of resident engagement to maintenance, and monitoring practices for GI systems are discussed herein. All maintenance indicators, tasks, and frequencies presented in the following chapters are recommended as best practice.

Chapter 1 – Types of Maintenance

An appropriately structured maintenance framework ensures that best management practices are in place to allow optimal functional performance and durability of GI systems. Integrating a suitably planned and developed maintenance framework within the municipal asset management plan will help achieve successful and cost-effective operations while mitigating or overcoming common challenges of GI systems. In general, the maintenance framework revolves around the following three types of maintenance which are defined in the following sections:

1. Preventive maintenance
2. Corrective maintenance
3. Predictive maintenance

In addition to the types of maintenance, there are five types of inspections that can be performed for GI systems, as follows:

1. Construction inspections
2. Warranty inspection
3. Routine operation inspections
4. Verification inspections
5. Forensic inspections and testing

Table 1 illustrates the types of inspections that are associated with each type of maintenance as denoted by the symbol “x”. These associations along with a description of each type of inspection are explained in the following sections.

Table 1: Types of inspections for each type of maintenance

	Construction Inspections	Warranty Inspection	Routine Operation Inspections	Verification Inspections	Forensic Inspections and Testing
Preventive Maintenance			x	x	
Corrective Maintenance	x	x	x	x	x
Predictive Maintenance				x	

To note, verification inspections are also primarily associated with the performance monitoring of GI systems, discussed further in Part 2 of this manual.

Preventive Maintenance

Preventive maintenance is the most common type of maintenance performed on GI systems. It relates to regular or routine maintenance tasks conducted throughout the asset's operating life to reduce the likelihood of failure. Preventive maintenance can be scheduled on a time or usage basis. Within Chapter 3, *Green Infrastructure Specific Measures*, preventive or routine maintenance tasks are specified at recommended time-based frequencies for each respective GI system to best preserve the operational function of the system and prevent failure conditions.

Depending on the operation environment, GIs located in highly sensitive, high priority, or high traffic areas may experience greater impact or usage which warrants an increase in preventive maintenance. The recommended frequency of each GI system may also be informed by routine operation inspections and other monitoring practices. Conducting routine operations inspections as defined below may help identify vulnerabilities and environmental condition changes experienced by certain GIs and provide feedback to optimize the frequencies of preventive maintenance tasks.

Routine Operation Inspections

Routine operation inspections are conducted to identify or address when maintenance tasks are needed and to determine when structural repair or further investigations are required to sustain the function of the GI. They should be performed each time a preventive or routine maintenance of the GI is conducted such as trimming vegetation, weeding, and trash, debris, sediment removal and typically involves the property owner and applicable contractors. Routine operation inspections should be completed and appropriately documented following a set of visual indicators and applicable testing specific for each GI type. In general, routine operation inspections are performed to confirm the following:

- Identify any routine maintenance that is required immediately or in the future to retain the GI function or to prevent further costly repairs;
- Determine if the recommended frequencies for routine maintenance are adequate or require adjustments; and
- Determine when structural repairs or further investigations are required due to possible issues in the GI.

Apart from preventive maintenance, other key timeframes where routine operation inspections should be performed include spring or early summer, after snow melt and prior to heavy storm event season. More frequent inspections are warranted for GIs located in highly sensitive, high priority, or high traffic and visibility areas.

Corrective Maintenance

Corrective maintenance involves maintenance tasks performed to rectify, repair, or rehabilitate systems with deficiencies and return it to design operational performance. Corrective maintenance may be initiated if an issue is detected through monitoring, when issues are identified by routine inspections, or when certain components or the entire system fails.

Any type of inspection can be categorized as corrective maintenance if issues identified during the inspection warrants immediate corrective actions. However, the following inspections are more heavily involved at the onset of corrective maintenance:

- construction inspections
- warranty inspection
- forensic inspections and testing

Construction Inspections

The objective of construction inspections is to ensure that the GI is constructed in accordance with the Contract Documents. Conducting these inspections may involve contractors, design consultants and applicable project managers. The following components should be prioritized during inspections to ensure construction practices remain acceptable:

- GI layout including location and dimensions are acceptable;

- GIs are installed conforming to final designs, at the appropriate time, and following the correct sequence, procedures, and equipment usages;

- Construction materials meet design specifications;

- Contributing drainage areas are stabilized and applicable Erosion and Sediment Control (ESC) or flow diversion features are in place and functional;

- Pre-treatment features are installed if required and are adequately maintained;

- Sensitive areas, natural heritage systems and proposed GI infiltration areas are fenced to prevent heavy vehicle traffic; and

- The location of existing underground utilities, services, and third-party infrastructure should be taken into account to ensure the construction of the GI system conforms to all required clearances and regulations. If applicable, the locations of any proposed adjacent utilities should be considered to limit disturbances or encroachment during construction activities. This will ensure the GI system will remain effective long-term following construction and avoids future relocation, alterations, or conflicts.

The timing of construction inspections is strategically sequenced during each phase of construction to ensure that all appropriate practices mentioned are adequately maintained. The phases of construction are specific to each type of GI; however, weekly inspections are recommended as the minimum frequency for all phases regardless of GI type. This frequency acts as a quality assurance against potential construction errors and to ensure a seamless transition into the system's operational phase. Construction inspections should be carried out during the following key construction phases:

1 During site preparation prior to GI excavation and grading. This is to confirm the stability of the contributing drainage area, adequacy of installed ESCs or flow diversion features, and adherence of construction materials to design specifications.

2 At excavation and grading completion, prior to pipe or sewer installation and backfillingm – if applicable to the specific GI system. This certifies all depths, slopes and elevations are acceptable

3 At completion of pipe or sewer installation – if applicable to the specific GI system – and prior to backfilling to ensure slopes and elevations are acceptable.

4 After final grading, prior to planting – if applicable to the specific GI system. This certifies that all depths, slopes and elevations are acceptable.

5 Prior to construction warranty periods. This includes hand-off points during construction where contractor responsibilities of work changes such as between servicing, paving and landscaping.

6 Following every large or significant storm event to ensure all erosion and sediment control (ESC) measures and pre-treatment features function as intended.

7 Prior to restart of construction after a seasonal or other pause which may occur at any time of the construction sequence.

All personnel performing construction inspections should be familiar with the required health and safety protocols discussed in Chapter 12, *Health and Safety*. The personnel present during specific inspections at key milestones should be appropriately selected. The *Toronto and Region Conservation Authority Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide*, *2016* (TRCA LID SWM IM) can be used as a reference for construction inspection tasks for specific GI. The link to this document can be found at: https://sustainabletechnologies.ca/app/uploads/2016/08/LID-IM-Guide-2016-1.pdf.

Warranty Inspections

Warranty inspections are performed prior to the completion of the construction contract and warranty period. They are performed as a condition of hand-off of GI ownership and maintenance responsibilities to the property owner. This type of inspection provides the final opportunity for the property owner to confirm that the GI has been constructed as per design specifications, meets all material requirements, and functions as intended. Therefore, warranty inspections should include highly comprehensive indicators and testing which may include continuous drainage monitoring, treatment performance monitoring, and simulated storm events. The monitoring aspects of warranty inspections are further explained in Part 2, Monitoring of Green Infrastructure of this manual.

In general, warranty inspections should confirm that:

- The constructed GI and its materials conform to design specifications;
- Plantings conform to planting design specifications and are fully established with acceptable cover, composition and condition;
- Trash, debris, or sediment accumulated in the contributing drainage area resulting from construction has been removed; and
- The overall GI system is ready for inspection and maintenance responsibilities to be handed-off to the property owner.

At a minimum, it is recommended that warranty inspections be performed:

- Immediately following the completion of site construction but prior to substantial completion of construction; and
- Prior to the completion of the construction contract or warranty period.

Typically, it should be a required condition of the Contract that warranty inspections be completed for GIs to the satisfaction of the property owner prior to the completion of the construction contract and the release of the contractor's Performance Bond. Conducting these inspections may involve parties including construction contractors, design consultants and applicable project managers.

Forensic Inspections and Testing

Forensic inspections and testing are undertaken when issues with the GI system are identified or suspected from other types of inspections. The inspection involves the same visual and testing indicators used in other inspections, but is intended to diagnose issues, determine causes and identify appropriate corrective actions. Conducting these inspections may involve parties including the property owner and applicable consultants. There are no prescriptive intervals for forensic inspections and testing is performed on an ad-hoc basis or as a follow-up requirement from other inspections. Examples of when this inspection type is warranted include the following:

- Inspections identify potential problems with standing water and vegetation cover/condition;
- Soil characterization testing indicates soil texture, organic matter, cation exchange capacity (CEC), pH level, or soluble salts are not within the acceptable range;
- Natural or simulated or both storm event testing reveals problems with drainage function or grading of the GI;
- Continuous monitoring tests indicate problems with the GI function or water treatment performance; and

- Surface infiltration tests show that infiltration or drainage rates are unacceptable and require corrective action.

Predictive Maintenance

Predictive maintenance consists of practices that monitor and maintain the performance and condition of the GI system during normal operations to reduce the likelihood of failures. Incorporating the different types of inspections explained previously can help forecast when the system may fail and determine the timing of performing predictive maintenance to prevent the system from reaching failure conditions. Monitoring GI systems through a series of testing indicators is the primary approach to establishing appropriate predictive maintenance practices.

Verification Inspections

Verification inspections are used to ensure that inspection and maintenance plans are being upheld by the property owner and determine if the functional performance of the GI remains acceptable as per design specifications. Conducting these inspections may involve parties including the municipality or property owner and applicable consultants. In general, verification inspections can be categorized as maintenance or performance verification inspections. Maintenance verification inspections involves monitoring the implementation of the operations and maintenance framework by responsible parties such as property owner to ensure that:

- The GI exists and has been adequately maintained in accordance to the maintenance framework; and
- Any required structural repairs or further investigation with the GI are identified.

It is recommended that maintenance verification inspections be conducted every 5-years following the end of the construction warranty period of the facility or prior to any property owner changes. More frequent maintenance verification inspections after the warranty period may be required for GI systems located in highly sensitive or populated areas, consisting of key components requiring greater up keeping such as sediment pads, suspended inlet filter, and so on, or applied within a new context. Specific visual indicators and simple testing indicators discussed in the following sections should be followed for this inspection. Documentation from routine operation inspections should be reviewed and if a lower level of service or incompliances are observed, recommended follow-up tasks should be completed by the property owner within a given timeframe. Enforcement actions may be warranted if incompliances by responsible parties persist.

Similarly, performance verification inspections utilize the same visual and testing indicators but involve more performance-based testing parameters specific for each GI. More frequent performance verification inspections may be warranted for GI systems located in highly sensitive or populated areas, but at a minimum, they should occur at 15-year intervals following the end of warranty period. Continuous monitoring of the drainage performance and simulated storm events may be required. This type of verification inspection falls in-line with the monitoring of GI discussed in Part 2 of this manual. In general, performance verification inspections confirm that:

- The GI exists and has been adequately maintained;
- The functional performance of the GI remains acceptable; and
- Any required structural repairs, rehabilitation, replacement, or further investigations due to suspected issues with the GI are identified.

Greater frequencies of performance verification inspections should also be considered if the GI consists of new technology, is applied within a new context, or if receiving waters of the GI are either highly sensitive or contain species at risk. documentation from routine operation inspections should be reviewed and if a lower level of service or incompliances are observed, recommended follow-up tasks should be completed by the property owner within a given timeframe. Enforcement actions may be warranted if incompliances by responsible parties persist.

Chapter 2 – Maintenance Indicators

To construct an effective maintenance framework, two types of maintenance indicators are used to provide a platform for the assessment of the condition and functional performance of a GI system. In total, 26 visual indicators and five testing indicators are used for all inspection types to determine the appropriate frequency of maintenance, possible repairs or rehabilitation needed, if further investigations are required, and the adequacy of the system at critical life cycle stages such as prior to the warranty/hand-off period and servicing. The application of the maintenance indicators varies between each type of GI system and the inspection being performed.

Inspection field report forms adapted from the 2016 TRCA LID SWM IM Guide are found in Appendix A, *Field Inspection Forms*. The templates are specific for each GI and are used to record maintenance observations, measurements, actions required, and other inspection details by adhering to the maintenance indicators discussed in the following section.

Visual Indicators

During routine operation inspections, which represents the majority of inspection work completed over the life cycle of a GI system, simple visual indicators are followed in sequence during the inspection which limits the need for highly trained or certified individuals to be present. This allows for an approach which is less costly, while still quick and effective. The framework also provides maintenance triggers or prompts and pass/fail criteria for each indicator in the following section for better clarity on the documentation process. The observations of conditions are to be recorded on inspection field data forms specific for each GI system, found in Appendix A, *Field Inspection Forms*. Maintenance observations, measurements, actions required, and other inspection details are to be recorded on these forms. Table 2 summarizes the inspection types required for each respective visual indicator and the “x” denotes where an indicator applies to an inspection type.

Table 2: Visual indicators (Adapted from TRCA LID SWM IM Guide, 2016)

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Ver-ification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity		x	x	x
3	Inlet Obstruction	x	x	x	x
4	Pre-treatment Sediment Accumulation	x	x	x	
5	Inlet Erosion		x	x	
6	GI Dimensions	x	x		x
7	Side Slope Erosion		x	x	
8	Surface Ponding Area	x	x		x
9	Standing Water		x	x	x
10	Trash		x	x	
11	Filter Bed Erosion		x	x	
12	Filter Bed Sediment Accumulation		x	x	x
13	Filter Bed Surface Sinking		x	x	
14	Mulch Depth	x	x	x	x
15	Surface Ponding Depth	x	x		x
16	Check Dams	x	x	x	x
17	Vegetation Cover	x	x	x	x
18	Vegetation Condition		x	x	
19	Vegetation Composition	x	x	x	
20	Monitoring Well Condition	x	x	x	x
21	Underdrain/Perforated Pipe Obstruction		x		x
22	Overflow Outlet Obstruction	x	x	x	x
23	Pavement Surface Condition		x	x	
24	Pavement Surface Sediment Accumulation	x	x	x	x
25	Control Structure Condition	x	x	x	x
26	Control Structure Sediment Accumulation	x	x	x	x

The following section describes the 26 visual indicators, provides a pass/fail descriptor, possible maintenance triggers, and follow-up actions to be undertaken. All information is general and will vary depending on the type of GI system which is discussed in Chapter 3, *Maintenance Practices for Green Infrastructure Systems*.

1 – Contributing Drainage Area Condition

Description

The contributing drainage area is the total designated area that drains to the GI system, which includes pervious, impervious surfaces and the GI area itself. Inspections should specifically compare current conditions with the final design or as-built drawings to identify any size or land cover changes. Inspections of the grading and relative elevation should be conducted with greater focus on inlets, high points, and low points and planting areas to ensure the entire system conveys and drains stormwater runoff as designed.

Pass and Fail Conditions

Pass: no changes in size or land cover of the contributing drainage areas are observed. There is also no accumulation of sediment, trash or debris, nor visible point sources of contaminants. The grading allows the entire system to convey and drain stormwater runoff as designed.

Fail: the size or land cover within the contributing area has changed from the design intent. There is sediment accumulation, point source of contamination present, and/or potential surface ponding. The grading and relative elevation has changed from the design and the system does not convey or drain stormwater as intended.

Maintenance Triggers

Visible point sources or excessive trash, debris, sediment or other pollutants are impairing the function of the GI. The size of the contributing drainage area differs from design or as-built drawings by 10 per cent or more, or land cover has changed. Elevation or grading changes may result from construction inaccuracies, baseline sedimentation or sedimentation from adjacent construction, or possible alterations to the filter bed by residents.

Follow-up tasks

Depending on the GI, tasks may include the removal of trash and debris, sweeping of paved areas to remove sediment accumulation, revegetating or mulching bare soil areas, regrading areas with incorrect elevations, addressing point sources of contamination, improving or installing erosion and sediment control practices or flow diversions to address sediment load from destabilized areas, and considering the increase of routine maintenance frequency.

2 – Inlet Structural Integrity

Description

Inlet structures vary between GI systems, but may include curb cuts or similar engineered structures, drains or pipes, and pavement edges. In general, signs of damage, structure displacement, missing or broken grates and excessive filter bed erosion near inlets should be identified while pavement and/or curb elevations should be confirmed to be acceptable during inspections.

Pass and Fail Conditions

Pass: no evidence of damage or displacement of the inlet structure is observed that may be preventing runoff from freely entering the GI. There should be no erosion next to the inlet.

Fail: inlet structure is damaged or displaced and would require repairs. Excessive erosion of the filter bed that impacts the inlet function or the integrity of the surrounding pavement may also be a failure indicator.

Maintenance Triggers

Any visual damage or displacement of the inlet structure and excessive erosion to the filter bed adjacent to the inlet which impairs the free flow of stormwater into the GI. Any missing or broken grates also presents safety and debris accumulation risks.

Follow-up tasks

Replace grates, repair damaged or displaced structures and erosion-affected areas, and if erosion persists, consider adding pre-treatment, flow spreader, or erosion control features to reduce concentrated flows.

3 – Inlet Obstruction

Description

Inlet structures vary between GI systems but may include curb cuts or similar engineered structures, drains or pipes, and pavement edges. During inspections, check to ensure the inlet and surrounding areas – pre-treatment feature, filter bed – are not obstructed due to damage or displacement of any structure, and accumulated trash, debris, sediment or vegetation. Sediment depth should also be measured and compared to acceptable ranges.

Pass and Fail Conditions

Pass: no obstructions at the inlet and stormwater runoff can freely enter the GI.

Fail: accumulated sediment, debris, and vegetation is preventing stormwater from entering the GI. Signs of ponding may be occurring near the pavement/inlet interface.

Maintenance Triggers

Accumulation of trash, debris, and sediment greater than 5cm. Trash, debris, sediment, or vegetation is obstructing more than one third of the inlet width or area.

Follow-up tasks

Removal and/or repair of any obstructions should be completed using hand-tools, and only if necessary, hydro-vac equipment may be used. Regrading at the inlet may also be required.

4 – Pre-treatment Sediment Accumulation

Description

Pre-treatment comprises of features such as sediment pads and filter strips or methods to attenuate, spread concentrated stormwater runoff flows and allow for sedimentation and filtration prior to entering the GI system. Inspections should be conducted to confirm that these features are functioning properly or requires cleaning. Sediment depth should also be measured and compared to acceptable ranges.

Pass and Fail Conditions

Pass: features are free of trash, debris, sediment, and vegetation. Rip-rap or stone features are not displaced and functions as designed.

Fail: accumulated trash, debris, sediment or vegetation impairs its function, restricts free inflow of stormwater, and impacts the performance of the GI.

Maintenance Triggers

Trash, debris, sediment, vegetation or other obstructions have accumulated to over 50 per cent of the pre-treatment feature and is preventing or impairing the water inflow to the GI.

Follow-up tasks

Remove trash, debris and sediment, replace any filters or geotextile, or consider increasing the maintenance frequencies of contributing drainage area sweeping or pre-treatment cleaning if sediment accumulation persists.

5 – Inlet Erosion

Description

Due to stormwater inflow, areas adjacent to the inlet may experience bare soil areas, excessive soil erosion such as rills or gullies, or mulch/stone/vegetation displacement.

Pass and Fail Conditions

Pass: no signs of soil erosion on the filter bed nor rip-rap or stone displacement is present.

Fail: soil erosion on the filter bed or rip-rap or stone displacement are visible.

Maintenance Triggers

Erosion rills, gullies, and bare soil areas are visible and in excess of 30 cm in length. Signs of surface ponding on the filter bed near the inlet such as poor vegetation growth and sediment accumulation are evident. Mulch has been displaced and is below the required layer depth.

Follow-up tasks

Repair any areas impacted by erosion, reseed bare soil areas, restore vegetation or mulch cover or potentially replacing these elements with stone, and consider installing a flow spreading device or turf reinforcement if erosion persists.

6 – GI Dimension

Description

The GI dimension should be confirmed to meet design specifications. Additional maintenance or stormwater management criteria may not be met if the GI dimension is undersized. Subsurface components can only be inspected during the construction phase prior to backfilling. Dimensions should be measured and soil depths should be determined using appropriate tools.

Pass and Fail Conditions

Pass: the footprint of the GI remains relatively unchanged from design specifications or final design and performs to stormwater management standards and vegetation spacing requirements.

Fail: field observations of the GI dimension(s) are significantly smaller than the final design dimensions specified, such that it affects the function or design intent of the GI in whole or in part.

Maintenance Triggers

GI dimensions differ from the final design or as-built by more than 10 per cent.

Follow-up tasks

Restoring the GI dimensions to the adequate design dimensions may be warranted if space is available, maintenance easements exist, or performance bonds are still active. If incorrect dimensions are observed during inspection, a stop work order can be issued to the construction contractor and corrective actions should be approved.

7 – Side Slope Erosion

Description

The condition of the slopes along the perimeter of the GI should be assessed for erosion rills or gullies, bare soil areas, ruts, poor vegetation growth, or damage from foot and vehicle traffic. Slopes that are too steep or have been eroded by concentrated flows from the inlet or unintended locations may also alter side slope(s).

Pass and Fail Conditions

Pass: no visible erosion rills or gullies, ruts, bare soil, or damage from foot and vehicle traffic observed on side slopes.

Fail: clear signs of erosion, damage, and bare soil areas are observed.

Maintenance Triggers

Erosion rills, gullies, and bare soil areas are visible and in excess of 30 cm in length. Bare soil areas and areas damaged by foot or vehicle traffic on side slopes present vegetation establishment difficulties.

Follow-up tasks

Repair eroded areas, replant bare soil areas, and restore the required mulch, soil and stone cover. Installation of flow diversions may be required if water is entering the GI at unintended locations. Regrading to reduce slope, installing barriers to prevent foot or vehicle traffic, and soil amendment may be required if problems persist.

8 – Surface Ponding Area

Description

The surface ponding area visual indicator is only applicable to GI systems specifically designed to allow surface ponding. Inspections should be conducted to compare current surface ponding area within the GI with the allowable maximum surface ponding area. The maximum ponding area can be measured and estimated by using the elevation of the overflow outlet to delineate the ponding perimeter.

Pass and Fail Conditions

Pass: in GI systems designed to allow surface ponding, the elevation of the maximum surface ponding area and the overflow outlet match the specified design criteria.

Fail: in GI systems designed to allow surface ponding, the overflow outlet may be either installed too low producing smaller ponding areas and reducing the capacity of the GI, or installed too high which results in standing water for prolonged periods and poor vegetation growth. The overflow outlet or filter bed media may also be obstructed.

Maintenance Triggers

The maximum surface ponding area differs from the specified design criteria by more than 25 per cent. The overflow outlet does not match the design dimensions or is obstructed. It is observed that water may have been overflowing from the GI at unintended locations based on mulch displacement and soil erosion.

Follow-up tasks

Regrading or alterations of the overflow outlet to match the specified design criteria. Removal of any obstructions at the overflow outlet may be required. The GI perimeter could be regraded to achieve the intended maximum surface ponding area.

9 – Standing Water

Description

Immediately following a storm event – typically within 24 hours, assess standing water in the GI and ensure that it is drained within the acceptable time period. Standing or ponded water remaining in a GI system longer than the acceptable drain down time or in GI systems not designed for surface ponding can indicate problems with the surface infiltration rate, the underdrain, overflow outlet, or an excessive maximum surface ponding depth.

Pass and Fail Conditions

Pass: no standing water on the surface of the GI visible in GI systems designed to not allow surface ponding. Otherwise, if the GI system is designed to allow surface ponding, standing water is observed to drain within the acceptable drain down time.

Fail: there is standing water in GI systems not designed for surface ponding, standing water remains after the acceptable drain down, or the presence of highly saturated soils on the surface of the GI. Algae presence, dead vegetation, bare soil areas, mosquito breeding, and sediment accumulation on pavement surfaces are indicators that the system is not draining completely between storm events and that ponding occurs regularly.

Maintenance Triggers

Standing water is observed on the GI surface and does not drain within the acceptable time period following a storm event. There is highly saturated soil and bare soil areas present.

Follow-up tasks

Confirm that maximum surface ponding depth is acceptable. Forensic inspections and testing – involving checking for sediment accumulation, infiltration rate, soil compaction, and organic matter content – may be conducted to determine the cause of slow drainage. If applicable, flush the underdrain to remove obstructions.

10 – Trash

Description

Ensure that there is no presence of trash in the GI which impacts the aesthetic value and may obstruct inlet and outlet structures.

Pass and Fail Conditions

Pass: no trash is present in the GI.

Fail: the GI contains trash that may obstruct inlet and outlet structures.

Maintenance Triggers

Observed trash within the GI system which impairs the aesthetic value or may obstruct the inlet or outlet structure.

Follow-up tasks

Trash should be removed while other recyclables should be sorted and disposed of appropriately. The contributing drainage area should also be assessed to determine any point sources for trash and if the problem persists, trash cans should be installed nearby to encourage appropriate disposal.

11 – Filter Bed Erosion

Description

Excessive filter bed erosion may be caused by concentrated flows, wind scour, and foot or vehicle traffic damage.

Pass and Fail Conditions

Pass: no signs of erosion, bare soil area, and the filter bed contains an adequate mulch depth.

Fail: erosion- on the filter bed surface such as gullies and bare soil areas due to regular concentrated flows or ponding or both .

Maintenance Triggers

Erosion rills, gullies, and bare soil areas are visible and in excess of 30 cm in length. Bare soil areas and areas damaged by foot or vehicle traffic within the filter bed present difficulties with establishing vegetation.

Follow-up tasks

Repair eroded areas of the filter bed, replant bare soil areas, irrigate as required until an adequate level of vegetation cover has been established, or restore the mulch, soil or stone cover. Regrade the contributing drainage area or the addition of flow diversions may be needed if water is entering the GI at unintentional areas. The addition of inlets, stone cover, amended soils and regrading of slopes may be undertaken if filter bed erosion persists.

12 – Filter Bed Sediment Accumulation

Description

The depth of accumulated sediment in the filter bed should be inspected to ensure it does not impede the surface infiltration rate, vegetation cover, or aesthetic of the GI. Measuring the depth of the sediment should be conducted at five locations on the filter bed and compared to previous inspections or the acceptable design range.

Pass and Fail Conditions

Pass: no signs of excessive sediment accumulation on the GI surface.

Fail: excessive sediment accumulation is visible which surpasses the allowable design depth.

Maintenance Triggers

The average sediment depth recorded by inspection is greater than the allowable design sediment accumulation depth of the system.

Follow-up tasks

The accumulated sediment should be removed by means of rake and shovel first while excavators and hydro-vac trucks should be used in extreme cases if required. Heavy equipment should remain off the GI filter bed to avoid compaction. If contaminants within the sediment such as oil and grease are suspected or identified, proper disposal methods should be determined through testing. Other tasks include restoring the filter bed surface grading, replanting and replacing the mulch cover, assessing the contributing drainage area to identify point sources of sediment, inspecting or installing additional pre-treatment features if applicable, or increasing the maintenance frequency if the problem persists.

13 – Filter Bed Surface Sinking

Description

Identify local depressions or holes on the surface of the filter bed. This may be caused by animal burrows, uneven settling, underdrain damage, or damage by foot or vehicle traffic which ultimately impedes the function of the GI.

Pass and Fail Conditions

Pass: filter bed or soil amendments remains level and appropriately graded with no signs of localized depressions.

Fail: there are local depressions on the filter bed surface leading to preferential ponding and potential waterlogged vegetation.

Maintenance Triggers

Local surface depression depths are greater than 10 cm or animal burrows are visible on the surface of the filter bed.

Follow-up tasks

Repair the local depressions and fill animal burrows with filter media that meet design requirements. If applicable, the underdrain should be inspected to ensure it remains undamaged. If depressions are caused by foot and vehicle traffic, consider installing a physical barrier around the GI.

14 – Mulch Depth

Description

Verify that the mulch depth meets design criteria to ensure that its function to protect the soil, prevent weeds, and not disrupt water flow is maintained.

Pass and Fail Conditions

Pass: mulch depth falls within the acceptable range (50 mm – 10 mm depth) and covers all non-vegetated areas if applicable.

Fail: mulch depth is either greater than the acceptable range which may impede the function of the inlets, or may be below the acceptable range which leads to bare soil areas. Mulch that has been mounded at the base of a tree such that it resembles a "volcano form" is also a fail.

Maintenance Triggers

Mulch depth is inspected to be out of the acceptable design range, there are bare soil areas, mulch has been mounded at the base of a tree such that it resembles a "volcano form" or the depth of mulch is impairing the inflow of water to the GI.

Follow-up tasks

Add or redistribute mulch to maintain the acceptable design depth range and placement and to not impair the function of the GI components.

15 – Surface Ponding Depth

Description

Within GI systems designed to allow surface ponding, the maximum surface ponding depth should be measured to ensure it is acceptable or to determine if it differs from specific design standards. The maximum surface ponding depth can be estimated through measurement differences between the lowest filter bed elevation and the overflow outlet elevation.

Pass and Fail Conditions

Pass: an acceptable maximum surface ponding depth exists.

Fail: the measured maximum surface ponding depth is either lower or higher than the design standard, therefore reducing the performance efficiency of the GI system.

Maintenance Triggers

Maximum surface ponding depth differs from the specified design standards by more than 10 per cent.

Follow-up tasks

The filter media depth should be measured to ensure it meets the design requirements of the GI. Add, remove or redistribute the filter media to achieve the acceptable maximum surface ponding depth, or adjust the elevation of the overflow outlet.

16 – Check Dams

Description

Check dams should remain visible and not be covered with sediment in order to fulfill its function of retaining sediment and distributing the stormwater flow across the entire GI surface.

Pass and Fail Conditions

Pass: check dam structures remain visible and are functioning effectively.

Fail: excessive upstream sediment accumulation has impaired the function of the check dam. The check dam is physically damaged or removed.

Maintenance Triggers

The check dam structures are buried with sediment or are missing.

Follow-up tasks

All accumulated sediment should be removed with a rake or shovel. If contaminants within the sediment such as oil and grease are suspected or identified, proper disposal methods should be determined through testing. Other tasks include assessing the contributing drainage area to identify point sources of sediment, inspecting or installing additional pre-treatment features if applicable, or increasing the maintenance frequency if the problem persists.

17 – Vegetation Cover

Description

Vegetation cover can only be inspected during the growing season. Living vegetation cover across the designated planting areas can be estimated and compared to required levels. Insufficient vegetation cover can impede water and pollutant retention functions, degrade the aesthetic value of the GI, and contribute to filter bed erosion.

Pass and Fail Conditions

Pass: vegetation cover is dense and attractive in areas of the GI designated as a planting area to properly maintain the function of the system.

Fail: major portions of the designated planting areas contain bare soil or dead vegetation unsuited to provide the required aesthetic value and adequate stormwater treatment function.

Maintenance Triggers

The designated planting area in the GI contains less than 80 per cent living vegetation cover, that is to say a reduction of 20 per cent vegetation cover is observed.

Follow-up tasks

Core aerate bare soil regions, replant or reseed with plants as per specified planting details and water as required until the vegetation becomes properly established. If bare spots persist, consider increasing watering frequencies, especially during droughts, selecting more environmentally tolerable plant species, amending the topsoil or filter media with compost, or performing additional forensic testing to determine further plant mortality causes. Reference can be made to construction specification TS 5.10 for the growing medium requirements. For trees growing within the GI, contact 311 to initiate an Urban Forestry work order for inspection.

18 – Vegetation Condition

Description

Vegetation condition can only be inspected during the growing season. Inspections should note the condition of the vegetation growing within the designated planting area, the health state and aesthetic value. Not thriving, over-crowded, or over-grown vegetation should be identified.

Pass and Fail Conditions

Pass: vegetation is healthy and well-maintained.

Fail: grasses and other vegetation may be patchy, dying, not thriving, requires mowing, or is healthy but over-grown or over-crowded.

Maintenance Triggers

Vegetation that is not flourishing nor thriving and impairing aesthetic value and the function of the GI, or plants that are over-grown or over-crowded and obstructing sightlines.

Follow-up tasks

For vegetation that is not thriving or having difficulty establishing after two growing seasons, consider increasing watering frequency, especially during droughts, selecting more environmentally tolerant plant species, amending the topsoil or filter media with compost, or performing additional forensic testing to determine further causes. Over-grown vegetation should be trimmed to maintain sightlines, refer to Toronto Municipal Code Chapter 743, Streets and Sidewalks, Use of for rules around sightlines and the safety of right-of-way users while over-crowded vegetation should be thinned to improve aesthetics. For trees growing within the GI, contact 311 to initiate an Urban Forestry work order for inspection.

19 – Vegetation Composition

Description

Vegetation composition can only be inspected during the growing season. Assess the types of vegetation present against the vegetation specified in the planting design standards to identify species that did not survive, are not thriving, the portion of vegetation cover that is invasive or unwanted, and volunteer tree seedlings in unsuitable locations, where soil depth is less than 60 cm.

Pass and Fail Conditions

Pass: the vegetation identified in the GI matches the vegetation specified in the planting design with no invasive species and no volunteer tree seedlings.

Fail: volunteer tree seedlings are present or the vegetation is dominated by grasses and invasive species rather than vegetation specified in the planting design.

Maintenance Triggers

Observation of vegetation cover that contains invasive, unwanted species, or not species that have been specified in the planting design standards which diminishes the aesthetic value of the GI. Volunteer tree seedlings in unsuitable locations are present.

Follow-up tasks

Remove all invasive, unwanted or inappropriate species and replant with vegetation species specified in the planting design. Consider increasing maintenance frequencies or replanting with more tolerant species from the City's standard plant palettes (T-850.026) if the problem persists. For invasive species control, any pesticide use must comply with the Provincial Pesticides Act and follow the City's guidelines for Pesticide Use.

20 – Monitoring Well Condition

Description

During inspections, ensure the monitoring well remains accessible and assess the structure for damage, missing or unsecure cap, and obstructions or sediment accumulation. Damaged structures may allow untreated runoff stormwater, debris and sediment to enter and clog the screen/perforations in the standpipe. The water level in the GI should be measured using appropriate tools and methods.

Pass and Fail Conditions

Pass: monitoring well remains accessible, the cap is secured in place, and the structure is undamaged.

Fail: the function of the monitoring well is impaired due to damage, clogging by debris and sediment, or left uncapped and allows unauthorized access.

Maintenance Triggers

The function of the monitoring well is impaired due to damage to the structure. The cap is either missing or not secured to the structure or there are visual obstructions and clogging within the standpipe.

Follow-up tasks

Repair all damage to the monitoring well and ensure the media surrounding the standpipe are properly compact to prevent short-circuiting of water flow into the GI. Replace and secure the cap firmly and remove any obstructions or clogging using appropriate methods such as flushing or vacuuming.

21 – Underdrain/Perforated Pipe Obstruction

Description

Obstructions within the standpipe are best assessed using a waterproof snake camera system. Inspect the underdrain for damage, clogging, vegetation roots, or other undesirable obstructions to ensure the GI functions properly.

Pass and Fail Conditions

Pass: the underdrain remains unobstructed by sediment, debris or roots, it is undamaged, and functions as designed.

Fail: the underdrain may be clogged or damaged which inhibits its conveyance capacity and functionality.

Maintenance Triggers

There is structural damage, clogging from sediment and debris, roots are visible, and the overall conveyance capacity of the underdrain is compromised by more than one third of its intended design.

Follow-up tasks

Flush the full length of the underdrain using a hose at the upstream cleanout to remove accumulated sediment and debris. Drain snaking can be used to remove roots and a vacuum can be used to remove larger obstructions. Excavation may be involved for structural repairs or replacement of damaged, collapsed, or broken underdrains.

22 – Overflow Outlet Obstruction

Description

The outlet structure should be inspected for damage and obstructions that may impair its function. Trash, debris, mulch or sediment on or near the structure should be identified. Assess that the structure is not full of standing water to ensure flooding will not occur during extreme storm events.

Pass and Fail Conditions

Pass: the outlet structure is free of obstruction and damage which allows for its intended function.

Fail: obstructions such as trash, debris, and vegetation have reduced the capacity of the outlet structure to safely convey stormwater out of the GI. There may also be visible damage.

Maintenance Triggers

There is structural damage to the outlet structure and grate, obstructions affecting the outflow, the structure is sitting in standing water, or is displaced from its original design location or elevation.

Follow-up tasks

Remove trash, debris, and other obstructions from the outlet structure and if draining problems persist, use other methods such as drain snaking and vacuuming.

23 – Pavement Surface Condition

Description

Assess any damage, displacement, or deformation of the pavement surface that may impeded the function of the GI or may be a hazard. Inspect for missing or displaced pavers, ruts, cracks, gaps, aggregate fill conditions in joints, and excessive weed growth.

Pass and Fail Conditions

Pass: no damage, displacement, or sinking is observed on the pavement surface, there is adequate fill in the joints and minimal weeds growing in-between pavers.

Fail: identified deformations and displacements of the pavement present potential hazard or function problems to the GI.

Maintenance Triggers

There are potholes or sinkholes, missing or displaced pavers, and non-functioning edge restraints. Ruts or local depressions on the pavement surface are greater than 13 mm and over 3 m in length. Cracks on the permeable pavement are vertically offset by more than 6 mm and aggregate fill between paver joints are 17 mm below paver surface. Weed growth is extensive and is compromising the aesthetic value of the GI.

Follow-up tasks

Weeds should be removed, joint fillers are to be topped up to appropriate levels, and pavement surfaces to be swept and cleaned. Repair damaged or displaced areas of the pavement, replace broken or sunken areas, and patch potholes and large cracks or gaps. Edge restraints may be added if problems persist.

24 – Pavement Surface Sediment Accumulation

Description

Inspect the pavement surface for sediment accumulation and areas with fine sediment or sand which completely fills the joints. Sediment accumulation impairs the infiltration function of the GI system and can lead to undesirable surface ponding.

Pass and Fail Conditions

Pass: the pavement remains relatively clean with little no sediment accumulation.

Fail: joints between pavers are completely filled with fine sediment and sand, and other areas are covered by accumulated sediment.

Maintenance Triggers

Paver joints are completely filled with fine sediment or sand and portions of the pavement surface are covered with accumulated sediment.

Follow-up tasks

Sweep the pavement surface to remove coarse debris and to loosen finer sediment within the pavement joints or pores prior to vacuuming. Aggregate fill between interlocking pavers may need to be replaced or topped off. A forensic inspection and applicable testing may be undertaken if undesirable surface ponding persists.

25 – Control Structure Condition

Description

Assessment of the accessibility, safe entry, damage indicators, and malfunctions are to be conducted for the structure, for example catch basin, that controls the flow of stormwater in and/or out of the GI. Obstructions, missing ladder rungs, cracks, damages, and leakages should be identified.

Pass and Fail Conditions

Pass: the control structure is easily accessible and has no visible leaks, structural damages, or obstructions.

Fail: the control structure is missing components that compromises its safety, is obstructed, damaged, or contains leaks.

Maintenance Triggers

The control structure is inaccessible or cannot be accessed in a safe manner, there is damage to the structure, leaking and obstructions are visible, and components are missing.

Follow-up tasks

Repairs should be scheduled for any accessibility issues and damaged, displaced, or leaking areas in the structure. Forensic testing may also be performed to determine other causes of damage.

26 – Control Structure Sediment Accumulation

Description

Assess any accumulated sediment or debris in the control structure such as in catch basin sumps which may be obstructing the flow of stormwater into or out of the GI system. The depth of accumulated sediment should be measured and compared with previous inspections and acceptable levels.

Pass and Fail Conditions

Pass: insignificant accumulation of sediment within the control structure which does not impeded the flow of stormwater.

Fail: the control structure is full of sediment or debris and is impairing the flow of stormwater.

Maintenance Triggers

The accumulated sediment depth is greater than 10 cm or is obstructing the stormwater flow in and/or out of the GI.

Follow-up tasks

Entry into the control structure should be conducted by trained personnel with certified equipment. Sediment may be removed with pressure sprayers, shovels, and vacuum equipment. Inlet and outlet pipes should be flushed with a hose. If contaminants within the sediment such as oil and grease are suspected or identified, proper disposal methods should be determined through testing. Other tasks include assessing the contributing drainage area to identify point sources of sediment, inspecting or installing additional pre-treatment features if applicable, or increasing the maintenance frequency if the problem persists.

Testing Indicators

In conjunction with the visual indicators, testing indicators are recommended to be used to provide greater detailed inspections which may involve the gathering of samples and use of field instruments depending on the test type. These indicators primarily reflect the monitoring of GI discussed in Part 2 of this manual, but can be used in the forensic investigations should an issue require further investigation.

Table 3 lists the five (5) testing indicators. “x” denotes where an indicator should be used in an inspection type, and “(x)” denotes that the indicator is used only for performance verification.

Table 3: Testing indicators (Adapted from TRCA LID SWM IM Guide, 2016)

	Testing Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Soil Characterization Testing	x	x		(x)
2	Sediment Accumulation Testing	x	x	x	x
3	Surface Infiltration Rate Testing		x		(x)
4	Natural or Simulated Storm Event Testing		x		(x)
5	Continuous Monitoring		x		(x)

A brief description of each testing indicator is provided below while additional details including detailed methodologies and required equipment can be referred to in Part 2 of this manual.

1 – Soil Characterization Testing

Soil is an important component of GI systems because it significantly affects stormwater treatment performance and vegetation growth. To maintain adequate function, the soil layer should be placed at the specified depth and consist of a balanced texture and composition, according to standard City specifications. Soil which is overly compact or very fine in texture may impede the drainage function of the system, while a soil layer which is too shallow may lack suitable water treatment and vegetation growth properties. The organic composition is also critical to uphold as a highly organic or fertilized soil may leach nutrients into adjacent drainage systems and receiving waterbodies rather than help reduce them. Therefore, performing soil characterization testing at key inspection points is recommended to ensure that the quality of soil within the GI can perform its intended functions.

Soil texture, chemical properties and organic matter should be tested during construction, as per City specification TS 5.10. Soil characterization testing is highly recommended to be conducted as part of the warranty inspection to ensure that the soil material used conforms to the design specifications prior to the hand-off to property owners. Soil testing is also recommended to be performed during verification inspections to confirm that the soil quality is adequately maintained and is still within acceptable ranges. If required, GI issues such as poor vegetation growth and unacceptable drainage or water treatment performance may be diagnosed through forensic inspections and testing which involves soil characterization testing to determine corrective actions. Results of testing should be appropriately documented using the inspection field forms for each GI, found in Appendix A, *Field Inspection Forms*. The 2016 TRCA LID SWM IM Guide can be referenced for further information regarding acceptance criteria for select GIs, soil sampling methods, and equipment.

2 – Sediment Accumulation Testing

As part of the stormwater treatment function for GI systems, trash, debris, sediment, pollutants, and other contaminants are captured and retained by the system. Larger debris in the system can be easily spotted and removed during routine maintenance; however, fine sediment particles are difficult to identify until the accumulation is noticeable. Over time, sediment tends to accumulate near inlets, pre-treatment features, in areas where runoff attenuates and distributes, and on the filter bed. Excessive accumulation will eventually lead to clogging of the GI system which impairs the drainage and water treatment functions. These issues may also extend to downstream drainage systems due to overflowing untreated stormwater from the GI. Therefore, as part of preventive maintenance, the depth of sediment is recommended to be measured in key components of the GI system and compared with acceptable ranges to determine if removal is required.

The sediment accumulation testing should be completed at each type of inspection. During construction inspections, it ensures that erosion and sediment control measures are adequately installed and maintained to mitigate construction sediments from draining into the GI; during warranty inspections to confirm that the GI meets all acceptability criteria prior to hand-off and service; during routine operation inspections to determine the rate of sedimentation and accumulation to optimize the frequency of preventive maintenance; and during verification inspections to ensure that adequate maintenance is being performed to preserve the functional operation of the GI or to identify potential issues.

The 2016 TRCA LID SWM IM Guide provides additional information regarding acceptance criteria for select GIs, sediment accumulation testing methods, equipment, and key components that require testing.

3 – Surface Infiltration Rate Testing

Certain GI systems such as bioswales, filter strips, and infiltration trenches function to attenuate stormwater runoff in order to encourage its percolation into the underlying layers and ultimately replenish natural groundwater sources. However, the surface infiltration rate of the GI should be maintained at an acceptable range for the runoff water to be adequately treated and infiltrated into the system. Low infiltration rates may lead to excessive surface ponding and the eventual overflow of untreated stormwater to downstream drainage systems. Other issues of excessive surface ponding include poor vegetation growth, mosquito breeding and ice formation. Low infiltration rates may be caused by soils used that do not meet design specifications or the accumulation of sediment on the surface.

Therefore, surface infiltration rate testing is recommended to be performed as part of the warranty inspection and verification inspection to confirm that the GI remains in an acceptable performance range. Forensic inspections and testing may also include this test if performance issues with the surface infiltration are identified and require diagnostics and/or corrective actions.

The 2016 TRCA LID SWM IM Guide provides additional information regarding acceptance criteria for select GIs, surface infiltration rate testing methods, equipment, and key components that require testing.

4 – Natural or Simulated Storm Event Testing

GI systems involving inlets, such as curb cuts or similar engineered structures, drains or pipes, and pavement edges or other conveyances to capture stormwater runoff from contributing drainage areas into the system include bioretention, bioswales and enhanced grass swales. It is important that these inlet structures are designed and constructed adequately to avoid issues of insufficient receipt of flows into the system and runoff bypassing the inlet. This confirmation becomes crucial for underground inlet structures which are not visible, and malfunctions are difficult to identify through routine inspections. Therefore, natural or simulated storm event testing should be performed during warranty and verification inspections to ensure GIs continually receive adequate stormwater inflows.

To confirm the conveyances of the GI systems, the flow path of water can be observed and measurements of water levels within the GI can be taken during a natural storm event. In the case where inspections or monitoring are unable to be scheduled during the course of a natural storm event, flows can be simulated using a water tank truck or fire hydrant. In addition to confirming the conveyances to the GI, conducting natural or simulated storm event testing ensures the GI has been sized appropriately and drains at an acceptable rate. Therefore, it is recommended that this test be performed in conjunction with continuous monitoring as described in the following section.

The 2016 TRCA LID SWM IM Guide provides additional information regarding acceptance criteria for select GIs, natural or simulated storm event testing methods, equipment, potential triggers, and corrective actions.

5 – Continuous Monitoring

The most comprehensive testing that can be undertaken for a GI is continuous monitoring. This testing can provide quantitative data regarding drainage and water treatment performance during natural storm events which can be compared directly to design specifications. Continuous monitoring of natural storms involves specialized monitoring equipment to be installed for 6-months to 2-years in the GI system, while monitoring only requires three to five days for simulated storms. Trained personnel will be required to monitor the equipment periodically and collect data. As a result, continuous monitoring is the most costly and time-consuming inspection indicator, but may be required in certain situations to determine system performances. At minimum, continuous monitoring should be performed at warranty and verification inspections of the GI systems.

The 2016 TRCA LID SWM IM Guide provides additional - information regarding which situations warrant continuous monitoring, drainage and water treatment performance evaluation, testing methods, equipment, and key considerations.

Chapter 3 – Maintenance Practices for Green Infrastructure Systems

The following chapter describes maintenance practices for each GI system. This includes a brief overview of each system along with its respective recommended inspection and testing framework, routine maintenance, life cycle operations and maintenance, failure conditions, mitigation strategies, troubleshooting and Frequently Asked Questions (FAQs).

Stormwater Tree Trenches

System Overview

A continuous soil trench (CST) is a structure designed and built to contain an adequate volume of continuous growing media to support tree growth to maturity under a paved boulevard.

A stormwater tree trench (STT) is a continuous soil trench that is designed to capture, infiltrate and filter stormwater runoff from a drainage area beyond the footprint of the trench.

Stormwater tree trenches may vary in size and configuration but are designed to provide maximum soil volume for tree growth in order to achieve a healthy, mature tree size. Within constrained urban conditions, stormwater tree trenches can accommodate both the soil resources necessary for growing street trees to maturity and the unimpeded sidewalks necessary for pedestrian movement, within the same footprint.

This section includes the lifecycle activities required to maintain the stormwater management function of constructed, stormwater tree trenches. These requirements do not apply to all continuous tree trenches, green spaces or naturalized areas in the Right-of-Way, but only to engineered G.I. systems specifically designed and constructed to support stormwater management.

Key components of the stormwater tree trench systems for inspection and maintenance are tabulated in Table 6.

Inspection and Testing Framework

During each type of inspection, visual and testing indicators associated with stormwater tree trench systems should be used to determine the basis for planning field work. Table 4 summarizes the inspection types required for each respective indicator.

Table 4: Inspection and testing indicators framework for stormwater tree trenches (Adapted from TRCA LID SWM IM Guide, 2016)

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity		x	x	x
3	Inlet Obstruction	x	x	x	x
4	Pre-treatment Sediment Accumulation	Not Applicable			
5	Inlet Erosion		x	x	
6	GI Dimensions	x	x		x
7	Side Slope Erosion	Not Applicable			
8	Surface Ponding Area	Not Applicable			
9	Standing Water	Not Applicable			
10	Trash		x	x	
11	Filter Bed Erosion	Not Applicable			
12	Filter Bed Sediment Accumulation	Not Applicable			
13	Filter Bed Surface Sinking	Not Applicable			
14	Mulch Depth	x	x	x	x
15	Surface Ponding Depth	Not Applicable			
16	Check Dams	Not Applicable			
17	Vegetation Cover	x	x	x	x
18	Vegetation Condition	x	x	x	
19	Vegetation Composition	x	x	x	

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
20	Height of root flare / trunk flare above the soil.	x	x	x	
21	Monitoring Well Condition	Not Applicable			
22	Underdrain/Perforated Pipe Obstruction		x	x	x
23	Overflow Outlet Obstruction				
24	Pavement Surface Condition	Not Applicable			
25	Pavement Surface Sediment Accumulation	Not Applicable			
26	Control Structure Condition	Not Applicable			
27	Control Structure Sediment Accumulation	Not Applicable			
	Testing Indicators	**Inspection Type**			
		Construction	**Warranty**	**Routine Operation**	**Verification**
1	Soil Characterization Testing	x	x		(x)
2	Sediment Accumulation Testing	Not Applicable			
3	Surface Infiltration Rate Testing	x			
4	Natural or Simulated Storm Event Testing	Not Applicable			
5	Continuous Monitoring	Not Applicable			

In addition to these indicators, specific indictors for stormwater tree trenches should be followed during inspections as listed in Table 5.

Table 5: Specific indicators for stormwater tree trenches

Visual Indicators	Inspection Type			
	Construction	Warranty	Routine Operation	Verification
Pavement/Tree Opening Condition	x	x	x	
Tree Planting Area - Surround (e.g. fence, low wall / curb)	x	x	x	
Tree Condition	x	x	x	x
Height of Trunk Flare Above Soil	x	x	x	x
Trench Drain Obstruction		x	x	
Testing Indicators	**Inspection Type**			
	Construction	**Assumption**	**Routine Operation**	**Verification**
Foliar Leaf Analysis				x
Soil Moisture Testing	x	x	x	x

Timing of Construction Inspections

It is important to note that during the construction of the stormwater tree trench system, greater consideration and frequency should be placed on construction inspections at certain phases prior to and during construction which includes the following:

1 Inspection and selection of trees at the plant nursery or garden centre, prior to delivery to site.

2 Inspection of trees and root balls on site, prior to planting.

3 Review of growing medium testing reports and samples prior to delivery to site.

4 Inspect growing media on site at time of delivery, prior to placement in trenches.

5 Site preparation prior to excavation.

6 Excavation, backfilling and soil installation—to be done in tandem—and grading completion.

7 Installation of drainage pipe and connection of drainage pipe to catchbasin or approved drainage system.

8 Installation of aeration/passive irrigation pipes and connection of passive irrigation pipes to trench drain and pup catchbasin.

9 Installation of cleanout pipe.

10 Installation of automated irrigation system.

11 Final placement of growing medium and finished grading prior to planting.

12 Prior to construction hand-off or warranty.

13 Following large storm event.

14 Prior to restart of construction after a seasonal or other pause.

City specifications TS 5.30, C*onstruction Specification for Planting*, TS 5.10, *Construction Specification for Growing Medium*, TS 850, *Construction Specification for Continuous Soil Trench with Trees* and TS 853, *Construction Specification for Soil Cells* include detailed requirements for construction inspections for stormwater tree trenches.

Inspection field report forms adapted from the 2016 TRCA LID SWM IM Guide are found in Appendix A, *Field Inspection Forms*. The templates are specific for each GI and are used to record maintenance observations, measurements, actions required, and other inspection details.

Routine Maintenance

Recommended routine maintenance tasks and respective frequencies for each component of the stormwater tree trench system are listed in Table 6.

Inspection and maintenance of all City trees located in the right-of-way will be conducted by Urban Forestry staff or City contractors. If a City tree appears to require maintenance, contact 311 to initiate an Urban Forestry work order for inspection.

Prior to assumption by the City, the maintenance of a newly planted tree is typically covered by the warranty of the Contract under which the tree was planted. During this time, maintenance tasks such as tree watering and fertilizing are required relatively frequently until the tree establishes, especially during drought conditions. Such activities are typically covered by the product warranty and performed by qualified contractors. Tree pruning is important throughout the life of the tree. It is important to mitigate any deformations or detrimental growth habits during the early years of tree growth because it is difficult and costly to attempt correction as a tree matures without substantial branch removal.

Personnel conducting vegetation – not including trees – maintenance in open planting beds should be experienced with the designated planting plan, plant species identification, and weed removal and control methodologies.

Depending on the location, higher routine maintenance should be undertaken with GI practices in highly visible areas. Maintenance tasks such as trash, debris, and sediment removal or weeding and trimming of vegetation may be performed with greater frequency for storm water tree trenches. The maintenance of planters and open planting beds within the right-of-way is governed by Toronto Municipal Code, Chapter 743, (MC 743) and Urban Forestry standard practice.

Table 6: Key stormwater tree trench components and routine maintenance tasks (Adapted from TRCA LID SWM IM Guide, 2016)

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Trees	Tree growth to maturity is the primary function of a stormwater tree trench. The goal of the soil trench is to maximize the available soil volume for each tree, to ensure a thriving, healthy urban forest and street tree canopy. The many benefits of street trees include improving the microclimate of streets, providing shade and reducing the urban heat-island effects, improving air quality, carbon sequestration, reducing stormwater runoff and improving the overall aesthetics and livability of City streets.	Inspection and maintenance of all City trees shall be conducted by Urban Forestry staff or its contractors.		
Planting Beds	Stormwater tree trenches can appear as large, open tree planting areas along the sidewalk. These open soil areas are called planting beds. If longer than 3 m they should be surrounded by a raised curb, low wall or barrier such as fencing to minimize mulch loss.	Remove undesirable vegetation (tree seedlings, invasive / weeds).	6 months or as required by MC 743	3 months or as required by MC 743
		Remove trash and organic debris.		
		Refresh any areas of bark mulch to maintain complete coverage.	As required *Refer to MC 743*	As Required *Refer to MC 743*
		Maintain mulch depth min. 50 mm, max. 100 mm (or as specified) and a minimum of 40 mm from base of tree.		

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
		Add mulch to correct grade discontinuities in tree beds flush with the sidewalk.		
Pavement and Covered Trenches	Stormwater tree trenches can be covered by cast in place concrete or pre-cast concrete. These pavement surfaces can be supported by structural footings or they can be supported by soil cells. Tree planting areas can vary in size and can be surrounded by curbs, low walls and fences. In all cases the aim of these trenches is to provide the maximum possible soil volume in areas where there is insufficient space in the boulevard to accommodate pedestrian circulation and the large, open tree planting areas necessary for tree maturity.	Maintenance of pavement grade continuity and state of good repair	As Required *Follow Transp. Services standard practice*.	As Required *Follow Transp. Services standard practice*.
		Maintenance of tree surrounds and grates. Ensure that grates are level with sidewalk, and not injuring the tree.	As required *Refer to MC 743 and*	As Required *Refer to MC 743*
		Maintenance of tree grates – remove inner ring to allow tree growth.	3-5 years *Refer to MC 743*	3-5 years *Refer to MC 743*
Inlets	Inlets include trench drains and planter curb openings and pavement edges. Inlets must remain clear of any obstructions (e.g. trash, debris) to ensure runoff is conveyed to the soil trench and to prevent ponding on adjacent paved surfaces.	Remove trash, organic debris organic sediment	6 months	6 months
		Maintenance of all surface water drains free of debris.		
		Remove any plants within trench drains and within 100mm of trench drain entrance or exit.		

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Irrigation system	Irrigation for stormwater tree trenches may consist of automatic irrigation, irrigation bags or manual irrigation and is usually required for the first 2-5 years after planting. Once trees are established, irrigation is less critical, although tree watering may be required during times of drought. Covered stormwater tree trenches are constructed with trench drains or aeration / watering inlets to allow for manual irrigation of the system throughout the life of the trees.	Maintenance / replacement of irrigation system components including, filtration, controllers, sensors, sprinkler heads, drip irrigation lines.	As required	As required
		Winterize all watering systems to prevent winter damage and make the system operational in the spring.	Seasonal (Spring & Fall)	Seasonal (Spring & Fall)
		Flush or leach excess sodium from the soil by fully saturating passive irrigation system with water.	Annual (Spring)	Annual (Spring)
Growing Medium	In the stormwater tree trench, 'soil' refers to growing media, which consists of a mix of topsoil, coarse sand and compost components that will support the growth of trees and other vegetation in a number of planting conditions. The stormwater tree trench system aims to maximize the volume of growing medium (soil) available to each tree, aiming for a minimum of $30m^3$ per tree.	Test soil to determine soil structure, organic matter and confirm if microbial levels counts are satisfactory for intended vegetation.	At installation, then as required to diagnose performanc e issues.	At installation, then as required to diagnose performanc e issues.
		Organic fertilizing / Soil amendments – as recommended by soil testing or foliar analysis	As required	As required

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Soil Cells	Soil cells are modular structural components that allow stormwater tree trenches to extend beneath paved surfaces while maximizing the volume of non-compact growing media available to each tree. Soil cells support the root growth for large, mature trees and can also contribute to stormwater management. A suspended pavement system primarily used under the sidewalk or boulevard to provide non-compact soil volume to support healthy tree growth, while supporting traffic loads. They are also used to provide on-site stormwater management.	Not expected to require maintenance within design life.	n/a	n/a
		For replacement components, contact the manufacturer. Refer to TS 853, *Construction Specification for Soil Cells*.	As required	As required
Underdrain	Underdrains are installed in all stormwater tree trenches to ensure adequate drainage and to convey water to adjacent drainage systems. The underdrain consists of a perforated pipe surrounded with gravel or coarse sand and optionally wrapped with geotextile.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year
Vegetation (shrubs, grasses, ground covers, etc.)	Vegetation, including shrubs, ornamental grasses, perennials and other groundcovers can be a component of stormwater tree trenches present in open planters. Vegetation in open planters contributes to reducing urban heat-island effects, improving air quality,	Watering for the first two growing seasons (May to September) after planting or until vegetation is established	Weekly, or as required to maintain optimal soil moisture	Weekly, or as required to maintain optimal soil moisture
		Watering for the remainder of the GI lifespan	As required	As required

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	carbon sequestration, reducing stormwater runoff and improving the overall aesthetics and livability of City streets. Vegetation in open planters should be hardy and low-maintenance to reduce requirements for ongoing horticultural maintenance.	Remove undesirable vegetation (voluntary tree seedlings, invasive / weeds)	6 months or as required by MC 743	3 months or as required by MC 743
		Replace dead/diseased plants to maintain a minimum of 80% vegetation cover	1 year	6 months
		Prune shrubs following best practices.	1 year	1 year
		Cut back spent plants		
		Divide or thin overcrowded plants		

Life Cycle Operations and Maintenance

Infrastructure decisions are evaluated over a typical period of 50 years which can be considered the standard lifespan of a stormwater tree trench system and all its components. Stormwater tree trench systems will require routine maintenance to ensure the continued health and growth of the trees growing in them. As listed in Table 6, maintenance practices for trees fall under two categories for the establishment period and for the trees at maturity. The required maintenance for remaining components falls into two categories which either meets minimum required frequencies or pertains to high priority frequency. Depending on the location of the stormwater tree trench, the overall cost of maintenance for its service life will vary as trees located in very urban areas, or adjacent to busy roadways may subjected to greater impacts and require more maintenance due to salt loading, compaction and other stressors than trees planted in residential or park settings.

Failure Conditions

The main indicator of failure in stormwater tree trenches is tree decline or mortality. This is often the result of compounding and interrelated factors rather than a single factor. Such factors may include:

- excessive soil settlement
- modification of initial soil characteristics by utility access and post-access restoration procedures
- soil cell damage and failure
- insufficient or excessive soil moisture; drought or saturation
- excess soil sodium
- soil compaction
- pest infestation
- disease infection
- pollution
- physical injury, including vandalism

Excessive settlement, and the appearance of trees ‘sinking’ especially during the establishment period, is an indicator that subgrade conditions were not properly prepared prior to planting or that the soil trench was not backfilled sufficiently in relation to finished grade. Excessive settling of the growing medium beneath and surrounding new tree planting will have impacts on drainage, tree health and public safety, in the case of open planting beds.

Modifications of the initial soil characteristics from utility access cuts and associated restoration procedures often result in damage to the soil trench structure as well as replacement of growing medium with an unsuitable material, such as unshrinkable fill, or compacted granular material. Such disruption to the continuity of the soil trench creates a barrier to root growth and interrupts the movement of water, air and nutrients through the soil volume. Multiple utility cuts within one trench will impact tree health and may cause system failure over time, usually 5–10 years after the initial cut.

Damage or failure of the soil cell system would typically be caused by deficient construction methods, mechanical damage during excavation, or from overloading. Soil cell failure would cause surface pavements to become non-load bearing, to shift and eventually collapse, compromising public safety.

Accumulation of excessive sodium within the growing medium is the direct result of sodium chloride-based winter de-icing agent application in proximity to soil trenches. De-icing salts become dissolved in spring melt water and infiltrate trenches just as trees emerge from winter dormancy and may cause system failure within 1–2 years.

Overwatering, prolonged high ground water conditions and clogging of the drainage layers or underdrain may also cause the system to fail as the growing medium becomes saturated, compromising gas exchange and nutrient uptake and causing roots to become submerged and decayed.

These system malfunctions may have early visual indicators including leaf wilting, leaf discolouration and early leaf drop, but are easily detectable with routine soil testing and performance of maintenance tasks as recommended. However, once trees are in visible decline, the failure is difficult to reverse.

Mitigation Strategies

In ideal conditions, mitigation strategies to avoid impacts from utility cuts and repairs include the full reinstatement of soil trenches to their original condition, including the installation of appropriate growing medium. However, in most instances, where full reinstatement is not possible, a backfill material such as structural soil may be used to allow root growth and air, water and nutrient exchange despite the disruption to the trench.

Mitigation strategies to avoid soil cell system failure are preventative rather than corrective. Strategies include review and supervision during construction per manufacturer's requirements, as well as protection of soil cells during installation, to prevent excessive loading before full load bearing capacity is achieved.

- Additional preventative measures include the identification of soil cell installations in City records and with One Call, to avoid accidental damage during utility cuts and where possible, identification of soil cell installations in the field with permanent markers.

- Once soil cell failure has occurred, there is limited opportunity for mitigation to correct the damage. Damaged soil cells must be removed and replaced according to the manufacturer's recommendations, to restore the structural integrity of the trench and surrounding structures.

- In the event that a soil trench is decommissioned, the soil cell system should be removed in its entirety to prevent potential future soil instability or subsidence if unconsolidated material is left beneath the surface.

The primary mitigation strategy with respect to overwatering or oversaturation of the soil within the stormwater tree trench is to maintain underdrains in working order and to perform routine soil moisture testing with all watering operations.

In order to prevent the accumulation of salt within the stormwater tree trench, the use of sodium-chloride for de-icing should be eliminated or reduced in favor of less damaging compounds such as potassium-chloride.

Active mitigation strategies for salt accumulation in soil trenches include flushing the system thoroughly, to saturation with fresh dechlorinated water to remove excess salt from the soil. This should be performed in the spring, in the short period after thaw and prior to leaf budding.

If indicators of excess water or salt damage within the system persist, major rehabilitation work may be required if other mitigation strategies or major repair tasks listed in the following troubleshooting section are unsuccessful. In general, there are three types of rehabilitation activities for excess salt in stormwater tree trench systems:

- Underdrain – if flushing indicated irreparable blockage, hydro-vac truck or drain-snaking service may be required.

- Tree surround – change design of the tree opening to prevent overland flow of pollutants into the tree opening, for example add curbs or raised planters.

- Trees – replace tree species with an alternate species more tolerant of groundwater and pollutant conditions.

Troubleshooting and FAQs

The following section provides troubleshooting along with guidance on rehabilitation, repair work, and related tasks for stormwater tree trench systems.

Trees

The various indicators of tree health are too numerous to list in this document. The troubleshooting indicators listed herein are those that could be used as indicators of the health and function of the stormwater tree trench system as a whole.

For specific tree health inquiries including pest or disease control of City trees within the right-of-way, contact 311 to initiate an Urban Forestry work order for tree inspection.

For soil sampling and testing requirements, see TS 5.10.

Tree crown is sparse with wilted or dessicated leaves on twigs and branches, tree shows early fall coloration and leaf fall, foliage appears tufted or clumping …

Trees may be exhibiting signs of sodium damage. Conduct a soil test for factors such as macro/micro fertility, pH, bulk density as a mitigation measure. If soil is found to have excessively high sodium content, flush thoroughly to saturation with fresh dechlorinated water to alleviate excess sodium in the soil. If weather allows, spray trees with clean water to remove accumulated de-icing salt spray from leaves, twigs and buds.

Tree leaves are green and brittle or pale, leaves are dropping out of season, small roots are visible at the surface of the soil…

Trees may be over-watered. Test soil moisture and do not water until soil moisture is reduced to 10%. Test soil moisture weekly and if soil moisture does not decrease, underdrain may be clogged. Check underdrains and flush to clear any obstructions.

Soil remains wet / water is ponding at the surface of the soil or fungus/moss is apparent on soil….

Soil is saturated and trees may be over-watered. Test soil moisture and do not water until soil moisture is reduced to 10%.

Test soil moisture weekly and if soil moisture does not decrease, underdrain may be clogged. Check underdrains and flush to clear any obstructions. Excavation and replacement of underdrains is required if flushing indicates irreparable blockage.

Tree leaves are curled or wilted, yellowing or turning brown at the edges or tips…

Tree may be under-watered. Test soil moisture and water as required to maintain 10% - 20% soil moisture.

Trees have a sparse canopy with undersized leaves…

Tree may be under-watered. Test soil moisture and water as required to maintain 10% - 20% soil moisture.

Tree leaves are small, pale or yellowish…

Soil may also be excessively compacted, or pH may be too high, and soil may require amendments. Conduct a soil test for factors such as macro/micro fertility, pH, bulk density, with optional foliar analysis for additional information. Test results should include chemical composition of plant required nutrients, pH, salt and % organic matter and laboratory recommendations for nutrient applications.

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Bioretention Systems

System Overview

Bioretention systems are used to temporarily store stormwater runoff, provide filtration through designated filter media, and infiltration into the underlying native soil. These facilities may vary depending on the surrounding context, but are typically designed as a shallow, depressed planting bed or similar concrete structure to store captured runoff from minor storm events. To accommodate major storm events, overflow outlets such as beehive catch basins, bypasses or underdrains are required within the system to convey excess water to adjacent drainage systems. For water delivery into the system, stormwater runoff may be captured through inlet types, including curb cuts or similar concrete structures, drains or pipes connected to stormwater infrastructure, such as catch basins, and sheet flow from hard surfaces. The typical construction profile includes a gravel storage layer, choker layer, bioretention media layer, mulch layer and vegetation layer.

Designed and constructed, bioretention systems reduce the quantity of stormwater runoff, pollutants discharged into the storm sewer systems or receiving waters, such as lakes and rivers, and replenish groundwater resources. These systems also provide opportunities to enhance streetscape and landscape aesthetics. Key components of the bioretention systems for inspection and maintenance are tabulated in Table 7.

Inspection and Testing Framework

During each type of inspection, visual and testing indicators associated with bioretention systems should be used to determine the basis for planning field work. Table 7 summarizes the inspection types required for each respective indicator. In the table, “x” denotes where an indicator should be used in each inspection type and “(x)” denotes that the indicator is used only for performance verification.

Table 7: Inspection and testing indicators framework for bioretention (Adapted from TRCA LID SWM IM Guide, 2016)

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity		x	x	x
3	Inlet Obstruction	x	x	x	x
4	Pre-treatment Sediment Accumulation	x	x	x	
5	Inlet Erosion		x	x	
6	GI Dimensions	x	x		x
7	Side Slope Erosion		x	x	
8	Surface Ponding Area	x	x		x
9	Standing Water		x	x	x
10	Trash		x	x	
11	Filter Bed Erosion		x	x	
12	Filter Bed Sediment Accumulation		x	x	x
13	Filter Bed Surface Sinking		x	x	
14	Mulch Depth	x	x	x	x
15	Surface Ponding Depth	x	x		x
16	Check Dams	x	x	x	x
17	Vegetation Cover	x	x	x	x
18	Vegetation Condition		x	x	
19	Vegetation Composition	x	x	x	
20	Monitoring Well Condition	x	x	x	x
21	Underdrain/Perforated Pipe Obstruction		x		x
22	Overflow Outlet Obstruction	x	x	x	x
23	Pavement Surface Condition	Not Applicable			
24	Pavement Surface Sediment Accumulation	Not Applicable			
25	Control Structure Condition	Not Applicable			
26	Control Structure Sediment Accumulation	Not Applicable			
	Testing Indicators	**Inspection Type**			

		Construction	Warranty	Routine Operation	Verification
1	Soil Characterization Testing	x	x		(x)
2	Sediment Accumulation Testing	x	x	x	x
3	Surface Infiltration Rate Testing		x		(x)
4	Natural or Simulated Storm Event Testing		x		(x)
5	Continuous Monitoring		x		(x)

Routine Maintenance

Recommended routine maintenance tasks and respective frequencies for each bioretention component is listed in Table 8. Depending on the location, increased routine maintenance practices may be warranted for systems in highly visible areas, receiving flows from high traffic locations such as vehicle and pedestrian corridors, or draining to a sensitive receiving waterbody. Higher frequencies of maintenance tasks such as trash, debris, and sediment removal or weeding and trimming of vegetation may also be required for bioretention systems located within these high priority areas.

To note, tasks denoted with a six month frequency in Table 8 should ideally be performed in the spring and late fall/early winter. Tasks denoted with a three month frequency should ideally be performed in the spring, summer, early fall, and later fall/early winter. Vegetation watering throughout the lifespan of the GI is to be performed as required, but the frequency should be increased during drought conditions. Personnel conducting vegetation maintenance should be experienced with the designated planting plan, plant species identification, and weed removal/control methodologies. An 80 per cent vegetation cover should be achieved within two years of planting or prior to the warranty period. Woody vegetation should not be planted or become established in areas where snow storage may be warranted during winter.

Table 8: Key bioretention components and routine maintenance tasks (Adapted from TRCA LID SWM IM Guide, 2016)

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Contributing Drainage Area	Contributing drainage area is the designated area (including pervious, impervious, and GI area) where runoff is conveyed into the GI system. The area should be free of point source pollutants (e.g. leaks, spills) while trash, sediment, and debris should be regularly removed from pavements and regions of conveyance towards the GI (e.g. gutters, catch basins).	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Re-plant or seed bare soil areas		
Inlets	Inlets include curb cuts or similar engineered structures, drains or pipes, and pavement edges. Inlets must remain clear of any obstructions (e.g. trash, debris) to ensure runoff is conveyed to the GI system. Erosion control measures (e.g. stone cover or rip-rap) may be required for certain inlets to prevent concentrated flow induced erosion to the GI.	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Remove woody vegetation at inflow points		
Pre-treatment and Sediment Pad	Pre-treatment involves features or methods to attenuate and dissipate concentrated stormwater runoff flows prior to entering the GI system. Pre-treatment features (e.g. sediment pads) filter coarse suspended material in the runoff, thereby reducing the sediment accumulation within the GI over its operational period. Frequent maintenance is required for trash and debris removal.	Remove trash, natural debris and clippings	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Re-grade and re-plant eroded areas when ≥30cm in length	As required	As required
Perimeter	The perimeter of the GI system may consist of side slopes (mixture of mulch, stone and vegetation), vertical walls, or similar concrete structures to	Add stone or mulch to maintain 5-10cm depth for non-vegetated areas	2 years	2 years

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	permit stormwater to pond within. Inspections are to confirm an acceptable dimension of the GI, the maintenance of its structural integrity, and the continual provision of the designed surface ponding volume. Periodic maintenance may involve the repair of erosion rills and damage by vehicle or foot traffic.	Re-grade and re-plant eroded areas when ≥30cm in length	As required	As required
Filter Bed	The filter media bed of the GI consists of a flat or gently sloping surface covered with a mixture of vegetation, mulch and stone. The depth of the filter bed is engineered to allow adequate stormwater storage and to infiltrate all surface ponding within 24 hours following a storm event. Regular inspections of maximum ponding depth and required maintenance (trash, debris and sediment removal) should be conducted to avoid standing water which encourages mosquito breeding. Mulch, stone and vegetation cover are to be maintained routinely to prevent weed growth and soil erosion. Animal burrows, sunken areas, erosion rills, and vehicle or foot damage are to be repaired to maintain the designed storage and permeability of the GI.	Remove trash	6 months	3 months
		Re-distribute mulch or stone cover to maintain 5-10cm depth for non-vegetated areas		
		Remove accumulated sediment when ≥5cm depth	As required	As required
		Re-grade and restore cover over any animal burrows, sunken areas when ≥10cm in depth and erosion rills when ≥30cm in length		
		Add stone or mulch to maintain 5-10cm depth for non-vegetated areas	2 years	2 years
Vegetation (shrubs, grasses, ground covers, etc.)	Vegetation, including shrubs, ornamental grasses, perennials and other groundcovers within the GI intercepts, uptakes and transpires stormwater into the atmosphere. It promotes soil organisms which decompose	Watering during first two months after planting	3 days	3 days
		Watering for the remainder of the first two growing seasons (May to	As required	As required

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	pollutants and its root systems assist in maintaining soil structure and permeability. Similar to conventional planting beds, regular maintenance including weeding, mowing, pruning and irrigation during droughts are required. In the first 2 months of operations, the vegetation is to be irrigated frequently while the use of fertilizer is generally unnecessary (applied as required) as the GI functions to retain nutrients from the stormwater inflow. Care should be taken care to minimize soil compaction and vegetation disturbance during maintenance activities. Working from the perimeter or integrated "stepping pads" is a best practice.	Sep) after planting or until vegetation is established		
		Watering for the remainder of the GI lifespan	As required	As required
		Mow grass to maintain height between 10-15cm	1 month	2 weeks
		Remove undesirable vegetation (tree seedlings, invasive species/weeds)	6 months	3 months
		Replace dead/diseased plants to maintain a minimum of 80% vegetation cover	1 year	6 months
		Prune shrubs	1 year	1 year
		Cut back spent plants		
		Divide or thin out overcrowded plants		
Overflow Outlets	Overflow outlets (e.g. beehive catch basin) are installed to collect excess flows from large storm events and maintains maximum ponding depths. Periodic maintenance is to be undertaken to ensure the outlet structure remains unobstructed so stormwater can be safely conveyed to adjacent drainage systems.	Remove trash, natural debris, clippings, woody vegetation and sediment on grate	6 months	3 months
		Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Underdrain	Depending on the permeability of the underlying native soil or other constraints, underdrains may be installed below the filter media to collect and convey water to adjacent drainage systems. The underdrain consists of a perforated pipe surrounded with gravel and optionally wrapped with geotextile. A cleanout may be installed for periodic inspection and flushing of the underdrain for sediment removal to ensure water is drained from the GI within its designed timeframe. If vegetation roots penetrate into the underdrain, they can be removed by mechanical means (e.g. drill). If the roots belong to a tree, an Urban Forestry permit may be required before any work is performed. Contact 311 for more information. If required, flow-restrictors should be inspected and cleaned regularly.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year
Monitoring Well	Monitoring wells are standpipes extending from the surface of the filter bed to the bottom of the excavation. Perforations within the pipe allow for observation and measurement of the subsurface water level. Such monitoring helps ensure that the drainage system is functioning as designed over time. Monitoring wells should be securely capped, undamaged, and may require periodic flushing to remove accumulated sediment.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year

The main concern with maintenance tasks performed within the GI system is the compaction of the filter bed which diminishes the designed operational function of the system. Maintenance tasks involving vehicles or foot traffic on the filter bed should be avoided during wet weather due to the increased risk of soil compaction while the soil is saturated.

Life Cycle Operations and Maintenance

Infrastructure decisions are evaluated over a typical period of 50 years which can be considered the standard lifespan of bioretention systems and all its components. Bioretention systems will require maintenance tasks to be routinely performed to ensure continuing operation of the GI to design performance standards. Vegetation management activities should be routinely conducted throughout the lifetime of the system with the aim of maximizing biodiversity and preventing the spread of invasive species. As listed in Table 10, maintenance practices fall into two categories – minimum and high priority frequencies. Depending on the location of the GI, the overall cost of maintenance for its service life will vary. Bioretention systems require rehabilitation activities after 25 years of service to maintain an acceptable surface drainage performance. Following a minimal maintenance schedule will likely result in greater rehabilitation costs, but the difference may not be significant. A lifecycle cost analysis of two maintenance options for three types of bioretention systems is discussed in the 2016 TRCA LID SWM IM Guide.

In terms of end of life cycle activities, similar standards to other stormwater infrastructure and landscaping components are expected to apply to the decommissioning and disposal of bioretention system components. This may involve adhering to provincial regulations for the proper removal, disposal and replacement of materials, removal or capping of system components, and other required restorations to the area. However, for specific products and/or materials, it is recommended that manufacturer specifications are followed.

Failure Conditions

The main cause of failure for a bioretention system is surface clogging or blockage primarily due to an accumulation of trash, debris, sediment or other similar obstructions. Such malfunctions are easily detectible and maintenance tasks can be performed as needed to remediate. Clogging of the drainage layers or underdrain may also cause the system to fail but is more difficult to detect. However, any system malfunctions will likely cause surface ponding and poor outflow quality as water often bypasses the filter media and overflows through the outlet structure. The following mitigation strategies should be undertaken as required to prevent the decline of the system's level of service.

Mitigation Strategies

The primary mitigation strategy with respect to clogging and blockage within the GI is to maintain the condition of the contributing drainage area in order to prevent or reduce unwanted material from entering the system. Regular street sweeping within the catchment area of the GI system will reduce the loading of fine suspended solids which can clog the filter media over time. Street sweeping also reduces the GI maintenance frequency of trash, debris and sediment removal at the inlet or filter bed. During the winter, strategic application of de-icing and anti-skid substances within the contributing drainage area can lessen sedimentation and the need for clean-up maintenance.

Other active mitigation strategies include conducting routine maintenance of the bioretention system at the specified intervals to avoid the accumulation of trash, debris, and sedimentation. During the initial months of operation, the bioretention system should be visually inspected more frequently after rainfall events and outflow water quality should be gauged to determine sediment deposition rates.

If indicators of clogging or blockages within the system persist, major rehabilitation work may be required if other mitigation strategies or major repair tasks listed in the following troubleshooting section are unsuccessful. In general, the following three components for bioretention systems are most prone to necessitate rehabilitation activities as described in the troubleshooting section:

- soil – based on contamination and infiltration testing
- filter media – based on infiltration testing
- underdrain – if flushing indicated irreparable blockage

Troubleshooting and FAQs

If a decline in level of service is observed, the following section provides troubleshooting along with guidance on rehabilitation, repair work and related tasks for bioretention systems.

Inlets

The inlet is producing concentrated flows which results in filter bed erosion…

Install a sediment pad or regrade the feature to a design standard to reduce concentrated flow and promote sheet flow into the filter bed. Regrade damaged or eroded areas of the filter bed and replant or restore the mulch and/or stone cover. If further erosion occurs, consider replacing filter bed vegetation and mulch cover at inlets with stone material (e.g. rip-rap).

Filter Bed

The filter media is overly compacted and is clogging…

Possible tasks include core aerating up to a 30cm depth, removal of stone, mulch, vegetation and till up to 20cm of filter media, or replacement of compacted material with non-compacted filter media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

The filter media texture is too fine…

In the case of high percentages of silt and clay-sized particles, possible tasks include the removal of stone, mulch, vegetation and up to 20cm of filter media, or replacement of all or top 15cm of material with non-compacted filter media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Mulch maintenance…

Add mulch to maintain a depth of 5-10cm, every two years or as required.

Filter media contains soluble salts exceeding 2.0ms/cm…

As necessary, flush the affected area thoroughly with fresh dechlorinated water remove excess salts from the soil.

Filter media cation exchange capacity (CEC) is <10meq/100g…

Remove stone, mulch, and vegetation cover and top 5cm of filter media; spread and incorporate 5cm layer of compost into 20cm depth of filter media via tilling. Alternatively remove all or the top 15cm of material and replace with filter media to design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

There is a significant accumulation of sediment on the filter bed affecting the functional performance of the GI, and causing large surface ponding…

Accumulated sediment may be removed by hydro-vac truck. In extreme cases, remove the vegetation and top 5cm of contaminated filter media. Replace with filter media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant. If there is significant surface ponding over the maximum designed level, remove the accumulated sediment by methods mentioned above in addition to tilling the filter media up to a depth of 20cm. If excess ponding persists, remove and replace all plant material and the top 15cm of filter media.

Vegetation Growth

In general, ensure that dead or diseased plant material is replaced on a bi-annual to annual basis to maintain aesthetics and reduce possible negative impacts on healthy surrounding vegetation.

Poor vegetation growth due to low organic matter or phosphorus content…

As required, remove mulch, stone and vegetation and replace top 5cm of filter media with compost. Incorporate the compost layer by tilling 20cm into the filter media bed. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Poor vegetation growth due to filter media pH out of specification range (pH 6.0 to 7.8)…

If the soil pH is below 6.0, amend the soil with limestone to raise the pH back to neutrality, if the soil pH is greater than 7.8, amend the soil with compost or sulphur to lower the pH back to neutrality.

Underdrain

The perforated underdrain pipe is obstructed by sediment or roots…

If applicable, schedule hydro-vac truck or drain-snaking service to remove obstructions from the underdrain.

Bioswales

System Overview

A bioswale is a linear vegetated channel similar in geometry to an enhanced grass swale which also conveys, treats and attenuates stormwater runoff. However, its subsurface composition is more reflective of a bioretention system, consisting of filter media and storage gallery. An underdrain is optional depending on native soil infiltration rates. To reduce the velocity of runoff and promote sedimentation, filtration, evapotranspiration and infiltration, a combination of vegetation and aggregate may be incorporated in the bioswale in place of grasses. With its bioretention profile, bioswales are more effective than enhanced grass swales at removing pollutants and protecting downstream areas from erosion. Bioswales are also referred to as dry swales as they do not retain water for extended time periods following storm events. The system has a typical drawdown of 24 hours after design storm events while excessive flows from major storm events may be conveyed by a downstream outlet structure, for example culvert or pipe to an adjacent drainage system. Bioswale systems may also be adapted to either a hardscape or softscape context. In an urban or hardscape context, bioswales resemble bioretention systems as a shallow, depressed planting bed or similar concrete structure. However, bioswales can be differentiated from bioretention planters by the added outlet structure – in addition to the overflow structure – which conveys excess flows back to the roadway.

Designed and constructed appropriately, bioswales reduce the quantity of stormwater runoff and pollutants discharged into the storm sewer systems or receiving waters, such as lakes and rivers. Depending on the location, these systems also provide suitable snow storage area during winter months. Key components of the bioswale system for inspection and maintenance are tabulated in Table 9.

Inspection and Testing Framework

During each type of inspection, visual and testing indicators associated with bioswale systems should be used to determine the basis for planning field work. Table 9 summarizes the inspection types required for each respective indicator. In the table, “x” denotes where an indicator should be used in each inspection type and “(x)” denotes that the indicator is used only for performance verification.

Table 9: Inspection and testing indicators framework for bioswales (Adapted from TRCA LID SWM IM Guide, 2016)

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity		x	x	x
3	Inlet Obstruction	x	x	x	x
4	Pre-treatment Sediment Accumulation	x	x	x	
5	Inlet Erosion		x	x	
6	GI Dimensions	x	x		x
7	Side Slope Erosion		x	x	
8	Surface Ponding Area	x	x		x
9	Standing Water		x	x	x
10	Trash		x	x	
11	Filter Bed Erosion		x	x	
12	Filter Bed Sediment Accumulation		x	x	x
13	Filter Bed Surface Sinking		x	x	
14	Mulch Depth	x	x	x	x
15	Surface Ponding Depth	x	x		x
16	Check Dams	x	x	x	x
17	Vegetation Cover	x	x	x	x
18	Vegetation Condition		x	x	
19	Vegetation Composition	x	x	x	
20	Monitoring Well Condition	x	x	x	x
21	Underdrain/Perforated Pipe Obstruction		x		x
22	Overflow Outlet Obstruction	x	x	x	x
23	Pavement Surface Condition	Not Applicable			

24	Pavement Surface Sediment Accumulation	Not Applicable			
25	Control Structure Condition	Not Applicable			
26	Control Structure Sediment Accumulation	Not Applicable			
	Testing Indicators	**Inspection Type**			
		Construction	**Warranty**	**Routine Operation**	**Verification**
1	Soil Characterization Testing	x	x		(x)
2	Sediment Accumulation Testing	x	x	x	x
3	Surface Infiltration Rate Testing		x		(x)
4	Natural or Simulated Storm Event Testing		x		(x)
5	Continuous Monitoring		x		(x)

Routine Maintenance

Recommended routine maintenance tasks and respective frequencies for each bioswale component is listed in Table 10. Depending on the location, higher routine maintenance should be undertaken with GI practices in highly visible areas, receiving flows from high traffic areas such as from vehicle and pedestrian corridors, or draining to a sensitive receiving waterbody. Greater frequencies of maintenance tasks such as trash, debris, and sediment removal or weeding and trimming of vegetation may also be required for bioswale systems located within these high priority areas.

To note, tasks denoted with a six month frequency in Table 10 should ideally be performed in the spring and late fall/early winter. Tasks denoted with a three month frequency should ideally be performed in the spring, summer, early fall, and later fall/early winter. Vegetation watering throughout the lifespan of the GI is to be performed as required, but the frequency should be increased during drought conditions. Personnel conducting vegetation maintenance should be experienced with the designated planting plan, plant species identification, and weed removal/control methodologies. An 80 per cent vegetation cover should be achieved within two years of planting or prior to the end of the warranty period. Woody vegetation such as shrubs should not be planted or become established in areas where snow storage may necessary during winter.

Table 10: Key bioswale components and routine maintenance tasks (Adapted from TRCA LID SWM IM Guide, 2016)

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Contributing Drainage Area	Contributing drainage area is the designated area (including pervious, impervious, and GI area) where runoff is conveyed into the GI system. The area should be free of point source pollutants (e.g. leaks, spills) while trash, sediment, and debris should be regularly removed from pavements and regions of conveyance towards the GI (e.g. gutters, catch basins).	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Re-plant or seed bare soil areas		
Inlets	Inlets include curb cuts or similar engineered structures, drains or pipes, and pavement edges. Inlets must remain clear of any obstructions (e.g. trash, debris) to ensure runoff is conveyed to the GI system. Erosion control measures (e.g. stone cover or rip-rap) may be required for certain inlets to prevent concentrated flow induced erosion to the GI.	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Remove woody vegetation (e.g. shrubs) at inflow points		
Pre-treatment	Pre-treatment comprises of features or methods to attenuate and spread	Remove trash, natural debris and clippings	6 months	3 months

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	concentrated stormwater runoff flows prior to entering the GI system. Pre-treatment features (e.g. rip-rap) allow for sedimentation and filtration of coarse suspended material in the runoff to reduce the accumulation of sediment within the GI over its operational period. Bioswales can utilize catch basins with appropriate filters and sumps or vegetated filter strips if the system is in softscape. Frequent maintenance is required for trash and debris removal.	Remove accumulated sediment	1 year	6 months
		Re-grade and re-plant eroded areas when ≥30cm in length	As required	As required
Perimeter	The perimeter of the GI system may consist of side slopes (mixture of mulch, stone and vegetation), vertical walls, or similar concrete structures to permit stormwater to pond within. In softscape, side slopes will convey stormwater towards the channel bed. Inspections are to confirm an acceptable dimension of the GI, the maintenance of its structural integrity, and the continual provision of the designed surface ponding volume and conveyance capacity of the swale. Periodic maintenance is necessary to repair	Add stone or mulch to maintain 5-10cm depth for non-vegetated areas	2 years	2 years
		Replace dead/diseased plants to maintain a minimum 80% vegetation cover	1 year	6 months
		Re-grade and re-plant eroded areas when ≥30cm in length	As required	As required

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	erosion rills and damage by vehicle or foot traffic.			
Filter Bed	The filter media bed of the GI consists of a flat or gently sloping surface covered with a mixture of vegetation, mulch and stone. The depth of the filter bed is engineered to allow adequate stormwater storage and to infiltrate all surface ponding within 24 hours following a storm event. In softscape, the GI system is an open channel with a longitudinal slope and comprises of a 0.3m deep growing media layer covered with vegetation, mulch, and stone. This mixture encourages the filtration, percolation and evaporation of stormwater and the slope prevents extended surface ponding of the runoff. Regular inspections of maximum ponding depth and required maintenance (trash, debris and sediment removal) should be conducted to avoid standing water which encourages	Remove trash	6 months	3 months
		Re-distribute mulch or stone cover to maintain 5-10cm depth on non-vegetated areas		
		Core aerate (in softscape context)	5 years	3 years
		Remove accumulated sediment when ≥5cm depth	As required	As required
		Re-grade and restore cover over any animal burrows, sunken areas when ≥10cm in depth and erosion rills when ≥30cm in length		
		Add stone or mulch to maintain 5-10cm depth for non-vegetated areas	2 years	2 years

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	mosquito breeding. Mulch, stone and vegetation cover are to be maintained routinely to prevent weed growth and soil erosion. Animal burrows, sunken areas, erosion rills, and vehicle or foot damage are to be repaired to maintain the designed storage and permeability of the GI.			
Vegetation (shrubs, grasses, ground covers, etc.)	Vegetation, including shrubs, ornamental grasses, perennials and other groundcovers planted in the GI intercepts, uptakes and allows the transpiration of stormwater. It promotes soil organisms which decompose pollutants while the root systems assist in maintaining the soil structure and permeability. Similar to conventional planting beds, regular maintenance including weeding, mowing, pruning and irrigation during droughts are required. In the first 2 months of operations, the vegetation is to be irrigated frequently while the use of fertilizer is generally unnecessary (applied as required) as the GI functions to retain nutrients from the stormwater inflow.	Watering during first two months after planting	3 days	3 days
		Watering for the remainder of the first two growing seasons (May to Sept.) after planting or until vegetation is established	As required	As required
		Watering for the remainder of the GI lifespan	As required	As required
		Mow grass to maintain height between 10-15cm	1 month	2 weeks
		Remove undesirable vegetation (voluntary tree seedlings, invasive species/weeds)	6 months	3 months
		Replace dead/diseased plants to maintain a minimum of 80% vegetation cover	1 year	6 months
		Prune shrubs	1 year	1 year
		Cut back spent plants		
		Divide or thin out overcrowded plants		

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Overflow Outlets	Overflow outlets (e.g. beehive catch basin, or culvert/pipe in softscape) are installed to collect excess flows from large storm events exceeding the storage capacity and maintains maximum ponding depths. Periodic maintenance is to be undertaken to ensure the outlet structure remains unobstructed so stormwater can be safely conveyed to adjacent drainage systems. In hardscape, outlet structures placed downstream (similar geometry as inlet structures such as curb cuts and trench drains) are also used for bioswales to convey excess flows away from the GI. These outlet structures should be maintained in similar fashion to inlet structures.	Remove trash, natural debris, clippings, woody vegetation and sediment on grate	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Underdrain	Depending on the permeability of the underlying native soil or other constraints, underdrains may be installed below the filter media to collect and convey water to adjacent drainage systems. The underdrain consists of a perforated pipe surrounded with gravel and optionally wrapped with geotextile. A cleanout may be installed for periodic inspection and flushing of the underdrain for sediment removal to ensure water is drained from the GI within its designed timeframe. If vegetation roots penetrate into the underdrain, they can be removed by mechanical means (e.g. drill). If the roots belong to a tree, an Urban Forestry permit may be required before any work is performed. Contact 311 for more information. If required, flow-restrictors should be inspected and cleaned regularly.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Monitoring Well	Monitoring wells are standpipes extending from the surface of the filter bed to the bottom of the excavation. Perforations within the pipe allow the observation and measurement of the subsurface water level in the GI to ensure the designed drainage functionality is maintained during the service life. Monitoring wells should be securely capped, undamaged, and may require periodic flushing to remove accumulated sediment.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Typically for bioswales and similarly for bioretention systems, the main concern of maintenance tasks performed within the GI system is the compaction of the filter bed which diminishes the designed operational function of the system. Maintenance tasks involving vehicles or foot traffic on the filter bed should be avoided during wet weather due to the increased risk of soil compaction while the soil is saturated. Lightest equipment available, such as a push mower, shall be selected for maintenance tasks to lessen the compaction of the filter bed. The removal of sediment accumulation within the filter bed should also be performed by hand, and if required, excavators or vacuum equipment should remain off swale side slopes or planter beds to avoid damage.

Life Cycle Operations and Maintenance

Infrastructure decisions are evaluated over a typical period of 50 years which can be considered the standard lifespan of bioswale systems and all its components. However, the lifespan of systems located in softscape may extend beyond this threshold. Bioswale systems will require maintenance tasks to be routinely performed to ensure continuing operation of the GI to design performance standards. Vegetation management activities should be routinely conducted throughout the lifetime of the system with the aim of maximizing biosecurity and preventing the spread of invasive species. As listed in Table 10, maintenance practices fall into two categories which either meets minimum required frequencies or pertains to high priority frequency. Therefore, depending on the location of the GI, the overall cost of maintenance for its service life will vary. It should be noted that bioswale systems require rehabilitation activities following 25 years of service to maintain an acceptable surface drainage performance. Following a minimal maintenance option will likely result in greater rehabilitation costs, but the difference is not typically significant. A lifecycle cost analysis of two maintenance options for three types of bioswale systems is discussed in the 2016 TRCA LID SWM IM Guide.

In terms of end of life cycle activities, similar standards to other stormwater infrastructure and landscaping components are expected to apply to the decommissioning and disposal of bioswale system components. This may involve adhering to provincial regulations for the proper removal, disposal and replacement of materials, removal or capping of system components, and other required restorations to the area. However, for specific products or materials, it is recommended that manufacturer specifications are followed.

Failure Conditions

The main cause of failure for a bioswale system is surface clogging or blockage primarily due to an accumulation of trash, debris, sediment or other similar obstructions. Such malfunctions are easily detectible and maintenance tasks can be performed as needed. Clogging of the drainage layers or underdrain may also cause the system to fail but is more difficult to detect. However, any system malfunctions will likely cause surface ponding and poor outflow quality as water often bypasses the filter media and overflows through the outlet structure. The following mitigation strategies should be undertaken as required to prevent the decline of the system's level of service.

Mitigation Strategies

The primary mitigation strategy with respect to clogging and blockage within the GI is to maintain the contributing drainage area in order to prevent or reduce unwanted material from entering the system. Regular street sweeping within the catchment area of the GI system will reduce the loading of fine suspended solids which may clog the filter media over time. Street sweeping also reduces the maintenance frequency of trash, debris and sediment removal at the inlet or filter bed. During the fall, sediment and debris should be removed before snowfall occurs, and during the spring before snowmelt runoff. During the winter, strategic application of de-icing and anti-skid substances within the contributing drainage area can lessen sedimentation and the need for clean-up maintenance. Furthermore, the GI area should only be used as a snow storage facility provided there is sufficient volumetric capacity, the snow weight can be accommodated, and/or an adequate buffer from the curb to any plantings is provided to allow for snow drift. Consideration should also be made with operating snowplows adjacent to the GI system – mainly within softscape context – to prevent possible damages.

Other active mitigation strategies include conducting routine maintenance of the bioswale system at the specified intervals to avoid the accumulation of trash, debris, and sedimentation. During the initial months of operation, the bioswale system should be visually inspected more frequently after rainfall events and outflow water quality should be gauged to determine sediment deposition rates.

If indicators of clogging or blockagewithin the system persist, major rehabilitation work may be required if other mitigation strategies or major repair tasks listed in the following troubleshooting section are unsuccessful. In general, the following three components for bioswale systems are most prone to necessitate rehabilitation activities as described in the troubleshooting section:

- soil – based on contamination and infiltration testing
- filter media – based on infiltration testing
- underdrain – if flushing indicated irreparable blockage

Troubleshooting and FAQs

If a decline in level of service is observed, the following section provides troubleshooting along with guidance on rehabilitation, repair work and related tasks for bioswale systems.

Inlets

The inlet is producing concentrated flows which results in filter bed erosion…

Install a sediment pad or regrade existing feature back to level to reduce concentrated flow and promote sheet flow into the filter bed. Regrade damaged or eroded areas of the filter bed and replant or restore the mulch and/or stone cover. If further erosion occurs, consider replacing filter bed vegetation and mulch cover at inlets with stone material (e.g. rip-rap).

Filter Bed

The filter media is overly compacted and is clogging…

Possible tasks include core aerating up to a 30cm depth, removal of stone, mulch, vegetation and till up to 20cm of filter media, or replacement of compacted material with non-compacted filter media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

The filter media texture is too fine…

In the case of high percentages of silt and clay-sized particles, possible tasks include the removal of stone, mulch, vegetation and up to 20cm of filter media, or replacement of all or top 15cm of material with non-compacted filter media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Mulch maintenance…

Add mulch to maintain a depth of 5-10cm, every two years or as required.

Filter media contains soluble salts exceeding 2.0mS/cm …

As necessary, flush the affected area thoroughly with fresh dechlorinated water to remove excess salts from the soil.

Filter media cation exchange capacity (CEC) is <10meq/100g…

Remove stone, mulch, and vegetation cover and top 5cm of filter media, spread and incorporate 5cm layer of compost into 20cm depth of filter media via tilling. Alternatively remove all or the top 15cm of material and replace with filter media to design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

There is a significant accumulation of sediment on the filter bed affecting the functional performance of the GI, and causing large surface ponding…

Accumulated sediment may be removed by hydro-vac truck. In extreme cases, remove the vegetation and top 5 cm of contaminated filter media. Replace with filter media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant. If there is significant surface ponding over the maximum designed level, remove the accumulated sediment with methods mentioned above in addition to tilling the filter media up to a depth of 20 cm. If excess ponding persists, remove and replace all plant material and the top 15 cm of filter media.

There is observed damage to the filter bed or side slope from erosion rills, animal burrows, local sinking, and ruts…

Re-grade damaged portion and replace the stone, mulch, and vegetation cover. Areas with animal burrows, local sinking, and compacted areas should be tilled to a depth of 20 cm prior to re-grading.

Vegetation Growth

In general, ensure that dead or diseased plant material is replaced on a bi-annual to annual basis to encourage biodiversity and reduce possible negative impacts on healthy surrounding vegetation.

Poor vegetation growth due to low organic matter or phosphorus content…

As required, remove mulch, stone and vegetation and replace top 5 cm of filter media with compost. Incorporate the compost layer by tilling 20 cm into the filter media bed. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Poor vegetation growth due to filter media pH out of specification range (pH 6.0 to 7.8)…

If the soil pH is below 6.0, amend soil with limestone to raise the pH back to neutrality. If the soil pH is greater than 7.8, amend the soil with compost or sulphur to lower the pH back to neutrality.

Underdrain

The perforated underdrain pipe is obstructed by sediment or roots…

If applicable, schedule hydro-vac truck or drain-snaking service to remove obstructions from the underdrain.

Enhanced Grass Swales

System Overview

Enhanced grass swales, often referred to as enhanced vegetated swales, are slightly sloping and parabolic vegetated channels which incorporate amended soils to slow stormwater runoff and assist in contamination removal. The system features vegetation, typically grasses but may include herbs, shrubs or trees, stone or mulch which slows and conveys excess surface water to an adjacent drainage feature, for example sewer system or other GI. This system has similar surface geometry to a bioswale but is a lower maintenance alternative with generally lower stormwater management potential. Stormwater runoff may be conveyed into the system with inlets including curb cuts or similar concrete structures, drains or pipes connected to stormwater infrastructure, such as catch basins, and sheet flow from hard surfaces. Enhanced grass swales also allow the percolation of stormwater runoff typically within a drawdown time of 24 hours following a design storm event. A downstream outlet, for example culvert or pipe, may be installed to discharge excessive flows from major storm events.

Provided proper practices, enhanced grass swale systems reduce the quantity of stormwater runoff and pollutants discharged into the storm sewer systems or receiving waters, for example lakes and rivers. Depending on the location, these systems also provide suitable snow storage area during winter months. Key components of the enhanced grass swale systems for inspection and maintenance are tabulated in Table 12 below.

Inspection and Testing Framework

During each type of inspection, visual and testing indicators associated with enhanced grass swale systems should be used to determine the basis for planning field work. Table 11 summarizes the inspection types required for each respective indicator.

Table 11: Inspection and testing indicators framework for enhanced grass swales (Adapted from TRCA LID SWM IM Guide, 2016)

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity		x	x	x
3	Inlet Obstruction	x	x	x	x
4	Pre-treatment Sediment Accumulation	x	x	x	
5	Inlet Erosion		x	x	
6	GI Dimensions	x	x		x
7	Side Slope Erosion		x	x	
8	Surface Ponding Area	x	x		x
9	Standing Water		x	x	x
10	Trash		x	x	
11	Filter Bed Erosion		x	x	
12	Filter Bed Sediment Accumulation		x	x	x
13	Filter Bed Surface Sinking		x	x	
14	Mulch Depth	Not Applicable			
15	Surface Ponding Depth	x	x		x
16	Check Dams	x	x	x	x
17	Vegetation Cover	x	x	x	x
18	Vegetation Condition		x	x	
19	Vegetation Composition	x	x	x	
20	Monitoring Well Condition	Not Applicable			
21	Underdrain/Perforated Pipe Obstruction	Not Applicable			
22	Overflow Outlet Obstruction	x	x	x	x
23	Pavement Surface Condition	Not Applicable			
24	Pavement Surface Sediment Accumulation	Not Applicable			
25	Control Structure Condition	Not Applicable			

26	Control Structure Sediment Accumulation	Not Applicable			
	Testing Indicators	**Inspection Type**			
		Construction	**Warranty**	**Routine Operation**	**Verification**
1	Soil Characterization Testing	x	x		(x)
2	Sediment Accumulation Testing	x	x	x	x
3	Surface Infiltration Rate Testing		x		(x)
4	Natural or Simulated Storm Event Testing		x		(x)
5	Continuous Monitoring	Not Applicable			

Routine Maintenance

Recommended routine maintenance tasks and respective frequencies for each enhanced grass swale component is listed in Table 12. Depending on the location, greater routine maintenance should be undertaken with practices in highly visible areas, receiving flows from high traffic areas such as from vehicle and pedestrian corridors, or draining to a sensitive receiving waterbody. Greater frequencies of maintenance tasks such as trash, debris, and sediment removal or weeding and trimming of vegetation may also be required for enhanced grass swale systems located within these high priority areas.

Tasks with a six month frequency in Table 12 should ideally be performed in the spring and late fall/early winter. Tasks with a three month frequency should ideally be performed in the spring, summer, early fall, and later fall or early winter. Vegetation watering throughout the lifespan of the GI is to be performed as required, but the frequency should be increased during drought conditions. Personnel conducting vegetation maintenance should be experienced with the designated planting plan, plant species identification and weed removal or control methodologies. An 80 per cent vegetation cover should be achieved within two years of planting or prior to the warranty period. Woody vegetation should not be planted or become established in areas where snow storage may be warranted during winter.

Table 12: Key enhanced grass swale components and routine maintenance tasks (Adapted from TRCA LID SWM IM Guide, 2016)

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Contributing Drainage Area	Contributing drainage area is the designated area (including pervious, impervious, and GI area) where runoff is conveyed into the GI system. The area should be free of point source pollutants (e.g. leaks, spills) while trash, sediment, and debris should be regularly removed from pavements and regions of conveyance towards the GI (e.g. gutters).	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Re-plant or seed bare soil areas		
Inlets	Inlets include curb cuts or similar engineered structures, drains or pipes, and pavement edges. Inlets must remain clear of any obstructions (e.g. trash, debris) to ensure runoff is conveyed to the GI system. Erosion control measures (e.g. stone cover or rip-rap) may be required for certain inlets to prevent concentrated flow induced erosion to the GI.	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Remove woody vegetation (i.e. shrubs) at inflow points		

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Pre-treatment	Pre-treatment involves features or methods to attenuate and spread concentrated stormwater runoff flows prior to entering the GI system. Pre-treatment features (e.g. rip-rap) allow for sedimentation and filtration of coarse suspended material in the runoff to reduce the accumulation of sediment within the GI over its operational period. With enhanced grass swales, common pre-treatments include vegetated filter strips, rip-rap, sediment pads, and catch basins with appropriate filters and sumps. Frequent maintenance is required for trash, sediment, and debris removal.	Remove trash, natural debris and clippings	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Re-grade and re-plant eroded areas when ≥30cm in length	As required	As required
Perimeter	The perimeter of the GI system consists of side slopes (mixture of mulch, stone and vegetation), which conveys stormwater towards the channel bed. Inspections are to confirm an acceptable dimension of the GI, the maintenance of its structural integrity, and the continual provision of the designed conveyance capacity of the swale. Periodic maintenance is warranted to repair	Add mulch to maintain 5-10cm depth on non-vegetated areas	2 years	2 years
		Replace dead/diseased plants to maintain a minimum 80% vegetation cover	1 year	6 months
		Re-grade and re-plant eroded areas when ≥30cm in length	As required	As required

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	erosion rills and damage by vehicle or foot traffic.			
Filter Bed	The GI system is an open channel with a longitudinal slope and comprises of a 0.3m deep growing media layer covered with vegetation, mulch, and stone. This mixture encourages the filtration, percolation and evaporation of stormwater and the slope prevents surface ponding of the runoff. Regular inspections of the system's infiltration performance, maximum ponding depth, and required maintenance (trash, debris and sediment removal) should be conducted to avoid standing water which encourages mosquito breeding. Mulch, stone and vegetation cover are to be maintained routinely to prevent weed growth and soil erosion. Animal burrows, sunken areas, erosion rills, and vehicle or foot damage are to be repaired to minimize surface ponding within the GI.	Remove trash	6 months	3 months
		Re-distribute mulch cover to maintain 5-10cm depth on non-vegetated areas		
		Core aerate	5 years	3 years
		Remove accumulated sediment when ≥5cm depth	As required	As required
		Re-grade and restore cover over any animal burrows, sunken areas when ≥10cm in depth and erosion rills when ≥30cm in length		
		Add stone or mulch to maintain 5-10cm depth on non-vegetated areas		

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Vegetation (shrubs, grasses, ground covers, etc.)	Vegetation planted in the GI (including shrubs, ornamental grasses, perennials and other groundcovers) intercepts, uptakes and allows the transpiration of stormwater. It promotes soil organism which decomposes pollutants while the root systems assist in maintaining the soil structure and permeability. Regular maintenance including weeding, mowing, and irrigation during droughts are required. In the first 2 months of operations, the vegetation is to be irrigated frequently while the use of fertilizer is unnecessary as the GI functions to retain nutrients from the stormwater inflow.	Watering during first two months after planting	3 days	3 days
		Watering for the remainder of the first two growing seasons (May to Sept.) after planting or until vegetation is established	As required	As required
		Watering for the remainder of the GI lifespan	As required	As required
		Mow grass to maintain height between 10-15cm	1 month	2 weeks
		Remove undesirable vegetation (voluntary tree seedlings, invasive species/weeds)	6 months	3 months
		Replace dead/diseased plants to maintain a minimum of 80% vegetation cover	1 year	6 months
		Prune shrubs	1 year	1 year
		Cut back spent plants		
		Divide or thin out overcrowded plants		
Outlets	Outlets (e.g. culvert or pipe) are installed to collect excess flows from large storm events exceeding the storage capacity and maintains maximum ponding depths. Periodic maintenance is to be undertaken to ensure the outlet structure remains unobstructed	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Remove woody vegetation (i.e.		

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	so stormwater can be safely conveyed to adjacent drainage systems.	shrubs) at inflow points		

The main concern of maintenance tasks performed within the GI system is the compaction of the filter bed which diminishes the designed operational function of the system. Maintenance tasks involving vehicles or foot traffic on the filter bed should be avoided during wet weather due to the increased risk of soil compaction while the soil is saturated. Lightest equipment available, for example a push mower, should be used for maintenance tasks to lessen the compaction of the filter bed. The removal of sediment accumulation within the filter bed should also be performed by hand, and if required, excavators or vacuum equipment should remain off swale side slopes to avoid damage.

Life Cycle Operations and Maintenance

An enhanced grass swale system is relatively straightforward to maintain and should require minimal landscaping work above what is required for regular open public spaces. Therefore, the cost implications of maintaining this system is marginal in comparison to similar grass covered areas. Infrastructure decisions are evaluated over a typical period of 50 years which can be considered the standard lifespan of an enhanced grass swale system and all its components. However, the lifespan of such systems may extend beyond this threshold.

Regular inspections and maintenance will be required throughout the course of its operations to ensure continuing operation of the GI to design performance standards. Adequate access should be provided to all areas of the swale to facilitate routine maintenance tasks. As listed in Table 12, maintenance practices fall into two categories – required minimum and or required high priority frequencies. Therefore, depending on the location of the GI, the overall cost of maintenance for its service life will vary. It should be noted that enhanced grass swales may require rehabilitation activities after 25 years of service to maintain an acceptable surface drainage performance. Following a minimal maintenance program will likely result in greater rehabilitation costs, but the difference is not typically significant. In general, most of the operations and maintenance activities involve removal of unwanted materials, such as trash, debris, sediment and the upkeep of vegetation within the system. Vegetation management activities should be routinely conducted throughout the lifetime of the system with the aim of maximizing biodiversity and preventing the spread of invasive species.

In terms of end of life cycle activities, the decommissioning and disposal of enhanced swale components should be based on requirements from provincial regulations. This may involve the proper removal, disposal and replacement of materials, removal or capping of system components, and other required restorations to the area. However, for specific products and/or materials, it is recommended that manufacturer specifications are followed.

Failure Conditions

The main cause of failure for enhanced grass swales is the decline of the designed conveyance capacity resulting from erosion or compaction of the slopes and channel bed, accumulation of sediments altering the channel hydraulics, and channel and outlet blockage. This reduces the effectiveness of stormwater storage within the GI, the ability to safely convey design storm events and extreme flows from major storm events, and extends the emptying timeframe of the system which may cause excessive surface ponding and inundation of surrounding areas. The following mitigation strategies are recommended to be undertaken as required to prevent the decline of the system’s level of service.

Mitigation Strategies

To prevent any negative impacts to the design conveyance capacity of the enhanced grass swale, the system should remain clear of trash, debris, and sediment. The primary mitigation strategy with respect to blockage within the GI is to maintain the contributing drainage area in order to avoid or reduce unwanted material from entering the system. Regular street sweeping within the catchment area of the GI system will reduce the loading of fine suspended solids which can clog the filter media over time. Street sweeping also reduces the maintenance frequency of trash, debris and sediment removal at the inlet or filter bed. During the fall, sediment and debris should be removed before snowfall occurs, and during the spring before snowmelt runoff. During the winter, strategic application of de-icing and anti-skid substances within the contributing drainage area can lessen sedimentation and the need for clean-up maintenance. Furthermore, the GI area should only be used as a snow storage facility provided there is sufficient volumetric capacity and the snow weight can be accommodated. Consideration should also be made with operating snowplows adjacent to the GI system to prevent possible damages.

Other active mitigation strategies include conducting routine maintenance of the enhanced grass swale system at the specified intervals to avoid the accumulation of trash, debris, and sedimentation. More frequent inspections are to be undertaken following major storm events and during the first two years of the GI service life. This allows for early detection of erosion or possible blockage occurrences during elevated or sustained flows. If indicators of poor levels of service within the system persist, major rehabilitation work may be required if other mitigation strategies or major repair tasks listed in the following troubleshooting section are unsuccessful.

Troubleshooting and FAQs

If a decline in level of service is observed, the following section provides troubleshooting along with guidance on rehabilitation, repair work and related tasks for enhanced swale systems.

Inlets

The inlet is producing concentrated flows which results in filter bed erosion…

Install a sediment pad or regrade existing feature back to the appropriate elevation to reduce concentrated flow and promote sheet flow into the filter bed. Regrade damaged or eroded areas of the filter bed and replant or restore the mulch and/or stone cover. If further erosion occurs, consider replacing filter bed vegetation and mulch cover at inlets with stone material (e.g. rip-rap).

Filter Bed

The growing medium is overly compact…

Possible tasks include core aerating, removal of stone, mulch, vegetation and till up to 20cm of growing medium every three to five years, or replacement of overly compact material with non-compact growing media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Growing medium contains soluable salts exceeding 2.0mS/cm

As necessary, flush the affected area thoroughly with fresh dechlorinated water to alleviate excess salts in the soil.

There is a significant accumulation of sediment on the filter bed affecting the functional performance of the GI…

It is recommended that accumulated sediment be removed by hand using a rake and shovel where feasible to prevent excessive compaction of the filter bed. In extreme cases, hydro-vac equipment or an excavator can be used if in a manner which avoids damage or compaction to the side slopes and filter bed.

Surface ponding is observed to remain for more than 24 hours or the surface infiltration rate exceeds the acceptable range…

Remove the stone, vegetation and accumulated sediment. To reduce surface crusting and compaction, growing medium should be tilled to a depth of 20 cm or, replace the top 15 cm of material with growing media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

There is observed damage to the filter bed or side slope from erosion rills, animal burrows, local sinking, and ruts…

Re-grade damaged portion and replace the stone, mulch, and vegetation cover. Areas with animal burrows, local sinking, and compacted areas should be tilled to a depth of 20 cm prior to re-grading.

Vegetation Growth

In general, ensure that dead or diseased plant material is replaced on a bi-annual to annual basis to warrant biodiversity and reduce possible negative impacts on healthy surrounding vegetation. Bare soil areas should be re-seeded every six months to one year.

Poor vegetation growth due to low organic matter or phosphorus content…

As required, remove mulch, stone and vegetation and replace top 5 cm of growing medium with compost. Incorporate the compost layer by tilling 20 cm into the growing medium layer. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Poor vegetation growth due to filter media pH out of specification range (pH 6.0 to 7.8)…

If the soil pH is below 6.0, amend the soil with limestone to raise the pH back to neutrality. If the soil pH is greater than 7.8, amend the soil with compost or sulphur to lower the pH back to neutrality.

Green Gutter

System Overview

Green gutters are defined as shallow vegetated planters with low-growing grasses or sedums that extend the full length of a street section. Inlets positioned at intervals along its length convey stormwater runoff into the system while the vegetation and growing medium acts to attenuate, filter, and infiltrate the runoff. Outlets are located at the downstream terminal of the green gutter to convey any remaining runoff back to the roadway. Breaks integrated at intervals may be provided to accommodate pedestrian movements. This system can be used to separate corridors for different modes of transportation such as between cycling, vehicular and LRT infrastructure.

Designed and constructed appropriately, green gutter systems reduce the quantity of stormwater runoff and pollutants discharged into the storm sewer systems or receiving waters, such as lakes and rivers. These systems also provide opportunities to enhance streetscape and landscape aesthetics. Key components of the green gutter system for inspection and maintenance are tabulated in Table 14 below.

Inspection and Testing Framework

During each type of inspection, visual and testing indicators associated with green gutters should be used to determine the basis for planning field work. Table 13 summarizes the inspection types required for each respective indicator.

Table 13: Inspection and testing indicators framework for green gutters

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity		x	x	x
3	Inlet Obstruction	x	x	x	x
4	Pre-treatment Sediment Accumulation	x	x	x	

5	Inlet Erosion		x	x	
6	GI Dimensions	x	x		x
7	Side Slope Erosion		x	x	
8	Surface Ponding Area	x	x		x
9	Standing Water		x	x	x
10	Trash		x	x	
11	Filter Bed Erosion		x	x	
12	Filter Bed Sediment Accumulation		x	x	x
13	Filter Bed Surface Sinking		x	x	
14	Mulch Depth	x	x	x	x
15	Surface Ponding Depth	x	x		x
16	Check Dams	x	x	x	x
17	Vegetation Cover	x	x	x	x
18	Vegetation Condition		x	x	
19	Vegetation Composition	x	x	x	
20	Monitoring Well Condition	Not Applicable			
21	Underdrain/Perforated Pipe Obstruction		x		x
22	Overflow Outlet Obstruction	x	x	x	x
23	Pavement Surface Condition	Not Applicable			
24	Pavement Surface Sediment Accumulation	Not Applicable			
25	Control Structure Condition	Not Applicable			
26	Control Structure Sediment Accumulation	Not Applicable			
	Testing Indicators	**Inspection Type**			
		Construction	**Warranty**	**Routine Operation**	**Verification**
1	Soil Characterization Testing	x	x		(x)
2	Sediment Accumulation Testing	x	x	x	x
3	Surface Infiltration Rate Testing		x		(x)

4	Natural or Simulated Storm Event Testing		x		(x)
5	Continuous Monitoring	Not Applicable			

Routine Maintenance

Recommended routine maintenance tasks and respective frequencies for each green gutter component is listed in Table 14. Depending on the location, greater routine maintenance should be undertaken with practices in highly visible areas, receiving flows from high traffic areas such as from vehicle and pedestrian corridors, or draining to a sensitive receiving waterbody. Higher frequencies of maintenance tasks such as trash, debris, and sediment removal or weeding or trimming of vegetation may also be required for green gutter systems located within these high priority areas.

To note, tasks denoted with a six month frequency in Table 14 should ideally be performed in the spring and late fall or early winter. Tasks denoted with a three month frequency should ideally be performed in the spring, summer, early fall, and later fall or early winter. Vegetation watering throughout the lifespan of the GI is to be performed as required, but the frequency should be increased during drought conditions. Personnel conducting vegetation maintenance should be experienced with the designated planting plan, plant species identification and weed removal or control methodologies. An 80 per cent vegetation cover should be achieved within two years of planting or prior to the warranty period.

Table 14: Key green gutter components and routine maintenance tasks

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Contributing Drainage Area	Contributing drainage area is the designated area (including pervious, impervious, and GI area) where runoff is conveyed into the GI system. The area should be free of point source pollutants	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	(e.g. leaks, spills) while trash, sediment, and debris should be regularly removed from pavements and regions of conveyance towards the GI (e.g. gutters, catch basins).	Re-plant or seed bare soil areas		
Inlets	Inlets include curb cuts or similar engineered structures, drains or pipes, and pavement edges. Curb cut inlets may be installed intermittently along the GI length to provide greater stormwater runoff capture into the GI from adjacent roadways. Inlets must remain clear of any obstructions (e.g. trash, debris) to ensure runoff is conveyed to the GI system. Erosion control measures (e.g. sediment pad, rip-rap) may be required for certain inlets to prevent concentrated flow induced erosion to the GI.	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Remove woody vegetation at inflow points		
Pre-treatment and Sediment Pad	Pre-treatment involves features or methods to attenuate and spread concentrated stormwater runoff flows prior to entering the GI system. Pre-treatment features (e.g. sediment pads) allow for sedimentation and filtration of coarse suspended material in the runoff to reduce the	Remove trash, natural debris and clippings	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Re-grade and re-plant eroded areas when ≥30cm in length	As required	As required

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	accumulation of sediment within the GI over its operational period. Frequent maintenance is required for trash and debris removal.			
Perimeter	The perimeter of the GI system may consist of side slopes (mixture of mulch, stone and vegetation), vertical walls, or similar concrete structures to permit the conveyance of stormwater along its length. Inspections are to confirm an acceptable dimension of the GI, the maintenance of its structural integrity, and the continual provision of the designed surface ponding volume and conveyance capacity of the gutter. Periodic maintenance is necessary to repair erosion rills and damage by vehicle or foot traffic.	Add stone or mulch to maintain 5-10cm depth on non-vegetated areas	2 years	2 years
		Replace dead/diseased plants to maintain a minimum 80% vegetation cover	1 year	6 months
		Re-grade and re-plant eroded areas when ≥30cm in length	As required	As required
Filter Bed	The GI system is typically a parabolically shaped open channel with a longitudinal slope and topsoil/growing media layer covered with vegetation, mulch, and stone. This mixture encourages the filtration, percolation	Remove trash	6 months	3 months
		Re-distribute mulch or stone cover to maintain 5-10cm depth for non-vegetated areas		
		Core aerate (in softscape context)	5 years	3 years

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	and evaporation of stormwater and the slope prevents extended surface ponding of the runoff. The depth of the filter bed (primarily bioretention media and clean sand) is engineered to allow adequate stormwater storage and to infiltrate all surface ponding within 24 hours following a storm event. Regular inspections of maximum ponding depth and required maintenance (trash, debris and sediment removal) should be conducted to avoid standing water which encourages mosquito breeding. Mulch, stone and vegetation cover are to be maintained routinely to prevent weed growth and soil erosion. Animal burrows, sunken areas, erosion rills, and vehicle or foot damage are to be repaired to maintain the designed storage and permeability of the GI.	Remove accumulated sediment when ≥5cm depth	As required	As required
		Re-grade and restore cover over any animal burrows, sunken areas when ≥10cm in depth and erosion rills when ≥30cm in length		
		Add stone or mulch to maintain 5-10cm depth on non-vegetated areas	2 years	2 years
Vegetation	Vegetation planted in the GI (including ornamental grasses,	Watering during first two months after planting	3 days	3 days

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
(grasses, ground covers, etc.)	perennials and other groundcovers) intercepts, uptakes and allows the transpiration of stormwater. It promotes soil organisms which decompose pollutants while the root systems assist in maintaining the soil structure and permeability. Similar to conventional planting beds, regular maintenance including weeding, mowing, and irrigation during droughts are required. In the first 2 months of operation, the vegetation is to be irrigated frequently while the use of fertilizer is generally unnecessary (applied as required) as the GI functions to retain nutrients from the stormwater inflow.	Watering for the remainder of the first two growing seasons (May to Sept.) after planting or until vegetation is established	As required	As required
		Watering for the remainder of the GI lifespan	As required	As required
		Mow grass to maintain height between 10-15cm	1 month	2 weeks
		Remove undesirable vegetation (voluntary tree seedlings, invasive species/weeds)	6 months	3 months
		Replace dead/diseased plants to maintain a minimum of 80% vegetation cover	1 year	6 months
		Cut back spent plants		
		Divide or thin out overcrowded plants		
Overflow Outlets	Overflow outlets (e.g. curb cut outlets) are installed to collect excess flows from large storm events exceeding the storage capacity. Periodic maintenance is to be undertaken to ensure the outlet structure remains unobstructed so stormwater can be safely conveyed to adjacent drainage systems.	Remove trash, natural debris, clippings, woody vegetation and sediment on grate	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Underdrain	Depending on the permeability of the underlying native soil or other constraints, underdrains may be installed below the filter media to collect and convey water to adjacent drainage systems. The underdrain consists of a perforated pipe surrounded with gravel and optionally wrapped with geotextile. A cleanout may be installed for periodic inspection and flushing of the underdrain for sediment removal to ensure water is drained from the GI within its designed timeframe. If vegetation roots penetrate into the underdrain, they can be removed by mechanical means (e.g. drill). If the roots belong to a tree, an Urban Forestry permit may be required before any work is performed. Contact 311 for more information. Flow-restrictors should be inspected and cleaned regularly.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Life Cycle Operations and Maintenance

Infrastructure decisions are evaluated over a typical period of 50 years which can be considered the standard lifespan of a green gutter system and all its components. However, the lifespan of such systems may extend beyond this threshold due to its limited number of components. Green gutter systems will require maintenance tasks to be routinely performed to ensure continuing operation of the GI to design performance standards. Vegetation management activities should be routinely conducted throughout the lifetime of the system with the aim of maximizing vegetation vigour and preventing the spread of invasive species. As listed in Table 14, maintenance practices fall into two categories – minimum required frequencies and high priority frequency. Therefore, depending on the location of the GI, the overall cost of maintenance for its service life will vary. In general, most of the operations and maintenance activities involve removal of unwanted materials such as trash, debris, sediment and vegetation trimming and weeding to ensure the pollutant filtration and sediment retention properties of the filter bed are maintained.

In terms of end of life cycle activities, similar standards to other stormwater infrastructure and landscaping components apply to the decommissioning and disposal of green gutter system components. This involves adhering to provincial regulations for the proper removal, disposal and replacement of materials, removal or capping of system components, and other required restorations to the area. However, for specific products and/or materials, it is recommended that manufacturer specifications are followed.

Failure Conditions

Key issues that lead to the failure of green gutters include clogging within the pre-treatment features such as sediment pads which cause stormwater runoff to overtop the feature. As a result, the runoff may include trash, debris, sediment, pollutants, and contaminant loads which enter the GI system and impair its delivery of water quality benefits, for example filtration, flow attenuation and infiltration. Other malfunctions of the pre-treatment feature may concentrate flows and cause erosion of the filter bed. Inadequate construction of components such as inlets with low conveyance capacity towards the GI and an uneven filter bed which promotes standing water or erosion may also cause the system to fail. The following mitigation strategies are recommended to be undertaken as required to prevent the decline of the system’s level of service.

Mitigation Strategies

Overall, green gutters require regular maintenance practices at appropriate intervals to prevent failure of the system from occurring since these systems are mainly located in high traffic and high visibility areas.

Mitigation strategies begin with the stabilization of the contributing drainage area to the GI to avoid or minimize unwanted material from entering the system. Regular street sweeping within the catchment area of the GI system will reduce the loading of fine suspended solids which may clog the filter media over time. Street sweeping also reduces the maintenance frequency of trash, debris and sediment removal at the inlet or filter bed. During the fall, sediment and debris should be removed before snowfall occurs, and during the spring before snowmelt runoff. During the winter, strategic application of de-icing and anti-skid substances within the contributing drainage area can lessen sedimentation and the need for clean-up maintenance. Furthermore, the GI area should only be used as a snow storage facility provided there is sufficient volumetric capacity and the snow weight can be accommodated.

Other mitigation strategies include the removal of trash, debris, and sedimentation along with maintaining an acceptable height of vegetation and grasses. Greater attention on pre-treatment facilities is needed to ensure they remain clear of obstructions. More frequent inspections are to be undertaken following major storm events and during the first two years of the GI service life. This allows for early detection of erosion or other deficiencies of the system. Green gutters located adjacent to high traffic urban areas may experience increased levels of sediment loading and pollutant or contamination levels than systems in rural settings. Sediment or silt accumulation rates and surficial contaminants such as oil should be monitored often once the system is operational to establish appropriate removal frequencies. Immediate repairs should be made if signs of clogging, uneven flow distribution, and compaction of the filter bed are observed during periodic inspections. Remedial activities such as surface reseeding, re-leveling, and scarifying or spiking of the topsoil shall be undertaken as required to reinstate design levels. Further troubleshooting and possible actions are discussed below if lower levels of service within the system persists.

Troubleshooting and FAQs

If a decline in level of service is observed, the following section provides troubleshooting along with guidance on rehabilitation, repair work and related tasks for green gutter systems.

Inlets

The inlet is producing concentrated flows which results in filter bed erosion…

Install a sediment pad or regrade feature back to the appropriate elevation to reduce concentrated flow and promote sheet flow into the filter bed. Regrade damaged or eroded areas of the filter bed and replant or restore the mulch and/or stone cover. If further erosion occurs, consider replacing filter bed vegetation and mulch cover at inlets with stone material (e.g. rip-rap).

Filter Bed

The growing medium is overly compact…

Possible tasks include core aerating, removal of stone, mulch, vegetation and till up to 20 cm of growing medium every three to five years, or replacement of overly compact material with non-compact growing media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Growing medium contains soluble salts exceeding 2.0mS/cm …

As necessary, flush the affected area thoroughly with fresh dechlorinated water to remove excess salts from the soil.

There is a significant accumulation of sediment on the filter bed affecting the functional performance of the GI…

It is recommended that accumulated sediment be removed by hand using a rake and shovel where feasible to prevent excessive compaction of the filter bed. In extreme cases, hydro-vac equipment can be use in a manner which avoids damage or compaction to the side slopes and filter bed. If required, remove the vegetation and top 5 cm of contaminated growing medium. Replace with growing media that meets design standards.

Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Surface ponding is observed to remain for extended periods…

Remove the stone, vegetation and accumulated sediment. To reduce surface crusting and compaction, topsoil should be tilled to a depth of 20 cm or, replace the top 15 cm of material with growing media that meets design standards to decrease fine texture clogging. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

There is observed damage to the filter bed or side slope from erosion rills, animal burrows, local sinking, and ruts…

Re-grade damaged portion and replace the stone, mulch, and vegetation cover. Areas with animal burrows, local sinking, and compacted areas should be tilled to a depth of 20 cm prior to re-grading.

Vegetation Growth

In general, ensure that dead or diseased plant material is replaced on a bi-annual to annual basis to promote vegetation vigour and reduce possible negative impacts on healthy surrounding vegetation. Bare soil areas should be re-seeded every six months to one year.

Poor vegetation growth due to low organic matter or phosphorus content of topsoil…

Top dress with compost. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Poor vegetation growth due to filter media pH out of specification range (pH 6.0 to 7.8)…

If the soil pH is below 6.0, amend the soil with limestone to raise the pH back to neutrality. If the soil pH is greater than 7.8, amend the soil with compost or sulphur to lower the pH back to neutrality.

Filter Strip

System Overview

Filter strips are defined as gently-sloping, densely vegetated areas that treat runoff as sheet flow from adjacent impervious surfaces such as roadways, sidewalks, driveways, and parking lots. These systems typically comprise of a layer of amended topsoil or growing medium with increased water-retentive properties to enhance runoff attenuation, sedimentation, filtration, infiltration and evaporation. Filter strips may function as a stand-alone practice or as pre-treatment features where excess water can be conveyed to other adjacent GI or drainage systems.

Provided proper practices, filter strip systems reduce the quantity of stormwater runoff and pollutants discharged into the storm sewer systems or receiving waters, such as lakes and rivers. Depending on the location, these systems also provide suitable snow storage area during winter months and aesthetic value as attractive landscaped features. Key components of filter strip systems for inspection and maintenance are tabulated in Table 16.

Inspection and Testing Framework

During each type of inspection, visual and testing indicators associated with filter strips should be used to determine the basis for planning field work. Table 15 summarizes the inspection types required for each respective indicator. In the table, “x” denotes where an indicator should be used in each inspection type and “(x)” denotes that the indicator is used only for performance verification.

Table 15: Inspection and testing indicators framework for filter strips (Adapted from TRCA LID SWM IM Guide, 2016)

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity		x	x	x
3	Inlet Obstruction	x	x	x	x
4	Pre-treatment Sediment Accumulation	Not Applicable			
5	Inlet Erosion	Not Applicable			
6	GI Dimensions	x	x		x
7	Side Slope Erosion	Not Applicable			
8	Surface Ponding Area	Not Applicable			
9	Standing Water		x	x	x
10	Trash		x	x	
11	Filter Bed Erosion		x	x	
12	Filter Bed Sediment Accumulation	Not Applicable			
13	Filter Bed Surface Sinking		x	x	
14	Mulch Depth	Not Applicable			
15	Surface Ponding Depth	Not Applicable			
16	Check Dams	Not Applicable			
17	Vegetation Cover	x	x	x	x
18	Vegetation Condition		x	x	
19	Vegetation Composition	x	x	x	
20	Monitoring Well Condition	Not Applicable			
21	Underdrain/Perforated Pipe Obstruction	Not Applicable			

22	Overflow Outlet Obstruction	Not Applicable			
23	Pavement Surface Condition	Not Applicable			
24	Pavement Surface Sediment Accumulation	Not Applicable			
25	Control Structure Condition	Not Applicable			
26	Control Structure Sediment Accumulation	Not Applicable			
	Testing Indicators	**Inspection Type**			
		Construction	**Warranty**	**Routine Operation**	**Verification**
1	Soil Characterization Testing	x	x		(x)
2	Sediment Accumulation Testing	Not Applicable			
3	Surface Infiltration Rate Testing		x		(x)
4	Natural or Simulated Storm Event Testing	Not Applicable			
5	Continuous Monitoring	Not Applicable			

Routine Maintenance

Recommended routine maintenance tasks and respective frequencies for each filter strip component is listed in Table 16. Regular maintenance is required to ensure operational performance standards of the filter strip system are met; however, the tasks required are relatively straightforward and should generally require minimal landscaping work beyond what is required for regular open public spaces. Depending on the location, higher routine maintenance should be undertaken with practices in highly visible areas, receiving flows from high traffic areas such as from vehicle and pedestrian corridors, or draining to a sensitive receiving waterbody. Greater frequencies of maintenance tasks such as trash, debris, and sediment removal or weeding or trimming of vegetation may also be required for filter strips located within these high priority areas.

Tasks with a six month frequency in Table 16 should ideally be performed in the spring and late fall or early winter. Tasks with a three month frequency should ideally be performed in the spring, summer, early fall, and later fall or early winter. Vegetation watering throughout the lifespan of the GI is to be performed as required, but the frequency should be increased during drought conditions. Personnel conducting vegetation maintenance should be experienced with the designated planting plan, plant species identification and weed removal or control methodologies.

Table 16: Key filter strip components and routine maintenance tasks (Adapted from TRCA LID SWM IM Guide, 2016)

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Contributing Drainage Area	Contributing drainage area is the designated area (including pervious, impervious, and GI area) where runoff is conveyed into the GI system. The area should be free of point source pollutants (e.g. leaks, spills) while trash, sediment, and debris should be regularly removed from pavements and regions of conveyance towards the GI (e.g. gutters).	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Re-plant or seed bare soil areas	1 year	6 months
Inlets	The GI mainly receives sheet flow from inlets including pavement edges or pipes (e.g. downspouts). Inlets must remain clear of any obstructions (e.g. trash, debris) to ensure runoff is conveyed to the GI system. Erosion control measures (e.g. gravel level spreader may be required for inlets to prevent	Remove trash, natural debris, clippings, and sediment	6 months	3 months
		Reconfigure gravel level spreader if displaced		
		Remove accumulated sediment	1 year	6 months

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	concentrated flow induced erosion to the GI.			
Perimeter	The perimeter of the GI system should be inspected to confirm it adheres to design dimensions and footprint area. The depth and degree of compaction of soil amended areas should also be verified against the acceptable design criteria. Periodic maintenance may be required to repair erosion rills and damage by vehicle or foot traffic.	Re-seed bare soil areas	1 year	months
		Replace dead/diseased plants to maintain a minimum 80% vegetation cover	1 year	6 months
Filter Bed	The surface of the filter bed comprises of a gently sloping vegetated area that will receive stormwater runoff directed into the system via the inlet structure. It is composed of a minimum 0.15m thick topsoil layer which is typically amended to better facilitate stormwater attenuation, filtration, and evaporation. During any storm event, the GI should not pond water on the surface. Regular inspections for standing water should be performed along with trash and debris removal. Animal burrows, sunken areas, erosion rills, and vehicle or foot damage are to be repaired to minimize surface ponding within the GI.	Remove trash	6 months	3 months
		Core aerate	5 years	3 years
		Remove accumulated sediment when ≥5cm depth	As required	As required
		Re-grade and restore cover over any animal burrows, sunken areas when ≥10cm in depth and erosion rills when ≥30cm in length		
		Add stone to maintain 5-10cm depth for non-vegetated areas		

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Vegetation (grasses and ground covers)	Vegetation planted in the GI (typically grasses and other groundcovers) intercepts, uptakes and allows the transpiration of stormwater. It promotes soil organism which decompose pollutants while the root systems assist in maintaining the soil structure and permeability. Regular maintenance including weeding, mowing, pruning and irrigation during droughts are required. In the first 2 months of operations, the vegetation is to be irrigated frequently while a periodic top dressing of compost may be applied as required by degree of amendment of the soil.	Watering during first two months after planting	3 days	3 days
		Watering for the remainder of the first two growing seasons (May to Sept.) after planting or until vegetation is established	As required	As required
		Watering for the remainder of the GI lifespan	As required	As required
		Mow grass to maintain height between 10-15cm	1 month	2 weeks
		Remove undesirable vegetation (tree seedlings, invasive species/weeds)	6 months	3 months
		Replace dead/diseased plants to maintain a minimum of 80% vegetation cover	1 year	6 months

The main concern of maintenance tasks performed within the GI system is the compaction of the filter bed which diminishes the designed operational function of the system. Maintenance tasks involving vehicles or foot traffic on the filter bed should be avoided during wet weather due to the increased risk of soil compaction while the soil is saturated. Lightest equipment available, for example push mower, should be selected for maintenance tasks to lessen the compaction of the filter bed. The removal of sediment accumulation within the filter bed should also be performed by hand and heavier equipment should remain off the GI footprint to avoid damage.

Life Cycle Operations and Maintenance

A filter strip system is relatively straightforward to maintain and should require minimal landscaping work above what is required for regular open public spaces. Therefore, the cost implications of maintaining this system is marginal in comparison to similar grass covered areas. Infrastructure decisions are evaluated over a typical period of 50 years which can be considered the standard lifespan of filter strip systems and all its components. However, the lifespan of such systems may extend well beyond this threshold due to its simple design.

Regular inspections and maintenance will be required throughout the course of its operations to ensure continuing operation of the GI to design performance standards. Adequate access should be provided to all areas of the filter strip to facilitate routine maintenance tasks; however, this should be a nonissue due to its location being typically adjacent to impermeable surfaces. As listed in Table 16, maintenance practices fall into two categories which either meets minimum required frequencies or pertains to high priority frequency. Therefore, depending on the location of the GI, the overall cost of maintenance for its service life will vary. In general, most of the operations and maintenance activities involve removal of unwanted materials such as trash, debris, sediment and grass mowing to ensure the pollutant filtration and sediment retention properties of the filter bed are maintained. Vegetation management activities should be routinely conducted throughout the lifetime of the system with the aim of maximizing vegetation cover and preventing the spread of invasive species.

In terms of end of life cycle activities, the decommissioning and disposal of filter strip components should be based on requirements in the provincial regulations. This may involve the proper removal, disposal and replacement of materials, removal of system components, and other required restorations to the area. However, for specific products and/or materials, it is recommended that manufacturer specifications are followed.

Failure Conditions

Key issues that lead to the failure of filter strips include clogging at the impervious surface or vegetation interface which disturbs the sheet flow and inadequate construction which hinders the system’s delivery of water quality benefits. Since the filter strip system is mainly used as a pre-treatment facility prior to introducing stormwater runoff to adjacent drainage systems, failure of the system often results in additional damages in performance of downstream components.

Although gravel level spreaders may be used to improve the consistency of the sheet inflow to the vegetated area, any clogging issues of the feature will inhibit the performance of the filter strip by concentrating the flow in one area. Ideally, the entire area of the filter strip should be utilized during practice to achieve maximum operational performance. In addition, inadequate or poor construction including an insufficient drop from the pavement edge and inaccurate grading causing erosion and surface ponding may all lead to failure conditions of the system. The following mitigation strategies are recommended to be undertaken as required to prevent the decline of the system’s level of service.

Mitigation Strategies

Overall, the filter strip system incorporates simple technology and minimal components for its purpose, but it requires attention to detail to function effectively. Regular maintenance practices should be performed at appropriate intervals to prevent failures of the system from occurring.

It is important that the contributing drainage area consists of a gentle slope towards the GI with no other surface gradients to guarantee consistent sheet inflow. Construction of this area should be appropriately monitored while repairs to existing areas should be made to accommodate an even flow towards the GI. Higher consideration should be made for construction of the interface between the impermeable area and GI system to ensure a shallow slope or fall from the contributing drainage areas is provided as per standard design requirements. Proper establishment of the interface will allow consistent sheet flow across the GI surface area.

Other mitigation strategies include the removal of trash, debris, and sedimentation along with maintaining an acceptable height of vegetation/grasses. More frequent inspections are to be undertaken following major storm events and during the first two years of the GI service life. This allows for early detection of erosion or other deficiencies of the system. Filter strips located adjacent to high traffic urban areas may experience increased levels of sediment loading and pollutant or contamination levels than systems in suburban settings. Sediment or silt accumulation rates and surficial contaminants such as oil should be monitored often once the filter strip system is operational to establish appropriate removal frequencies. Immediate repairs should be made if signs of clogging of the gravel level spreader, uneven flow distribution, and compaction of the filter bed are observed during periodic inspections. Remedial activities such as surface reseeding, re-leveling, and scarifying or spiking of the growing medium shall be undertaken as required to reinstate design levels. Further troubleshooting and possible actions are discussed below if lower levels of service within the system persists.

Troubleshooting and FAQs

If a decline in level of service is observed, the following section provides troubleshooting along with guidance on rehabilitation, repair work and related tasks for filter strip systems.

Inlets

The inlet is producing concentrated flows which results in filter bed erosion…

Install a gravel flow spreader or regrade feature back to the appropriate elevation to reduce concentrated flow and promote sheet flow into the filter bed. Regrade damaged or eroded areas of the filter bed and replant or restore the mulch and/or stone cover. If gravel flow spreader was previously installed, realign, replenish or remove stone material and clean all sediment deposits or replace with new material that meets design standards. If further erosion occurs, consider adding turf reinforcement or replacing filter bed vegetation at inlets with stone material (e.g. rip-rap).

Filter Bed

The growing medium is overly compact…

Possible tasks include core aerating, removal of stone, mulch, vegetation and till up to 20 cm of growing medium every three to five years, or replacement of overly compact material with non-compact growing media that meets design standards. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Growing medium contains soluble salts exceeding 2.0mS/cm …

As necessary, flush the affected area thoroughly with fresh dechlorinated water to remove excess salts from the soil.

There is a significant accumulation of sediment on the filter bed affecting the functional performance of the GI…

It is recommended that accumulated sediment be removed by hand using a rake and shovel where feasible to prevent excessive compaction of the filter bed. In extreme cases, hydro-vac equipment or an excavator should be used in a manner which avoids damage or compaction to the side slopes and filter bed.

Surface ponding is observed to remain for more than 24 hours or the surface infiltration rate is out of the acceptable range…

Remove the stone, vegetation and accumulated sediment. To reduce surface crusting and compaction, growing medium should be tilled to a depth of 20 cm or, replace the top 15 cm of material with new growing media that meets design standards to alleviate fine texture clogging. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

There is observed damage to the filter bed or side slope from erosion rills, animal burrows, local sinking, and ruts…

Re-grade damaged portion and replace the stone, mulch, and vegetation cover. Areas with animal burrows, local sinking, and overly compact areas should be tilled to a depth of 20 cm prior to re-grading.

Vegetation Growth

In general, ensure that dead or diseased plant material is replaced on a bi-annual to annual basis to ensure vegetation cover and reduce possible negative impacts on healthy surrounding vegetation. Bare soil areas should be re-seeded every six months to one year.

Poor vegetation growth due to low organic matter or phosphorus content of topsoil…

Top dress with compost. Replace stone, mulch and vegetation cover as required and where possible, reuse or transplant.

Poor vegetation growth due to filter media pH out of specification range (pH 6.0 to 7.8)…

If the soil pH is below 6.0, amend the soil with limestone to raise the pH back to neutrality. If the soil pH is greater than 7.8, amend the soil with compost or sulphur to lower the pH back to neutrality.

Permeable Pavements

System Overview

In contrast to conventional impervious pavements where precipitation such as rainwater and snowmelt flow over the surface, permeable pavements include joints or pores or both (porous pavements) which allow water to drain through the surface. Infiltrated water may be temporarily stored within the clear stone – washed gravel – aggregate base beneath which it either percolates into the underlying native soil or is conveyed to other drainage systems via an underdrain. Permeable pavements are installed in low to medium traffic roads, parking areas, driveways, and pedestrian walkways.

Permeable pavements may be categorized by the type of surface layer used as follows:

- Permeable Interlocking Concrete Pavers (PICP): consist of precast modular concrete units and pervious concrete or rubber/plastic composite designed to allow fine, washed aggregate within the joint spacing;
- Porous asphalt: utilizes minimal fine aggregate in combination with a bituminous binder to allow the formation of connected pores within the flexible pavement structure; and
- Pervious concrete: also utilizes minimal fine aggregate in combination with a cementitious binder to allow the formation of connected pores within the rigid pavement structure.

Properly designed and constructed, permeable pavement systems reduce the quantity of stormwater runoff, pollutants discharged into the storm sewer systems or receiving waters such as lakes and rivers, and replenish groundwater resources. Key components of permeable pavement systems for inspection and maintenance are tabulated in Table 18.

Inspection and Testing Framework

During each type of inspection, visual and testing indicators associated with permeable pavements should be used to determine the basis for planning field work. Table 17 summarizes the inspection types required for each respective indicator. In the table, “x” denotes where an indicator should be used in each inspection type and “(x)” denotes that the indicator is used only for performance verification.

Table 17: Inspection and testing indicators framework for permeable pavements (Adapted from TRCA LID SWM IM Guide, 2016)

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity	Not Applicable			
3	Inlet Obstruction	Not Applicable			
4	Pre-treatment Sediment Accumulation	Not Applicable			
5	Inlet Erosion	Not Applicable			
6	GI Dimensions	x	x		x
7	Side Slope Erosion	Not Applicable			
8	Surface Ponding Area	Not Applicable			
9	Standing Water		x	X	x
10	Trash		x	X	
11	Filter Bed Erosion	Not Applicable			
12	Filter Bed Sediment Accumulation	Not Applicable			
13	Filter Bed Surface Sinking	Not Applicable			
14	Mulch Depth	Not Applicable			
15	Surface Ponding Depth	Not Applicable			
16	Check Dams	Not Applicable			
17	Vegetation Cover	Not Applicable			
18	Vegetation Condition	Not Applicable			
19	Vegetation Composition	Not Applicable			
20	Monitoring Well Condition	x	x	x	x
21	Underdrain/Perforated Pipe Obstruction		x		x

22	Overflow Outlet Obstruction	x	x	x	x
23	Pavement Surface Condition	x	x	x	
24	Pavement Surface Sediment Accumulation	x	x	x	x
25	Control Structure Condition	x	x	x	x
26	Control Structure Sediment Accumulation	x	x	x	x
	Testing Indicators	**Inspection Type**			
		Construction	**Warranty**	**Routine Operation**	**Verification**
1	Soil Characterization Testing	Not Applicable			
2	Sediment Accumulation Testing	Not Applicable			
3	Surface Infiltration Rate Testing		x		(x)
4	Natural or Simulated Storm Event Testing		x		(x)
5	Continuous Monitoring	Not Applicable			

Routine Maintenance

Recommended routine maintenance tasks and respective frequencies for each permeable pavement component is listed in Table 18. Depending on the location, greater routine maintenance should be undertaken with practices in highly visible areas, receiving flows from high traffic areas such as from vehicle and pedestrian corridors, or draining to a sensitive receiving waterbody. Higher frequencies of maintenance tasks such as trash, debris, and sediment removal or weeding/vegetation removal may also be required for permeable pavement systems located within these high priority areas.

Tasks with a six month frequency in Table 18 should ideally be performed in the spring and late fall/early winter. Tasks with a three month frequency should ideally be performed in the spring, summer, early fall, and later fall or early winter. Any sweeping and vacuuming activities should be done in dry weather.

Table 18: Key permeable pavement components and routine maintenance tasks (Adapted from TRCA LID SWM IM Guide, 2016)

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Contributing Drainage Area	Contributing drainage area is the designated area (including pervious, impervious, and GI area) where runoff is conveyed into the GI system. The area should be free of point source pollutants (e.g. leaks, spills) while trash, sediment, and debris should be regularly removed from pavements and regions of conveyance towards the GI (e.g. gutters).	Remove trash, natural debris, clippings, and sediment	6 months	3 months
			1 year	6 months
Pavement Surface	Surface inspections should be conducted to verify GI dimensions, damages, deformation (e.g. ruts), unevenness, open joints, and sediment accumulation. Ponding on the surface indicates a malfunction of the system and should not occur on the permeable pavement. PICP, porous asphalt, and pervious concrete require regular sweeping and vacuuming to remove sediment from joints and pores along with periodic removal of trash and natural debris. Snow removal and application with de-icing salt should be performed as required in the winter. Due to	Remove trash, natural debris and clippings (rakes and leaf blowers)	6 months	3 months
		Remove accumulated sediment (sweep and vacuum)	1 year	6 months
		Replace/top up joint fill material		
		Remove undesirable vegetation (voluntary tree seedlings, invasive species/weeds)		
		Plow snow and apply de-icing salt during winter	As required	As required

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	clogging issues of joints and pores, sand should not be used as an anti-slip agent.	re-paint lines/parking space divisions (if applicable)	3 years	3 years
Overflow Outlets	Overflow outlet structures (e.g. catch basin, curb cut) are installed to collect excess flows exceeding the storage capacity of the GI usually during major storm events. Periodic maintenance is to be undertaken to ensure the outlet structure remains unobstructed so stormwater can be safely conveyed to adjacent drainage systems.	Remove trash, natural debris, and sediment on grate	6 months	3 months
		Flush out accumulated sediment with hose or pressure washer	1 year	1 year
Underdrain	Depending on the permeability of the underlying native soil, underdrains may be installed below the storage layers to collect and convey water to adjacent drainage systems. The underdrain consists of a perforated pipe surrounded with gravel and optionally wrapped with geotextile. A cleanout may be installed for periodic inspection and flushing of the underdrain for sediment removal to ensure the subsurface water storage capacity is drained from the GI within its designed timeframe.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Monitoring Well	Monitoring wells are standpipes extending from the surface of the pavement to the bottom of the excavation. Perforations within the pipe allow for observation and measurement of the subsurface water level. Such monitoring helps ensure that the drainage system is functioning as designed over time. Monitoring wells should be securely capped, undamaged, and may require periodic flushing to remove accumulated sediment.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year
Control Structure	If present, the control structure can be a manhole or catch basin where the underdrain connects. Access through the control structure to the underdrain allows for damage and sediment accumulation inspections.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Life Cycle Operations and Maintenance

Permeable pavements require regular maintenance activities during its service life to ensure acceptable performance levels. Similar to conventional impervious pavements, the surface of permeable pavements is assumed to require rehabilitation after 30 years of operation to maintain the surface drainage performance at an acceptable level. However, the remainder of the subsurface infrastructure and components can typically have a lifespan of 50 years.

Operations and maintenance activities of permeable pavement practices fall into two categories as listed in Table 18 which either meets minimum required frequencies or pertains to high priority frequency. Therefore, depending on the location of the

GI, the overall cost of maintenance for its service life will vary. In general, most of the operations and maintenance are preventative activities to maintain the drainage integrity of the pavement surface. This involves special winter considerations and the removal of unwanted materials such as trash, debris, and sediment to avoid clogging.

In terms of end of life cycle activities, similar standards to other stormwater infrastructure and roadway components apply to the decommissioning and disposal of permeable pavement system components. This may involve adhering to provincial regulations for the proper removal, disposal and replacement of materials, removal or capping of system components, and other required restorations to the area. However, for specific products and/or materials, it is recommended that manufacturer specifications are followed.

Failure Conditions

The function of permeable pavement systems is intended to effectively capture, treat, store, infiltrate, or discharge design storm events in a controlled manner. The main failure condition resides at the surface where clogging of the GI inhibits the infiltration of rainwater into the subsurface. Surface ponding or significant ice formation is a clear indicator that the system is malfunctioning and requires immediate remedial action. Clogging of the drainage layers or underdrain may also be the cause of surface ponding and result in system failure.

Failure may also occur if the permeable pavement does not provide sufficient structural resistance to withstand the loading imposed on the surface. Depressions, rutting, cracked or broken paver units are detrimental to the structural performance and present hazards for the users. The following mitigation strategies should be undertaken as required to prevent the decline of the system's level of service.

Mitigation Strategies

To reduce the potential of clogging within the joints or pores or both of the permeable pavement surface, mitigation strategies begin with the stabilization of the contributing drainage area to the GI. This includes monitoring any water runoff from adjacent impermeable pavements and avoiding the drainage of adjacent landscaped areas into the GI to limit the amount of eroded soil entering the system. Standard cosmetic sweeping, brushing, and vacuuming of the whole GI surface should be conducted regularly while conventional street sweeping should be maintained on contributing impervious drainage areas. Other sources and activities which lead to sediment buildup on the pavement surface should be limited or prohibited to prevent clogging of joints and/or pores. For example, access to construction vehicles should be prohibited as they may track sediment onto the pavement surface. Storage of soil, compost, sand, salt, or unwashed gravel on the permeable pavement should also be prohibited or if necessary, be temporarily placed on top of tarps or geotextile. Sealants should not be used to repair permeable pavements.

For winter operations and maintenance, snowplows can be used on permeable pavements for snow removal. Plow blades should be slightly raised off the surface with a shoe attachment or rubber spacer to allow a buffer that reduces the risk of dislodging pavers and displacement of joint fill material. Permeable pavement should not be used as a facility to store snow since its function may be impaired by clogging and sediment accumulation upon melting. Furthermore, sand should not be used as an anti-slip agent as it may clog joints and pores. De-icers should be used sparingly as permeable pavements are designed to drain freely with no surface ponding which reduces ice formation.

If indicators of clogging or blockages within the system persist, major rehabilitation work may be required if other mitigation strategies or major repair tasks listed in the following troubleshooting section are unsuccessful.

Troubleshooting and FAQs

If a decline in level of service is observed, the following section provides troubleshooting along with guidance on rehabilitation, repair work and related tasks for permeable pavement systems.

Pavement Surface

There are major cracks, spalling or raveling of the porous asphalt or pervious concrete surfaces…

Small potholes or cracks can be filled with patching mixes. Larger potholes and cracks may require sectional surface layer cutting and replacement as required. Where possible, replacements should use the same permeable material.

Paver unit is missing, damaged or displaced…

Replace or reset paver units by hand and restore joint fill material conforming to design standards.

Surface infiltration rate is <250mm/hr

Thorough sweeping and vacuuming with a pure vacuum sweeper should be conducted to remove accumulated sediment. Replace any joint fill material removed by vacuuming. If needed or if clogging in joints/pores are visible, pre-treatment of the affected pavement surfaces such as water-assisted techniques or additional sweeping should be performed prior to vacuuming. If surface infiltration rates remain unacceptable, all pavers, bedding, joint fill, and top 5 cm or base aggregate should be removed and replaced with materials that meet design standards/specifications.

Underdrain

The perforated underdrain pipe is obstructed by sediment…

If applicable, schedule hydro-vac truck or drain-snaking service to remove obstructions from the underdrain.

Infiltration Trench

System Overview

Infiltration trenches are typically underground systems used to treat and temporarily store stormwater below ground in shallow geotextile-lined excavations filled with clear stone—washed gravel. The temporary storage within the trench allows for the treatment and percolation of stormwater into the underlying native soil. Stormwater runoff may be conveyed into the system through inlets including curb cuts or similar concrete structures and drains or pipes connected to stormwater infrastructure, for example catch basins. Depending on the infiltration rate of the native soil, an underdrain may be installed to collect and discharge excess water to adjacent drainage systems if the storage is over capacity. In addition, overflow outlets, for example beehive catch basins or similar control structures are required to convey overflow or excess water in the system to adjacent drainage systems following major storm events.

Provided proper practices, infiltration trench systems reduce the quantity of stormwater runoff, pollutants discharged into the storm sewer systems or receiving waters, for example lakes and rivers and replenish groundwater resources. Infiltration galleries may also be located underneath features such as parking lots, roads, parks, and landscaped areas which allows for usage versatility in urban areas. Key components of infiltration trench systems for inspection and maintenance are tabulated in Table 20.

Inspection and Testing Framework

During each type of inspection, visual and testing indicators associated with infiltration trench systems should be used to determine the basis for planning field work. Table 19 summarizes the inspection types required for each respective indicator. In the table, “x” denotes where an indicator should be used in each inspection type and “(x)” denotes that the indicator is used only for performance verification.

Table 19: Inspection and testing indicators framework for infiltration trench (Adapted from TRCA LID SWM IM Guide, 2016)

	Visual Indicators	Inspection Type			
		Construction	Warranty	Routine Operation	Verification
1	Contributing Drainage Area Condition	x	x	x	x
2	Inlet Structural Integrity		x	x	x
3	Inlet Obstruction	x	x	x	x
4	Pre-treatment Sediment Accumulation	x	x	x	
5	Inlet Erosion		x	x	
6	GI Dimensions	x	x		x
7	Side Slope Erosion		x	x	
8	Surface Ponding Area	x	x		x
9	Standing Water		x	x	x
10	Trash		x	x	
11	Filter Bed Erosion		x	x	
12	Filter Bed Sediment Accumulation		x	x	x
13	Filter Bed Surface Sinking		x	x	
14	Mulch Depth	x	x	x	x
15	Surface Ponding Depth	x	x		x
16	Check Dams	x	x	x	x
17	Vegetation Cover	x	x	x	x
18	Vegetation Condition		x	x	
19	Vegetation Composition	x	x	x	
20	Monitoring Well Condition	x	x	x	x
21	Underdrain/Perforated Pipe Obstruction		x		x
22	Overflow Outlet Obstruction	x	x	x	x
23	Pavement Surface Condition	Not Applicable			

24	Pavement Surface Sediment Accumulation	Not Applicable			
25	Control Structure Condition	Not Applicable			
26	Control Structure Sediment Accumulation	Not Applicable			
	Testing Indicators	**Inspection Type**			
		Construction	**Warranty**	**Routine Operation**	**Verification**
1	Soil Characterization Testing	x	x		(x)
2	Sediment Accumulation Testing	x	x	x	x
3	Surface Infiltration Rate Testing	Not Applicable			
4	Natural or Simulated Storm Event Testing		x		(x)
5	Continuous Monitoring		x		(x)

Routine Maintenance

Recommended routine maintenance tasks and respective frequencies for each infiltration trench component is listed in Table 20. Depending on the location, greater routine maintenance should be undertaken with practices in highly visible areas, receiving flows from high traffic areas such as from vehicle and pedestrian corridors, or draining to a sensitive receiving waterbody. Higher frequencies of maintenance tasks such as trash, debris, and sediment removal or weeding may also be required for infiltration trench systems located within these high priority areas.

Tasks with a six month frequency in Table 20 should ideally be performed in the spring and late fall or early winter. Tasks with a three month frequency should ideally be performed in the spring, summer, early fall, and later fall or early winter.

Table 20: Key infiltration trench components and routine maintenance tasks (Adapted from TRCA LID SWM IM Guide, 2016)

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Contributing Drainage Area	Contributing drainage area is the designated area (including pervious, impervious, and GI area) where runoff is conveyed into the GI system. The area should be free of point source pollutants (e.g. leaks, spills) while trash, sediment, and debris should be regularly removed from pavements and regions of conveyance towards the GI (e.g. gutters).	Remove trash, natural debris, and sediment	6 months	3 months
			1 year	6 months
Inlets	Inlets include curb cuts or similar engineered structures, drains or pipes, and pavement edges. Inlets must remain clear of any obstructions (e.g. trash, debris) to ensure runoff is conveyed to the GI system. Erosion control measures (e.g. stone cover, flow spreader) may be required for certain inlets to prevent concentrated flow induced erosion to the GI filter bed. Pipe inlets may consist of perforations and lined with geotextile which distributes the flow throughout the GI.	Remove trash, natural debris, and sediment	6 months	3 months
		Remove accumulated sediment	1 year	6 months
		Remove shrubs at inflow points		
Pre-treatment and Sediment Pad	Pre-treatment comprises of features or methods to attenuate and spread concentrated stormwater runoff flows prior to entering the GI system. Pre-treatment features allow for the settlement and filtration of coarse suspended material in the runoff to reduce the	Remove trash, and natural debris	6 months	3 months

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	accumulation of sediment within the GI over its operational period. These features may include geotextile-lined stone inlets, screens or filters, oil-grit separators, catch basins with appropriately sized sumps, and other similar engineered structures. Frequent maintenance is required for trash and debris removal.	Remove accumulated sediment	1 year	6 months
Filter Bed	The filter bed consists of a clear stone bed where the infiltration components are installed. The filter bed and geotextile fabric liner should be routinely inspected for sediment accumulation. Periodically, the removal of accumulated sediment will be required by means of hydro-vac equipment to maintain the GI's infiltration function.	Remove accumulated sediment when ≥ 8cm depth which requires the GI to be fully drained prior	6 months	3 months
Vegetation (shrubs, grasses, ground covers, etc.)	Vegetation planted in and around the GI (including shrubs, ornamental grasses, perennials and other groundcovers) intercepts, uptakes and allows the evapotranspiration of stormwater. It promotes soil organisms which decomposes pollutants while the root systems assist in maintaining the soil structure and permeability. Similar to conventional planting beds, regular maintenance including weeding, mowing, pruning and irrigation during droughts are required. In the first 2 months of operations, the vegetation is to be irrigated frequently while the	Watering during first two months after planting	3 days	3 days
		Watering for the remainder of the first two growing seasons (May to Sep) after planting or until vegetation is established	As required	As required
		Watering for the remainder of the GI lifespan	As required	As required
		Mow grass to maintain height between 10-15cm	1 month	2 weeks

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
	use of fertilizer is generally unnecessary (applied as required) as the GI functions to retain nutrients from the stormwater inflow.	Remove undesirable vegetation (tree seedlings, invasive species/weeds)	6 months	3 months
		Replace dead/diseased plants to maintain a minimum of 80% vegetation cover	1 year	6 months
		Prune shrubs	1 year	1 year
		Cut back spent plants		
		Divide or thin out overcrowded plants		
Overflow Outlets	Overflow outlet structures (e.g. beehive catch basin) are installed to collect excess flows exceeding the storage capacity of the GI usually during major storm events. Periodic maintenance is to be undertaken to ensure the outlet structure remains unobstructed so stormwater can be safely conveyed to adjacent drainage systems.	Remove trash, natural debris, and sediment on grate	6 months	3 months
		Flush out accumulated sediment with hose or pressure washer	1 year	1 year

Component	Description	Routine Maintenance Task	Frequency Interval	
			Minimum	High Priority
Underdrain	Depending on the permeability of the underlying native soil, underdrains may be installed within the clear stone fill or bedding to collect and convey water to adjacent drainage systems. The underdrain consists of a perforated pipe surrounded with gravel and optionally wrapped with geotextile. A cleanout may be installed for periodic inspection and flushing of the underdrain for sediment removal to ensure the subsurface water storage capacity is drained from the GI within its designed timeframe.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year
Monitoring Well	Monitoring wells are standpipes extending from the surface to the bottom of the excavation. Perforations within the pipe allow for observation and measurement of the subsurface water level. Such monitoring helps ensure that the drainage system is functioning as designed over time. Monitoring wells should be securely capped, undamaged, and may require periodic flushing to remove accumulated sediment.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year
Control Structure	If present, the control structure can be a manhole or catch basin where the underdrain connects. Access through the control structure to the underdrain allows for damage and sediment accumulation inspections.	Flush out accumulated sediment with hose or pressure washer	1 year	1 year
		Remove accumulated sediment when ≥ 10cm depth	As required	As required

Life Cycle Operations and Maintenance

Infrastructure decisions are evaluated over a typical period of 50 years which can be considered the standard lifespan of an infiltration trench system and all its components. However, the lifespan of these systems may extend beyond this threshold if proper maintenance is performed throughout its service life. Infiltration trench systems require maintenance tasks to be routinely performed to ensure continuing operation of the GI to design performance standards. If applicable, vegetation management activities should be routinely conducted throughout the lifetime of the system with the aim of maximizing biodiversity and preventing the spread of invasive species. As listed in Table 20, maintenance practices fall into two categories which either meets minimum required frequencies or pertains to high priority frequency. Therefore, depending on the location of the GI, the overall cost of maintenance for its service life will vary.

In terms of end of life cycle activities, similar standards to other stormwater infrastructure and landscaping components are expected to apply to the decommissioning and disposal of infiltration trench system components. This may involve adhering to provincial regulations for the proper removal, disposal and replacement of materials, removal or capping of system components, and other required restorations to the area. However, for specific products and/or materials, it is recommended that manufacturer specifications are followed.

Failure Conditions

Infiltration components are most susceptible to failure due to clogging from sediment. If adequate pre-treatment features are not installed to remove suspended solids and fine silts from the stormwater runoff, the system may fail more frequently. Infiltration trenches are also more prone to failure during the construction phase if the construction sequence is not followed correctly, construction sediment clogs the pit, or by reduction of the native soil infiltration rate due to heavy compaction from construction equipment. Depending on the severity of the clogging, there may be standing water in the pit which encourages mosquito breeding and poor water outflow quality affecting adjacent downstream drainage systems. The following mitigation strategies should be undertaken as required to prevent the decline of the system's level of service.

Mitigation Strategies

To reduce the potential of clogging in the infiltration trench, mitigation strategies begin with the stabilization of the contributing drainage area to the GI. This includes monitoring any water runoff from adjacent impermeable pavements and avoiding the collection of drainage from adjacent landscaped areas into the GI to limit the amount of eroded soil entering the system. Stockpiling of soil, compost or unwashed gravel within the contributing drainage area and inlet area should be prohibited to prevent clogging by sediment. Regular street sweeping within the catchment area of the GI system will also reduce the loading of fine suspended solids which may clog the filter media over time.

Pre-treatment features for the GI should be adequately maintained and routinely cleaned of trash, debris, contaminants and other obstructions. Inlet structures should be stabilized with appropriate erosion control and protection to minimize erosion and promote shallow sheet flow into the infiltration trench.

During construction, traffic and heavy vehicles should avoid travelling over the proposed location of the infiltration trench to minimize soil compaction. The trench should remain offline or non-operational until construction is complete and/or should not serve as a sediment control device to reduce heavy sediment buildup in the pit. During its service life, routine inspections should be performed to ensure the facility drains within the maximum acceptable timeframe.

If indicators of clogging or blockages within the system persist, major rehabilitation work may be required if other mitigation strategies or major repair tasks listed in the following troubleshooting section are unsuccessful.

Troubleshooting and FAQs

If a decline in level of service is observed, the following section provides troubleshooting along with guidance on rehabilitation, repair work and related tasks for infiltration trench systems.

Underdrain

The perforated underdrain pipe is obstructed by sediment, trash, roots, or debris…

If applicable, schedule hydro-vac truck or drain-snaking service to remove obstructions from the underdrain.

Pipe caps are missing or damaged…

Replace missing or damaged caps.

Filter Bed

The average sediment accumulation is ≥8cm in depth or the drainage performance is not within an acceptable range…

The system must be fully drained for the accumulated sediment to be removed through means of hydro-vac equipment.

Control Structure

The structure or pipe connection is leaking and impairing the water storage capacity or function of the GI system…

Repair of the cracks or sealing of leaks will be required. Depending on the type, location or severity of the repair, this may require the GI system to be fully drained.

Chapter 4 – Resident Engagement Protocol

GI systems, especially those located within urbanized areas, serve as aesthetic amenities and heavily impact the visual appearance of their surrounding environment. Features such as planters with lush vegetation contribute to the overall aesthetic value of the area. Therefore, it is important that adequate maintenance practices are in place to ensure GI conditions and functions are upheld. However, this also presents ample opportunities for the public such as residents and community members to be engaged and support the practices that preserve the function of GI systems long-term. This section outlines strategies which can be implemented to increase resident involvement during inspection and maintenance practices and improve the resiliency of the maintenance framework. For more information regarding the resident engagement protocol for GI, see *Community Engagement for Green Infrastructure in the Right-of-Way* manual.

Co-inspections

To improve the thoroughness and consistency of GI inspections conducted by property owners or responsible parties, municipalities should consider sending an inspector to assist or supervise during the inspection. Co-inspections are ideally implemented during the first few inspections as municipal inspectors can assist responsible parties in familiarizing inspection processes, identify issues, and immediately address questions or concerns. Co-inspections may also be performed periodically or as requested to reinforce or verify maintenance practices.

The following are maintenance and inspection activities that can be completed by the residents of Toronto, in conjunction with the *Community Engagement for Green Infrastructure in the Right-of-Way* manual:

Notify the City when the GI in my neighbourhood:

- Has leaf damage or fungus
- Has mushrooms growing in it

- Has pest-ridden trees and vegetation
- Has dead trees and vegetation
- Has consistent pooling water observed
- Has become visibly clogged
- The inlet is visibly damaged, crushed or blocked

What the resident can do without engaging the City:

- Remove trash and debris

Part 2 – Monitoring of Green Infrastructure

The implementation of monitoring programs for GI systems play a crucial role in assessing the performance of GI design installations over a period of time. Monitoring is the most comprehensive approach to inspecting GI systems as it quantifies drainage and water treatment performance, enabling direct comparisons to design specifications and regulatory criteria. In this manner, obtaining and evaluating data for certain parameters verifies that systems are functioning and performing as intended. Monitoring also provides the critical feedback needed that can be used to improve or adjust current maintenance practices and help refine design standards of future GI. This section will discuss the types of monitoring inspections to be performed during the warranty period and beyond; water quantity and quality, tree health, tree growth, soil and vegetation health parameters measured during monitoring; and monitoring FAQs.

Furthermore, this part of the document adopts information from the *2019 Green Street Performance Monitoring Guidance Manual (PMGM)* which provides a great resource on monitoring practices for GI systems mostly situated in an urban context. The PMGM was developed by Toronto Water to support Green Streets projects through performance monitoring plan recommendations. It includes comprehensive material such as monitoring approaches, water quantity and quality parameters, monitoring equipment, and data analysis techniques. This manual, *Life Cycle Activities for Green Infrastructure in the Right-of-Way*, builds on fundamental aspects of the PMGM, and differs in aspects such as frequency and performance. However, content from the PMGM has been inserted in this manual where material is complementary or may be supplemented in certain sections.

Chapter 5 – Monitoring Inspection Types

This section discusses the types of monitoring inspections that can be performed for GI systems, which include performance monitoring and long-term monitoring. Many of the testing indicators previously discussed in Part 1 – Maintenance of Green Infrastructure such as soil characterization testing, sediment accumulation testing, surface infiltration rate testing, natural or simulated storm event testing and continuous monitoring, are applicable to the performance monitoring of GI systems. All monitoring parameters and frequencies presented in the following chapters are recommended as best practice.

Performance Monitoring

The primary type of monitoring is performance monitoring, which determines if the GI function and performance remain in an acceptable range or require corrective actions. Monitoring practices can be conducted at any time during the life cycle of a GI, but is highly recommended to be implemented as part of the construction, warranty, verification and forensic inspection periods.

It is recommended that pre-construction data be collected before GIs are constructed to provide a platform for baseline benchmarking and to track the relative performance of the GI over time. As outlined in the PMGM, there is a significant lack of pre-construction information available pertaining to existing GI assets installed in Toronto. This data gap hinders effective asset management and continual improvement. Therefore, the implementation of new GI practices within Toronto presents opportunities to address such gaps.

Construction Monitoring Inspections

Monitoring practices should be conducted as soon as GI construction activities begin to ensure site activities are conducive to satisfactory future operations of the GI system. During the construction period, construction activities and methodologies should be monitored as a form of quality control/assurance to verify that the GI is installed in accordance with design specifications. During construction, it is important that the Owner’s representative monitor the adequate deployment of erosion and sediment control measures, appropriate construction activities that does not compromise the integrity of the native soil infiltration rates, and adequate excavation or sizing of the GI footprint. Discovering problems in the GI through post-construction monitoring can prove to be more difficult and costly if remedial actions are required, especially with subsurface components.

The key timeframes for monitoring implementation are generally consistent with the timing of construction inspections mentioned in the maintenance section within Part 1 of this manual. Sampling and laboratory testing to confirm that physical and chemical properties of GI components – such as soil – meet design specifications are also recommended at frequencies specified in the following sections.

Warranty Monitoring Inspections

Conducting monitoring inspections at the end of the construction warranty period prior to the hand-off of the GI to the property owner is crucial for confirming if the system was installed as designed, utilizes materials conforming to the design specifications, and functions properly. Warranty inspections and monitoring serve as a final verification to help avoid property owners from assuming responsibility of GI that may already require maintenance or repairs due to defects. It is critical that all applicable testing, including soil characterization testing, sediment accumulation testing, surface infiltration rate testing, natural or simulated storm event testing, and continuous monitoring, are performed to confirm that the GI functions as intended and meets performance criteria. The monitoring data should also be assessed to validate the assumed hydrologic and hydraulic functions of the GI. If outflow is present, water quality should be assessed and verified to be compliant with regulatory standards to determine the effectiveness of the GI prior to ownership hand-off.

Verification Monitoring Inspections

Sampling and testing are recommended to be performed during verification inspections to determine if the GI systems are adequately maintained and if monitoring parameters are within acceptable ranges. Results from the monitoring practices can provide valuable feedback pertaining to improvements or optimizations of life cycle activities, such as maintenance. These inspections are typically scheduled every five years; however, the PMGM has outlined the following monitoring structure that is recommended to be implemented for new GI systems.

To assist in filling data gaps and verifying that literature correlations are appropriately reflected, the monitoring program should be divided into two phases. The same equipment and procedures should be used for accurate assessments. Phase 1 should incorporate the monitoring of all newly installed GI with the goal of obtaining as much data as possible of various GI practices and storm events. The PMGM makes reference to the Philadelphia Water Department where this approach served as the pilot stage. Gathering monitoring data involving water quantity parameters, such as flow, retention, and infiltration helped with accelerating targets of stormwater management every five years. Phase 2 will involve directly monitoring only GIs within dissimilar sites than previously monitored, or GIs located in sensitive or high priority areas. This phase will ensure that literature correlations, assumptions and approximated indirect approaches are appropriately representing field results.

Following this monitoring structure, the performance parameters obtained can be used based on specific site contexts and provide a comparison basis for future verification monitoring inspections of GI.

Forensic Monitoring Inspections

Monitoring practices can be incorporated as part of forensic inspections when issues with the GI system are identified or suspected. Since more comprehensive and potentially destructive sampling and testing may be required to diagnose issues and to determine appropriate corrective actions, continuous monitoring of the parameters—as outlined in the subsequent sections—of the GI is the preferred, non-invasive approach to diagnose issues within the system.

Long-Term Monitoring

Long-term monitoring consists of many of the same parameters used in performance monitoring and can be considered a type of performance monitoring extended over many years throughout the GI life cycle. Since locations and site contexts vary based on the GIs, weather conditions and the need for maintenance will also fluctuate. Long-term monitoring provides seasonal data, presents better opportunities to analyze similar design storm events for direct performance comparisons, strengthens results obtained through regular monitoring practices, and can be used to determine whether GI issues are acute or chronic.

Outlined in the PMGM, objectives that can be achieved with long-term monitoring, include determining:

1. The number of GIs required to be constructed to achieve critical mass;
2. If GIs are performing as anticipated;
3. How GIs perform over time and when rehabilitation should occur; and,
4. The storm event size that will produce outflow, and what the water quality is when outflow occurs.

Continuous monitoring discussed as part of the testing indicators in Part 1 of this manual can be considered as a long-term monitoring practice. The 2016 TRCA LID SWM IM Guide can be referenced for further information regarding continuous monitoring.

Chapter 6 – Water Quantity

Water Quantity Parameters

This section presents the parameters to be monitored and best practices to be adopted to assess water quantity management performance of the standard GI systems. For each monitoring parameter, an overview of recommendations are provided in Table 21, pertaining to monitoring frequency, performance targets, monitoring methods, and required equipment. Additional information regarding the types of monitoring equipment available, specific methods of testing regarding each respective parameter, and sampling location and frequency is listed in the following sections

.

Table 21: Summary of water quantity monitoring parameters

	Description	Frequency	Equipment / Specialties	Targets
Recession Rate	Recession rate is the change of storage volume over time and is determined by a combination of infiltration and evapotranspiration. Systems equipped with an underdrain or slow release outflow may also affect the recession rate. In general, the rate is defined as the vertical and horizontal outflows of water where the storage volume is below the surface.	• Continuous • At warranty • During verification inspections (every 5 years) • As required	Water level logger	Original storage volume +/- 10%, unless otherwise specified in project design criteria
Bypass Flow	By-pass flow is the resulting runoff from the contributing drainage area that does not get conveyed or captured in the GI. This can be caused by blockages or clogging of the inlet and outlet, higher intensity rainfall, insufficient or loss of stormwater storage, and/or backwater in the GI system.	• At warranty • During verification inspections (every 5 years) • As required	Simulated storm testing, water level loggers	No bypass flow, unless specified in project design criteria
Inflow	Inflow is the amount of water flowing into the GI. The measurement of this parameter is critical for determining the basis of GI performance and for accurate flow balance calculations.	• At warranty • During verification inspections (every 5 years) • As required	Weirs, flumes, chambers, pipes, or water level loggers	Refer to project design criteria
Return Flow	Return flow is the amount of flow that goes back to the sewer system or downstream to an adjacent drainage system. This parameter is important to quantify the amount of water that enters the sewer system and how much water the GI is diverting.	• At warranty • During verification inspections (every 5 years) • As required	See the following sections for additional details.	Refer to project design criteria

	Description	Frequency	Equipment / Specialties	Targets
Surface Infiltration	Surface infiltration is the rate at which water percolates or flows through the surface or permeable pavement surface into the subsurface storage layers of the GI. This serves as an effective method at treating stormwater and improving water quality.	• At warranty • During verification inspections (every 5 years) • As required	Infiltrometers or permeameters	Refer to project design criteria
Soil Moisture and Temperature	Soil moisture is a parameter which indicates the frequency and amount of irrigation needed to maintain the vegetation within the GI. Soil temperature should also be recorded when performing infiltration testing to show any variations of environmental conditions during inspections.	• At warranty • During verification inspections (5 years) • As required	Dielectric sensors and thermometers	Refer to project design criteria
Evapo-transpiration	Evapotranspiration is the combination of evaporation and transpiration of water from soil and plants that is transferred to the atmosphere.	• At warranty • During verification inspections (every 5 years) • As required	See the following sections for additional details.	Refer to project design criteria
Storage Volume	The storage volume of a GI includes both the subsurface storage and the surface detention or retention storage. Using field measurements of the storage dimensions and the monitored depth of water in the GI, a depth-volume curve may be developed to monitor storage volume.	• At warranty • During verification inspections (every 5 years) • As required	Water level loggers	Refer to TRCA LID SWM IM Guide, or project design criteria

Table 22 displays what type of measurements are most commonly undertaken for each respective GI system. "D" denotes direct measurement (e.g. sampling), "I" denotes indirect measurement (e.g. estimating), and "I/D" denotes both indirect and direct measurement.

Table 22: Common monitoring parameters measurements based on GI type (adapted from PMGM, 2019)

GI System	Recession Rate	Bypass Flow	Inflow	Return Flow	Surface Infiltration	Soil Moisture	Evapo-transpiration
Bioretention	D	I	I/D	I	D	D	I
Bioswale	D	I	I/D	I	D	D	I
Enhanced Grass Swale	D	I	I		D	D	I
Green Gutter	D	I	I		D	D	I
Filter Strip	D	I	I		D	D	I
Permeable Pavement	D		I	I	D		
Infiltration Trench	D	I	I/D	I		D	I

Recession Rate or Subsurface Infiltration

Typically, the water level in the GI is continually monitored with level loggers which are housed in observation or monitoring wells. The recession rate can be estimated using observation well data derived from performance monitoring and testing. Based on expected rate, performance can be determined from comparisons between field infiltration rates—taken at the excavated depth of the GI—and post-construction monitoring results.

Bypass Flow

Routinely measuring bypass flow may be difficult as the flow is typically minimal and shallow along the curb. It is possible to estimate bypass volume by doing a series of simulated runoff tests where the bypass flow path is temporarily blocked with sandbags. Bypass flow can be calculated as the difference between as-constructed and sandbag flows.

Another way to determine when outflow has bypassed the GI is to compare ponding depth to overflow elevation. This can be done by installing a level logger in a shallow well to determine surface ponding depth and the rate which ponding water infiltrates. It can be determined if bypass has occurred if the ponding depth exceeds the overflow elevation specified during design.

Corrective measures should be taken if there is a substantial amount observed during site visits, or evidence of poor inlet capture efficiency is suspected based on review of the continuous monitoring records.

Inflow

There are several methods for measuring the inflow as follows:

1. The preferred method is to install weirs, flumes, chambers or pipes at the inlet and using a discharge equation provided by the manufacturer to directly determine the inflow. If the installation of such devices are unfeasible, other methods are to be considered.

2. The change in storage volume can be monitored over time to estimate the inflow to the system. By using water level logger data, the storage volume may be calculated by depth-to-volume relationships or equations for specific GI.

3. If a GI receives flows as sheet flow or contains multiple inlets which makes inflow into the GI unmeasurable, the inflow volume may be estimated based on the storm and rainfall event depth and the size and runoff coefficient of the contributing drainage area. In general, the inflow calculation will involve the multiplication of the precipitation depth from nearby rain gauges by the contributing drainage area.

4. The Modified Simple Method derived by the Credit Valley Conservation (CVC) can be used to better approximate inflow to a GI system based on runoff.

5. To note, it is recommended to compare both direct and indirect methods of monitoring early in the monitoring program of the GI to determine the accuracy. It may be more time, cost and resource effective to base inflow results on indirect methods if it is proved to be more accurate.

Additionally, the CVC states that it may not always be realistic to monitor inflow, but it is important to represent inflow to validate influent event mean concentrations. Alternatively, another option is simultaneous sampling of flow from a nearby untreated drainage area if sampling inflow to the GI is not feasible. This is also necessary to calculate pollutant removal efficiency ratios by comparing outflows from the GI to those from the untreated drainage area. This method uses a control site as a basis for its measurements, but this method brings in uncertainty when assuming the conditions at the control site are representative of the actual GI site.

Return Flow

Return flow can only be measured in GI systems equipped with an underdrain or slow release outflow. An indirect method of measuring the return flow is to temporarily block the outlet and use the difference between infiltration rates of the blocked and unblocked scenarios to derive the return flow.

Surface Infiltration

Surface infiltration rates can be measured using infiltrometers or permeameters which provide measurements of the saturated hydraulic conductivity (K_S). The relationship shown in Figure 1 and Figure 2 can be used to derive the infiltration rate (I).

Saturated Hydraulic Conductivity, K_s (centimetres/second)	Percolation Time, T (minutes/centimetre)	Infiltration Rate, 1/T (millimetres/hour)
0.1	2	300
0.01	4	150
0.001	8	75
0.0001	12	50
0.00001	20	30
0.000001	50	12

Figure 1: Approximate relationships between saturated hydraulic conductivity, percolation time and infiltration rate (Adapted from TRCA LID SWM IM Guide, 2016)

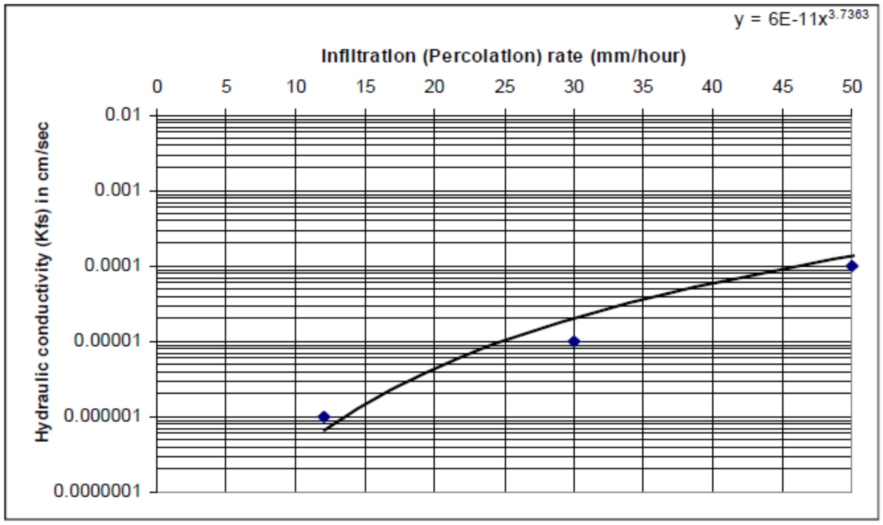

Figure 2: Approximate relationship between infiltration rate and saturated hydraulic conductivity (Adapted from TRCA LID SWM IM Guide, 2016)

It is recommended that multiple field measurements be taken – minimum of five (5) recommended in addition to one every 25 m^2 for filter media and 250 m^2 for permeable pavement – to obtain a more representative mean value of K_s due to spatial variability, difference in degree of compaction, and moisture content inconsistencies. Testing areas should be thoroughly saturated before taking measurements; therefore, testing should ideally be conducted after a storm event.

An alternate method for determining surface infiltration rates specific to bioretention systems involves using piezometers and pressure transducers to monitor the depth of water. Two monitoring wells are required to be installed where one will consist of a deep, perforated piezometer to quantify infiltration through the GI while the other well will be shallow with perforations above the surface to house the second piezometer which measures ponding.

The TRCA LID SWM IM Guide can also be referenced for methodologies and equipment usage as part of the surface infiltration testing.

Soil Moisture and Temperature

Dielectric sensors may be installed to indirectly measure the volumetric water content of the soil which can be used to estimate the soil moisture storage. The TRCA LID SWM IM Guide can be referenced for specific methods and equipment usage as part of the soil characterization testing.

Evapotranspiration

Measurements of evaporation may be negligible or may be assumed a value in applicable situations. If this parameter is viewed to be significantly impactful to the performance of the GI, evapotranspiration can be calculated indirectly using a water balance if all other variables are known. For example, the value of evapotranspiration can be solved from the difference between the inputs, for example; runoff and the outputs, for example the sum of bypass, infiltration, overflow and outlet flow, where applicable. Direct in-situ evapotranspiration rates can be measured through other methods but may be costly and time-consuming.

Storage Volume

Storage volume can be monitored by developing depth-volume curves based on the physical measurements of the storage and then monitoring the depth of water in the GI using level loggers. A monitoring well or access point should be integrated within the design of the GI to permit measurement of the depth of water in underground storage. Recession rate is the critical performance indicator as it includes all hydrologic processes contributing to water leaving the system after a storm event.

Water Quantity Equipment

This section has been largely adopted from the PMGM and outlines the common monitoring equipment that is used to measure water quantity. There is a large market for monitoring equipment and a wide variety of products that can be used for monitoring parameters.

Monitoring Well

A monitoring well is a permanent structure that serves as a place where monitoring equipment can be installed and has an access point for maintenance. An observation well, manhole, or catch basin can be used as a monitoring well, as long as the dimensions of the well are known and it is protected from anything that has the potential to impact the equipment housed inside.

Trail Camera

The purpose of a trail camera installed on site is to observe how the site is functioning during wet weather from a remote location. It is recommended by other municipalities and conservation authorities to install on-site, especially during the first year, to see how the GI or treatment train is performing. Installing trail cameras saves on time and labour costs as staff will not need to physically go to site during storm events. The cameras can be pointed at a gauge or monitor, or at the entire GI, and should be placed out of plain sight to avoid vandalism or theft.

Trail cameras can be programmed to take pictures at regular time intervals, can be triggered by motion, such as rain events, and can take videos of the storm events. They are also useful to determine the period that ponding occurs, a system takes to drain down, or if a site needs immediate maintenance.

Weirs and Bubbler Water Level Sensor

A weir is a designed vertical structure placed across an open channel that allows water to flow through a flow rated notch. Each type of weir notch opening has a specific discharge equation for determining the flow rate through the weir opening.

The primary advantage of a weir is that it can be used to regulate flow in a natural channel with irregular geometry. Natural channels are often common within GI facilities particularly within bioswales and enhanced grass swales. Weirs collect flow measurements by creating a partial dam which results in backwater conditions upstream of the weir. The water will then pass over the weir to free-flow conditions on the downstream side of the weir. The flow rate is then calculated based on the geometry of the weir notch and recorded water level behind the weir. It is important to ensure the weir is sealed properly because the leaks will skew the flow results. The larger the area in the inlet, the less accurate the readings are. It is typical to install a larger notch weir at the inlet as flows are higher, and a smaller notch weir at the outlet as flows are lower.

To determine flow, a weir needs to be used with a bubbler sensor. The bubbler sensor can calculate water level, as it uses an internal air compressor to force a metered amount of air through a bubble line submerged in the flow channel. By measuring the pressure needed to force air bubbles out of the line, the water level is accurately determined. Flow is then determined by the water level data. Bubbler sensors are suitable for small channels, and are not affected by wind, steam, foam or turbulence.

Area-Velocity Sensors

Area-velocity sensors can also be used to determine flow if the pipe dimensions are unknown. Area-velocity sensors monitor and record the mean velocity and depth meter using Doppler wave technology. The velocity sensor transmits a continuous ultrasonic wave, then measures the frequency shift of returned echoes reflected by air bubbles or particles in the flow to determine the velocity. Another sensor will measure the mean level to record depth (Pittsburgh Water and Sewer Authority n.d.). The recorded level and velocity by sensors within the open channel flow meter are then converted to a flow rate based on the continuity equation *Flow = Velocity * Channel Area*.

It is to note that these sensors can clog and will need to be well maintained.

Soil Moisture Sensor

The soil moisture probe is used to determine the moisture in the soil. It needs to be used with a data logger which stores the data and can measure moisture throughout the depth of the entire bioretention media. The probe can be used at various locations as a sleeve can be installed at the site and the probe can be inserted when measurements are needed. The sample port needs to be installed beforehand as it is a critical monitoring infrastructure for this equipment.

These sensors help to explain how long stormwater is available for trees to benefit and help refine irrigation schedule.

Water Level Sensors

Level Logger and Pressure Transducer

Self-contained water level loggers are devices that continuously monitor the water level inside a monitoring well to determine the depth of water in a GI system. An additional logger can be used as a pressure transducer which needs to be used alongside the level logger to record changes in barometric pressure. One barometric logger or weather station can be used to compensate all of the water level loggers in that area. It is recommended to keep the barometric pressure logger at a low enough depth to prevent the logger from freezing in the winter. The data should be downloaded monthly if telemetry is not available.

Ultrasonic Non-Contact Level Transmitter

Another way to measure water level is to use an ultrasonic non-contact level transmitter. It works by emitting a pulse which bounces off objects or water level, returning an echo to the sensor (CVC 2015). The distance from the transmitter to the bottom of the pipe must be known and these ultrasonic transmitters are sometimes unable to read accurately during turbulent or noisy hydraulic conditions. They are helpful when using weirs or flumes.

Permeameter and Infiltrometer

Permeameters or infiltrometers are tools to measure the infiltration rate through soil or permeable pavement. Double ring infiltrometers are commonly used to measure hydraulic conductivity of the soil and can then be converted to infiltration rate. These are portable tools that can be moved to different locations and should be used with a ruler and stopwatch. The change in depth between two points is measured in the inner cylinder and the time taken is recorded. The purpose of the outer cylinder is to ensure the water from the inner cylinder flows downwards, and not laterally. ASTM D3385 standard should be followed when completing the double ring infiltrometer test.

Guelph permeameter testing is similar to the double ring infiltrometer test in that both estimate the vertical movement of water through the bottom of the test area. It is a constant-head well permeameter consisting of a mariotte reservoir that maintains a constant water level inside an augered hole that is typically four inches deep, cored into the unsaturated soil. (A.J. Erickson 2010). Both methods should be done with water constantly poured to maintain a constant head. After a certain period of time, the infiltration rate will become constant. When constant, the rate of infiltration is assumed to be equivalent to the saturated hydraulic conductivity. Steady state conditions may require about 20 to 30 minutes, but the duration of this experiment is dependent on the type and initial moisture content of the soil.

The double ring infiltrometer and Guelph permeameter tests are not appropriate in gravelly soils or in other soils where an adequate seal with the casing cannot be established (City of Portland 2016). This is because it only accounts for vertical infiltration. If a secure seal cannot be used, other infiltration testing methods that do not solely measure vertical infiltration needs to be used.

Data Loggers

Data loggers are additional equipment used with other sensors and probes to store data. They are commonly used with rain gauges and soil moisture probes.

Data is available to be stored via telemetry or on-board memory, where data retrieval has to be done on site. Telemetry is preferred as it removes the need to go to site to download data and reduces the risk of losing data, as it is downloaded at regular time intervals.

Chapter 7 – Water Quality

Water Quality Parameters

This section presents the parameters to be monitored and best practices to be adopted to assess water quality management performance of the GI systems. For each monitoring parameter, recommendations are provided pertaining to monitoring frequency, performance targets, and monitoring methods.

It is recommended that water quantity parameters be measured and assessed prior to collecting water quality samples, as many GI systems retain water inflow from routine storms which are known to entrain the most pollutants. As such, water quality testing does not provide high value information unless there is an outflow from the GI system. It is further recommended that each GI with an outflow be tested at one location point to verify that any assumptions or correlations used for the site-specific environment are accurate.

The site-specific environment where a GI is located may vary based on the condition of the catchment area, type of land use, frequency of land use used, and whether snow is removed or stored on site. Knowing the water quality parameters from GI systems can provide a better understanding of its performance. Figure 3 illustrates the typical concentrations of pollutants that are identified in urban stormwater. This provides a list of water quality parameters that may be sampled and a basis for comparison to satisfactory water quality levels in surface waters as denoted by the Provincial Water Quality Objectives (PWQO). An overview of the water quality parameters is provided in Table 23 and targets are provided according to the PWQO. Further information regarding the targets or the overall water quality objectives can be referenced in the 1994 publication of Water Management: Policies, guidelines, PWQO's (Ministry of Environment and Energy 1994). Additional information regarding the parameters and equipment is provided in the following sections.

Parameter	Units	PWQO	Observed Concentrations
Escherichia coli	CFU/100 mL	-	10,000 to 16 x 10^5
Total Suspended Solids (TSS)	mg/L	-	87 – 188
Total Phosphorus (TP)	mg/L	0.03 (interim)	0.3 – 0.7
Total Kjeldahl Nitrogen (TKN)	mg/L	-	1.9 – 3.0
Phenols	mg/L	0.001	0.014 – 0.019
Aluminum (Al)	mg/L	-	1.2 – 2.5
Iron (Fe)	mg/L	-	2.7 – 7.2
Lead (Pb)	mg/L	0.005 (interim)	0.038 – 0.055
Silver (Ag)	mg/L	0.0001	0.002 – 0.005
Copper (Cu)	mg/L	0.005	0.045 – 0.46
Nickel (Ni)	mg/L	0.025	0.009 – 0.016
Zinc (Zn)	mg/L	0.020 (interim)	0.14 – 0.26
Cadmium (Cd)	mg/L	0.0002	0.001 – 0.024

Source: Adapted from OMOE, 2003

Figure 3: PWQO versus typical pollutant concentration in urban stormwater (PMGM, 2019; CVC and TRCA, 2010)

Table 23: Summary of water quality parameters, frequencies, equipment, and targets

	Description	Frequency / Location	Equipment / Specialties	Targets (Ministry of Environment and Energy 1994)
Escherichia Coli	Escherichia Coli (E. Coli) is a fecal coliform bacterium that is commonly found in the intestines of animals and humans. E. Coli detection in water indicates that there is either sewage or animal waste contamination. The implementation of GI has shown to reduce E. Coli contamination levels in water sources by approximately 60% to 90% according to the 2016 TRCA LID SWM IM Guide.	• At warranty • During verification inspections (every 5 years) • As required • Test in CSO areas	Water sample and laboratory testing. See the following sections for additional details.	100 E. Coli per 100mL (Based on generic mean of at least 5 samples)

	Description	Frequency / Location	Equipment / Specialties	Targets (Ministry of Environment and Energy 1994)
Total Suspended Solids	Total suspended solids (TSS) is the amount of fine particulate matter in suspension within the stormwater. Since pollution is largely associated with sediment, this parameter is a good indicator of the water quality. Contributing sources of TSS include construction, winter road sanding, vehicle emissions, pavement wear, gravel, clay, silt, bacteria, and algae.	• At warranty • During verification inspections (every 5 years) • As required • Test in all areas	Water sample and laboratory testing. See the following sections for additional details.	As per project design criteria. See the following sections for additional details.
Total Phosphorous	Total and soluble phosphorus are common pollutants which can be released from a variety of sources, including illicit connections of septic systems to storm sewers, detergents, and fertilizers.	• At warranty • During verification inspections (every 5 years) • As required • Test in all areas	Water sample and laboratory testing. See the following sections for additional details.	Current scientific evidence is insufficient to develop a firm target at this time. See PWQO Appendix A for information on general guidelines.
Chlorides, Sodium, Calcium	Chlorides, sodium and calcium are primarily sourced from de-icing salts and higher levels of these pollutants are particularly concerning for water protection areas. Chlorides also serve as an indicator of urban population and road density.	• At warranty • During verification inspections (every 5 years) • As required (likely after winter season)	Water sample and laboratory testing. See the following sections for additional details.	Chlorine: 2 µg/L

	Description	Frequency / Location	Equipment / Specialties	Targets (Ministry of Environment and Energy 1994)
Phenols	Phenols are organic compounds used as an anti-caking ingredient in road salts to help keep them granular.	• At warranty • During verification inspections (every 5 years) • As required (likely after winter season)	Water sample and laboratory testing. See the following sections for additional details.	1 µg/L
Metals	Metals in stormwater may originate from tire wear, insecticides, galvanized building materials, motor oil, vehicle exhaust, paint and rusting automobile bodies.	• At warranty • During verification inspections (every 5 years) • As required	Water sample and laboratory testing. See the following sections for additional details.	Zinc: 30 µg/L Copper: 5 µg/L Cadmium: 0.2 µg/L Lead: 1 to 5 µg/L (Interim) depending on hardness (mg/L). See PWQO for more information and/or other metals.
Polycyclic Aromatic Hydrocarbons	Polycyclic aromatic hydrocarbons (PAHs) are organic compounds or chemicals that may be present in certain petroleum products. Point sources include spills, leaks, vehicle emissions, and asphalt breakdowns.	• May only be required if GI is near an industrial site or parking lot • At warranty • During verification inspections (every 5 years) • As required	Water sample and laboratory testing. See the following sections for additional details.	As per project design criteria
Total Nitrogen	Total Nitrogen (TN) is the total amount of nitrates, nitrites, ammonia, and organically bonded nitrogen within the water.	• Especially required adjacent to aquatic systems or water courses • At warranty • During verification inspections (every 5 years) • As required	Water sample and laboratory testing. See the following sections for additional details.	As per project design criteria

	Description	Frequency / Location	Equipment / Specialties	Targets (Ministry of Environment and Energy 1994)
Total Kjeldahl Nitrogen	Total Kjeldahl Nitrogen (TKN) TKN is the sum of ammonia plus organically bound nitrogen but does not include nitrates or nitrites.	• Especially required adjacent to aquatic systems or water courses • At warranty • During verification inspections (every 5 years) • As required	Water sample and laboratory testing. See the following sections for additional details.	As per project design criteria
Turbidity	Turbidity is the measurement of relative clarity of the water.	• As required to confirm TSS	Water sample and laboratory testing. See the following sections for additional details.	Suspended matter should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10%.
Temperature	Temperature affects a number of physical and biological water quality parameters and therefore, remains an important parameter to monitor.	• Especially important for vegetated systems • At warranty • During verification inspections (every 5 years) • As required	Thermometer. See the following sections for additional details.	In general, the natural thermal regime of any body of water shall not be altered so as to impair the quality of the natural environment. In particular, the diversity, distribution and abundance of plant and animal life shall not be significantly changed. See PWQO Appendix A for information on waste discharge heat.

Escherichia Coli

It is recommended to test for E.coli in areas downstream of combined sewer overflows or areas where high fecal levels have been detected.

Total Suspended Solids

Though TSS is a good indicator for water quality it should not negate the need to test for other parameters. The City of Toronto Wet Weather Flow Management Guidelines (WWFMG) suggests an annual reduction of TSS by 80 per cent for stormwater management facilities. TSS has been selected by the City as a surrogate for other water quality parameters because sediment is also an efficient carrier of toxicants and trace metals, which are often associated with the particulate phase.

It is recommended to measure TSS at all sites as it is a main indicator for overall water quality.

Total Phosphorus

It is recommended to measure TP at all sites.

Chlorides, Sodium and Calcium

It should be noted that no bioretention media can filter chloride (CVC 2015). It is recommended to monitor chlorides if the site is located in a protected area or if winter sampling is a site-specific objective.

Phenols

It is recommended to measure phenols when chlorides are measured.

Metals

Zinc, Copper, lead, and cadmium are the most common metals to sample in total and soluble forms. It is recommended to test for the aforementioned metals at all sites as they are commonly found in road runoff, but should be of particular interest at sites with industrial contributing drainage areas.

Polycyclic Aromatic Hydrocarbons

There are several types of PAH compounds and the most common ones in urban settings are chrysene, fluoranthene, and pyrene (Selbig 2009). It is recommended to test for PAHs when possible but particularly at sites with industrial contributing drainage areas or parking lots upstream.

Total Nitrogen

Nitrogen is a very important parameter to measure as high levels can lead to eutrophication in aquatic systems and high levels are dangerous in drinking water. It also affects algae growth and can be toxic to fish when reaching watercourses. Additionally, nutrient rich soils have the potential to increase loadings after the water is infiltrated. It is important to track these loadings and concentrations over time.

Total Kjeldahl Nitrogen

It is recommended to measure TN instead of TKN as it is also includes nitrates and nitrites. These are important to track as they are highly soluble and will stay in solution of runoff after leaving the root zone and can reach the water table (STEP 2009).

Turbidity

Turbidity can be useful to compare first flush to samples over the course of a storm to optically determine water clarity and the effectiveness of the GI in retaining sediment. It is not recommended to measure turbidity at all sites as TSS provides a similar, more conclusive understanding of water clarity. Turbidity can be measured at select sites to validate the accuracy of the TSS as a function of turbidity correlation.

Temperature

Temperature is also measured as a by-product of continuously measuring other parameters so it would not require additional resources or funding. Given the opportunity, the trend of temperature overtime through GI facilities should be studied to identify any relationship or significant change in temperature due to its implementation. Adjacent streams and water bodies may contain thermally sensitive species that should be considered when implementing any stormwater management facilities.

Water Quality Equipment

This section has been largely adapted from the PMGM and outlines the common monitoring equipment that is used to measure water quality. As mentioned, there is a large market for monitoring equipment and a wide variety of products that can be used for monitoring parameters.

Automatic Sampler

The purpose of an autosampler is to automatically obtain composite samples over the course of one storm event. This removes the need for staff to go out to location to physically take samples, and provides the ability to take composite samples over the course of a storm event to give a better representation of the quality over the course of the storm. Automated sampling techniques are generally the preferred method for collecting flow weighted composite samples for calculating individual pollutant event mean concentrations and ultimately the pollutant removal effectiveness of the GI facility. This is primarily because automated sampling can be programmed to collect individual samples at known flow increments throughout long duration storm events in lieu of the continuous effort required for many individual manual samples throughout the same storm event. Furthermore, it is difficult to predict when a storm event will begin so an autosampler allows for samples during the entire event.

Auto-samplers are typically battery or AC powered and come refrigerated to help with the preservation of samples. Some do not function at subfreezing temperatures without retrofit, so heaters and thermostats can be purchased to enable yearround continuous monitoring in cold climates (Pittsburgh Water and Sewer Authority n.d.).

To have the autosampler triggered at a storm event, a triggering device is needed to alert the sampler when to take the sample. The trigger is typically an open channel flow monitoring device, but automated samplers can also be configured to take samples based on rain gage or level sensor data (Pittsburgh Water and Sewer Authority n.d.). Autosamplers can be used to see how accurate the literature correlations are.

Soil Quality

It can be beneficial to take soil samples from the bioretention media every year as a method of pollutant tracking. These are samples are taken at a shallow and deep depth, relative to the depth of the bioretention media.

Chapter 8 – Tree Health and Tree Growth

Tree Health and Growth Parameters for Monitoring

Structural, Tree and Root Health Monitoring

Frequency: Annually during the warranty period –2 first years, every 3 years during the first 10 years, and after 10 years, at 5 to 7 year intervals.

Targets: There are no quantitative targets for structural integrity, tree health and root health monitoring. Targets are based on qualitative indicators of health, such as vigorous growth, correct form and the absence of physical damage or decay.

Structural Integrity Monitoring:

Parameter	Quantitative / Qualitative Target
Overall Form and Habit	Trunk has a visible, significant lean (y/n)
	Imbalances in the canopy structure (e.g. From aggressive pruning around aerial wires) (y/n)
	Proximity / interference with buildings, wires, and other trees (y/n)
Tree Trunk	Visible cavities and stress cracks (y/n)
	Hollow sound when struck (y/n)
Major Branches	Visible cavities and stress cracks at major branch forks (y/n)
	Dead or hazardous limbs (y/n)
See Root Health below - Roots are critical to the structural integrity of trees	

Tree Health Monitoring:

Parameter	Quantitative / Qualitative Target
Overall Form and Habit	Tree appears healthy (y/n)
	Major injury (e.g. Wind damage, lightning strike, vandalism) (y/n)
	Major broken branches (y/n)
	Crown or leader die back (y/n)
	Tree is dead (y/n)
Bark	Bark is healthy and undamaged (y/n)

	Major injury (e.g. Struck by vehicle, vandalism) (y/n)
	Bark bruising, scarring, rot (y/n)
Foliage	Foliage appears dense and healthy, typical of the species (y/n)
	Foliage discolouration, yellowing, scalding (y/n)
	Foliage loss at crown (y/n)
	Foliage loss concentrated in one portion of the canopy (y/n)
	Dispersed foliage loss throughout the canopy (y/n)
	Complete defoliation (yes / no)
See Root Health Monitoring below – Root health is critical to the overall health of trees.	
See Pest and Disease Monitoring below – the presence of pests or disease will impact the overall health of trees.	
See Chapter 9 Soil Health Parameters for Monitoring below – Soil health is critical to the overall health of vegetation.	

Root Health Monitoring:

Parameter	Quantitative / Qualitative Target
Base of Tree / Root Flare	Root flare visible above finished grade (y/n)
	Visible girdling at tree grate (y/n)
	Adventitious roots and girdling roots (y/n)
	Visible fungus or mushroom growth at base of tree (y/n)
Large Woody Roots	Recent root pruning / transplanting (y/n)
	Root system restricted to a restricted planting area (y/n)
	Visible pavement heaving surrounding the tree (y/n)
	Broken or injured roots from adjacent construction (e.g. lowering the soil level, installing pavement, repairing sidewalks, or digging trenches, etc.). (y/n)
Fibrous Roots	Visible fibrous roots at surface of soil (y/n)
	Visible healthy / new fibrous roots within top 12-18" of soil (y/n)
	Evidence of dead / decaying fibrous roots (y/n)
See Chapter 9 Soil Health Parameters for Monitoring below – Soil health is critical to the overall health of vegetation.	

Methods: Visual inspection of tree for overall form and habit. Visual inspection of base of tree, trunk, bark and major branches. Visual inspection of tree canopy, quality and colour of foliage. Visual inspection of soil and surrounding area.

If internal decay is suspected, sounding and incremental boring can be used to detect internal voids, decay or structural weaknesses that cannot be observed with a visual inspection.

Hand dig at base of tree to expose woody and fibrous root system with a small trowel or shovel, taking care not to damage major roots.

Foliar analysis and soil testing by an accredited laboratory to monitor soil fertility and identify potential causes of failing health.

Equipment: Shovel, hand shears, hammer or wood mallet, chainsaw, increment borer, cordless drill. Fall arrest system if upper level branch inspection is required.

Specialized Training: International Society of Arboriculture (ISA) Certified Arborist, or approved equivalent, qualifications for tree climbing as required.

Pest and Disease Monitoring

Frequency: Bi-annually during the establishment period – 2 first years, as-required into maturity.

Targets: There are no quantitative targets for pests and disease monitoring. Targets for pest and disease monitoring are based on qualitative indicators and the presence of visible pests and disease are indicative that further investigation and maintenance is required.

Parameter	Quantitative / Qualitative Target
Pests / Insects	Adults, larvae or nests visible on bark, leaves, base of tree (yes / no)
Evidence of Boring Insect	Visible damage on tree trunk / branches, base of tree (yes / no)
Leaf Damage	Scald, spots, scales, or signs of insects feeding (yes / no)
Leaf Fungus	Black / white fungus or mildew (yes / no)
Leaf Discolouration	Yellowing or pale leaf colour (yes / no)
Defoliation	Partial defoliation (yes / no)
	Complete defoliation (yes / no)

Woody trunk and branch abnormalities	Branch tip death, galls, knots (yes / no)
Fungus / Mushrooms	Visible on tree or in soil at base of tree (yes / no)

Methods: Visual inspection for pests or disease on leaves and stems, check for fungus in soil (visible / smell). Visual inspection for trunk damage indicative of Emerald Ash Borer or Asian Longhorn Beetle and so on.

Equipment: n/a

Specialized Training: International Society of Arboriculture (ISA) Certified Arborist, or approved equivalent for pest and disease identification.

Chapter 9 – Soil Health

Soil Health Parameters for Monitoring

Frequency: Test soil annually to determine soil structure, organic matter and if appropriate microbial counts are present and suitable for intended vegetation. Biological amendments may be recommended.

Soil texture, chemical properties and organic matter should be tested during construction, according to TS 5.10*, Construction Specification for Growing Medium*. Soil health and biology should be tested as required during the establishment period – first four years – then annually into maturity to inform of any necessary soil amendments or in response to poor tree health.

Targets: Targets should be referred to in design specifications or as established in the design criteria. The TRCA LID SWM IM Guide can also be referenced for performance targets.

Physical Parameters include soil compaction, aggregate stability, available water capacity, bulk density, infiltration, soil structure and macropores, soil depth and water holding capacity.

Chemical Parameters include pH, macronutrients (ppm)

(N, P, K, Ca, Mg, S), micronutrients, soluble salt, electrical conductivity, and reactive carbon.

Biological Parameters include organic matter, total organic carbon, active carbon, soil respiration, microbial biomass C and N, particulate organic matter, potentially mineralizable N, soil enzymes and presence of earthworms.

Methods: Perform a visual inspection of soil composition and inspect for presence of earthworms and other invertebrates in the soil. Test soil compaction and moisture on site.

Collect soil samples taken from the root zone that are representative of the area in question. Approximately 3–4 cups of soil, bagged and sent to an approved soil testing lab.

Equipment: Soil probe, trowel or shovel, soil auger, soil moisture meter, piezocone penetrometer.

Specialized Training: Personnel conducting soil tests should be experienced with the designated soil sampling and testing protocols and equipment.

For additional soil sampling and testing requirements, refer to TS 5.10.

Chapter 10 – Vegetation Health

Vegetation Health Parameters for Monitoring

Vegetation Health Monitoring

"Vegetation" within the context of this manual refers to all plants except trees. Due to their importance and size within the right-of-way, trees are treated separately and are under the management and care of Urban Forestry. Refer to Chapter 8, Tree Health and Growth Parameters for Monitoring.

Frequency: Annually and into maturity, however, greater monitoring effort should be given during the establishment period. The duration of this critical phase varies from plant to plant however, most plants establish within 2 – 4 years after planting. It is during this time that the plant should be developing healthy and widespread root systems. This can only occur if the required level of moisture, air and nutrients is available. For this reason, vegetation health and soil health should be considered synonymous in practice.

Targets: There are no quantitative targets for Vegetation Health monitoring, there is no testing and data is obtained by visual inspection only. Targets are based on qualitative indicators of health, such as planting bed density, vigorous growth, correct form, and the absence of physical damage or decay.

Parameter	Quantitative / Qualitative Target
Planting Bed Health	Vegetation in planting bed appears healthy (y/n)
	One species of plants in planting bed is in decline / dead (y/n)
	Plants in one area of planting bed are in decline / dead (y/n)
	Plant decline / death dispersed throughout planting area (y/n)
	Visible fungus or mushroom growth in planting bed (y/n)
	Presence of invasive plants or weeds in planting bed (y/n)
	All plants are in decline / dead (y/n)
Individual Plant Health	Foliage appears dense and healthy, typical of the species (y/n)

Parameter	Quantitative / Qualitative Target
	Vigorous fibrous root growth is observable within top 150 mm of soil (y/n)
	Foliage discolouration, yellowing, scalding (y/n)
	Dispersed foliage loss throughout the plant (y/n)
	Complete defoliation (yes / no)
See Pest and Disease Monitoring below – the presence of pests or disease will impact the overall health of vegetation.	
See Chapter 9 Soil Health Parameters for Monitoring above – Soil health is critical to the overall health of vegetation.	

Methods: Visual inspection of planting bed for plant density and for overall form and habit. Visual inspection of each plant, quality and colour of foliage. Visual inspection of soil according to Chapter 9, *Soil Health*.

Hand dig to expose fibrous roots with a small trowel or shovel, taking care not to damage plants. It is especially important to take care when digging in a bed that contains a tree or if there is a tree nearby. Tree roots can extend many meters beyond the observable tree trunk. If a root is accidentally exposed, quickly and carefully cover it with moist soil as roots dry out very quickly. Damage such as root severing, tearing or root bark removal not only affects the tree's ability to sustain and anchor itself in place, it also creates opportunities for pathogens to enter the tree. Urban trees are relatively more stressed and thus more susceptible to disease and pests.

Foliar analysis and soil testing by an accredited laboratory may be necessary in order to monitor soil fertility and identify potential causes of failing health.

Equipment: Shovel or hand trowel, hand shears.

Specialized Training: Personnel conducting vegetation maintenance in open planting beds should be experienced with the designated planting plan, plant species identification, and weed removal and control methodologies.

Pest and Disease Monitoring

Frequency: Bi-annually during the establishment period, annually into maturity.

Targets: There are no quantitative targets for pests and disease monitoring. The presence of visible pests and disease, leaf damage, discolouration, loss of foliage and so on are qualitative indicators that maintenance is required.

Parameter	Quantitative / Qualitative Target
Pests / Insects	Adults, larvae or nests visible on stems, leaves, base of plants (yes / no)
Leaf Damage	Scald, spots, scales, or signs of insects feeding (yes / no)
Leaf Fungus	Black / white fungus or mildew (yes / no)
Leaf Discolouration	Yellowing or pale leaf colour (yes / no)
Defoliation	Partial defoliation (yes / no)
	Complete defoliation (yes / no)
Shrub soody stem abnormalities	Branch tip death, galls, knots (yes / no)
Fungus / Mushrooms	Visible on plants or in soil at base of plants (yes / no)

Methods: Visual inspection for pests and disease on leaves and stems, check for fungus in soil using both visible and smell.

Equipment: n/a

Specialized Training: Personnel conducting vegetation maintenance in open planting beds should be experienced with the designated planting plan, plant species identification and weed removal and control methodologies for pest and disease identification.

Irrigation and Drainage Systems Monitoring

Frequency: Bi-annually, in fall, before winterizing and in spring, before making the system operational, during the establishment period and into maturity.

Targets: Monitoring targets for irrigation systems will be specific to each individual system, however, the following include key parameters to monitor, if applicable.

Parameter	Quantitative / Qualitative Target
Irrigation zones	Visual inspection for patterns, wet/dry spots, poor plant health.
	Visual inspection for leaks or missing components.
Water Quality	pH, salinity, hardness, etc.

Parameter	Quantitative / Qualitative Target
Water Usage	Gallons per minute (gpm) / Litres per second.
Rainfall	If available, measure local rainfall in mm – adjust irrigation to respond to local rainy season / drought.
Soil Conditions	Visual inspection for standing water or dry spots.
	Test soil for texture, water holding capacity & infiltration rate, soil moisture, compaction, salinity.
See Chapter 9 Soil Health Parameters for Monitoring above – Soil health is critical to the overall health of vegetation.	

Methods: Perform a visual inspection of trench drain – after removing cover – and clean out. Perform a visual inspection of irrigation zones and test soil moisture on site.

Collect soil samples that are representative of the area and plant material. Approximately 3 to 4 cups of soil, bagged and sent to an approved soil testing lab.

Read meters on a regular basis, at least monthly during growing season. If meters are not available, measure applied irrigation water using precipitation gauges in the irrigated area.

Equipment: Soil probe, trowel or shovel, soil auger, soil moisture meter, rain gauge.

Specialized Training: Irrigation systems training. Personnel conducting soil tests should be experienced with the designated soil sampling and testing protocols and equipment.

For additional soil sampling and testing requirements, refer to TS 5.10.

Chapter 11 – Monitoring Frequently Asked Questions

This section lists FAQs for monitoring practices of GI systems.

What type of site context warrants increased monitoring practices to be conducted?

Typically, GIs located in sites which are observed to contain high loading of contaminants and pollutants within the stormwater will require more monitoring. As outlined in the PMGM, mapping of pollutant loads over time on a sewershed basis would be beneficial to identify areas of concern, but would also justify where a GI should be implemented.

In addition, GIs which are implemented in areas where there may be gaps in historic monitoring data, new contexts with limited information on stormwater quality, or regions of high sensitivity, should all be continuously monitored until a firm understanding of the results, correlations, and relationships have been developed.

In particular, stormwater tree trenches (SWT) will require more monitoring than typical continuous soil trenches, which typically receive no monitoring at all. Monitoring of soil quality, as well as passive irrigation and aeration systems should be implemented to ensure the continued stormwater management function of these GI practices.

Do I need specialized equipment to carry out monitoring of GI?

Depending on the type of monitoring task, specialized equipment will likely be required to properly and accurately perform the task. Calibrated sensors, cameras, and programed data loggers are designed to collect accurate samples that are best representative of in-field conditions. Such specialized equipment is required to maintain the integrity of the samples and to ensure testing results are able to be processed in the most consistent way possible. The TRCA LID IM guide also provides information on various testing methods and the specialized equipment required to carry out these tasks. Some testing includes the use of commonly available equipment, such as shovels, trowels, and buckets; however, following preferred testing methods involving more calibrated equipment, such as soil corers are recommended for the efficiency of collection and to uphold the integrity of the samples.

Chapters 6 and 7 of this manual both contain a section which explicitly discusses common monitoring equipment that is used to measure water quantity, water quality, and meteorological parameters. Furthermore, it is noted that samples collected from the field will eventually require processing within laboratories. Therefore, this stage will heavily involve the use of specialized equipment to conduct a variety of testing and analyses.

Do I need specialized training to carry out monitoring of GI?

In most cases, certified personnel who have received specialized training are required to carry out the monitoring of GI to ensure that sampling and testing is performed appropriately according to monitoring procedures or protocols. This guarantees that good and safe reporting habits are upheld, and the collected data remains accurate, consistent, and is less likely to be tampered with. The location of the GI may warrant specialized training, such as inspections involving entry into underground structures or confined spaces. The use of specialized equipment is also commonly required. In some cases, simpler equipment such as soil pH testers may only need inspectors to be familiar with proper usage and further specialized training would not be required.

It is good to acknowledge that in some cases, monitoring can effectively be performed through partnerships with academia or newly trained task forces. Further innovation can make monitoring more cost effective, accessible, and accurate.

What's the difference between monitoring and maintenance?

Monitoring involves the practice of routinely observing, measuring and recording parameters such as water quantity and quality to ensure they remain within the desirable range. Monitoring is also used to inform the maintenance management of the GI systems which includes determining the appropriate frequency or type of maintenance required. Therefore, an economical maintenance program that avoids unnecessary interventions can be built through comprehensive monitoring practices. On the other hand, maintenance is the practice of taking corrective, preventive, or predictive actions to keep these parameters within desirable ranges. The types of maintenance are discussed in Part 1 of this document.

What is the benefit of monitoring GI if it is already well designed and well maintained?

Monitoring is required to quantify the effectiveness of a GI system's performance over time. Although a GI system has been well-designed and undergoes prescribed routine maintenance practices, the effectiveness of the system is not proven until specific design parameters are monitored and compared to acceptable levels. Specific GI site contexts will vary and not be identical to one another. Implementing monitoring will help identify these deviations.

Monitoring practices are needed to verify that the GI is performing the function as intended in the design, as maintenance primarily focuses on visual indicators which may be periodically deceiving. The more monitoring undertaken, the more understanding of the functionality, strengths, and vulnerabilities of the various GI systems will be gained. Monitoring is essential to adapt maintenance plans and procedures, and evolve design to result in sustainable, resilient, and cost-effective GI. Monitoring data is valuable to inform lessons learned and feedback into improving future GI designs.

Chapter 12 – Health and Safety

It is important to recognize that all individuals performing any inspections, maintenance or monitoring practices discussed in this document are subject to all applicable health and safety standards. It is the responsibility of the individuals performing any lifecycle activities to become familiar and fully comply with applicable regulations and codes, health and safety policies and procedures provided by their organizations or businesses, and the health and safety requirements of the constructor and/or material supplier where applicable. Regardless of the type of work carried out or where the work is completed, health and safety is a top priority and a main goal outlined by the City of Toronto's *Field Services Manual (*2016) which aims to achieve a zero injuries workplace. The Engineering & Construction Services (ECS) division has also developed a comprehensive health and safety program which can apply to the maintenance and monitoring of GI and is briefly discussed in this chapter. This program is also detailed in Appendix H, *Health and Safety* of the *Field Services Manual*.

Other documents that may be referenced for health and safety include, but not limited to, the following:

- Occupational Health and Safety Act (OSHA)
- Ontario Traffic Manual (OTM) Book 7: Temporary Conditions
- Employment Standards Act (ESA)
- O. Reg. 239/02 and O. Reg 366/18: Minimum Maintenance Standards for Municipal Highways (Sections 16.1 – 16.7 in particular)
- Accessibility for Ontarians with Disabilities Act (AODA)

Purpose

The intent of this health and safety section is to present a summary and guidelines to employees working on GI projects in the field, on construction sites, facilities or areas of similar nature. It is noted that the maintenance and monitoring of GI systems can occur at any time and in any setting. Therefore, it is vital that all employees doing such work are responsible for familiarizing themselves and fully complying with applicable legislation, the City's health and safety policies, procedures, guidelines or best practices, and site specific health and safety requirements and considerations.

Roles and Responsibilities

As defined under the OHSA, a competent person or worker, in relation to specific work, means a worker who:

1. is qualified because of knowledge, training and experience to organize the work and its performance;
2. is familiar with the OSHA with the provisions of the regulations that apply to the work; and,
3. has knowledge of all potential or actual danger to health or safety in the workplace.

The following roles and responsibilities must be followed by inspectors and contract administrators, but may also apply to other employees under applicable circumstances.

- Use, wear and inspect any equipment, protective devices or clothing as required.
- Attend the contractor's safety orientation and meetings as per the contractor's health and safety program.
- Use and operate only the equipment and tools that employees are competent and qualified to do so and in a safe manner.
- Do not remove or make ineffective any protective device required by the manufacturer, contractor or the employer.
- Do not remove or deface hazardous material identification.
- Report any instances of safety deficiencies such as unsafe conduct by others, defective equipment, tools or personal protective equipment (PPE) to their supervisor immediately, and to the site foreman where construction site safety is concerned.

- Report any safety violation to their supervisor immediately, regardless of the parties involved, and to the site foreman where construction site safety is concerned.

General Safety Rules

The following general safety rules have been referenced from the City's *Field Services Manual* (2016). They reflect best practices that should be adopted in various environments by any worker.

Safety in the Office or Trailer

- Maintain good housekeeping
- Close filing cabinet drawers when not in use
- Use chairs in an appropriate manner
- Carry sharp items in an appropriate manner
- Do not stand in entrances or exits particularly behind closed doors
- Use handrails when using stairs
- Practice good ergonomics
- Ensure that Material Safety Data Sheets (MSDS's) are on site

Safety in the Field

- Notify contractor when on site
- Be aware of the potential hazards on site
- Use appropriate personal protective equipment (PPE)
- Use only equipment that is in good condition
- Watch for damaged power cords, trip hazards, unprotected rebar and other poor housekeeping deficiencies

- Ensure appropriate controls are in place when dealing with hazards
- Become familiar with emergency and rescue procedures
- Know the access and egress points
- Do not operate equipment and machinery without authorization
- Before accessing mobile equipment work zones, make eye contact with the operator to ensure that they have seen and acknowledge you
- Know the traffic plan of the site
- Remain aware of the environment and surroundings at all times, for instance, do not take pictures, write notes, or use cell phone until you are away from hazardous areas

Personal Protective Equipment (PPE)

- Wear CSA approved footwear (Ω TYPE 1 Boot)
- Wear CSA approved hardhat (TYPE 2 CLASS E)
- Wear appropriate high-visibility vest or other appropriate hi-vis clothing and if at night, wear reflective silver stripes encircling each arm and leg
- Wear other personal protection equipment as required
- Hoodies, loose clothing, long hair, and loose jewellery should be taken off or tucked or tied in tight to the body to avoid entanglements.

Conditional PPE as Required for Specific Hazards

- safety glasses, goggles, visors, face shields etc.
- hearing protection
- respirators
- Tyvek suits
- fall protection equipment
- gloves, barrier creams

- personal flotation devices
- any other PPE as determined through risk assessments

Glossary

Bioretention Systems – are purposed to temporarily store stormwater runoff, provide filtration through designated filter media, and infiltration into the underlying native soil. They are typically designed as a shallow, depressed planting bed or similar concrete structure to store captured runoff from minor storm events.

Bioswales – consists of linear vegetated channels which convey, treat and attenuate stormwater runoff. The subsurface composition of the system consists of a filter media, storage gallery, and optional underdrain dependent upon native soil infiltration rates.

Canadian Standards Association (CSA) – is a non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems and personnel in Canada.

Catch basin – Box like underground concrete structure with openings in the curb and gutter designed to collect runoff from the streets and the pavement.

City – The City of Toronto—the corporation—and will be referred to as the City for the purposes of this document.

Construction Inspections – inspections to ensure that the GI is constructed in accordance with Contract Documents.

Construction Monitoring Inspections – are monitoring practices performed during construction phases of the GI to ensure site activities are conducive to satisfactory future operations of the GI system.

Consulting Engineer – A professional engineer or firm of engineers retained by the City or a developer and skilled and experienced in municipal work and land development projects and registered with the Professional Engineers of Ontario.

Continuous Soil Trench (CST) – is a structure designed and built to contain an adequate volume of continuous growing media to support tree growth to maturity under a paved boulevard.

Contract Administrator – The individual or firm responsible for overseeing the construction and administration of the works and representing the City's interest.

Contributing Drainage Area – is the total designated area that drains to the GI system, which includes pervious, impervious and the GI area itself.

Corrective Maintenance – involves maintenance tasks performed to rectify, repair, or rehabilitate systems with deficiencies and return it to design operational performance.

Design Storm Event – is a rainfall (or other precipitation) event or pattern of events with a hypothetical depth of rainfall over a duration in hours that would occur for the stated return frequency such as 2-year or 10-year. A design storm event is typically specified by regulations for the purpose of analyzing existing drainage, designing drainage facilities, or assessing other impacts from the flow of surface water.

Enhanced Grass Swales – are slightly sloping and parabolic vegetated channels which incorporate amended soils to slow stormwater runoff and assist in contamination removal.

Erosion and Sediment Control (ESC) – is the process whereby the potential for erosion and/or eroded soil being transported and/or deposited beyond the limits of the construction site is minimized.

Establishment Period (Trees) – Establishment is a period of reduced growth and vigour experienced by a tree after planting in the landscape, typically lasting from 2 to 5 years.

Filter Strips – are gently-sloping, densely vegetated areas that treat runoff as sheet flow from adjacent impervious surfaces such as roadways, sidewalks, driveways, and parking lots.

Forensic Inspections and Testing – undertaken when issues with the GI system are identified or suspected from other types of inspections.

Forensic Monitoring Inspections – are monitoring practices performed when issues with the GI system are identified or suspected during the operational phase.

Green Gutters – are shallow vegetated planters extending along the length of a street section with inlets and outlets to convey stormwater runoff. The vegetation and filter media acts to attenuate, filter, and infiltrate the runoff.

Green Infrastructure (GI) – “natural and human-made elements that provide ecological and hydrological functions and processes. Green infrastructure may include components such as natural heritage features and systems, parklands, stormwater management systems, street trees, urban forests, natural channels, permeable surfaces, and green roofs” – Toronto Official Plan

Hardscape – refers to all hard elements, such concrete, in a landscape. In the context of this document, hardscape refers to an urban or built context.

Infiltration Trenches – are underground systems used to treat and temporarily store stormwater below ground in shallow geotextile-lined excavations filled with clear stone (i.e. washed gravel). The temporary storage allows for the treatment and percolation of stormwater into the underlying native soil.

Large or Significant Storm Event – describes a rainfall event during which ≥15mm have been received within 24 hours and/or has an intensity of ≥5mm/hr and during which at least 10 mm have been received.

Lifecycle Activities – in the context of this manual, it includes maintenance (preventative, corrective, and predictive) and monitoring (performance and long-term) activities required to support the GI system over its service life.

Long-Term Monitoring – is monitoring consisting of many of the same parameters used in performance monitoring but extends over many years throughout the GI life cycle.

Maintenance Indicators – two (2) types: visual and testing indicators, used to provide a platform for the assessment of the condition and functional performance of a GI system.

Natural Heritage System (NHS) – a network of interconnected natural features and areas such as wetlands, woodlands, valley lands, lakes and rivers which support natural processes necessary to maintain biological and geological diversity, natural functions, viable populations of indigenous species and ecosystems.

Performance Monitoring – determines if the GI function and performance remain in an acceptable range or require corrective actions.

Permeable Interlocking Concrete Pavers (PICP) – is a type of permeable pavement consisting of precast modular concrete units and pervious concrete or rubber/plastic composite designed to allow fine, washed aggregate within the joint spacing.

Permeable Pavements – comprise of joints and/or pores which allows water to infiltrate the surface and be temporarily stored within the clear stone (i.e. washed gravel) aggregate base beneath. Water then either percolates into the underlying native soil or is conveyed to other drainage systems via an underdrain.

Pervious Concrete – is a type of permeable pavement which utilizes minimal fine aggregate in combination with a cementitious binder to allow the formation of connected pores within the rigid pavement structure.

Porous Asphalt – is a type of permeable pavement which utilizes minimal fine aggregate in combination with a bituminous binder to allow the formation of connected pores within the flexible pavement structure.

Predictive Maintenance – consists of practices that monitor and maintain the performance and condition of the GI system during normal operations to reduce the likelihood of failures.

Preventive Maintenance – relates to regular or routine maintenance tasks conducted throughout an asset's operating life to reduce the likelihood of failure. Preventive maintenance can be scheduled on a time or a usage basis.

Provincial Water Quality Objectives (PWQO) – are numerical and narrative criteria for chemical and physical indicators representing a satisfactory level for surface waters (i.e. lakes and rivers) and, where it discharges to the surface and/or the ground water of the Province.

Root Flare / Trunk Flare – Root flare, also called the trunk flare, is the swelling at the base of trees where roots join the trunk. The root flare should be visible at the soil surface.

Routine Operation Inspections – conducted to identify or address when maintenance tasks are needed and to determine when structural repair or further investigations are required to sustain the function of the GI. They should be performed each time a preventive or routine maintenance of the GI is conducted.

Softscape – refers to all living and horticultural elements, such as plants, in a landscape. In the context of this document, softscape refers to a suburban or rural context.

Stormwater Tree Trench (STT) – is a continuous soil trench that is designed to capture, infiltrate and filter stormwater runoff from a drainage area beyond the footprint of the trench.

Testing Indicators – used to provide greater detailed inspections which may involve the gathering of samples and use of field instruments dependent on the test type. A total of five visual indicators are discussed in this manual.

Verification Inspections – ensures that inspection and maintenance plans are being upheld by the property owner and determines if the functional performance of the GI remains acceptable as per design specifications.

Verification Monitoring Inspections – are monitoring practices including sampling and testing performed during the operational phase to determine if GI systems are adequately maintained and if monitoring parameters are within acceptable ranges.

Visual Indicators – represents simple visual attributes followed during inspections to identify GI system conditions. A total of 26 visual indicators are discussed in this manual.

Volunteer Tree Seedling – are seedlings that grow on their own rather than being purposefully or deliberately planted.

Warranty Inspections – performed prior to the termination of construction contracts and warranty or establishment periods of planting and GI systems.

Warranty Monitoring Inspections – are conducted at the end of the construction warranty period prior to the hand-off of the GI to the property owner to confirm if the system was installed as designed, utilizes materials conforming to the design specifications, and functions properly.

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Appendix A – Field Inspection Forms