LOW IMPACT DEVELOPMENT STORMWATER MANAGEMENT PRACTICE INSPECTION AND MAINTENANCE GUIDE

Toronto and Region Conservation for The Living City

Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities for implementing technologies;
- develop supporting tools, guidelines and policies; and
- promote broader use of effective technologies through research, education and advocacy.

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

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ASAE	American Society of Agricultural Engineers
BMP	best management practice
CDA	contributing drainage area
CEC	cationic exchange capacity
C of A	Certificate of Approval
CIESC	Certified Inspector of Erosion and Sediment Controls
CPESC	Certified Professional in Erosion and Sediment Control
CPT	cone penetration test
CSA	Canadian Standards Association
CSO	combined sewer overflow
DPS	Development Permit System (Ontario)
EC	electrical conductivity
ECA	Environmental Compliance Approval
EFVM	electric field vector mapping
EPDM	ethylene propylene diene terpolymer
ESC	erosion and sediment control
FIT	forensic inspection and testing
GIS	geographic information systems
I:P	impervious to pervious drainage area (ratio)
LID	low impact development
LOI	loss on ignition
NPV	net present value
OMOECC	Ontario Ministry of the Environment and Climate Change
OM	organic matter
P	Phosphorus
PAHs	polycyclic aromatic hydrocarbons
PCPs	polychlorinated biphenyls
PICP	permeable interlocking concrete pavers
PSD	particle-size distribution
PSI	pounds per square inch
SA	surface area
SAR	sodium adsorption ratio
SME	saturated media extract
SP	saturated paste
SWM	stormwater management
TCLP	toxicity characteristic leaching procedure
TPO	thermoplastic polyolefin
VOCs	volatile organic compounds

INTRODUCTION

Integration of Low Impact Development (LID) best management practices (BMPs) into stormwater management (SWM) systems is widely advocated to better address the potential stormwater-related impacts of urbanization on the health of receiving waters. A substantial amount of guidance is available on the planning and design of LID BMPs (CVC & TRCA, 2010) and their construction (CVC, 2012) and some municipalities and conservation authorities commonly require them to be a part of new SWM systems.

However, even with sound design, LID BMPs may not provide the intended level of treatment if they are not installed properly or protected from damage during construction. Experiences with early applications have shown that failures are often due to:

- Practices not being constructed as designed or with specified materials;
- Lack of erosion and sediment controls (ESCs) during construction; and/or
- Lack of rigorous inspection prior to assumption.

A 2009 survey of stormwater BMPs in the James River watershed (Virginia) by the Center for Watershed Protection found approximately half (47%) of the 72 BMPs deviated in one or more ways from the original design, or were receiving inadequate maintenance (CWP, 2009). Similar results have been revealed from surveys of stormwater detention ponds in Ontario (Drake et al., 2008; LSRCA, 2011), highlighting the need for thorough inspections of BMPs prior to assumption and a proactive approach to stormwater infrastructure operation and maintenance.

Therefore, it is important to conduct timely inspections during construction and detailed inspection and testing prior to assumption to ensure that LID BMPs are:

- Built according to approved plans and specifications;
- Installed at an appropriate time during overall site construction and with protective measures to minimize risk of siltation or damage; and
- Fully operational and not in need of maintenance or repair at the time of assumption by the property owner or manager.

Like all stormwater BMPs, LID practices are designed to retain pollutants carried by urban runoff and all have a finite capacity to perform this function in the absence of maintenance, until their treatment performance declines or they no longer function as intended. Their functional and treatment performance will only be sustained over the long term if they are adequately inspected and maintained. Under the Ontario Water Resources Act, provincial approvals for SWM facilities and BMPs (i.e., Ontario Ministry of the Environment and Climate Change's Environmental Compliance Approvals process) typically make the property owner responsible for all inspection and maintenance tasks and associated record keeping (Zizzo et al., 2014). A proactive, routine inspection and maintenance program will also:

- Identify maintenance issues before they significantly affect the function of the BMP;
- Help to optimize the use of program resources by providing the feedback needed to determine when structural repairs are needed and to adjust the frequency of routine inspection and maintenance tasks where it is warranted; and
- Help to improve BMP design guidance and develop standards.

Unlike conventional SWM systems that centralize treatment facilities in few locations on publicly owned land (e.g., detention ponds) an LID design approach involves smaller scale practices distributed throughout the drainage area, potentially on both public and private land. Implementing an LID approach to system design has major implications on municipalities and property managers with respect to operating the stormwater infrastructure they are responsible for, as it increases the number and types of BMPs to be tracked, inspected and maintained.

Municipalities already face significant challenges in tracking, inspecting and maintaining their own conventional stormwater infrastructure (i.e., catchbasins, storm sewers, oil and grit separators, ponds and detention facilities) and ensuring practices on private property are adequately maintained. Such challenges include:

- Establishing sustainable program funding mechanisms;
- Securing dedicated program staff;
- Tracking BMP locations and responsible parties;
- Dealing with designs that are not conducive to access or ease of maintenance;
- Private owners that are unaware of inspection and maintenance responsibilities;
- Administering compliance and enforcement procedures; and
- Implementing technologies or software to support field data collection, reporting and database management.

Integrating LID BMPs into infrastructure asset management programs represents a substantial challenge to implementing an LID approach to SWM in many municipalities and organizations (CVC, 2010). In addition to those noted above, implicit with such an approach are the following additional challenges:

- Lack of experience with inspection and maintenance of LID BMPs;
- Administering legal agreements to ensure inspection and maintenance on private property;
- Distributed, decentralized practices are more numerous so require more effort to track; and
- Lack of detailed guidance and templates for program design and implementation.

This guidance document is intended to assist municipalities and property managers with developing their capacity to integrate LID SWM BMPs into their infrastructure asset management programs. Part 1 of the document provides guidance on designing an effective LID BMP inspection and maintenance program, based on experiences and advice from jurisdictions in Canada and the United States, and adapted to an Ontario context. Part 2 of the document provides recommended standard protocols for inspection, testing and maintenance of the following types of structural LID BMPs:

- Bioretention and dry swales;
- Enhanced swales;
- Vegetated filter strips and soil amendment areas;
- Permeable pavements;
- Underground infiltration systems;
- Green roofs; and
- Rainwater cisterns.

Guidance in Part 2 includes recommended inspection, testing and maintenance tasks specific to each BMP type, a summary of staff skills and equipment required to complete them, sampling and testing procedures and estimated costs over a 50 year BMP life cycle. Drawing upon the information provided in this document, municipalities and property managers will be better able to design or adapt their infrastructure asset management programs to include LID BMPs effectively, and understand the tasks, procedures and estimated costs involved in adequately inspecting and maintaining them.

PART 1 – DESIGNING AN EFFECTIVE LID INSPECTION AND MAINTENANCE PROGRAM

1.0 SETTING THE PROGRAM SCOPE

Whether the context is a municipality or another organization involved in the management of properties where stormwater BMPs are present, some important scoping decisions need to be made at the onset of developing an inspection and maintenance program. The following questions highlight preliminary work and key decisions that need to be made to establish the scope of an LID BMP inspection and maintenance program.

1.1 How Many BMPs are to be Included in the Program?

A critical first step in setting the program scope is conducting an inventory of all existing and anticipated future BMPs within the organization's jurisdiction. The inventory should include information on both the physical and regulatory condition of each BMP. The physical condition includes the type of BMP, design parameters, and associated conveyances. The regulatory condition addresses whether the BMP was part of a provincial approvals process (i.e., Ontario Ministry of the Environment and Climate Change's (OMOECC) Environmental Compliance Approval (ECA), formerly known as Certificate of Approval (CofA)) or is part of a maintenance agreements between the municipality and the property owner or located within an easement that is accessible for inspection and maintenance tasks.

Managers must also decide what elements of the overall drainage infrastructure system should be included in the program. For example, will the program be limited to the BMP itself or will it include the conveyance system (e.g., gutters, catchbasins, pipes, pretreatment devices) leading to and from it? It may be decided not to include some BMPs in the program, for example, if they treat a very small drainage area (e.g., residential rain gardens, soakaways, rain barrels, permeable driveways) or if they were not designed or installed to meet regulatory requirements/requirements or as part of a municipal program (e.g., stormwater utility fee credit program or combined sewer overflow abatement plan).

1.2 Who is Responsible?

Assigning responsibility for inspection and maintenance tasks is an important policy question for municipalities and one that may have multiple answers depending on the location and function of the BMP. For example, the local municipality may be responsible for BMPs on public land and within public rights-of-way, but maintenance of BMPs on private land may be a shared responsibility or left to the property owner, manager or home owners association. This decision may depend on the status of easements, maintenance agreements and whether maintenance tasks are routine and aesthetic in nature, or involve structural repairs or rehabilitation. Three general approaches to assigning responsibility for LID BMP inspection and maintenance tasks are described further in Section 2.0.

1.3 What is the Current Status of Legal Tools for Inspection and Maintenance?

When part of a SWM system approved under an OMOECC ECA process, stormwater utility fee credit program, or combined sewer overflow (CSO) abatement program, municipalities must have the legal authority to require inspection and maintenance of BMPs located on private property, or it is likely that these duties will be neglected. The proper legal authority includes assigning maintenance responsibility through a municipal stormwater infrastructure program policy, legally binding maintenance agreements between the municipality and property owner, easements that provide adequate access to BMPs, and enforcement mechanisms. Section 3.3 contains guidance on types of legal tools that could be applied and critical elements of each to enable them to be used to require inspection and maintenance of BMPs on private property.

1.4 What "Level of Service" is Desired for the BMP or Program?

The desired level of service for an individual BMP or an entire inspection and maintenance program encompasses the frequency and type of inspection and maintenance activities that will be undertaken. For example, will BMP inspections be done on an annual basis or more frequently for high priority/visibility ones? Will this vary based on the size and type of BMP, whether the practice is on public or private land, or other factors such as implications if treatment performance is not maintained (e.g., within drainage areas of sensitive receiving waters or species at risk habitat)? Will maintenance be performed in response to complaints or emergencies or will it be based on preset schedules and findings from routine inspections? Table 1.1 outlines several key level of service decisions that need to be made by a municipality prior to program design and is intended to help managers of stormwater infrastructure with planning for the future as their programs develop and evolve.

1.5 Who is Responsible for Routine Maintenance Versus Structural Repairs?

Types of maintenance activities range from routine maintenance tasks like removal of accumulated trash, debris, and small amounts of sediment, weeding and trimming vegetation to more costly and complex structural repairs and rehabilitation of clogged or damaged components. Table 1.2 provides more examples of the differences between routine and structural maintenance tasks. One option for municipalities is to assign responsibility for routine maintenance tasks that are largely aesthetic in nature to the property owner while retaining responsibility for structural repairs. As municipal programs become more sophisticated, some routine maintenance tasks like sediment removal may be taken over by the municipality to avoid or prolong the need for more costly structural repairs.

Table 1.1: *Municipal stormwater BMP Inspection and Maintenance Program level of service matrix (adapted from CWP, 2008).*

Level of Service	BMPs Included	Maintenance Tasks	Maintenance Frequency	Inspectors	Inspection Frequency	Feedback from Experience
LOWER HIGHER	BMPs on public land and within rights-of-way + High priority, high visibility, and/or large BMPs on private land within easements and covered by agreements + All or most BMPs on private land within easements and covered by agreements	Repair immediate threats to public health and safety + Repair structural items: clogged or broken parts, erosion problems + Routine mowing, weeding, remove trash and debris, replace vegetation + Includes retrofitting or reconstructing BMPs	React to complaints and emergencies + Establish preset schedule for routine inspection and maintenance tasks + Conduct structural repairs in response to Routine Operation, Maintenance and Performance Verification inspections	Rely on owners/ managers or their contractors to inspect, maintain and keep track of records. Inspectors send reports to responsible party and municipality Co-inspections with public inspector and responsible party or their consultants Periodic Maintenance and Performance Verification inspections System of certified private inspectors	Complaint driven Annual or semi-annual More frequent for high priority BMPs Maintenance Verification inspections every 5 years Performance Verification inspections every 15 years	Anecdotal + Feedback used to modify list of acceptable BMPs based on maintenance or performance record + Feedback used to modify municipal programs and BMP design guidance or standards

Notes: (+) means that services are cumulative (level of service includes all previous tasks too).

Table 1.2: *Examples of routine maintenance versus structural repair tasks (adapted from CWP, 2008).*

Routine Maintenance Tasks	Structural Repair Tasks
• Mowing, trimming, weeding vegetation • Removal of trash and debris • Replacing individual dead plants, seeding bare spots • Core aeration • Removal of sediment and debris accumulated in pretreatment practices, inlets or outlets • Flushing pipes	• Unclogging inlets, pipes, catchbasin sumps, filter beds, outlets • Repairing or replacing broken or missing parts (e.g., pipes, wells, grates, manholes, valves, seals, pavements, curbs) • Regrading to remedy extreme soil erosion or sedimentation • Replacing large quantities of failed plantings, filter media or topsoil

1.6 Should the Responsible Party Use In-House Resources, a Contractor or Both?

Large municipalities and property management organizations with numerous properties and BMPs to maintain may choose to use in-house staff to conduct BMP maintenance. However, for small to medium-sized organizations, employing private contractors is often more efficient than hiring new staff and purchasing equipment. Another option is entering into an agreement with neighboring local municipalities, the upper-tier municipality or other property managers with stormwater BMPs to maintain to share responsibilities and maximize economies of scale in the use of equipment and personnel.

1.7 How will Maintenance Requirements be Tracked, Verified and Enforced?

For municipalities, enabling policies and program tracking and evaluation systems are key components of an effective stormwater BMP inspection and maintenance program. Before a development proposal is approved, each BMP in the SWM plan that contributes to meeting regulatory requirements should at a minimum, have an inspection and maintenance plan prepared and included in submissions for plan review and approval. Ideally, each BMP that contributes to meeting regulatory requirements should be part of an ECA or maintenance agreement that includes inspection and maintenance plans specific to each type of BMP in the associated site or subdivision plan. Section 3.3.2 describes key elements of maintenance agreements. When up-to-date inspection and maintenance records are not on file with the municipality and cannot be produced by the property owner, or a BMP is found through inspection to be inadequately maintained, mechanisms to enforce compliance with the conditions of the ECA or maintenance agreement must be in place.

2.0 APPROACHES TO ASSIGNING RESPONSIBILITIES

A critical policy decision facing municipalities regarding inspection and maintenance of stormwater infrastructure is who will be responsible, and for what types of tasks because the decision affects how the program will be designed. In general, there are three approaches a community can use to implement a stormwater infrastructure inspection and maintenance program:

1. Property owner approach: Property owners are responsible for performing all inspection, maintenance and repair/rehabilitation for BMPs on their properties and associated record keeping. The municipality provides inspection and maintenance plan templates, property owner outreach education resources and inspects, maintains and repairs BMPs on their land and within infrastructure rights-of-way.
2. Public approach: Municipality is responsible for performing or tracking inspection, maintenance and repair/rehabilitation of all BMPs that qualify for inclusion in their stormwater infrastructure program, whether located on public or private land (e.g., could include those implemented as part of a stormwater utility fee credit program or CSO abatement plan).
3. Hybrid approach: A hybrid approach consisting of both public and private entities responsible for various inspection, maintenance and repair tasks.

Each of these approaches is described further in Table 2.1 and the following sections.

2.1 Property Owner Approach

In a community where the property owner approach is applied, which is the approach being implemented across Ontario through the OMOECC ECA process, the property owner is responsible for all BMP inspection and maintenance, structural repairs and record keeping associated with such tasks. In this approach, the municipality is responsible for all inspection and maintenance tasks associated with stormwater BMPs they own, including those located in infrastructure rights-of-way. A municipal policy is needed that establishes the legal basis for the stormwater infrastructure inspection and maintenance program and establishes criteria regarding what BMPs qualify for inclusion. Placing routine inspection and maintenance responsibilities in the hands of property owners significantly reduces the costs to the municipality, and may be the best option for small communities that cannot afford to allocate municipal staff to inspect and maintain BMPs on private property.

Yet the municipality still plays a significant role under this approach. As the approvers of stormwater plans, municipalities are responsible for developing and maintaining an inventory of BMPs required to meet regulatory requirements, and verifying that they continue to exist. Over the operating phase of the BMP life cycle municipalities may also conduct periodic inspections to verify that ECA, or maintenance agreement conditions are being satisfied (i.e., Maintenance Verification inspections) and that the functional performance of the BMP remains acceptable (i.e., Performance Verification inspections). In this approach they would also be responsible for making sure the property owner

Table 2.1: *Three general approaches to assigning responsibilities.*

Typical Program Characteristics	Strengths/Weaknesses
Property Owner Approach	
◖ Property owner responsible for all inspection and maintenance tasks ◖ Property owner responsible for maintaining an inventory of all BMPs they own and record keeping related to inspection, maintenance and repair, including results from periodic inspections to verify performance ◖ Municipality responsible for educating property owners about the BMP and inspection and maintenance needs ◖ Municipality responsible for legal tools to require/enforce maintenance for regulated BMPs on private property	**Strengths:** ◖ Least costly approach for municipalities **Weaknesses:** ◖ Highest potential for non-compliance
Public Approach	
◖ Municipality responsible for inspection and maintenance tasks for all regulated BMPs and any others that qualify for inclusion in their program (e.g., part of a stormwater utility fee credit program or CSO abatement plan) ◖ BMPs required to meet regulatory requirements should only be located on public property or in rights-of-way ◖ Municipality responsible for maintaining an inventory of all BMPs that qualify for inclusion in their program and record keeping related to inspection, maintenance and repair, including results from periodic inspections to verify maintenance and performance	**Strengths:** ◖ Municipality has the most control over maintenance practices and schedules ◖ Compliance enforcement issues are minimized **Weaknesses:** ◖ Most costly approach for municipalities
Hybrid Approach	
◖ Municipality inspects and maintains BMPs on public land, and within rights-of-way or easements on private property ◖ Property owner responsible for performing some inspection and maintenance tasks and record keeping ◖ Municipality responsible for an inventory of all BMPs that qualify for inclusion in their program, and periodic inspections to verify maintenance and performance ◖ Municipality responsible for educating property owner about the BMP and inspection and maintenance needs ◖ Municipality responsible for legal tools to require/enforce maintenance of regulated BMPs on private property	**Strengths:** ◖ Maximum flexibility ◖ Useful during transition from property owner to public approaches as programs mature **Weaknesses:** ◖ Potential for non-compliance if roles & responsibilities are not made clear to all parties

receives information about the BMP, how it works and its inspection and maintenance needs upon assumption. It is also the role of the municipality to keep track of inspection and maintenance activities for all BMPs they own. If the municipal program fails to fulfill these roles, an inadequate level of maintenance is inevitable.

2.2 Public Approach

In a community where a purely public approach to managing stormwater infrastructure is applied, the municipality is responsible for inspection and maintenance of all BMPs that qualify for inclusion in their program, as established by a municipal policy, which could include those on private property in some cases. In most cases, qualifying BMPs should be located on public land or within a right-of-way that allows the municipality periodic access to conduct inspection and maintenance tasks. For existing BMPs required to meet regulatory standards that are located on private property and not within a right-of-way, the municipality would need to establish an easement to allow periodic access by municipal staff or their contractors for inspection, testing and repair.

While this approach is not common due to high administrative costs and extensive staffing needs, it offers some advantages. The need for maintenance agreements, enforcement and the associated administrative burden is minimized, and the municipality has more control over when and how inspection and maintenance tasks take place. As a municipality grows and their stormwater infrastructure program matures, there may be opportunities to transition from a property owner approach to hybrid or public approaches.

In general, this approach requires the municipality to establish a reliable source of program funding to support collection and management of detailed information about each BMP, and to maintain a team of dedicated program staff. An important first step for municipalities considering a transition to this approach is to conduct an inventory of existing BMPs and associated conveyances to help set the program scope (i.e., what BMPs will qualify for inclusion) and determine immediate maintenance needs.

2.3 Hybrid Approach

A hybrid approach that divides responsibilities for stormwater BMP inspection and maintenance tasks between public and private entities is the most common because it provides the most flexibility for program design. Municipalities using this approach are typically shifting responsibility for some inspection and maintenance tasks from private property owners to the municipality because they are not being performed or reported on as specified in ECAs or maintenance plans/agreements (i.e., compliance issues).

As in the property owner and public approaches, the municipality inspects and maintains BMPs they own on public land, and within rights-of-way and easements. In a hybrid approach, not all BMPs required to meet regulatory standards would need to be located on public land or within rights-of-way. Those located on private property should be part of an ECA or maintenance agreement and consideration given to establishing an easement around the BMP for access. Routine inspection and maintenance of BMPs on private property and structural repairs could be the responsibility of either the municipality or property owner which would need to be specified in ECAs or maintenance agreements. As in a property owner approach, the municipality is responsible for educating private property owners about the BMPs and their inspection and maintenance needs. The municipality is also responsible for the legal tools to require and enforce inspection and maintenance of BMPs on private property (i.e., stormwater infrastructure program policy, maintenance agreements, easements).

In a community that blends public and property owner approaches, BMP inspection and maintenance responsibilities must be clearly documented and communicated for program success. One pitfall in a hybrid approach is when responsibilities are not systematically assigned and communicated. Municipal program staff must understand the conditions of each ECA and maintenance agreement and ensure that private property owners understand their responsibilities. Some recommended methods to assign and communicate inspection and maintenance responsibilities include:

- Use ECA templates or maintenance agreements that clearly document responsibilities for inspection and maintenance tasks;
- Use inspection and maintenance plan templates specific to each type of BMP that clearly describe the required tasks, frequencies and reporting procedures;
- Use easements to clearly document property access rights and responsibilities of both parties See Section 3.3.4 for further guidance on easements;
- Develop and distribute outreach educational materials about what LID stormwater BMPs are, how they work, and their inspection and maintenance needs geared for private property owners and their contractors (i.e., landscaping, road, sewer and roof maintenance contractors);
- Conduct Maintenance Verification inspections of BMPs on private property with representatives of both the municipality and private property owner present, during which inspection and maintenance responsibilities are explained or reiterated; and
- Provide links to BMP specific inspection and maintenance guidance on the municipal stormwater infrastructure program web site.

3.0 STEPS IN PROGRAM DEVELOPMENT

The following sections outline a recommended process for establishing an LID stormwater BMP inspection and maintenance program. Figure 3.1 summarizes eight (8) process steps that are critical in developing municipal SWM BMP inspection and maintenance programs, regardless of the chosen approach to assigning responsibilities (i.e., applicable to any approach), some of which should occur concurrently.

3.1 Develop BMP Inventory

To decide what BMPs will be included in the program and the level of service that can be provided within the constraints of available resources (e.g., funding, staff, equipment), a good understanding is needed of the number of BMPs that already exist and those that are in the planning approvals stage. Combined with information on typical life cycle costs of inspection and maintenance (see Section 7.0 for BMP specific information), it is possible to estimate program budget needs or determine the level of service that can be met with available resources.

The inventory should include compiling information on the physical and regulatory condition of each BMP. The physical condition includes the type of BMP, design criteria and parameters, functional performance targets and associated conveyances. The regulatory condition addresses whether the BMPs were subject to a provincial approvals process (i.e., OMOECC ECA or CofA) or if they are covered by maintenance agreements between the municipality and the property owner and located within rights-of-way or easements that are accessible for inspection and maintenance tasks.

At a minimum, the inventory should capture all BMPs designed or installed to meet regulatory requirements/requirements through the planning approvals process. To the greatest extent possible, retrofitted BMPs subject to a stormwater utility fee credit or to meet combined sewer overflow (CSO) abatement plan or mandatory downspout disconnection program requirements should also be included in the inventory. The level of effort required to collect information about BMPs on private land may warrant excluding them from the inventory or municipal program, such as voluntary lot level BMPs on residential properties (e.g., rain barrels, rain gardens, soakaways, permeable driveways). Inventory work should include collecting information about the conveyances that deliver stormwater to the BMP in addition to the BMP itself. Table 3.1 lists types of information that should be included in a BMP inventory. To gain an understanding of the immediate maintenance needs of existing BMPs, it is recommended that the inventory include field inspections in addition to desktop work to compile available records.

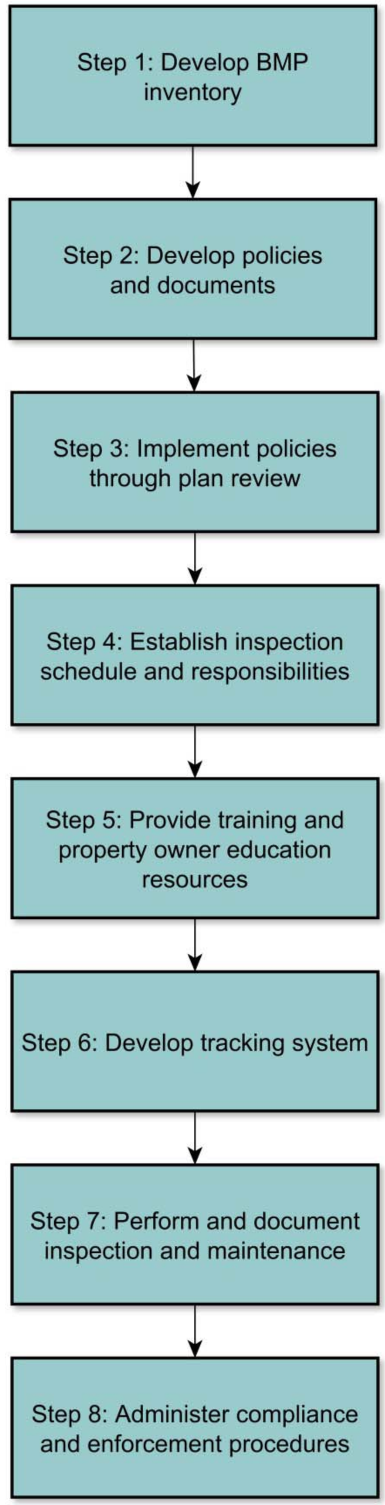


Figure 3.1: *Summary of recommended program development steps.*

Table 3.1: *BMP inventory checklist.*

Physical Condition	Regulatory Condition
• Location of BMP (watershed, subwatershed, property address, BMP geographic coordinates) • Type of BMP • Design criteria and functional performance targets • BMP design features (e.g., Contrinbuting Drainage Area (CDA) size and imperviousness, BMP footprint area, water storage volume/design storm, pipe size, pretreatment devices, filter/growing media specifications, etc.) • Conveyance design features (e.g., pipe size, pretreatment devices, etc.) • Structural integrity (e.g., pavement, curbs, catchbasins, manholes, inlet/outlet, observation wells, etc.) • Status of sediment/trash maintenance • Measured sediment accumulation rate • Inlet/outlet obstruction or erosion • Evidence of standing water • Status of vegetation	• Is BMP on public or private land? • Is BMP within a right-of-way? • Is BMP within an easement? • Is the BMP adequately accessible for inspection and maintenance? • Are there any utility easements that could complicate BMP maintenance/repair? • Are copies of the final approved stormwater plan, design brief /drawings on file? • Is there an OMOECC ECA (formerly CofA)? • Is it part of an approved site plan or subdivision agreement? • Is a maintenance plan or agreement in place? • Are copies of as-built drawings on file? • Are historical inspection and maintenance records available?

3.2 Develop Program Policies and Documents

This step requires critical policy-making decisions that will serve as the foundation for program budget and staffing and for determining the appropriate levels of service for the program. A typical first decision may be determining responsibility for routine inspection and maintenance versus structural repairs. In some communities, simple routine tasks such as inspection of inlets, outlets and vegetation and routine weeding, trimming, mowing and trash removal are performed by the property owner. Table 1.1 provides additional considerations for level of service policy decisions.

For a municipality, the program's legal and administrative foundation must be established in a municipal stormwater management policy (e.g., stormwater utility by-law, sewer use by-law), standard maintenance agreement templates and development permit application forms.

The overarching policy that establishes the municipal stormwater management program must include the following critical elements to be able to require inspection and maintenance of BMPs on private property and to authorize the municipality to enforce ECA and maintenance agreement conditions:

1. Legal authority for a municipality to manage stormwater and applicability provisions that dictate what BMPs will be included in the municipal program versus those that are exempt, and conditions for granting a variance;
2. Description of the permitting and stormwater plan review process including required plan review submission documents and conditions for approval;
3. Requirement that all permanent stormwater BMPs be routinely inspected and maintained by the responsible party, including those not subject to, or part of an OMOECC ECA;
4. Requirement for a maintenance agreement recorded with property title for BMPs on private property that specify right-of-entry for Maintenance and Performance Verification inspections by municipal staff or their contractors;
5. Requirement for BMP specific inspection and maintenance plans that are part of the maintenance agreement, set the schedule of inspection and maintenance tasks and describes reporting requirements and procedures;
6. Requirement for easements around BMPs and/or connections to municipal infrastructure on private property that provide access for Maintenance and Performance Verification inspections, and structural repairs;
7. Maintenance agreement compliance and enforcement provisions;
8. Requirement for a performance bond to cover the cost of rehabilitation or reconstruction needed to address any deficiencies revealed through inspection and testing; and
9. Requirement for as-built plans certified by a professional engineer and landscape architect (where applicable) and satisfactory Assumption inspection prior to release of the performance bond.

Other important program documents that form the administrative foundation of the municipal program include:

- SWM system design criteria that include requirements for features that help reduce the frequency of structural repairs (e.g., pretreatment devices upstream of BMPs) and that improve ease of inspection and maintenance tasks (e.g., features that allow the BMP to be taken off-line or drained by gravity). See Section 4.0 for tips on stormwater BMP design standards and plan review process that will improve inspection and maintenance program success;
- Standard maintenance agreement templates;
- Standard easement conditions and specifications (i.e., when required, width, rights of grantor and grantee);
- Standard inspection and maintenance plan templates for each type of BMP;
- Performance bond template;
- Notice of violation letter template;
- Schedule of penalties for non-compliance with maintenance agreement conditions;
- Educational materials on BMP function, key components, inspection and maintenance requirements and reporting procedures to educate property owners and inspectors (i.e.,

consultants, contractors and municipal staff). Guidance provided in Part 2 of this document can be used to develop BMP specific outreach education materials.

More detailed guidance on the legal and administrative foundation for a municipal stormwater program is provided in the Center for Watershed Protection guide, Managing Stormwater In Your Community: A Guide for Building and Effective Post-Construction Program (CWP, 2008), including a model municipal stormwater policy development tool and examples of maintenance agreements and maintenance easements.

In the context of a proposed new development or redevelopment of a property, the Province of Ontario provides a legislative framework that allows municipalities to place conditions on property titles regarding matters relating to sustainable development and environmental protection, including SWM. The Ontario Development Permit System (DPS) established by Ontario Regulation 608/06, came into effect January 1, 2007. Municipalities can use the DPS to apply conditions to a development permit related to periodic stormwater BMP inspection and maintenance tasks considered necessary for protection of the natural environment and public health and safety. Because the DPS conditions are registered to the property title, this makes them binding for all subsequent owners of the property. However, this only applies when a development permit is required. The DPS is not suitable for ensuring inspection and maintenance of voluntary stormwater BMPs retrofitted into existing developments. For more information about the Ontario Development Permit System see the Ontario Ministry of Municipal Affairs and Housing website (www.mmah.gov.on.ca).

An example of an Ontario municipality using the powers granted by the DPS is the City of Toronto, where green roofs are required for new residential, industrial, commercial and institutional developments with a certain size of roof area through the Green Roof By-law (City of Toronto, 2010). Green roof maintenance plans are required through site plan approvals and are attached to the property title so responsibilities are transferred when property ownership changes.

3.3 Implement Policies through Plan Review

3.3.1 Stormwater plan Review Submission Requirements

The plan review process should ensure that all the documents necessary for ensuring stormwater BMPs are inspected and maintained are in place when a development or redevelopment proposal is approved. These include:

- Maintenance agreement that is recorded with the property title that identifies the responsible party and the applicable lot(s) and specifies right-of-entry for Maintenance and Performance Verification inspections by municipal staff or their contractors;
- Inspection and maintenance plan specific to each type of BMP in the subdivision or site plan, which are part of the approved stormwater plan and maintenance agreements for BMPs located on private property. Guidance provided in Section 7.0 of this document can be used to develop BMP specific inspection and maintenance plan templates, which will need to be

prepared by the municipality to reflect how responsibilities for inspection, maintenance and record keeping tasks are assigned in that jurisdiction. Municipal templates should be provided to the design consultant who would prepare the BMP specific plans as part of document submissions for planning approval. The municipality should provide the BMP specific inspection and maintenance plan to the property owner or purchaser along with broadly accessible information about the BMP, its maintenance needs and sources for additional guidance;

- Maintenance easements around BMPs on private property that provide access to municipal staff or their contractors to perform Maintenance and Performance Verification inspections that are of adequate size to complete the maintenance tasks involved and recorded on the final property survey and title;
- Performance bonds, to provide a financial guarantee that the BMPs are installed correctly and maintained for a certain warranty period prior to assumption by the responsible party. Refer to Tool 7 in the Center for Watershed Protection guide, Managing Stormwater In Your Community: A Guide for Building and Effective Post-Construction Program (CWP, 2008) for more detailed guidance.
- Detailed design and landscaping plan drawings that include BMP features needed for inspection and maintenance. Such features should include monitoring wells in infiltration BMPs, standpipes or manholes connected to sub-drains for inspection and routine flushing, paths for accessing the BMP with equipment needed to perform routine maintenance task (e.g., jet-vac trucks and vacuum sweeping equipment), and pretreatment devices to extend the lifespan of BMPs and delay the need for structural repairs/rehabilitation (e.g., unclogging pipes and filter beds). See Section 4.0 for more detail on key considerations about BMP inspection and maintenance needs during final design and plan review stages.

Consideration of the inspection and maintenance needs of LID BMPs by plan reviewers (i.e., provincial, municipal and conservation authority staff) should occur early in the plan review and approvals process. Document submission requirements for subsequent stages should be clearly communicated to the applicant. Requirements for BMP features needed for inspection and maintenance and pretreatment devices should be communicated to the applicant to help ensure they are considered during detailed design of the BMPs and included on final design and construction drawings.

At an early stage in the design and planning approvals processes it is a good idea to include individuals that will be responsible for performing inspection and maintenance tasks (e.g., property manager or their contractors, municipal roads and parks operations departments) in the review of the proposal. This can help identify design features that will make performing the work easier, and avoid approving BMPs that the organization may not have the capacity to inspect and maintain. If there is a stormwater utility fee and credit program in place, this is the stage when decisions around fees and credits also need to be made.

Once the plan is approved, the project moves to the construction phase, during which inspections are performed to verify that BMPs on the plan are installed correctly. Accurate documentation should be provided and centralized so that inspectors, and ultimately the parties responsible for maintenance, can locate the BMPs and understand their specifications. The types of documents needed from the plan review process to build an effective stormwater infrastructure asset management system and BMP tracking database are listed below. The use of georeferenced databases that can be linked to geographic information systems (GIS) and mobile devices for data collection is recommended to assist with locating BMPs in the field, keeping track of inspection results and maintenance records, scheduling Maintenance and Performance Verification inspections and determining when compliance enforcement actions are warranted.

- Project information: name of project, location, file or tracking number, file location;
- Plan reviewer contact information;
- Information from stormwater plan: number and type of BMPs, where they are located (address, lot number), design specifications, approved engineering and landscaping plan drawings and details;
- Copies of the property survey and title showing easements;
- Copies of ECAs or maintenance agreements;
- Inspection and maintenance plans specific to the BMP type;
- Performance bond form.

3.3.2 Maintenance Agreements

In Ontario, ECAs issued by OMOECC include conditions regarding BMP operation, maintenance, inspection and testing (i.e., monitoring), and associated record keeping and provide a potential mechanism for enforcing compliance with BMP inspection and maintenance plans. They include a Change of Owner section that requires notification of the OMOECC when property ownership changes. When a property is purchased, the new owner acquires the conditions of applicable ECAs.

For permanent BMPs that are not part of an OMOECC ECA, a maintenance agreement (i.e., contract) between the municipality and the property owner may be needed to guarantee that specific inspection and maintenance tasks are performed over its life cycle. It usually specifies enforcement actions that the municipality may take in cases of non-compliance. The maintenance agreement should be registered in the property title. When a property where a BMP subject to a maintenance agreement exists is sold, it is important that mechanisms are in place to update municipal stormwater infrastructure program databases, ideally in an automated manner (e.g., linked to a centralized property information system).

Critical elements to be included in a standard maintenance agreement template are as follows (Herrera Environmental Consultants and Washington Stormwater Center, 2013):

- Identifies the applicable lot;
- Links the agreement with the property title so the conditions transfer to the new owner when the property is sold;

- Identifies and characterizes the BMP(s) on site (e.g., as-built drawings, property survey showing rights-of-way or easements);
- Includes inspection and maintenance plans specific to BMP type;
- Assigns long-term responsibilities for routine inspection and maintenance tasks and non-routine, structural repairs;
- Describes compliance and enforcement procedures and timelines;
- Specifies right-of-entry by the municipality for periodic Maintenance and Performance Verification inspections and to perform necessary maintenance or structural repairs.

3.3.3 Inspection and Maintenance Plans

Inspection and maintenance tasks and their respective frequencies vary depending on the type of BMP and local contexts (i.e., some BMPs may warrant a greater level of service due to their location or characteristics of the receiving water). The inspection and maintenance plan sets the schedule for Assumption inspections, routine tasks and Maintenance and Performance Verification inspections and must be part of stormwater plans and maintenance agreements. It also describes record keeping and reporting procedures which will vary by municipality.

Standard templates for inspection and maintenance plans that are specific to the type of BMP need to be developed by the municipality to reflect how responsibilities for the various tasks and associated record keeping are assigned. Section 7.0 in Part 2 of this document provides information needed to prepare template inspection and maintenance plans for seven types of LID BMPs. Depending on level of service policy decisions, municipalities may choose to refine the frequencies of certain tasks for some types of BMPs or in certain local contexts. However, what is described in Section 7.0 should be considered to be recommended minimum standards.

Key elements to be included in BMP specific inspection and maintenance plan templates are:

- Brief overview of what the BMP is, how it works, what benefits it provides and its key components, including generic diagrams;
- Inspection tasks and frequencies (i.e., inspection schedule);
- Field inspection data form or checklist;
- Routine maintenance requirements (tasks and frequencies) and checklist;
- Include acceptance criteria with tolerance limits or ranges for visual and functional performance testing indicators that trigger when maintenance, repair, rehabilitation or further inspection is needed;
- Operating instructions for outlet component (if applicable);
- Structural repair procedural options;
- Record keeping requirements and reporting procedures.

3.3.4 Maintenance Easements

A maintenance easement is a legal instrument that grants the municipality right-of-entry to a private property for the purpose of inspecting and maintaining municipal or private infrastructure. Securing easements after a BMP has been built and after properties are occupied is time-consuming and has uncertain results. Therefore municipalities should strive to secure maintenance easements around regulated BMPs to be located on private property during the planning process through the review of stormwater plans. To be of legal standing, the easement must be shown on the property survey and recorded in the title. They should be included in the maintenance agreement but may be a separate document in instances when a maintenance agreement is not in place.

Maintenance easements should cover:

- The footprint of the BMP;
- Routes that facilitate access to the BMP by equipment needed for maintenance (e.g., irrigation equipment, hydro-vac trucks, vacuum sweepers) or repair (e.g., construction equipment) and a sufficient margin around all components to perform the work; and
- Conveyances and pretreatment devices associated with BMPs (if applicable under the level of service provided according to the stormwater infrastructure program criteria).

Access requirements for inspection, maintenance and structural repairs will vary depending on the type of BMP. Different standards may be needed than those typically used by municipalities for stormwater detention ponds. The municipality will need to develop standard easement templates for each type of BMP that specify when they are required, their width and rights of the grantor and grantee, along with procedures for recording easements. Access routes within easements, with suitable load-bearing capacity, should extend to all BMP components that will require access by heavy machinery for maintenance or repair, including conveyances and pretreatment devices, inlets and outlets.

3.4 Establish Inspection Responsibilities and Schedule

Over the various life cycle phases of a BMP there are four distinct categories of inspection activities, with different objectives and procedures associated with each category.

1. Construction: During construction inspections are needed to ensure that the BMP installation procedures are appropriate, that adequate ESCs are in place to prevent the BMP function from being compromised, and that materials meeting the specifications in the approved design drawings are used.
2. Assumption: When construction is completed, an as-built survey and thorough inspections are needed to confirm that the BMP was installed as designed with specified materials and is functioning properly.
3. Routine Operation: Over the operating phase routine inspections are needed to determine if the preset schedule of routine maintenance tasks specified in the inspection and maintenance

plan is sufficient and to identify when structural repairs are needed or further investigations into BMP function are warranted.

4. Maintenance and Performance Verification: Also over the operating phase, as the BMP ages, periodic inspections should be done to ensure compliance with the ECA or maintenance agreement conditions and BMP specific inspection and maintenance plan, and to evaluate functional performance and determine when repair, rehabilitation or replacement is warranted.

There are a variety of ways that inspection responsibilities could be assigned. The following subsections provide recommendations and describe some options for establishing inspection responsibilities and schedules. Detailed guidance on critical timing of inspections, the types of indicators that should be used, inspection and testing procedures and criteria for acceptance, and triggers for follow-up action specific to each LID BMP type, is provided in Part 2.

3.4.1 Construction Inspections

Construction inspections should be a shared responsibility between the property owner or their project manager, the designers (i.e., engineer and landscape designer) and the construction contractors.

Many municipalities already conduct some form of inspection of infrastructure they will eventually assume during its construction. Those that do not might choose to work with internal departments (e.g., road or building inspectors, parks/landscaping inspectors) or other agencies (e.g., conservation authorities) that routinely conduct inspections at active construction sites. With adequate training and staff resources, it might be possible to integrate stormwater BMP inspection duties during construction into existing programs. If the workload or skill set needed is beyond what existing programs can handle, or the timing of other types of inspections do not coincide with critical timing of BMP construction inspections, hiring of trained contractors or allocation of dedicated stormwater infrastructure program staff may be necessary.

There are a number of legitimate options to consider regarding who to involve in inspections during BMP construction:

- Consultants and contractors retained by the project proponent/developer or property owner;
- Consultants retained by the municipality (when they are not the proponent or property owner but still choose to be involved);
- Existing municipal inspection staff (e.g., inspectors of ESCs, roads, buildings);
- Dedicated stormwater infrastructure program staff.

Table 3.2 describes some pros and cons for each option.

When responsibility for conducting construction inspections is left entirely to the project proponent/developer or property owner (typically the case), individuals performing them should not be limited to employees of the construction contractor. In this scenario, the designers of the BMP (i.e., engineering and landscape design professionals) should be involved. It may be desirable to involve the project manager (where applicable), whether they are an employee of the proponent/developer or property owner or a consultant. The proponent/developer or property owner should ensure their construction contractors and inspectors are trained in, and experienced with installing and inspecting ESCs (e.g., Certified Professional in Erosion and Sediment Control – CPESC; Certified Inspector of Erosion and Sediment Controls - CIESC) and LID SWM BMPs (e.g., conservation authority training workshops).

Table 3.2: *Pros and cons of using different construction inspection options.*

PROS	CONS
Using Consultants and Contractors Retained by the Developer or Property Owner	
◖ Allows the designers (i.e., engineers and landscape architects), who are most familiar with the BMP, to be involved ◖ Cost is borne by the developer/owner ◖ Inspector observations are made independent of political pressures ◖ Municipality can concentrate on stormwater infrastructure program administration and outreach education	◖ Potential for conflict of interest issues if those involved are limited to employees of the construction contactor
Using Existing Municipal Inspection Staff	
◖ Efficient use of staff ◖ Helps with integration of inspection of ESCs on municipal construction sites ◖ Allows inspectors to stay with the project through the entire construction period	◖ May stretch existing staff beyond their capabilities ◖ Stormwater BMP inspections might not get adequate attention ◖ Critical timing of BMP inspections may not coincide with other types of inspections
Using Dedicated Stormwater Infrastructure Program Staff	
◖ Inspectors can concentrate on stormwater BMPs ◖ Inspector is specifically trained for their duties ◖ Follow-up and enforcement is easier	◖ In many municipalities and property management organizations, would require hiring additional staff ◖ Requires additional communication and coordination between inspectors with different responsibilities

The frequency of Construction inspections may be determined by the municipal stormwater infrastructure program policy or may be general program targets (e.g., weekly, after large storm events, as triggered by construction milestones and hand-off points between different contractors). At a minimum, inspections should occur just prior to the onset of BMP construction to ensure compliance with erosion and sediment control plans and after any large storm event (e.g., 15 mm rainfall depth or greater) during the BMP construction period.

Sections 6.1 and 6.1.1 provide further guidance on Construction inspection objectives and tasks, skills required by inspectors, and a recommended stepwise process for conducting them. Section 7.0 provides detailed guidance regarding critical timing of Construction inspection tasks for each type of LID BMP. Further guidance on best practices to avoid common pitfalls during construction of LID BMPs is provided in Credit Valley Conservation's Low Impact Development Construction Guide (CVC, 2012).

Feedback from Construction inspections should be used to correct any issues associated with BMP installation or ESCs and to identify when changes to the installation procedures, ESCs or BMP design are needed due to site circumstances or complications encountered.

In cases where the project proponent or property owner uses a formal bidding process to select a construction contractor, opportunities exist to include special provisions in tender documents or contracts that will help ensure that LID BMPs receive adequate inspection and maintenance during construction. Special provisions are technical specifications for products, procedures and techniques to be used during construction. Construction supervisors use these technical specifications to ensure contractors comply with minimum standards and design details.

Special provisions in tender documents or construction contracts related to LID BMP installation that can be included to help ensure adequate inspection and maintenance during construction include the following (CVC, 2014a):

1. Clearly outline the work required to install each type of BMP and list the activities involved;
2. Detail the product and material specifications and whether approved equivalents are permissible;
3. Outline installation procedures for each type of BMP and critical points in the sequence of activities when Construction inspections are required before proceeding further (e.g., checking elevations and grades of excavations and pipes prior to backfilling);
4. State any testing requirements or quality assurance documentation for construction materials that must be received and accepted prior to delivering the material to the site (e.g., filter media, aggregate material);
5. Specify maintenance tasks the contractor is responsible for, including procedures and conditions for when or how frequently they need to be done (e.g., sediment removal from BMP pretreatment devices and conveyance structures, maintenance of plantings over the warranty/establishment period).

For more detail and examples of how special provisions relating to LID BMPs can be used in construction tender documents and contracts refer to Credit Valley Conservation's Grey to Green Retrofit Guides (e.g., CVC, 2014b).

3.4.2 Assumption Inspections

Assumption inspections should be a shared responsibility between the property owner or their project manager, the designers (engineering and landscape design professionals) and construction contractors involved in the project. When the municipality is not the property owner, they may choose to not be involved in performing or reviewing such inspection work but should still receive copies of Assumption inspection records so that an inventory database of permanent stormwater BMPs on private property that connect to municipal infrastructure can be developed and maintained. Other terms for such inspections include deficiency, project acceptance or certification inspections.

At a minimum, Assumption inspections should be performed:

1. Immediately after site construction (including landscaping) ends (i.e., the deficiency inspection) prior to substantial completion of construction, release of performance bonds (if applicable) and beginning of the warranty or establishment period, and;
2. Prior to termination of the warranty or establishment period (e.g., 2 years after substantial completion of construction), release of any maintenance holdbacks (if applicable) and assumption by the property owner.

Feedback from inspections should be used to correct any deviations from the approved design or material specifications not approved through change orders, deficiencies in BMP function due to how it was designed or installed and to initiate follow up to replace failed plantings that are under warranty. Once satisfactory results from Assumption inspections are achieved the performance bond(s) are released and the property owner assumes the BMP and becomes responsible for inspection and maintenance tasks. At this stage, documentation of results from Assumption inspections, and records describing the maintenance tasks performed over the establishment or warranty period should be provided by the consultant or municipality to the property owner. The municipality should also receive this information if they are not the inspector or owner and the BMP qualifies for inclusion in their program.

Sections 6.1 and 6.1.2 provide further guidance on Assumption inspection objectives and tasks, timing of inspections and skills required by inspectors. Section 7.0 provides detailed guidance specific to each type of LID BMP regarding key components to be inspected and what visual and testing indicators should be used. Appendix D provides template field data forms for recording inspection results.

There are a variety of approaches to ensuring thorough and satisfactory Assumption inspections of LID BMPs are completed prior to assumption by the property owner but the following contractual and administrative strategies should be considered.

Performance Bonds, Letters of Credit and Cash Sureties

A common method for ensuring BMPs are ready for acceptance/assumption at the end of construction and prior to termination of the construction contract is to require that a performance bond, letter of credit or cash surety be submitted by the contractor to the property owner as a condition of the contract, ideally in an amount equivalent to the full cost of the work. In such cases, construction contracts should specifically require that thorough inspection and testing of the BMPs be completed to the satisfaction of the property owner or their project manager and design consultants as a condition of Assumption, contract termination and release of the performance bond, letter of credit or cash surety.

Holdbacks in Construction Tenders or Contracts

The property owner can specify in construction tenders or contracts to retain a certain percentage of the total value of the work done for a period of 12 months from the date of final completion. In such cases, construction contracts should specifically require that thorough inspection and testing of the BMPs be completed to the satisfaction of the property owner or their project manager, design consultants and construction contractors as a condition of Assumption, contract termination and release of the holdback amount.

3.4.3 Routine Operation Inspections

Routine Operation inspections should be the responsibility of the property owner or their contractors. At a minimum, Routine Operation inspections should occur annually, but twice annually (in spring and fall seasons) is preferable for vegetated BMPs. More frequent inspections may be warranted for highly visible BMPs, those receiving drainage from high traffic areas (vehicle or pedestrian), or those designed with larger than recommended impervious drainage area to pervious BMP footprint area ratio (i.e., I:P ratio).

Feedback from inspections should be used to immediately address routine maintenance needs, schedule structural repairs or further investigations into potential problems with BMP function and to adjust the preset schedule of routine maintenance tasks to optimize the use of program resources.

Sections 6.1 and 6.1.3 provide further guidance on Routine Operation inspection objectives and tasks, timing of inspections and skills required by inspectors. Section 7.0 provides detailed guidance specific to each type of LID BMP regarding key components to be inspected and what visual and testing indicators should be used, routine maintenance tasks and recommended minimum frequencies. Appendix D provides template field data forms for recording inspection results.

3.4.4 Verification Inspections

Verification inspections should be the responsibility of the municipality or be a shared responsibility between the property owner (e.g., hires consultant to perform and document the inspections) and municipality (e.g., approves and tracks documentation). A Verification inspection could replace one Routine Operation inspection that the property owner is responsible for that year.

For permanent BMPs designed and installed to meet regulatory or municipal program requirements, inspections to verify compliance with ECA or maintenance agreement conditions and associated BMP specific inspection and maintenance plans (i.e., Maintenance Verification inspections) should occur on five (5) year intervals beginning after the date of assumption. Maintenance Verification inspections should also be performed when property ownership changes to ensure the new owner is not assuming a BMP that has been neglected by the previous owner, and to help educate the owner about their inspection and maintenance and record keeping responsibilities. Inspection and testing to verify that functional performance remains acceptable (i.e., Performance Verification inspections) should at a minimum, occur on fifteen (15) year intervals beginning after the date of assumption. More frequent Performance Verification inspections may be warranted for BMPs draining to highly sensitive receiving waters or habitat of species at risk. Testing of functional performance (e.g., surface infiltration rate testing, natural or simulated storm event testing, continuous monitoring) is done in addition to Maintenance Verification inspection indicators (i.e., visual indicators and sediment accumulation testing).

Feedback from Maintenance and Performance Verification inspections should be used to initiate compliance enforcement actions if warranted and schedule structural repairs or further investigations into observed problems with BMP function.

Sections 6.1 and 6.1.4 provide further guidance on Verification inspection objectives and tasks, timing of inspections and skills required by inspectors. Section 7.0 provides detailed guidance specific to each type of LID BMP regarding key components to be inspected and what visual and testing indicators should be used, and structural repair options. Appendix D provides template field data forms for recording inspection results.

3.5 Provide Training and Property Owner Education Resources

Property owners are often unaware of what a LID BMP is, what benefits it provides, what they are responsible for, and what components need to be regularly inspected and maintained. Municipal and conservation authority staff, design professionals, construction contractors and project managers involved in projects that include LID BMPs need to be trained on their design, construction, inspection, maintenance and monitoring. Providing access to training programs and educational resources about LID BMPs, targeted to these audiences is essential for stormwater infrastructure program success.

3.5.1 Inspector Training

Since LID BMPs are an innovative approach to SWM and experience with their design, construction and operation is limited in most organizations, training programs for consultants or staff that will be responsible for conducting LID BMP inspections will be needed. Inspectors of LID BMPs will need to be trained on:

- Installation and inspection of ESCs;
- Best practices to avoid common pitfalls during construction that can affect BMP function;
- Construction material specifications for LID BMPs;
- Inspection needs for each type of BMP (i.e., what to inspect and test as part of each type of inspection);
- Workplace health and safety procedures for conducting the work (e.g., confined space entry and rescue training for underground components);
- How to perform inspection tasks and testing (i.e., procedures, soil and water sampling and test methods);
- Minimum acceptable functional performance criteria and triggers for follow-up actions; and
- How to use inspection field data forms or other data management tools (e.g., mobile devices linked to a centralized BMP tracking database).

The inspectors should not only understand the above noted topics "on paper" but also understand how they translate in the field. Access to inspector training programs that feature hands-on, experiential learning opportunities with a full range of LID BMP types should be provided.
Consideration should be given to developing an accredited stormwater BMP inspector training program to promote consistency and quality control. Such a program could include training material catered to the specific needs of property owners, engineering and landscape design professionals, construction contractors, municipalities and conservation authorities.

3.5.2 Property Owner Education

Educational resources that inform property owners about LID BMPs, their inspection and maintenance needs and owner responsibilities are critical for successfully implementing an LID approach to SWM. Such resources could also support programs that promote environmental stewardship and adoption of sustainable practices at the watershed, municipal or neighbourhood scales.

Property owner education resources about LID BMPs should cover the following frequently asked questions, at a minimum (CWP, 2008; Herrera Environmental Consultants and Washington Stormwater Center, 2013):

- What is it? (i.e., describe the BMP and mention other commonly used terms);
- What does it do? (i.e., describe the functions and benefits it provides);
- What are my responsibilities as a BMP owner? (i.e., describe the property owners responsibilities regarding BMP inspection and maintenance, record keeping and reporting);
- What does routine inspection and maintenance involve? (i.e., describe the key components that need to be routinely inspected and recommended minimum frequencies of associated maintenance tasks);

- How do I know if it is functioning adequately? (i.e., describe minimum acceptable functional performance criteria in terms of conditions when further investigation or structural repair is needed to address issues with BMP function).
- How do I repair it (i.e., describe procedural options and equipment needed); and
- Where do I look for more information? (i.e., describe where additional resources can be accessed).

Information provided in Part 2 of this document can be used to develop property owner education resources for each type of LID BMP.

3.6 Develop Tracking System

Regardless of whether the municipality or property owner is performing BMP inspection and maintenance tasks, keeping track of these activities is essential. In large municipalities or property management organizations, advanced database systems with links to GIS and mobile devices for field data collection may be needed. An automated notification system could be added to send notices to property owners when inspection and maintenance records need to be submitted, or when an inspection identifies the need for maintenance, repair or further investigation. Table 3.3 describes types of information that should be included in the BMP database.

3.7 Perform and Document Inspection and Maintenance

Once policy decisions have been made regarding what BMPs qualify for inclusion in the municipal program and what inspection and maintenance tasks municipalities will be involved in for BMPs on private property, important questions may still remain about who will do the work to get it done most effectively. The assignment of specific duties will vary depending on whether it is an individual property owner, a property management organization or municipality, and the size of the organization. It is common for all but the largest municipalities or property management organizations to rely at least partially on contractors to conduct infrastructure inspection, maintenance and repair tasks because of equipment costs and the special skills and training needed by individuals performing the work. Table 3.4 describes some options for assigning specific inspection and maintenance duties in both municipal and property owner contexts.

Table 3.3: *Information to include in a BMP tracking database.*

Information Type	Description
BMP identifier	Unique identifier for the BMP
Lot description	Unique identifier for the lot where the BMP is located or legal description of the lot
Municipal permit number	Unique identifier for the development permit
ECA number	Reference to the ECA the BMP is part of
BMP location	Property address and geographic coordinates
Property owner	Address and contact information for the property owner

Date of assumption	Date the owner assumed responsibility for the BMP
Plans	Copies of the stormwater and landscaping plans and drawings
BMP design and performance criteria	BMP type, dimensions, treatment capacity and minimum functional performance criteria
As-built drawings	Copies of as-built drawings certified by design professionals
ECA/maintenance agreement and inspection and maintenance plan	Copy of the ECA or maintenance agreement and associated inspection and maintenance plan
Easement information	Copy of property survey showing easement and title of easement
Inspection records	Documentation from inspection and testing including test results and follow-up actions.
Maintenance records	Maintenance tasks completed
Structural repair records	Repair work orders, date completed, costs
Photographs	Photos of key components for inspection and maintenance and observed deficiencies that warrant maintenance, repair or further investigation.

Another option is forming partnerships between neighbouring local municipalities, local and upper-tier municipalities or other nearby property owners with stormwater BMPs to maintain to maximize economies of scale in hiring contractors/consultants, training and using staff, and obtaining and using necessary equipment.

Regardless of who performs the inspection and maintenance tasks, the following sections provide some tips for ensuring the work is done efficiently and produces the information and feedback needed for an effective program.

Table 3.4: *Options for assigning responsibilities for inspection and maintenance tasks.*

Program Task	Municipality	Contractor
Construction and Assumption inspections	Professional Engineer or Certified Engineering Technologist and Landscape Architect or Horticultural Professional	Professional Engineer or Certified Engineering Technologist and Landscape Architect or Horticultural Professional
Routine Operation inspections	Operations crew leaders or supervisors	Maintenance crew leader or supervisor
Routine maintenance – vegetated components	Parks operations staff	Landscape maintenance service contractor
Routine maintenance – non-vegetated components	Public works and transportation operations staff	Stormwater infrastructure maintenance service contractor
Structural repairs – vegetated components	Parks operations staff	Landscape maintenance service contractor
Structural repairs – non-vegetated components	Public works and transportation operations staff	Stormwater infrastructure maintenance service contractor

Maintenance and Performance Verification inspections	Professional Engineer or Certified Engineering Technologist and Landscape Architect or Horticultural Professional	Professional Engineer or Certified Engineering Technologist and Landscape Architect or Horticultural Professional

3.7.1 Require As-Built Drawings

Through the plan review process, property owners and municipalities should require that as-built drawings be provided that reflect any changes or material/plant substitutions from the approved engineering and landscaping design drawings, details and specifications that were necessary to overcome complications encountered during construction. Once construction of the BMP is completed, the construction contractor and/or engineering and landscape design professional should prepare as-built drawings, design professionals should certify (i.e., sign) them, and submit copies to the property owner (and municipality for regulated BMPs on private property). Standards for as-built drawings will vary by municipality but could be as simple as electronic copies of the approved design drawings (including BMP landscaping/planting plan), details and specifications marked up with changes or material/plant substitutions. The as-built drawings should be entered into the BMP inventory and tracking database(s) so they may be referred to during Acceptance and Verification inspections.

3.7.2 Use Standard Forms for Documentation of Field Activities

Standard inspection data forms for each type of LID BMP should be used to document observations and test results from site visits. BMP inventory and tracking database(s) should be designed to provide the means of uploading the information and associated photographs remotely from mobile devices. Section 7.0 provides standard inspection field data form templates for seven types of LID BMPs. Program managers can use these templates or customize them to best suit their needs.

3.7.3 Take Photographs

Inspectors should take photographs of key components of each type of BMP during Assumption inspections so they can be referred to during future inspections. Section 7.0 provides guidance on what the key components to be inspected and maintained are for each type of LID BMP. The visual records created can be used to train staff or contractors performing routine inspection and maintenance tasks to recognize the key components and what they looked like when the BMP was new.

When a maintenance or performance issue is encountered through visual inspection that warrants structural repair(s), the problem/deficiency and outcome(s) of repair/rehabilitation work should also be documented with photographs, where feasible. The visual records created can be used to train staff or contractors about minimum acceptable functional performance criteria and conditions that trigger the need for follow-up actions.

3.7.4 Document Structural Repair Items

Inspectors should clearly document items that require structural repairs on inspection field data forms and through photographs. The inspector may also mark up a copy of the as-built drawings to note problem areas and potential corrections. The inspection form should contain a field for recording information about any work orders for maintenance or repair issues as follow-up to the inspection. Such record keeping can be used during the next inspection to help confirm that the maintenance or repair was done correctly or if it was effective at addressing the cause of the problem.

3.8 Administer Compliance and Enforcement Procedures

The province or municipality is responsible for enforcement procedures when owners of regulated BMPs are found to not be in compliance with ECA or maintenance agreement conditions regarding inspection and maintenance. Provisions in the municipal stormwater policy must specifically define inspection and maintenance compliance methods, enforcement procedures and timeframes. Municipalities should be responsible for educating property owners about their responsibilities and applicable compliance methods and enforcement procedures.

A tiered enforcement procedure is often best. Initially the non-compliant property owner can be notified of inspection and maintenance task deficiencies. If tasks described in the ECA/maintenance agreement and BMP specific inspection and maintenance plan continue to not be performed or documented adequately, a more formal notice of violation that outlines specific tasks and a schedule for completing them can be issued. In cases of continued non-compliance or negligence, or where lack of maintenance poses a threat to public health and safety, penalties (e.g., fines) may be issued. Alternatively, if a property standards by-law allows, the municipality may choose to enter the property to inspect and undertake necessary maintenance or structural repairs and bill applicable costs to the property owner or apply them to property taxes.

Table 3.5 summarizes several compliance and enforcement methods that should be considered for ensuring regulated BMPs on private property are adequately inspected and maintained.

Table 3.5: *Review of available compliance methods.*

Method	Stage of Compliance	Description
ECA or maintenance agreement	Established during the planning approvals process. Used during the operating life cycle of the BMP as basis for enforcement	A contract between a municipality and a property owner designed to guarantee that specific inspection and maintenance tasks are performed and recorded.
Property Standards by-law	Used during the operating life cycle of the BMP as basis for enforcement	Municipal by-law that provides right-of-entry to a private property by the municipality or their contractors to perform necessary inspection, maintenance or repair work and specifies conditions for determining when property standards are being neglected and how associated costs are recovered (e.g., bill the property owner for associated costs or apply them to property taxes).
Notice of violation	First stage of enforcement after inspection and documentation of non-compliance/negligence	The property owner is sent a notice of violation letter outlining the nature of the violation, the specific actions needed to come into compliance, a schedule for completing the remedies and subsequent enforcement procedures that can be undertaken if the actions are not performed by the owner.
Stormwater utility fee credit revocation	Escalating level of enforcement if notice of violation does not lead to compliance	In cases where a stormwater utility fee and credit program exist, the municipality can revoke or reduce the credit provided to the property owner for having the BMP on their property if, through inspection, it is found to not be in compliance with ECA/maintenance agreement and inspection and maintenance plan provisions or functional performance is no longer acceptable.
Civil penalty	Escalating level of enforcement if notice of violation does not lead to compliance	As an incentive for compliance, the municipality can levy a monetary penalty for non-compliance. This penalty can be a fixed amount, or the amount could increase with the severity of the violation or frequency of reoccurrence.

4.0 KEY CONSIDERATIONS DURING BMP DESIGN AND PLAN REVIEW

Designing LID BMPs with ease of inspection and maintenance in mind is critical to the affordability of stormwater infrastructure asset management programs and must be considered during design and an early stage in the plan review and approval process. The following sections provide tips on tailoring the design of LID BMPs to help reduce the frequency of structural repairs and make inspection and maintenance tasks easier and cheaper to perform.

4.1 Provide Runoff Pretreatment

Pretreatment refers to techniques or devices used to retain coarse materials suspended in stormwater runoff, either through filtration or settling, before it enters the BMP. Proper pretreatment extends the operating phase of the BMP's life cycle by reducing the rate of accumulation of coarse sediment. Thereby, pretreatment helps delay the need for structural repairs like unclogging filter beds, pipes and orifices. Common pretreatment devices include vegetated filter strips, grass swales, geotextile-lined inlet filters, check dams, forebays, eavestrough screens or filters, oil and grit separators (i.e., hydrodynamic separators) and manholes containing baffles, filters and sumps. One important consideration for pretreatment is that these devices require frequent (i.e., annual) sediment and trash removal maintenance and should be easy to access.

4.2 Design Low Maintenance Conveyance Systems

The design of conveyance systems that carry stormwater into the BMP should anticipate potential maintenance issues and include features to minimize or avoid them. For example, during large storm events, rapidly flowing water into or out of the BMP often causes erosion in vegetated practices. Inlet and outlet designs should consider protective features that prevent erosion. The size of inlets to BMPs and their slope also needs careful consideration as small, gently sloping openings are easily clogged with coarse debris and sediment which could cause stormwater flows to by-pass or not enter the BMP, increasing maintenance needs. Curb cuts should curve into the BMP so that flowing stormwater does not have to turn sharply to enter and inlets should be sloped at between 5 and 10%. Inlets should also be easily accessible and unobstructed by permanent covers to make trash, sediment and debris removal maintenance easy to perform. When designing stormwater infiltration BMPs, consideration should be given to where the majority of trash, sediment and debris will accumulate in the BMP and where snow storage will occur (a significant source area for sediment and debris). Infiltration BMPs should include pretreatment devices, inlet designs or forebays that allow accumulation to occur without blocking inflow (e.g., 5 cm change in grade between pavement surface and BMP surface) and that isolate sedimentation areas from the main portions of the filter bed so that the area disturbed through routine sediment removal maintenance is minimized.

4.3 Include Inspection and Maintenance Features

Planning and design of LID BMPs should consider how they will be maintained (e.g., what equipment is needed?) and what features are needed to perform necessary inspection and maintenance tasks. For example, to understand whether or not a stormwater infiltration practice is draining at an adequate rate, features such as monitoring wells that extend to the bottom of the practice will be needed.

The following list provides some examples of inspection and maintenance features that should be considered in the BMP design process.

- For infiltration BMPs, monitoring wells that extend to the bottom and standpipes or manholes connected to sub-drains that allow access for drainage performance verification through water level measurements and routine flushing of sediment from pipes;
- For infiltration BMPs, sub-drain pipes should be 200 mm in diameter and be connected to manholes, maintenance hatches or standpipes (for standpipes, it is best to use two (2) 45 degree couplings) to allow for inspection by closed circuit camera (i.e., push camera) and sediment removal by jet-vac equipment;
- Lockable caps on monitoring wells and sub-drain clean-out standpipes to prevent unauthorized access, tampering, or vandalism;
- Features for taking the BMP off-line or draining stored water by gravity to improve ease of inspection and sediment removal maintenance tasks;
- Inlets should be readily accessible from surface conveyances, catchbasins, manholes or access hatches to avoid the need for specialized equipment for inspection (e.g., closed circuit or remote controlled cameras);
- For vegetated BMPs, consideration should be given to what source of water will be drawn upon for irrigation during the establishment/warranty period, how it will be delivered to the BMP (e.g., is equipment with sufficient volume and pressure available?), and in some cases an irrigation system should be part of the BMP design (e.g., green roofs);
- For vegetated BMPs in high pedestrian traffic areas, consider the need for walkways or stepping stones and barriers to help limit foot traffic to designated portions of the BMP, or discourage it altogether if it is causing vegetation maintenance issues;
- For underground pretreatment devices or BMPs, the associated manholes or maintenance hatches should be close to a drivable surface/path that can support the heavy vehicles needed for sediment removal maintenance (e.g., hydrovac trucks) and consider installing a staff gauge or graduated measuring tape to allow sediment depth to be assessed visually from the ground surface, without having to enter the confined space;
- Safe and efficient means of accessing and exiting a green roof site for installation, inspection and maintenance is a primary consideration as it will influence the time and effort required to transport tools, equipment and materials to and from the site; and

- For green roofs, tie-off points for ladders and personal fall protection safety equipment should be incorporated in the roof design for use by individuals performing inspection and maintenance work.

4.4 Include Planting Plans

All vegetated BMP designs should include planting plans that specify species that can tolerate both wet and dry conditions and, for BMPs that will receive de-icing salt laden runoff during winter, species that are salt tolerant. Where possible, planting should done during the wettest seasons/months of the year (e.g., early spring and mid-to-late fall) to help minimize the need for irrigation during the establishment/warranty period. Use of drought-tolerant and native species will help minimize or eliminate the need for irrigation during the operating phase of the BMP life cycle. Good vegetation cover on the surface and side slopes of BMPs helps to maintain infiltration function, contributes to runoff volume reduction function through evapotranspiration, and helps prevent erosion of soil or mulch by flowing water.

Both common and botanical (i.e., species) names should be used on planting plans so that inspectors and maintainers of the vegetation are better able to recognize or develop the means of recognizing the plants in the field and distinguishing them from weeds. Planting plans should also specify the planting method (e.g., seed vs. sod) and plant or container size (e.g., saplings vs. caliper tree; plugs vs. pots; bare root vs. root ball). Any deviations from the planting plan or species substitutions should be noted on as-built drawings/planting plans.

All construction contracts that include vegetation should specify a minimum two (2) year warranty period (i.e., establishment period) for the plants, which begins after planting is completed, and ends when the BMP is assumed by the owner. Over the warranty/establishment period the contractor is responsible for routine maintenance tasks (e.g., watering, weeding, and sediment and trash removal). Consideration should be given to specifying a phased approach to planting in construction contracts, in which planting occurs in two stages (e.g., fall and the following spring; spring and the following fall) to help ensure the full palette of plants specified in the plan are available. Thereby, any failed plantings from the first stage of planting are sure to be replaced in the second. If many or all plantings of a certain species do not survive the first phase, they can be substituted with another more tolerant or suitable species in the second.

4.5 Plan for Sediment Removal and Disposal

As mentioned previously, it is recommended that, where possible, pretreatment devices be included in BMP designs that help retain coarse sediment and debris in an easily accessible location before it enters the BMP itself. However even with pretreatment devices in place, fine sediment will inevitably reach the BMP and accumulate over time. LID BMP designs need to consider how sediment can be removed from associated manhole sumps, pretreatment devices, inlets and pipes, and include adequate features and routes for access by necessary equipment.

Examples of equipment that may be needed for sediment removal includes the following:

- For permeable pavements, regenerative air sweeper (for routine maintenance) or vacuum sweeper (for rehabilitation) equipment (e.g., street cleaner trucks or more compact units) will be needed, so designs should allow access to the majority of the surface by necessary equipment (e.g., minimize obstructions and sharp corners);
- For inlets, grass filter strips, gravel diaphragms, check dams and forebays of surface BMPs, use of a vacuum sweeper truck with hose attachment, soil blower truck (operated in reverse), sidewalk vacuum or hand tools (e.g., rakes and shovels) are options;
- For removing sediment from the filter beds of vegetated BMPs, use of a vacuum truck with hose attachment, soil blower truck (operated in reverse) or hand tools are options that can minimize the need to remove established vegetation, while use of a small excavator or backhoe can also be effective, but will require vegetation removal and transplanting (where feasible) or replacement after the work is completed;
- For underground BMPs (e.g., underground infiltration systems, soil cells) and associated pretreatment devices (e.g., manhole sumps, hydrodynamic/oil and grit separators, isolator rows, forebays), and in-line filters, hydro-vac trucks will likely be needed.

For underground conveyances (i.e., catchbasins, manholes, pipes), BMPs, pretreatment devices, and in-line filters, sediment removal often requires crews performing the work to enter confined spaces. Contractors or staff performing the work must have confined space entry training to satisfy occupational health and safety requirements (Ont. Reg. 632/05 – Confined Spaces Regulation).

How the material removed from conveyances, LID BMPs, pretreatment devices and in-line filters will be safely and sustainably managed also needs consideration. Due to the small drainage area of most LID BMPs, the rate at which they accumulate sediment and associated contaminants tends to be low in comparison to centralized stormwater treatment facilities like stormwater ponds or detention chambers/tanks that receive drainage from much larger areas. As a result, the potential for sediment accumulated in LID BMPs to qualify as contaminated according to Ontario Brownfields Regulation 153/04 standards for soil and sediment (OMOE, 2011) is low.

Most often, contractors or staff performing sediment removal maintenance procedures will be cleaning multiple BMPs and pretreatment devices at multiple sites on any given day. At the end of the day, the mixture of material collected either manually, or by vacuum equipment (e.g., regenerative air or vacuum sweeper, vacuum/soil blower truck, hydro-vac truck) will include a mixture of re-usable, recyclable and non-recyclable constituents. In order to recover reusable and recyclable materials and minimize the volume of material needing to be managed otherwise, the mixture should be screened to isolate trash (for recycling or disposal), natural debris and mulch (for composting), and gravel- to pebble-sized aggregates (for washing and re-use) from finer (i.e., sand- to clay-sized) material. The sand- to clay-sized material (i.e., material passing a 2 mm diameter (ASTM No. 10) sieve) should then be assessed and managed in accordance with provincial regulations (O.Reg. 347).

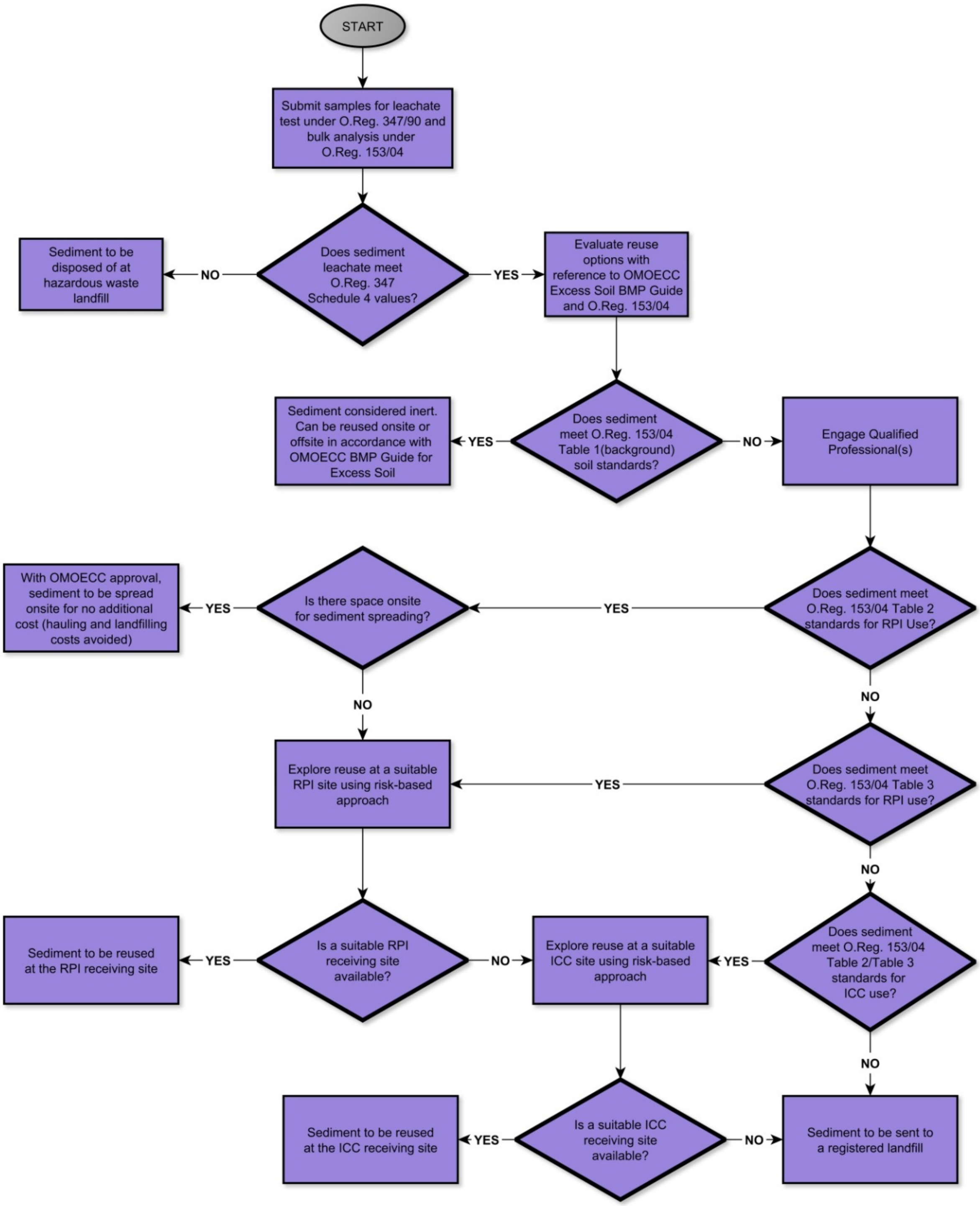


Figure 4.1: *Recommended process for determining reuse and disposal options for sediment from stormwater management BMPs (Source: Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands (TRCA and CH2M, 2016).*

Note: This flow chart does not depict OMOECC policy but rather a recommended approach based on TRCA's understanding of current OMOECC operational practices.

Laboratory testing to determine if beneficial reuse (e.g., spreading on landscaped areas or blending with other constituents for use as a soil conditioner) of the remaining sand- to clay-sized constituents is an option that should be considered. Determining beneficial reuse options for all constituents of the accumulated material could provide substantial savings in terms of costs associated with transporting and managing the material off-site. For more detailed guidance on what types of testing should be done on sediment accumulated in SWM BMPs and what standards to apply to determine when beneficial re-use is an option, refer to Chapter 9 of the Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands (TRCA and CH2M, 2016). The following flow chart (Figure 4.1) provides an overview of the process recommended in the aforementioned guide for determining sediment reuse and disposal options.

4.5.1 Recommended Laboratory Testing for Characterizing Sediment Quality

The selection of sediment quality analysis parameters should reflect the CDA's land use characteristics and reported spill history. The following are the suggested minimum lists of analytes that would be suitable for sites with no history of point source contamination. It is recommended that the OMOECC be contacted to determine if any spill events or other site specific circumstances would require additional analytes as well. The following step-by-step process would provide the data needed to evaluate the feasibility of beneficial use of the sediment or landfill disposal options.

Step 1A: O.Reg. 347 Leachate Test

As required by O.Reg. 347, testing of leachate toxicity by the Toxicity Characteristic Leaching Procedure (TCLP), establishes whether or not the sediment is hazardous waste, which would require disposal at a hazardous waste facility. This information is typically required by the OMOECC as a key first step in characterizing sediment. It may be advisable to conduct this analysis concurrently with Step 1B (O.Reg. 153/04 Bulk Soil Analysis) so that samples for both tests can be collected during the same visit.

A list of the 27 recommended analytes to be examined to assess leachate toxicity is provided below. This list is a subset of the analytes in O.Reg. 347 Schedule 4. Contaminants from Schedule 4 that are omitted from the list are those that are not found in sediment from BMPs draining residential, commercial and institutional sites.

- Arsenic
- Barium
- Boron
- Cadmium
- Chromium
- Fluoride
- Lead
- Mercury
- Selenium
- Silver
- Uranium
- 1,1-Dichloroethylene
- 1,2-Dichlorobenzene
- 1,2-Dichloroethane
- 1,4-Dichlorobenzene
- Benzene
- Carbon tetrachloride
- Chlorobenzene
- Chloroform
- Dichloromethane
- Methyl Ethyl Ketone
- Tetrachloroethylene
- Trichloroethylene
- Vinyl chloride
- Cyanide, weak acid dissociable
- Nitrate and Nitrite as N
- Total Polychlorinated Biphenyls (PCBs)

Step 1B: O.Reg. 153/04 Bulk Soil Analysis

Bulk soil analysis based on the O.Reg. 153/04 Standards is carried out to evaluate whether sediment is suitable for beneficial use or requires landfill disposal. The OMOECC has, on a case-by-case basis, accepted the contaminant thresholds in O.Reg. 153/04 Table 1 as a basis for classifying sediment as inert. Inert sediment can be used off-site without regulatory approval. Sediments that exceed Table 1 soil standards would require a risk evaluation to identify potential beneficial use options according to land use type (see Figure 4.1).

The following is a base list of bulk soil analytes to be tested. It may be necessary to include additional analytes if land use activities in the CDA or past spills are believed to have introduced contaminants that are listed in the Standards but not included in this list.

- Trace metal scan including hot water extractable boron
- Cyanide
- Polycyclic Aromatic Hydrocarbons (PAHs)
- Petroleum Hydrocarbons (PHCs)
- Sodium Adsorption Ratio (SAR)
- Electrical Conductivity (EC)
- Particle Size Distribution (PSD)

Step 2: Topsoil Analysis and Certified Crop Advisor Report for Beneficial Use Evaluations

The topsoil analysis would only be conducted if the O.Reg. 153/04 bulk soil tests determine that the sediment does not require landfill disposal due to high contamination levels. Topsoil analysis would be necessary to demonstrate that amending the receiving site soils with the sediment would provide a benefit to the soils, as required by the Nutrient Management Act, without inhibiting plant growth. The list of analytes to be considered includes:

- Trace metal scan including hot water extractable boron
- SAR
- EC
- pH
- Soil Organic Matter (OM)
- Extractable (i.e., Available) Nutrients
- PSD

5.0 OPPORTUNITIES FOR PUBLIC INVOLVEMENT

Providing educational materials to property owners can improve compliance with ECAs and maintenance agreements. Stormwater BMP inspector training courses or workshops should be made available that teach participants about the various BMPs, what environmental protection benefits they provide and how to perform inspection and maintenance tasks. Table 5.1 provides a list of typical public stakeholders and strategies for involving them in BMP inspection and maintenance. The following sections describe the strategies further.

Table 5.1: *Key stakeholders in stormwater BMP maintenance and involvement strategies.*

Stakeholder Group	Involvement Strategies
Primary Stakeholders	
• Property owners • Consultants and contractors • Municipal inspectors • Municipal operations staff	• Inspector training workshops or certification programs • Educational brochures and mailings to property owners • Co-inspections involving property owner or their consultants and municipal representatives
Other Stakeholders	
• Residents of neighbourhoods where LID BMPs are present • Elected officials	• Volunteer/Adopt-a-BMP program with training and recognition/rewards • Internet resources for basic information and answers to frequently asked questions about LID BMPs.

5.1 Co-Inspections

Municipal inspectors can accompany property owners or their consultants on inspections to help promote thoroughness and consistency. During these inspections, the municipal staff can immediately address any questions or concerns the property owner may have about the municipal program and explain available options for performing necessary maintenance or repair work.

5.2 Training for Inspectors

Training workshops can help ensure thoroughness and consistency in how BMP inspection tasks are conducted. In addition, the peer-to-peer interaction that occurs at such workshops and courses provides participants with opportunities to share field experiences, challenges and solutions. Tying training to an accreditation or certification program can also be a motivator to encourage participation.

5.3 Volunteer/Adopt-a-BMP Programs

To help ease the inspection and maintenance burden for LID BMPs located on public land or in right-of-way, municipalities might consider coordinating a volunteer program that recruits motivated individuals, service groups, neighbourhood associations, or school groups to help with some routine tasks like trash removal or weeding. This approach works for highly visible BMPs that have safe and easy access. Volunteers could also report potential problems or more labor-intensive maintenance needs to the municipality. Certificates of accomplishment, prizes, publicity or other incentives can be used to recruit volunteers and provide a rewarding experience.

5.4 Website Resources

Municipalities should provide access to resources on their website that provide basic information and answer frequently asked question about LID BMPs, written in broadly accessible, non-technical language. Consideration should be given to providing a means for residents to report specific BMP maintenance issues, request an inspection or ask technical questions on-line.

PART 2 – INSPECTION AND MAINTENANCE OF LID PRACTICES

OVERVIEW

With the realization that conventional stormwater detention ponds do not address all the potential impacts of urbanization on our rivers, lakes and wetlands, regulators have begun to require that Low Impact Development (LID) best management practices (BMPs) be integrated into municipal stormwater management (SWM) systems. An LID approach to SWM system design involves smaller-scale BMPs distributed throughout the drainage areas upstream of end-of-pipe practices, potentially on both publicly and privately owned land.

Implementing such an approach to system design has implications on municipalities and property managers with respect to stormwater infrastructure asset management as it increases the number and types of BMPs that need to be inspected, tracked and maintained. Operationalizing an LID approach to SWM requires municipalities and property managers to develop their capacity to inspect and maintain BMPs that most have little or no experience with.

To assist with this challenge, Part 2 of this guide provides detailed guidance on inspection, testing and maintenance of seven (7) types of LID BMPs including the following topics:

- A recommended framework of inspection types that should be performed over the life cycle of SWM BMPs, and the LID BMP specific indicators and tests to use during each type of inspection (Section 6.0);
- BMP specific inspection, testing and maintenance tasks, recommended frequencies, structural repair procedural options and estimates of life cycle costs (Section 7.0);
- Standard inspection and testing protocols for twenty-nine (29) visual indicators and eight (8) types of testing including quantitative triggers for follow-up actions (Section 8.0 and Appendix C) and inspection field data forms for documenting results (Appendix C).

The recommended inspection and testing framework focuses on visual indicators and simple tests to identify potential problems or deficiencies with LID BMPs during construction, before assumption by the property owner and over their operating life cycle. Taking a proactive approach to inspection will avoid assuming BMPs that are already in need of maintenance or repair. Feedback from routine inspections can be used to optimize the frequency of maintenance tasks, avoid more costly repair work, extend the BMPs operating life cycle and save money over the long-term. Utilizing visual indicators for routine inspections, which represent the majority of inspection work over the lifespan of an LID BMP, makes them easier, faster and cheaper to perform. It also limits the need for involving highly trained professionals and technicians to more detailed inspections during construction, prior to assumption and periodic intervals to verify that the BMPs are being maintained and performing adequately.

6.0 INSPECTION AND TESTING FRAMEWORK

6.1 Types of Inspections

The recommended framework for LID stormwater infrastructure inspection and testing programs is organized according to the two main phases in the life cycle of a BMP, construction and routine operation, and involve five types of inspections:

1. Construction inspections
2. Assumption inspections
3. Routine Operation inspections
4. Verification inspections
5. Forensic Inspection and Testing (FIT)

Figure 6.1 describes the inspection framework in terms of BMP life cycle phase, sequence and responsible parties and Table 6.1 summarizes details regarding objectives, timing/frequency and inspector qualifications. Figure 6.2 illustrates a typical inspection timeline for an LID BMP over a 50 year life cycle.

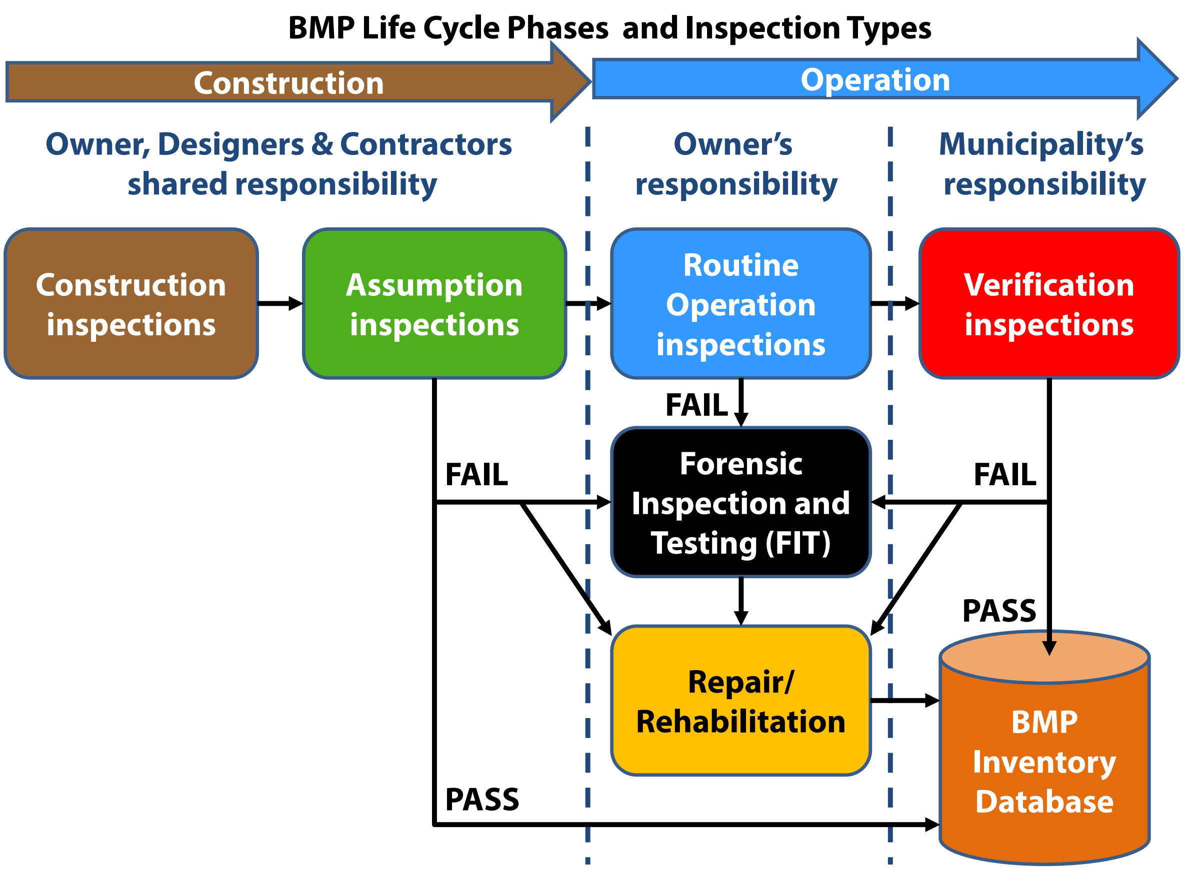


Figure 6.1: *Stormwater BMP life cycle phases, inspection types and responsibilities.*

Table 6.1: *Summary of stormwater BMP inspection types.*

Inspection Type	Objectives	Parties Involved	Timing or Frequency	Inspector Qualifications
Construction inspections	Ensure adequate ESCs are in place and BMP is installed at an appropriate time, as designed with specified materials	Construction contractors, design consultants & project manager	Several points in the construction sequence specific to BMP type; weekly and after any large storm event (e.g., 15 mm rainfall depth)	Certified design professionals (engineers and landscape architects) or technologists (engineering or environmental technologists)
Assumption inspections	Confirm BMP was installed as designed with specified materials, is functioning properly, and determine if BMP is ready to be assumed	Construction contractors, design consultants & project manager	After construction is completed, prior to termination of contracts and warranty or establishment periods	Certified design professionals (engineers and landscape architects) or technologists (engineering or environmental technologists)
Routine Operation inspections	Identify/address minor maintenance needs and determine when structural repair or further investigation into BMP function is needed	Property owner and their contractors	Annually, in the spring at a minimum. Bi-annually (twice per year) in spring and fall for vegetated BMPs	Operations or maintenance crew leaders trained and experienced in road, drainage and landscaping inspections, maintenance and record keeping
Verification inspections	Ensure compliance with inspection and maintenance plan conditions and determine if BMP functional performance remains acceptable	Municipality (property owner and their consultants may also be involved)	Maintenance Verification inspections every 5 yrs.; Performance Verification inspections every 15 yrs.	Certified design professionals (engineers and landscape architects) or technologists (engineering or environmental technologists)
Forensic Inspection and Testing (FIT)	Investigate/diagnose suspected problems with BMP function and determine corrective actions	Property owner and their consultants (municipalities may also be involved)	As needed, triggered by results from other types of inspections	Certified design professionals (engineers and landscape architects) or technologists (engineering or environmental technologists)

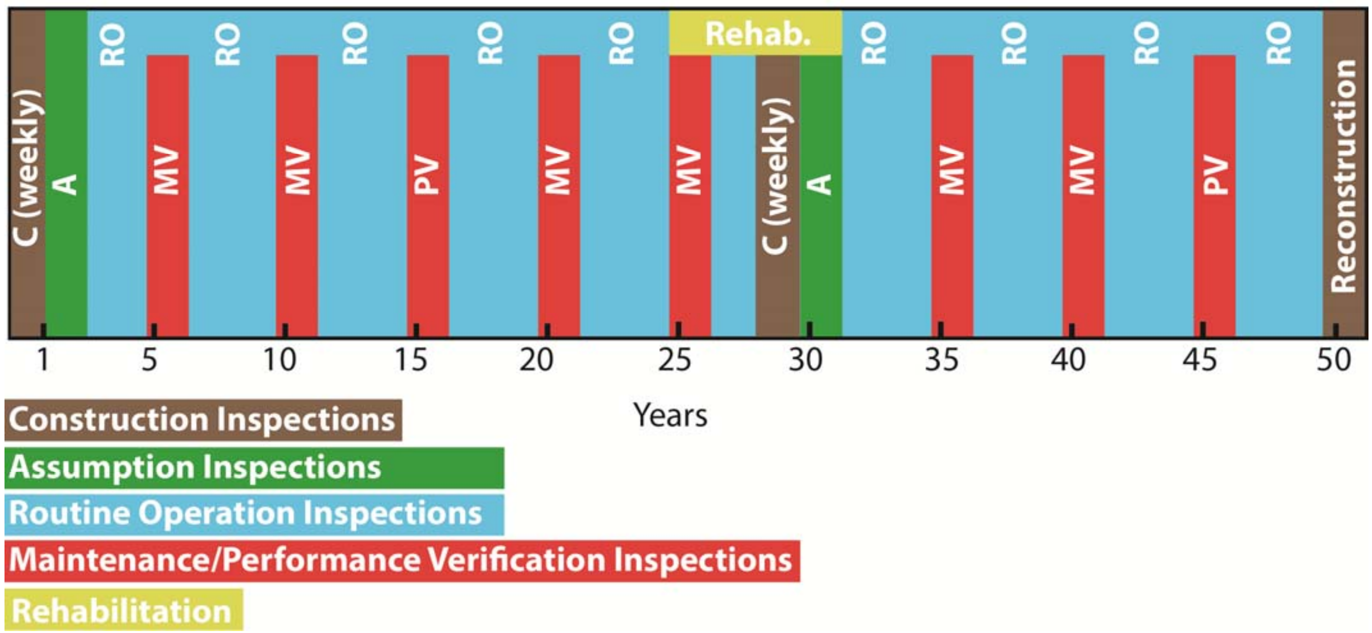


Figure 6.2: *Typical inspection timeline for LID BMPs over a 50 year life cycle.*

The objectives of inspection and testing work and the indicators and tests performed differ for each type of inspection. The following sections describe in greater detail the objectives of each type of inspection, the recommended timing or frequency of inspection and testing work, and the training or specific skills required for staff involved in performing the work.

6.1.1 Construction Inspections

Inspections during construction are done to ensure the following:

1. BMP layout (i.e., location and footprint dimensions) is acceptable;
2. Construction materials meet design specifications;
3. CDA (CDA) is stabilized or erosion and sediment controls (ESCs) or flow diversion devices are in place and adequately maintained;
4. Fencing to restrict heavy vehicle traffic from sensitive areas (e.g., natural heritage features, locations of infiltration BMPs) is in place and adequately maintained;
5. BMPs are installed as designed (i.e., within acceptable tolerances), at an appropriate time in the overall site construction sequence and with suitable equipment and procedures; and
6. Pretreatment and flow diversion devices are functioning and adequately maintained.

Construction inspections take place during several points in the construction sequence, specific to the type of LID BMP (see Section 7.0 for detailed guidance for each BMP type), but at a minimum should be done weekly and include the following:

1. During site preparation, prior to BMP excavation and grading to ensure the CDA is stabilized or that adequate ESCs or flow diversion devices are in place and certify that construction materials meet design specifications;
2. At completion of excavation and grading, prior to installation of pipes/sewers and backfilling to ensure depths, slopes and elevations are acceptable;
3. At completion of installation of pipes/sewers, prior to backfilling to ensure slopes and elevations are acceptable;
4. After final grading, prior to planting to ensure depths, slopes and elevations are acceptable;
5. Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the servicing, paving, building and landscaping contractors);
6. After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure ESCs and pretreatment or flow diversion devices are functioning and adequately maintained.

Construction inspections should be performed by trained professionals that are experienced with interpreting construction drawings and the use of surveying equipment (e.g., professional engineer, landscape architect or certified engineering/environmental technologist) and are accredited inspectors of ESCs. Individuals involved in performing or reviewing inspection work during construction should include design professionals and construction contractors at a minimum, and may also include representatives of the property owner (e.g., municipality or project manager) at critical milestones.

Figure 6.3 illustrates a recommended process for conducting Construction inspections. Table 6.2 provides guidance on each step of the process.

Further guidance on conducting inspections of LID BMPs during construction, and tips regarding common pitfalls and ways of avoiding them are provided in Credit Valley Conservation's Low Impact Development Construction Guide (CVC, 2012).

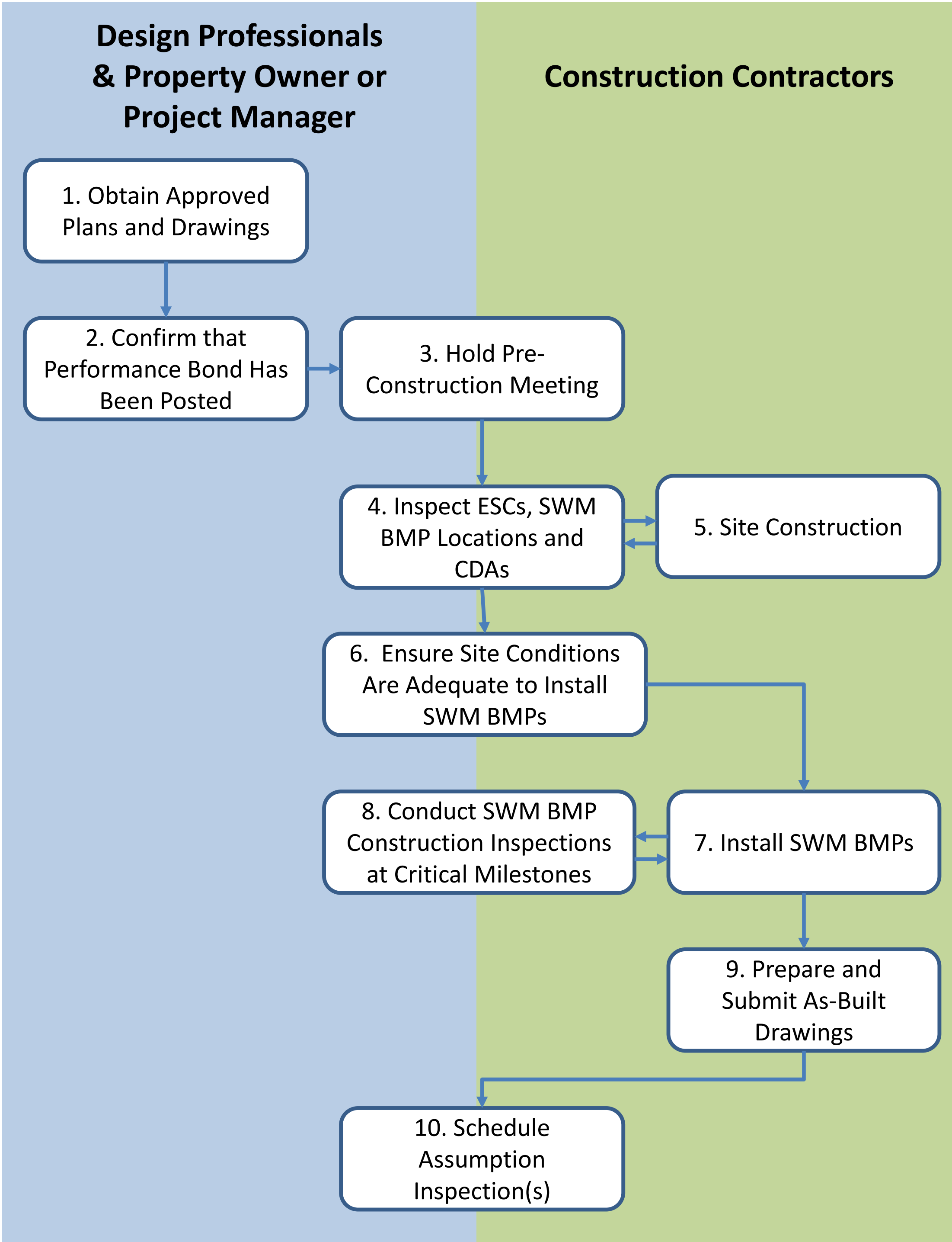


Figure 6.3: *Recommended process for conducting inspections during construction (Adapted from CWP, 2008).*

Table 6.2: *Description of tasks involved in the inspection process during construction. (Adapted from CWP, 2008).*

Process Step	Description
1. Obtain approved plans and drawings	Copies of approved plans, final construction and landscaping plan drawings and contracts are needed. Other information needed by inspectors includes the following: ◖ Summary of how the SWM system meets regulatory requirements; ◖ List of all SWM BMPs to be used at the site; ◖ Set of drawings and details illustrating the types, locations and specifications of SWM BMPs to be used at the site; ◖ Permits; ◖ Contact information for designers and construction contractors; ◖ Construction schedule.
2. Confirm performance bond has been posted (where applicable)	The contractors should post adequate performance bonds or other sureties to ensure costs incurred to address any deficiencies revealed through inspections can be covered. Inspectors should ensure that the bond has been posted before any construction activities begin.
3. Hold pre-construction meeting	A pre-construction meeting should be held prior to any construction activity. The meeting should review the stormwater BMPs to be installed, installation procedures and construction sequence. Critical milestones in the construction sequence, when inspections are needed before proceeding further, should be established. It is recommended that the following parties attend the meeting: ◖ Design professionals (e.g., engineer & landscape architect); ◖ Construction site foreman; ◖ Representatives of relevant construction contractors (e.g., servicing, paving, landscaping); ◖ (Optional) Property owner or their representatives (e.g., project manager or municipal inspector).
4. Inspect ESCs, SWM BMP locations and CDAs	Project site visits and inspections should be conducted according to an established schedule. These inspections can be conducted on a regular basis (e.g., weekly) or at critical milestones in the construction sequence. Such inspection work should focus on the following; ◖ Ensure ESCs remain in place and continue to function; ◖ Fencing around protected natural heritage features and stormwater infiltration BMP locations (where possible), remains in place throughout the construction process; ◖ Track construction sequence and progress towards critical milestones; ◖ Ensure permanent LID BMPs are not placed on-line prematurely during grading or before the CDA has been stabilized and conveyances have been cleaned out.
5. Site construction	Contractors should be made aware of locations of sensitive natural heritage features that should not be disturbed, locations of infiltration BMPs that should not be subject to heavy vehicle traffic or material storage to avoid excessive soil compaction, and critical milestones in the construction sequence when inspections are needed.

6. Ensure site conditions are adequate to install SWM BMPs	Construction of some types of BMPs should not be completed until the CDA is stabilized to help avoid contamination or clogging of inlets, pretreatment devices, and filter beds. Inspectors should ensure that the procedures and sequence of activities detailed on construction drawings and in contracts or tender documents is followed and that the condition of ESCs and the CDA, including conveyances are adequate to complete installation of permanent BMPs. This might take place at several points in the construction sequence as different phases of the project are stabilized.
7. Install SWM BMPs	Installation of permanent BMPs should commence only once verbal or written notice from the inspector has been received indicating that site conditions are adequate to do so.
8. Conduct SWM BMP construction inspections at critical milestones	Although inspectors cannot be on-site during the entire construction sequence, it is critical that inspections take place at critical milestones such as: ◖ After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure ESCs and pretreatment or flow diversion devices are functioning and adequately maintained; ◖ Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the grading, servicing, paving, building and landscaping contractors); ◖ At completion of rough grading and excavation of permanent BMPs, prior to installation of pipes/sewers and backfilling to ensure elevations, depths and grades are acceptable; ◖ Inspection of test results/quality assurance documents for construction materials prior to delivery; ◖ After placement of sub-drain system pipes and downstream conveyances (e.g., catchbasins, manholes), prior to backfilling to ensure elevations, depths and grades are acceptable; ◖ After final grading but prior to planting to ensure elevations, depths and grades are acceptable; ◖ After planting to ensure the right type of plants have been installed in appropriate locations and acceptable quantities.
9. Prepare and submit as-built drawings	Once installation is complete, the designers and construction contractors must prepare as-built drawings for each permanent SWM BMP that describe all approved change orders and any other deviations from the final design drawings that occurred during construction. Design consultants should certify that the BMP has been constructed in accordance with the as-built drawings. Information on as-built drawings should include: ◖ Routes for inspection and maintenance access; ◖ Dimensions (horizontal and vertical) and orientation; ◖ Invert elevations and grades of inlets, outlets, risers, embankments; ◖ Plant material installed (common name, species name & quantity).
10. Schedule Assumption inspection(s)	Upon completion of as-built drawings, the inspector schedules the Assumption inspections. Assumption inspections completed to the satisfaction of the property owner or their design consultants must be done prior to the termination of construction contracts and release of the performance bond.

6.1.2 Assumption Inspections

Assumption inspections are done as a condition of assumption of ownership and maintenance responsibilities for a BMP by the property owner, prior to the termination of construction contracts and warranty or establishment periods for plantings. Other terms for such inspections include deficiency, project acceptance or certification inspections. This type of inspection represents the last opportunity that the property owner has to confirm that the BMP was installed as designed, with the specified materials and is functioning properly. Therefore, Assumption inspections must be both timely and thorough and involve the most comprehensive set of indicators and test procedures. For stormwater infiltration BMPs (i.e., bioretention, permeable pavement, underground infiltration systems), testing may include continuous monitoring of drainage and treatment performance during natural or simulated storm events (Section 8.6). Completion of Assumption inspections to the satisfaction of the property owner or their design consultants prior to the termination of construction contracts and release of the contractor's performance bond should be a required condition included in all contracts involving construction of stormwater BMPs.

Assumption inspection and testing work is done to ensure the following:

- BMPs are installed in accordance with as-built construction and landscaping drawings with materials that meet design specifications;
- Any sediment, trash or debris accumulated on the CDA, in conveyances to the BMP and in pretreatment devices during construction has been removed;
- BMPs are functioning properly;
- Plantings match specifications on the as-built landscaping plan drawing, have been adequately maintained during their warranty period and have become established (i.e., indicators for vegetation cover, composition and condition are within acceptable ranges);
- The BMP is ready for inspection and maintenance responsibilities to be assumed by the property owner.

At a minimum, Assumption inspections should be performed:

- Immediately after site construction (including landscaping) ends (i.e., the deficiency inspection) prior to substantial completion of construction, release of performance bonds (if applicable) and beginning of the warranty or establishment period, and;
- Prior to termination of the warranty or establishment period (e.g., 2 years after substantial completion of construction), release of any maintenance holdbacks (if applicable) and assumption by the property owner.

Prior to conducting Assumption inspections, the property owner or their project manager must receive as-built drawings signed by the design professionals that describe all approved change orders and any other deviations from the final design drawings/plans that occurred during construction. The results of Assumption inspection and testing work should be compared to as-built drawings and planting plans to determine if the BMP was constructed properly and is ready to be assumed. Municipalities will have their own standards for as-built drawings but they can be as simple as electronic copies of the final design drawings legibly marked up with all change orders, deviations or substitutions that were necessary during construction.

Ideally, Assumption inspections should be performed by individuals involved in the design and construction of the BMP being inspected and may also involve the property owner or their representative (e.g., project manager, municipal inspector). At a minimum they should be performed by trained professionals that are experienced with interpreting construction drawings and the use of surveying, soil sampling and testing and environmental monitoring equipment (e.g., professional engineer or certified engineering or environmental technologist). To confirm that plantings match those specified in planting plans, inspectors should include individuals experienced in plant identification that are able to distinguish plantings from weeds (e.g., landscape architect, landscaping technician). It is a good idea to also include individuals that will be responsible for performing Routine Operation inspections as well, to provide an opportunity to familiarize them with the BMP features and their condition at assumption. Further guidance regarding contractual and administrative approaches to ensuring thorough and satisfactory Assumption inspections of stormwater BMPs are completed prior to assumption by the property owner are provided in Section 3.4.2.

Documentation of the results of Assumption inspections should include photographs for each visual indicator relevant to the BMP, which can be used to train individuals responsible for Routine Operation inspections on what features to inspect and maintain.

Upon completion of Assumption inspections to the satisfaction of the property owner or their consultants that confirm the BMP is properly installed and in good working order, the performance bond can be released and construction contracts can be terminated. Upon release of the bond, it is a good idea for the design consultants to issue a certificate of completion, which provides good documentation for the property owner that is assuming the BMP, and the construction contractors regarding this transfer of responsibilities.

6.1.3 Routine Operation Inspections

As part of regularly scheduled visits to the BMP for routine maintenance (e.g., trimming vegetation, weeding, trash and sediment removal, clearing of inlets and outlets) over the operating phase of the BMP life cycle, inspections involving a sub-set of visual indicators and simple sediment accumulation tests should be performed. Routine Operation inspections are done to ensure the following:

- Any routine maintenance needs are identified and immediately addressed before they affect BMP function/performance or require more costly structural repair work;
- Determine if the preset schedule of routine maintenance tasks specified in the inspection and maintenance plan is adequate or needs adjustment;

- Identify when structural repairs are needed or investigations into suspected problems with BMP function are warranted.

At a minimum, Routine Operation inspections should be performed annually in the spring or early summer, prior to the on-set of summer thunder storms. For vegetated BMPs, inspections should be performed every time maintenance crews visit the site to maintain vegetation, which is typically a minimum of twice annually in the spring and fall seasons. More frequent inspections may be warranted for highly visible BMPs, those receiving drainage from high traffic areas (vehicle or pedestrian), or those designed with larger than recommended impervious drainage area to pervious BMP footprint area ratio (i.e., I:P ratio), which will be more prone to accumulation of trash and sediment. <u>The minimum frequency of Routine Operation inspections, the indicators and test to be used, and record keeping/reporting requirements must be specified in the BMP specific inspection and maintenance plan</u>.

<u>Records describing the routine maintenance tasks performed and/or the results of Routine Operation inspections must be documented and tracked over the operating life cycle of the BMP by the property owner so that they can be reviewed as part of Maintenance Verification inspections to confirm compliance with ECA or maintenance agreement conditions and inspection and maintenance plans</u>.

Routine Operation inspections should be performed by individuals trained in road, drainage and landscaping inspection, maintenance and associated record keeping (e.g., operations or maintenance crew leaders). Further suggestions regarding options for delegating responsibilities for Routine Operation inspections are provided in Section 3.4.3. The first Routine Operation inspection a BMP receives should involve all parties that will be responsible for routine inspection and maintenance tasks at the same time to serve as a training exercise. Documentation from Assumption inspections (e.g., completed field data forms and photographs for each visual inspection indicator) should be referred to during the first Routine Operation inspection to help train individuals on what BMP features to inspect and maintain.

The following documents should be provided to property owners taking on responsibility for routine inspection and maintenance of LID BMP, following the satisfactory completion of Assumption inspections:

- As-built drawings signed by the design professionals;
- ECA or maintenance agreement and BMP specific inspection and maintenance plan(s);
- Records from Assumption inspections, including any Forensic Inspection and Testing work completed and photographs of components to be routinely inspected and maintained; and
- Records describing maintenance tasks performed by contractors over the warranty or establishment period.

6.1.4 Verification Inspections

For a permanent BMP designed and installed to meet regulatory or municipal program requirements, periodic inspection and testing over the operating phase of its life cycle is needed to verify property owner compliance with ECA or maintenance agreement conditions and inspection and maintenance plans, and to determine if functional performance remains acceptable. Feedback from Verification inspections should be used to initiate compliance enforcement actions if warranted and schedule structural repairs or further investigations into observed problems with BMP function.

Verification inspections should be the responsibility of the municipality or be a shared responsibility between the property owner (e.g., hires consultant to perform and document the inspections) and municipality (e.g., approves and tracks documentation). These types of inspections can be further classified into Maintenance Verification inspections and Performance Verification inspections.

Maintenance Verification Inspections

Maintenance Verification inspections are performed to verify the following:

- The BMP continues to exist;
- The BMP has been maintained in accordance with the conditions of the ECA or maintenance agreement and inspection and maintenance plan;
- Identify when structural repairs are needed or investigation into suspected problems with BMP function are warranted.

<u>Maintenance Verification inspections should be conducted on five (5) year intervals beginning after the date of assumption and involve review of documentation from Routine Operation inspections, selected visual inspection indicators and simple sediment accumulation tests</u>. They should also be performed when property ownership changes to ensure the new owner is not assuming a BMP that has been neglected by the previous owner, and help educate the owner about their inspection and maintenance and record keeping responsibilities. <u>The minimum frequency of Maintenance Verification inspections, the indicators and test to be used, and record keeping/reporting requirements must be specified in the BMP specific inspection and maintenance plan</u>.

Inspections should be performed by individuals familiar with the contents and conditions of the ECA or maintenance agreements and associated inspection and maintenance plan. Inspectors should be experienced in the inspection of road and drainage infrastructure and landscaping. A Maintenance Verification inspection could replace the need for one Routine Operation inspection that the property owner is responsible for that year and may be conducted as co-inspections with the property owner or their contractor where feasible.

If the Maintenance Verification inspection reveals any failing conditions for visual indicators or if test results do not meet Acceptance Criteria or trigger the need for follow up tasks (e.g., routine maintenance; Forensic Inspection and Testing work; structural repairs; rehabilitation), the municipality sends a letter to the property owner informing them that the BMP has been found to not be in compliance with the maintenance agreement and plan (and the reasons why) and gives them a timeframe for completing follow-up tasks. If the property owner fails to complete follow-up tasks within the timeframe specified by the municipality, enforcement actions are warranted. The nature and severity of enforcement actions will differ depending on the municipality but may include loss of stormwater utility fee credits, billing of the property owner for necessary maintenance or repair work performed by the municipality or third party, or fines.

Performance Verification Inspections

Performance Verification inspections are performed to verify the following;

- The BMP continues to exist;
- The BMP is being maintained in accordance with the conditions of the ECA or maintenance agreement and associated inspection and maintenance plan;
- Function performance remains acceptable or when further investigation into observed problems with BMP function is warranted;
- Identify when structural repair, rehabilitation or replacement is needed.

<u>Performance Verification inspections should, at a minimum, be conducted on fifteen (15) year intervals beginning after the date of assumption and involve the use of the same visual and testing indicators used for Maintenance Verification inspections, plus functional performance testing indicators specific to the BMP type. For infiltration BMPs, continuous monitoring of drainage performance during natural or simulated storm events may also be undertaken</u>. More frequent Performance Verification inspections and/or inclusion of continuous monitoring of water treatment performance during natural storm events may be warranted in the following scenarios:

- When the BMP is a new or hybrid technology for which limited treatment performance evaluation results are available;
- When the BMP is being applied in a certain context for the first time;
- Where the receiving water is highly sensitive; or
- Where the receiving water is habitat for a species at risk.

<u>The minimum frequency of Performance Verification inspections, the indicators and test to be used, and record keeping/reporting requirements must be specified in the BMP specific inspection and maintenance plan</u>.

Performance Verification inspections should be performed by individuals familiar with the contents and conditions of ECAs, maintenance agreements and BMP-specific inspection and maintenance plans and be trained in, and experienced with inspecting LID SWM BMPs. Individuals must also be trained in the use of soil sampling and testing and environmental monitoring equipment (e.g., engineer, engineering or environmental technologist). A Performance Verification inspection also serves as the Maintenance Verification inspection for that year.

The results of Performance Verification inspections should be provided to the property owner along with any recommendations for follow-up tasks or corrective actions that arise from them and timeframes for completing them. If the property owner fails to complete follow-up tasks within the timeframe specified by the municipality, enforcement actions are warranted. The nature and severity of enforcement actions will differ depending on the municipality but may include loss of stormwater utility fee credit, billing the property owner for necessary maintenance or repair work completed by the municipality or their contractors, or fines.

6.1.5 Forensic Inspection and Testing

When results from other types of inspections identify a potential problem with BMP function, Forensic Inspection and Testing (FIT) work is undertaken as a follow-up task to investigate the situation and come up with a plan to address any confirmed problems. FIT work involves the application of a similar set of inspection and testing indicators as those used in Performance Verification inspections, but focuses on diagnosing suspected problems with the following objectives in mind:

- Confirm whether or not problems with BMP function exist;
- Identify the causes of confirmed problems;
- Determine corrective actions needed.

Forensic Inspection and Testing is done on an as-needed basis, as follow-up from other types of inspections where potential problems with BMP function are suspected. Instances when FIT work is warranted include the following:

- Visual inspections reveal potential problems with standing water, vegetation cover/condition (i.e., widespread failure of plantings), control structure condition or cistern structural integrity (Section 8.1 and Appendix C);
- Soil characterization testing indicates soil texture, organic matter, cationic exchange capacity, phosphorus or soluble salts is not within Acceptance Criteria ranges (Section 8.2);
- Surface infiltration rate testing indicates surface drainage rate is less than trigger values for follow-up/corrective action (Section 8.4);
- Results from natural or simulated storm event testing indicate problems with site grading or drainage function of the BMP or conveyances to it (Section 8.5);
- Results from continuous monitoring indicate problems with BMP functional or water treatment performance (Section 8.6).

These specialized inspections must be a shared responsibility of the property owner (e.g., hires consultant to perform and document the inspections) and municipality (e.g., approves and tracks documentation), as they will determine what corrective actions are needed, which could involve structural repairs, rehabilitation or replacement of the BMP. Results of FIT work and any corrective actions that follow it should be recorded in BMP inventory and tracking databases maintained by the municipality. FIT work should be performed by individuals trained in, and experienced with inspecting LID SWM BMPs, landscaping, and diagnosing the causes of observed problems with function. Individuals must also be trained in the use of soil sampling and testing and environmental monitoring equipment (e.g., engineer, engineering or environmental technologist). The results of FIT work should be provided to the property owner along with any recommendations for follow-up tasks that arise from them and timeframes for completing them. If the property owner fails to complete follow-up tasks within the timeframe specified by the municipality, enforcement actions are warranted. The nature and severity of enforcement actions will differ depending on the municipality but may include loss of stormwater utility fee credit, billing the property owner for necessary maintenance or repair work completed by the municipality or their contractors, or fines.

6.2 Inspection and Testing Indicators

The recommended framework for inspection of LID BMPs relies on a set of twenty-nine (29) visual indicators and eight (8) types of tests to rapidly determine if they are ready to be put into service, assumed by the property owner, to assess their maintenance condition, and to periodically evaluate their functional performance. To the greatest extent possible, quantitative triggers have been established for each indicator and test to determine when routine maintenance, structural repair or rehabilitation or other follow-up tasks (e.g., further investigation) are warranted. The set of visual and testing indicators to be used for a given LID BMP will vary depending on the type of inspection and BMP and must be described in the BMP specific inspection and maintenance plan. For Routine Operation inspections, which will be the most frequent type of inspection over the operating life cycle of the BMP (once or twice annually), the focus is on simple visual indicators that can be rapidly assessed by leaders or supervisors of field crews that perform routine maintenance work . This limits the need to involve highly trained design professionals and technicians to Construction, Assumption and Verification inspections and FIT work that require inspectors to be experienced with a variety of environmental sampling, testing and monitoring equipment and data analysis and interpretation.

Table 6.3 describes the recommended framework of inspection and testing indicators that should be used as part of each type of inspection. Table 6.4 describes the recommended inspection and testing framework according to LID BMP Type, showing what visual indicators and tests apply to each. Individual tables for each type of LID BMP are provided in Section 7.0, that describe the visual inspection and testing indicators that should be used during each type of inspection for that type of BMP.

Section 8 and Appendix C describe each type of indicator in detail and provides guidance on sampling protocols, test methods, acceptance criteria, triggers for follow up actions and suggestions for follow-up tasks specific to each indicator.

6.2.1 Visual Indicators

The visual indicators approach allows for a rapid assessment of an LID BMP within a few hours by visually examining the condition of key components in a logical sequence. The observed condition for each indicator is recorded on an inspection field data form, documented by photographs (ideally georeferenced photos) and compared to quantitative or qualitative triggers to determine if follow-up tasks are warranted (e.g., routine maintenance, structural repair, further investigation).

Table 6.3: *Matrix of inspection and testing indicators by inspection type.*

INSPECTION AND TESTING FRAMEWORK		Inspection Type			
Section	**Indicator**	**Construction**	**Assumption**	**Routine Operation**	**Verification**
Visual Indicators					
C.1	CDA condition	x	x	x	x
C.2	Inlet//Flow spreader structural integrity		x	x	x
C.3	Inlet/Flow spreader obstruction	x	x	x	x
C.4	Pretreatment sediment accumulation	x	x	x	
C.5	Inlet erosion		x	x	
C.6	BMP dimensions	x	x		x
C.7	Side slope erosion		x	x	
C.8	Surface ponding area	x	x		x
C.9	Standing water		x	x	x
C.10	Trash		x	x	
C.11	Filter bed erosion		x	x	
C.12	Mulch depth	x	x	x	x
C.13	Filter bed sediment accumulation		x	x	x
C.14	Surface ponding depth	x	x		x
C.15	Filter bed surface sinking		x	x	x
C.16	Check dams	x	x	x	x
C.17	Vegetation cover	x	x	x	x
C.18	Vegetation condition		x	x	
C.19	Vegetation composition	x	x	x	
C.20	Monitoring well condition	x	x	x	x
C.21	Sub-drain/Perforated pipe obstruction		x		x
C.22	Overflow outlet obstruction	x	x	x	x
C.23	Pavement surface condition		x	x	
C.24	Pavement surface sediment accumulation	x	x	x	x
C.25	Control structure condition	x	x	x	x
C.26	Control structure sediment accumulation	x	x	x	x
C.27	Green roof structural integrity		x	x	x
C.28	Cistern structural integrity	x	x	x	x
C.29	Cistern sediment accumulation		x	x	
Testing Indicators					
8.2	Soil characterization testing	x	x		(x)
8.3	Sediment accumulation testing	x	x	x	x
8.4	Surface infiltration rate testing		x		(x)
8.5	Natural or simulated storm event testing		x		(x)
8.6	Continuous monitoring		x		(x)
8.7	Green roof irrigation system testing	x	x	x	
8.8	Green roof leak detection testing	x	x		x
8.9	Cistern pump testing		x	x	(x)

(x) denotes indicators to be used for Performance Verification inspections only (i.e., not for Maintenance Verification inspections)

Table 6.4: *Matrix of inspection and testing indicators by BMP type.*

INSPECTION AND TESTING FRAMEWORK		BMP TYPE						
Section	**Indicator**	**Bioretention & Dry Swales**	**Enhanced Swales**	**Vegetated Filter Strips & Soil Amendments**	**Permeable Pavements**	**Underground Infiltration Systems**	**Green Roofs**	**Rainwater Cisterns**
Visual indicators								
C.1	CDA condition	x	x	x	x	x		x
C.2	Inlet//Flow spreader structural integ.	x	x	x		x		x
C.3	Inlet/Flow spreader obstruction	x	x	x		x		x
C.4	Pretreatment sediment accumulation	x	x			x		x
C.5	Inlet erosion	x	x					
C.6	BMP dimensions	x	x	x	x	x	x	x
C.7	Side slope erosion	x	x					
C.8	Surface ponding area	x	x					
C.9	Standing water	x	x	x	x		x	
C.10	Trash	x	x	x	x		x	
C.11	Filter bed erosion	x	x	x			x	
C.12	Mulch depth	x						
C.13	Filter bed sediment accumulation	x	x			x		
C.14	Surface ponding depth	x	x					
C.15	Filter bed surface sinking	x	x	x				
C.16	Check dams	x	x					
C.17	Vegetation cover	x	x	x	x		x	
C.18	Vegetation condition	x	x	x	x		x	
C.19	Vegetation composition	x	x	x	x		x	
C.20	Monitoring well condition	x			x	x		
C.21	Sub-drain/Perforated pipe obstruction	x			x	x		
C.22	Overflow outlet obstruction	x	x		x	x	x	x
C.23	Pavement surface condition				x			
C.24	Pavement surface sediment accum.				x			
C.25	Control structure condition				x	x		x
C.26	Control structure sediment accum.				x	x		
C.27	Green roof structural integrity						x	
(continues on the following page)								

INSPECTION AND TESTING FRAMEWORK		BMP TYPE						
Section	**Indicator**	**Bioretention & Dry Swales**	**Enhanced Swales**	**Vegetated Filter Strips & Soil Amendments**	**Permeable Pavements**	**Underground Infiltration Systems**	**Green Roofs**	**Rainwater Cisterns**
C.28	Cistern structural integrity							x
C.29	Cistern sediment accumulation							x
Testing								
8.2	Soil characterization testing	x	x	x			x	
8.3	Sediment accumulation testing	x	x	x		x		x
8.4	Surface infiltration rate testing	x	x	x	x			
8.5	Natural or simulated storm event testing	x	x		x	x		
8.6	Continuous monitoring	x			x	x		
8.7	Green roof irrigation system test						x	
8.8	Green roof leak detection system test						x	
8.9	Cistern pump test							x

In Appendix C, visual indicators are organized by BMP component (e.g., CDA Condition; Inlet Obstruction; Inlet Erosion; etc.). It is recommended that the components relevant to the BMP under inspection be examined in the order they appear as they follow a logical progression that mirrors how water is delivered to and flows through the BMP. Following this sequence will reinforce the inspector's understanding of the function of the BMP while helping to hone in on the cause of any observed issues with its condition or function.

6.2.2 Testing Indicators

In addition to visual indicators, which are used during all types of inspections, a set of testing indicators are also recommended for use in the more rigorous inspection work involved in Construction, Assumption and Verification inspections. The tests can involve collection of both soil and water samples and may involve submitting samples to analytical laboratories for testing. They can also involve the use of specialized field instruments or devices to conduct in-situ field testing of soil characteristics, sediment depth, BMP water levels, and outflow rates and volumes. Notes and sketches describing the sampling approach (i.e., number of samples collected, locations and depths) along with test results should be recorded on inspection field data forms. Test results should be compared to quantitative acceptance criteria or trigger values for follow-up to determine if further testing/investigation, routine maintenance, or repair/rehabilitative tasks are warranted.

In Section 8.0, testing indicators are organized according to the following eight (8) types of tests:

1. Soil Characterization Testing;
2. Sediment Accumulation Testing;
3. Surface Infiltration Rate Testing;
4. Natural or Simulated Storm Event Testing;
5. Continuous Monitoring;
6. Green Roof Irrigation System Testing;
7. Green Roof Leak Detection Testing;
8. Cistern Pump Testing.

7.0 BMP SPECIFIC INSPECTION, TESTING AND MAINTENANCE

7.1 Bioretention and Dry Swales

7.1.1 BMP Overview

Bioretention is a general term that refers to stormwater treatment practices that temporarily store runoff in shallow, depressed planting beds or other structures (e.g., concrete planters) and treat it by sedimentation, filtration through highly permeable soil (i.e., filter media) and the root zones of plants, infiltration into underlying sub-soil and evaporation back to the atmosphere. Runoff water is delivered to the practice through inlets such as curb-cuts or other concrete structures, sheet flow from paved areas, or pipes connected to other stormwater conveyances (e.g., catchbasins, roof downspouts). The planting bed and side slopes are typically covered with a mixture of vegetation, mulch and stone. Water that is in excess of the surface ponding or storage capacity overflows to an adjacent drainage system (e.g., municipal storm sewer or other BMP). Bioretention is typically designed to capture runoff from small to medium-sized storm events. An overflow outlet or bypass is necessary to safely convey flows from major storm events. Filtered water is either infiltrated into the underlying native sub-soil or collected by a sub-drain and discharged to the municipal storm sewer system. Key components of bioretention practices for inspection and maintenance are described in Table 7.1 and Figure 7.1.

Properly functioning bioretention practices reduce the quantity of runoff and pollutants being discharged to municipal storm sewers and receiving waters (i.e., rivers, lakes and wetlands) and can help replenish groundwater resources. In addition to their SWM benefits, bioretention areas provide aesthetic value as attractive landscaped features.

A variety of terms can be used to describe design variations for the practice of bioretention. Rain gardens or bioretention cells are depressed planting beds located on individual lots that receive drainage from small to medium-sized areas. Depending on the permeability of the underlying native sub-soil and other constraints, bioretention practices may be designed without a sub-drain for full infiltration, with a sub-drain for partial infiltration, or with an impermeable liner and sub-drain for filtration only. The sub-drain pipe may feature a flow restrictor (e.g., orificed cap, ball valve) in BMPs designed to control peak flow rate. Bio-filters are another name for lined, filtration only bioretention practices. A linearly oriented bioretention practice may be referred to as a bioretention swale (i.e., bio-swale) or dry swale. When contained within engineered structures they may be referred to as stormwater planters or soil cells. Bioretention practices can be adapted to fit into many different contexts and provide a convenient area for snow storage and treatment.

Table 7.1: *Key Components of Bioretention and Dry Swales for Inspection and Maintenance.*

Component	Description
Contributing Drainage Area	The area from which runoff directed to the BMP originates. CDAs include impervious and pervious areas draining to the BMP and the BMP itself. CDAs should be free of point sources of pollutants (e.g., leaking waste containers, spills, failing ESCs). Trash, sediment and debris should be removed regularly from pavements and other conveyances (e.g., gutters, catchbasins, eavestroughs) draining to the BMP.
Inlets	Inlets can be pavement edges (for BMPs receiving sheet flow), curb-cuts, pipes or other engineered structures. Inlets must remain unobstructed to ensure that stormwater enters the BMP as designed. Scour protection features (e.g., stone cover, flow spreader) may also be needed for curb-cut or pipe inlets to prevent erosion of the filter bed from concentrated flow.
Pretreatment	Pretreatment refers to techniques or devices used to slow down and spread out concentrated stormwater flow and retain coarse materials suspended in runoff through filtration or settling, before it enters the BMP. Proper pretreatment extends the operating life cycle of the BMP by reducing the rate of accumulation of coarse sediment in the BMP. Common pretreatment devices include vegetated filter strips, geotextile-lined stone inlets, gravel diaphragms, forebays, check dams, eavestrough screens or filters, oil and grit separators (i.e., hydrodynamic separators) and manholes containing baffles or filters and sumps. Pretreatment devices require frequent (e.g., annual or bi-annual) trash, sediment and debris removal.
Perimeter	Side slopes of the BMP, covered by a mixture of vegetation, mulch and stone with slopes of 2:1 (H:V) or less that surround the filter bed and allow for surface ponding. For stormwater planters the perimeter may be a concrete or masonry structure with vertical walls. Inspection of the perimeter is done to confirm the dimensions of the BMP are acceptable, ensure the structural integrity of side slopes or vertical walls is maintained and confirm that the BMP continues to provide the designed surface ponding water storage capacity. Periodic maintenance of side slopes may be needed to repair erosion rills or damage from vehicle or foot traffic.
Filter bed	Flat or gently sloping area composed of a 0.5 to 1 metre deep layer of filter media soil covered by a mixture of vegetation, mulch and stone where surface ponding and infiltration of runoff occurs. Bioretention practices are designed to infiltrate all water ponded on the surface within 24 hours of the end of a storm to prevent conditions supportive of mosquito breeding. Filter beds should be checked for presence of standing water. Trash should be removed from the filter bed regularly. Mulch or stone cover should be maintained on non-vegetated areas to prevent weed growth and soil erosion. Accumulated sediment should be periodically removed to maintain infiltration function. Repair of animal burrows, sunken areas, erosion rills or damage from vehicle or foot traffic may also be needed to prevent short circuiting of flow through the filter media soil. Maximum ponding depth should be checked to ensure designed water storage capacity is maintained.
Vegetation	Bioretention practices rely on vegetation to intercept, uptake and evapotranspire stormwater and provide habitat for soil organisms that break down pollutants. Plant roots also help to maintain soil structure and permeability. Routine maintenance of vegetation is the same as a conventional planting bed (i.e., weeding, mowing, pruning, irrigation during droughts). In the first 2 months of

	establishment, plantings need to be irrigated frequently (e.g., bi-weekly). As bioretention practices are intended to retain nutrients from inflowing stormwater, applying fertilizer to the filter bed should not be a part of routine maintenance.
Overflow Outlets	Flows exceeding the storage capacity of the BMP are conveyed to an adjacent drainage system via an overflow outlet structure (e.g., pipe, standpipe, curb-cut, swale, catchbasin). Overflow outlet structures must be kept free of obstructions to ensure stormwater is safely conveyed during major storm events.
Sub-drain	Sub-drains are optional components that may be included where the permeabililty of the underlying native sub-soil is low or, due to other constraints, an impermeable liner is required. They are installed below the filter media soil layer to collect and convey treated water to an adjacent drainage system. Sub-drains are comprised of perforated pipes wrapped in a gravel blanket and in some cases geotextile filter fabric. The perforated pipe must be kept free of obstructions to ensure that the subsurface water storage capacity of the BMP drains within a specified time period. A maintenance port standpipe may be connected to the perforated pipe to provide a means of flushing and inspecting it. Perforated pipes should be routinely flushed with water to remove sediment. Trimming of plant roots that have penetrated the perforated pipes may be warranted periodically. If the sub-drain is equipped with a flow-restrictor (e.g., orificed cap, ball valve) to attenuate flow rates, the flow restrictor must be inspected and cleaned regularly.
Monitoring well	Standpipes that extend from above the surface of the filter bed to the bottom of the excavation and contain perforations or slots to allow observation and measurement of subsurface water level in the BMP. Monitoring wells are needed to determine if the BMP drains within an acceptable time period and to track drainage performance over its operating lifespan. Standpipes should be securely capped on both ends and remain undamaged and free of sediment which may require periodic flushing.

7.1.2 Inspection and Testing Framework

Table 7.2 describes what visual and testing indicators should be used for bioretention practices during each type of inspection and provides a basis for planning field work. Numbers in the first column refer to the part of Section 8.0 and Appendix C that provides detailed guidance on standard protocols and test methods for assessing the respective indicator.

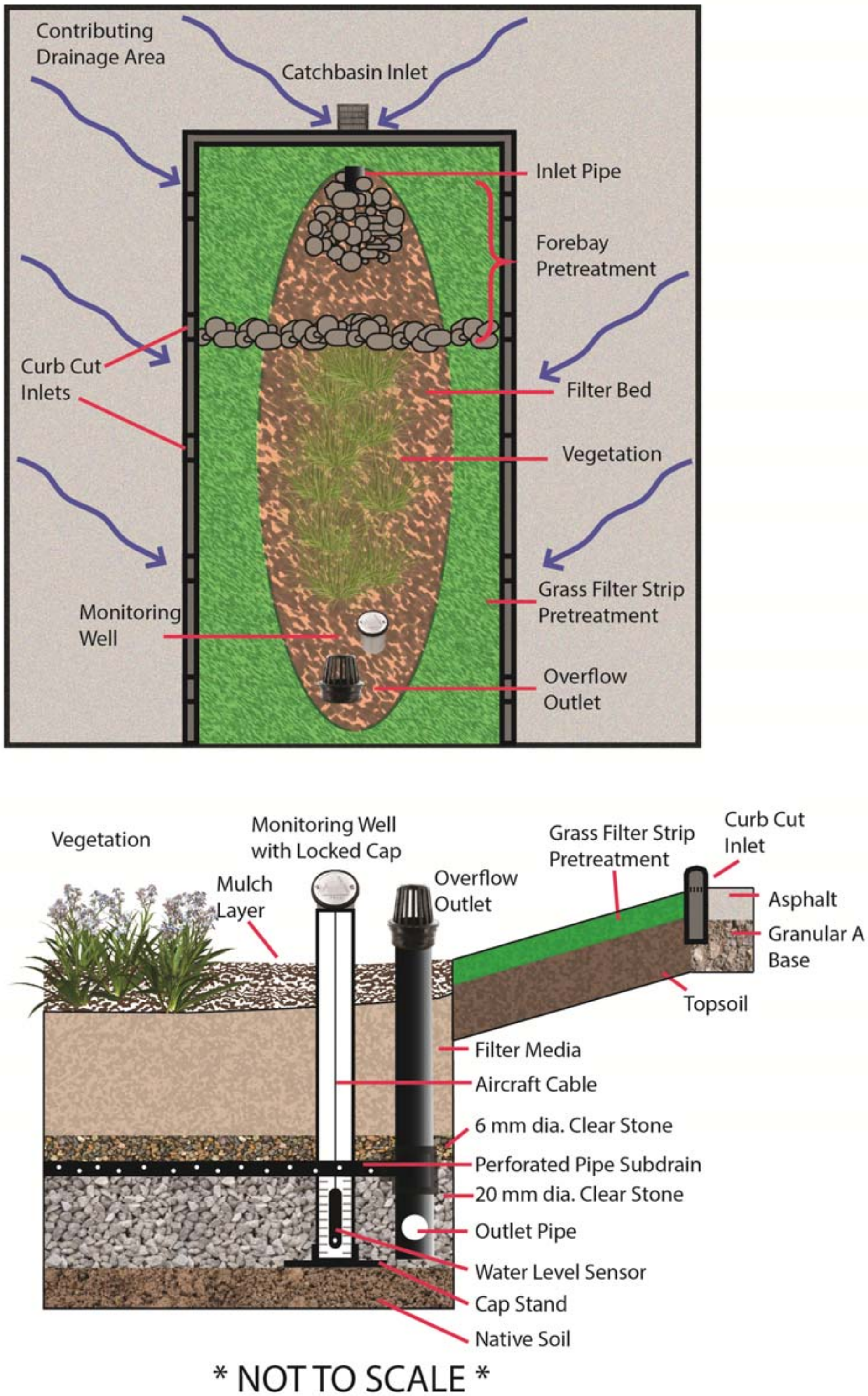


Figure 7.1: *Generalized plan and cross-section views of a bioretention cell showing key components.*

Table 7.2: *Inspection and testing indicators framework for bioretention and dry swales.*

INSPECTION AND TESTING FRAMEWORK					
BIORETENTION & DRY SWALES		Inspection Type			
Section	**Indicator**	**Construction**	**Assumption**	**Routine Operation**	**Verification**
Visual indicators					
C.1	CDA condition	x	x	x	x
C.2	Inlet/Flow spreader structural integrity		x	x	x
C.3	Inlet/Flow spreader obstruction	x	x	x	x
C.4	Pretreatment sediment accumulation	x	x	x	
C.5	Inlet erosion		x	x	
C.6	BMP dimensions	x	x		x
C.7	Side slope erosion		x	x	
C.8	Surface ponding area	x	x		x
C.9	Standing water		x	x	x
C.10	Trash		x	x	
C.11	Filter bed erosion		x	x	
C.12	Mulch depth	x	x	x	x
C.13	Filter bed sediment accumulation		x	x	x
C.14	Surface ponding depth	x	x		x
C.15	Filter bed surface sinking		x	x	x
C.16	Check dams	x	x	x	x
C.17	Vegetation cover	x	x	x	x
C.18	Vegetation condition		x	x	
C.19	Vegetation composition	x	x	x	
C.20	Monitoring well condition	x	x	x	x
C.21	Sub-drain/Perforated pipe obstruction		x		x
C.22	Overflow outlet obstruction	x	x	x	x
Testing Indicators					
8.2	Soil characterization testing	x	x		(x)
8.3	Sediment accumulation testing	x	x	x	x
8.4	Surface infiltration rate testing		x		(x)
8.5	Natural or simulated storm event testing		x		(x)
8.6	Continuous monitoring		x		(x)

(x) denotes indicators to be used for Performance Verification inspections only (i.e., not for Maintenance Verification inspections)

7.1.3 Critical Timing of Construction Inspections

Construction inspections take place during several points in the construction sequence, specific to the type of LID BMP, but at a minimum should be done weekly and include the following:

1. During site preparation, prior to BMP excavation and grading to ensure the CDA is stabilized or that adequate ESCs or flow diversion devices are in place and confirm that construction materials meet design specifications;
2. At completion of excavation and grading, prior to installation of pipes/sewers and backfilling to ensure depths, slopes and elevations are acceptable;
3. At completion of installation of pipes/sewers, prior to backfilling to ensure slopes and elevations are acceptable;
4. After final grading, prior to planting to ensure depths, slopes and elevations are acceptable;
5. Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the storm sewer servicing, paving, building and landscaping contractors);
6. After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure ESCs and pretreatment or flow diversion devices are functioning and adequately maintained.

Table 7.3 describes critical points during the construction sequence when inspections should be performed prior to proceeding further. Table 7.3 can also be used as a checklist during Construction inspections, in addition to the Inspection Field Data Forms provided in Appendix C.

7.1.4 Inspection Field Data Forms

Template forms for recording inspection observations, measurements, sampling location details and follow-up actions have been prepared for each LID BMP type and can be found in Appendix C.

Table 7.3: *Critical timing of construction inspections - bioretention and dry swales.*

Construction Sequence Step and Timing	Inspection Item	Observations [1]
Site Preparation – after site clearing and grading, prior to BMP excavation and grading	Natural heritage system and tree protection areas remain fenced off	
	ESCs protecting BMP layout area are installed properly	
	CDA is stabilized or runoff is diverted around BMP layout area	
	BMP layout area has been cleared and is staked/delineated	
	Benchmark elevation(s) are established nearby	
	Construction materials have been confirmed to meet design specifications	
BMP Excavation and Grading - prior to installation of pipes/sewers and backfilling	Excavation location, footprint, depth and slopes are acceptable	
	Excavated soil is stockpiled outside the CDA	
	Embankments/berms (elevations, slopes, compaction) are acceptable	
	Excavation bottom and sides roughened to reduce smearing and compaction	
BMP Installation – after installation of pipes/sewers, prior to backfilling	Structural components (e.g., foundation, walls) installed according to plans, if applicable	
	Impermeable liner installed correctly, if applicable	
	Installations of sub-drain pipes (e.g., locations, elevations, slopes), standpipes/monitoring wells are acceptable	
	Sub-drain trench dams installed correctly (location, elevation)	
Landscaping – after final grading, prior to planting	Filter bed depth and surface elevations at inlets are acceptable	
	Maximum surface ponding depth is acceptable	
	Filter bed is free of ruts, local depressions and not overly compacted	
	Planting material meets approved planting plan specifications (plant types and quantities)	

Notes:

1. S = Satisfactory; U= Unsatisfactory; NA = Not Applicable

7.1.5 Routine Maintenance

Table 7.4 describes routine maintenance tasks for bioretention practices, organized by BMP component, along with recommended minimum frequencies. It also suggests higher frequencies for certain tasks that may be warranted for BMPs located in highly visible locations or those receiving flow from high traffic areas (vehicle or pedestrian). Tasks involving removal of trash, debris and sediment and weeding/trimming of vegetation for BMPs in such contexts may need to be done more frequently (i.e., higher standards may be warranted).

Individuals conducting vegetation maintenance and in particular, weeding (i.e., removal of undesirable vegetation), should be familiar with the species of plants specified in the planting plan and experienced in plant identification and methods of removing/controlling noxious weeds. Key resources on these topics are provided below:

- Agriculture and Agri-food Canada's WeedInfo database, http://www.weedinfo.ca/en/
- Ontario Ministry of Agriculture, Food and Rural Affairs' Ontario Weed Gallery, http://www.omafra.gov.on.ca/english/crops/facts/ontweeds/weedgal.htm
- Ontario Ministry of Agriculture, Food and Rural Affairs' Noxious Weeds In Ontario list, http://www.omafra.gov.on.ca/english/crops/facts/noxious_weeds.htm
- Ontario Invasive Plant Council's Quick Reference Guide to Invasive Plant Species, http://www.ontarioinvasiveplants.ca/files/Invasives_booklet_2.pdf
- Oregon State University Stormwater Solutions, 2013, Field Guide: Maintaining Rain Gardens, Swales and Stormwater Planters, Corvallis, OR.
- Plants of Southern Ontario (book), 2014, by Richard Dickinson and France Royer, Lone Pine Publishing, 528 pgs.
- Weeds of North America (book), 2014, by Richard Dickinson and France Royer, University of Chicago Press, 656 pgs.

Table 7.4: *Routine Maintenance Tasks for Bioretention and Dry Swales.*

Component	Routine Maintenance Task	Frequency[1] Minimum[2]	Frequency[1] High[3]
Contributing Drainage Area	• Remove trash, natural debris, clippings and sediment	BA	Q
	• Remove accumulated sediment. • Re-plant or seed bare soil areas	A	BA
Inlets and Outlets	• Remove trash, natural debris and clippings	BA	Q
	• Remove accumulated sediment • Remove woody vegetation at inflow points	A	BA
Pretreatment & Flow spreaders	• Remove trash, natural debris, clippings	BA	Q
	• Remove accumulated sediment	A	BA
	• Re-grade and re-plant eroded areas when ≥30 cm in length	AN	AN
Perimeter	• Add stone or mulch to maintain 5 to 10 cm depth on non-vegetated areas	Every 2 years	Every 2 years
	• Re-grade and re-plant eroded areas when ≥30 cm in length	AN	AN
Filter bed	• Remove trash • Re-distribute mulch or stone cover to maintain 5 to 10 cm depth on non-vegetated areas	BA	Q
	• Remove accumulated sediment when ≥ 5 cm depth • Re-grade and restore cover over any animal burrows, sunken areas when ≥ 10 cm in depth and erosion rills when ≥ 30 cm in length	AN	AN
	• Add mulch or stone cover to maintain 5 to 10 cm depth where specified in the planting plan	Every 2 years	Every 2 years
Vegetation	• Watering during first two months after planting	BW	BW
	• Watering for the remainder of the first two (2) growing seasons (i.e., May to September) after planting or until vegetation is established	AN	AN
	• Watering for the remainder of the BMP lifespan	D	AN
	• Mow grass to maintain height between 10 to 15 cm.	M	BM
	• Remove undesirable vegetation (e.g., tree seedlings, invasives/weeds)	BA	Q
	• Replace dead/diseased plants to maintain a minimum of 80% vegetation cover[4]	A	BA
	• Prune shrubs and trees • Cut back spent plants • Divide or thin out overcrowded plants	A	A
Sub-drain & Monitoring well	• Flush out accumulated sediment with hose or pressure washer	A	A

Notes:

1. A = Annually; AN = As needed based on Routine Operation inspections; BA = Bi-annually or twice per year, ideally in the spring and late fall/early winter; BM = Bi-monthly; BW = Bi-weekly or twice per week; M = Monthly; D = During drought conditions classified by Agriculture and Agri-Food Canada's Canadian Drought Monitor as severe (D2) or higher (AAC, 2015); Q = Quarterly or four times per year, ideally in the spring, summer, early fall and late fall/early winter; W = Weekly.
2. These frequencies are recommended as the minimum necessary to ensure the BMP functions adequately over its expected lifespan.
3. High priority BMPs such as or those draining to a sensitive receiving waterbody, those receiving drainage from high traffic areas, or those designed with larger than recommended impervious drainage area to pervious BMP footprint area ratios (i.e., I:P ratios), may warrant a higher frequency of routine maintenance tasks involving removal of trash/debris/sediment and mowing/weeding/trimming of vegetation.
4. More frequent inspections may be warranted for highly visible BMPs, those receiving drainage from high traffic areas (vehicle or pedestrian), or those designed with larger than recommended impervious drainage area to pervious BMP footprint area ratio (i.e., I:P ratio), which will be more prone to accumulation of trash and sediment.
5. Aim to achieve 80% vegetation cover in planting areas by the end of the establishment/warranty period for the original plantings (e.g., two years after planting).

Tips to help preserve BMP function

- Because the risk of compaction is higher when filter media soil is saturated, any maintenance tasks involving vehicle (e.g., ride mower) or foot traffic on the filter bed should not be performed during wet weather;
- Use push mower to maintain bioretention practices with grass as vegetation cover or the lightest ride mower equipment available to minimize compaction of the filter bed;
- Use a mulching mower to maintain bioretention practices with grass as vegetation cover or leave clippings on the surface to help maintain organic matter and nutrients in the filter media;
- Pruning of mature trees should be performed under the guidance of a Certified Arborist;
- Woody vegetation should not be planted or allowed to become established where snow will be piled/stored during winter; and
- Removal of sediment accumulated on the filter bed surface should be performed by hand with rake and shovel, or vacuum equipment where feasible. If a small excavator is the chosen method, keep the excavator off the BMP footprint to avoid damage to side slopes/embankments and compaction of the filter media.

7.1.6 Rehabilitation and Repair

Table 7.5 provides guidance on rehabilitation and repair work specific to bioretention and dry swales organized according to BMP component.

Table 7.5: *Rehabilitation and repair guidance for bioretention and dry swales.*

BMP Component	Problem	Tasks
Inlets	Inlet or flow spreading device is producing concentrated flow and causing filter bed erosion	Add flow spreading device or re-grade existing device back to level to promote sheet flow to the filter bed. Regrade damaged portion of the filter bed and replant or restore mulch/stone cover. If problem persists, replace filter bed vegetation/mulch cover with stone at inlets.
Filter bed	Filter media is overly compacted	Core aerate; or remove stone, mulch and vegetation cover and till filter media to a depth of 20 cm; or remove and replace with uncompacted material that meets design specifications. Replace stone, mulch and vegetation cover (re-use/transplant where possible).
	Filter media texture is too fine (i.e., % silt and clay-sized particles too high)	Remove stone, mulch and vegetation cover and till filter media to a depth of 20 cm; or remove and replace all or the uppermost 15 cm of material with filter media that meets design specifications. Replace stone, mulch and vegetation cover (re-use/transplant where possible).
	Filter media organic matter or phosphorus content too low AND vegetation not thriving	Remove stone, mulch and vegetation cover and uppermost 5 cm of filter media, spread 5 cm compost, incorporate into filter media to 20 cm depth by tilling. Replace stone, mulch and vegetation cover (re-use/transplant where possible).
	Filter media pH is out of specification range (6.0 to 7.8) AND vegetation not thriving	If soil pH is lower than 6.0, amend with ground limestone to raise the pH back to neutrality. If soil pH is higher than 7.8, amend with compost or sulphur to lower the pH back to neutrality.
	Filter media cationic exchange capacity is <10 meq/100 g	Remove stone, mulch and vegetation cover and uppermost 5 cm of filter media, spread 5 cm compost, incorporate into filter media to 20 cm depth by tilling; or replace all or the uppermost 15 cm of material with filter media that meets design specifications. Replace stone, mulch and vegetation cover (re-use/transplant where possible).
	Filter media soluble salts content exceeds 2.0 mS/cm	Flush the affected area thoroughly with fresh water.
Filter bed	Local or average sediment accumulation ≥ 5 cm in depth	For local accumulation areas (e.g., at inlets) remove stone and use vacuum equipment to remove accumulated sediment/mulch, or to minimize disturbance of vegetation cover. Sediment from local areas can be removed with hand tools (e.g., rake and shovel). For large BMPs, use of a small excavator may be preferable. Restore grades with filter media that meets design specifications. Replace stone, mulch and vegetation cover (re-use/transplant where possible).

	Surface ponding remains for > 24 hours or surface infiltration rate is out of acceptable range	Remove stone, accumulated sediment/mulch, and vegetation cover. Till the exposed filter media to a depth of 20 cm to eliminate surface crusting or macropores and reduce compaction, or remove and replace the uppermost 15 cm of material with filter media that meets design specifications. Replace stone, mulch and vegetation cover (re-use/transplant where possible).
	Damage to filter bed or slide slope is present (e.g., erosion rills, animal burrows, local sinking, ruts)	Regrade damaged portion by shovel and replant or restore mulch/stone cover. Animal burrows, local sinking and compacted areas should be tilled to 20 cm depth prior to re-grading.
Sub-drain	Sub-drain perforated pipe is obstructed by sediment or roots	Schedule hydro-vac truck or drain-snaking service to remove the obstruction.

7.1.7 Life Cycle Costs of Inspection and Maintenance

Estimates of the life cycle costs of inspection and maintenance have been produced using the latest version of the LID Life Cycle Costing Tool (STEP, 2016; TRCA & U of T, 2013b) for three design variations (full infiltration, partial infiltration and no infiltration) to assist stormwater infrastructure planners, designers and asset managers with planning and preparing budgets. For each design variation, life cycle cost estimates have been calculated for two level-of-service scenarios: the minimum recommended frequency of inspection and maintenance tasks (i.e., Table 7.2 and Table 7.4 "Minimum Frequency" column), and a high frequency scenario (i.e., Table 7.2 and Table 7.4 "High Frequency" column) to provide an indication of the potential range.

The general assumptions used in developing version 1.1 of the LID Life Cycle Costing Tool (TRCA & U of T, 2013b) are outlined in detail in the report titled "Assessment of the Life Cycle Costs of Low Impact Development Stormwater Management Practices" (TRCA and U of T, 2013a). Assumptions for the Minimum Maintenance Frequency scenario can be viewed in the latest version of the spreadsheet tool (STEP, 2016) using the default values and a CDA of 2,000 m^2, and are briefly summarized here. Assumptions regarding design and material specifications are based on guidance provided in the LID SWM Planning and Design Guide (CVC & TRCA, 2010).

Capital costs included within the category of construction include those related to site assessment, and conceptual and detailed design related tasks such as borehole analysis and soil testing. All material, delivery, labour, equipment (rental, operation, operator), hauling and disposal costs are accounted for within the construction costs of the facility. Standard union costs were derived from the RSMeans database in 2010 and have been adjusted for 5 year inflation of 8.79% (2010 to June, 2015). Costs include overhead and inflation to represent contractor pricing. It was assumed the practice is part of a new development (i.e., not a retrofit), thereby excluding (de)mobilization costs unless a particular piece of equipment would not normally have been present at the site. Additionally, it was assumed that excavated soil associated with construction of the BMP would be reused elsewhere on site. Overhead costs were presumed to consist of construction management (4.5%), design (2.5%), small tools (0.5%), clean up (0.3%) and other (2.2%).

Assumptions regarding maintenance frequencies and requirements and the life span of each practice are based on both literature and practical experience. Life cycle and associated maintenance costs are evaluated over a 50 year timeframe, which is the typical period over which infrastructure decisions are made.

For bioretention it is assumed that some rehabilitation (e.g., rehabilitative maintenance) work will be needed on the filter bed surface once the BMP reaches 25 and 50 years of age in order to maintain functional drainage performance at an acceptable level. Included in the rehabilitation costs are (de)mobilization costs, as equipment would not have been present on site. Design costs were not included in the rehabilitation as it was assumed that the original LID practice design would be used to inform this work. The annual average maintenance cost does not include rehabilitation costs and therefore represents an average of routine maintenance tasks, as outlined in Table 7.4. All cost value estimates represent the net present value (NPV) as the calculation takes into account average annual interest (2%) and discount (3%) rates over the evaluation time periods.

For all bioretention design variations, the CDA has been defined as a 2,000 m^2 impervious pavement area plus the footprint area of a bioretention cell that is 133 m^2 in size, as per design recommendations. The impervious area to pervious area ratio (I:P ratio) used to size the BMP footprint is 15:1, which is the maximum ratio recommended in the LID SWM Planning and Design Guide (CVC & TRCA, 2010). It is assumed that water drains to the cell through curb inlets spaced 6 m apart with stone cover on the filter bed at the inlets to dissipate the energy of the flowing water.

While orientation (i.e., cell versus swale) and choice of components (e.g., inlet/outlet structures etc.) can vary widely, design variations for bioretention practices can be broken down into three main categories. They can be designed to drain through infiltration into the underlying subsoil alone (i.e., Full Infiltration design, no sub-drain), through the combination of a sub-drain and infiltration into the underlying subsoil (i.e., Partial Infiltration design, with a sub-drain), or through a sub-drain alone (i.e., No Infiltration or "filtration only" design, with a sub-drain and impermeable liner). For Full Infiltration systems, an overflow is provided for storms up to 37 mm based on a subsoil infiltration rate of 20 mm/hour. Two standpipe wells are part of the design (one subdrain inspection/flushing port at the upstream end and one sub-surface water storage reservoir monitoring well at the downstream end). Partial Infiltration systems have a sub-surface water storage reservoir with a perforated pipe sub-drain within it. The depth of the reservoir is sized to store flow from a 25 mm rain event over the CDA based on native soil infiltration rate of 10 mm/hour. The No Infiltration system includes an impermeable liner between the base and sides of the BMP and surrounding native sub-soil, to prevent infiltration.

Estimates of the life cycle costs of bioretention and dry swales in Canadian dollars per unit CDA ($/$m^2$) are presented in Table 7.6. The LID Life Cycle Costing Tool allows users to select what BMP type and design variation applies, and to use the default assumptions to generate planning level cost estimates.

Users can also input their own values relating to a site or area, design, unit costs, and inspection and maintenance task frequencies to generate customized cost estimates, specific to a certain project, context or stormwater infrastructure program.

For all BMP design variations and maintenance scenarios, it is assumed that rehabilitation of part or all of the filter bed surface will be necessary once the BMP reaches 25 and 50 years of age to maintain acceptable surface drainage performance (e.g., surface ponding drainage time). Filter bed rehabilitation for bioretention and dry swales is assumed to typically involve the following tasks and associated costs:

- Remove mulch, stone and vegetation cover, separating and re-using existing materials and plants to greatest extent feasible (all stone is re-used, 2/3 of vegetation is transplanted);
- Remove uppermost 15 cm of soil from the filter bed surface;
- Spread 15 cm of filter media that meets design specifications, thoroughly wet the material, allow time to settle, and rake to restore grade;
- Construction and Assumption inspection and testing work, including soil characterization testing to confirm that filter media meets design specifications;
- Surface infiltration rate testing, to confirm that acceptable drainage performance has been restored;
- Restore mulch or stone cover and transplant/plant vegetation;
- Perform routine vegetation maintenance tasks (i.e., watering, weeding, trimming) at recommended frequencies over the two (2) year establishment period for the plantings; and
- Replace plants that don't survive the initial establishment period (assumes 10% and 20% of plant material does not survive the first year for Minimum Recommended and High Frequency maintenance scenarios, respectively).

Table 7.6: *Life cycle cost estimates for bioretention and dry swales.*

Bioretention & Dry Swales	Minimum Frequency			High Frequency		
Design Variation	**Full Infiltr.**	**Partial Infiltr.**	**No Infiltr.**	**Full Infiltr.**	**Partial Infiltr.**	**No Infiltr.**
Construction Costs	$17.02	$22.17	$21.80	$17.02	$22.17	$21.80
Rehabilitation Costs	$4.83	$4.78	$4.78	$4.50	$4.41	$4.41
Rehabilitation Period (years in service)	25	25	25	25	25	25
50 YEAR EVALUATION PERIOD						
Average Annual Maintenance	$0.66	$0.70	$0.70	$0.94	$0.98	$0.98
Maintenance and Rehabilitation	$37.59	$39.09	$39.09	$51.75	$53.25	$53.25
25 YEAR EVALUATION PERIOD						
Average Annual Maintenance	$0.70	$0.75	$0.75	$1.03	$1.08	$1.08
Maintenance and Rehabilitation	$20.53	$21.33	$21.33	$28.36	$29.16	$29.16

Notes:

1. Estimated life cycle costs represent NPV of associated costs in Canadian dollars per square metre of CDA ($\$/m^2$).
2. Average annual maintenance cost estimates represent NPV of all costs incurred over the time period and do not include rehabilitation costs.
3. Rehabilitation cost estimates represent NPV of all costs related to repair work assumed to occur every 25 years, including those associated with inspection and maintenance over a two (2) year establishment period for the plantings.
4. Full Infiltration design life cycle costs are lower than Partial and No Infiltration designs due to the absence of a sub-drain to construct, inspect and routinely flush.
5. Rehabilitation costs for Full Infiltration designs are estimated to be 26.4 to 28.4% of the original construction costs for High and Minimum Recommended Frequency maintenance program scenarios, respectively.
6. Rehabilitation costs for Partial Infiltration designs are estimated to be 19.9 to 21.6% of the original construction costs for High and Minimum Recommended Frequency maintenance program scenarios, respectively.
7. Rehabilitation costs for No Infiltration designs are estimated to be 20.2 to 21.9% of the original construction costs for High and Minimum Recommended Frequency maintenance program scenarios, respectively.
8. Maintenance and rehabilitation costs over a 25 year time period for the Minimum Recommended maintenance scenario are estimated to be roughly equivalent to the original construction cost for Partial Infiltration and No Infiltration designs (96.2% and 97.8%, respectively), and 1.21 times the original construction cost for Full Infiltration design.

9. Maintenance and rehabilitation costs over a 25 year time period for the High Frequency maintenance scenario are estimated to be 1.32 times the original construction costs for Partial Infiltration, 1.34 times for No Infiltration designs, and 1.67 times for Full Infiltration designs.
10. Maintenance and rehabilitation costs over a 50 year time period for the Minimum Recommended Frequency maintenance scenario are estimated to be approximately 1.76 times the original construction cost for Partial Infiltration designs, 1.79 times the original construction cost for No Infiltration designs, and 2.21 times the original construction cost for Full Infiltration designs.
11. Maintenance and rehabilitation costs over a 50 year time period for the High Frequency maintenance scenario are estimated to be approximately 2.40 times the original construction cost for Partial Infiltration designs, 2.44 times the original construction cost for No Infiltration designs, and 3.04 times the original construction cost for Full Infiltration designs.

7.2 Enhanced Swales

7.2.1 BMP Overview

Enhanced grass swales are gently sloping vegetated open channels designed to convey and treat stormwater runoff. They can also be referred to as enhanced vegetated swales or enhanced grass swales. Check dams and vegetation in the swale spreads out and slows the flow of water to enhance sedimentation, filtration through the soil and root zones of plants and evaporation back to the atmosphere. Runoff water is delivered to the practice through inlets such as curb-cuts or other concrete structures, sheet flow from paved areas, or pipes connected to other stormwater conveyances (e.g., catchbasins, roof downspouts). The planting bed and side slopes are typically covered with a mixture of vegetation and stone, vegetation and mulch. They do not feature sub-drains like dry swales do. Water not ponded behind check dams, nor absorbed by or evaporated from the filter bed is conveyed to an adjacent drainage system (e.g., municipal storm sewer or other BMP) at the lowest downstream point by an outlet structure (e.g., ditch inlet catchbasin). Key components of enhanced swales for inspection and maintenance are described in Table 7.7 and Figure 7.2.

Properly functioning enhanced swales reduce the quantity of pollutants and runoff being discharged to municipal storm sewers and receiving waters (i.e., rivers, lakes and wetlands). In addition to their SWM benefits, enhanced swales provide aesthetic value as attractive landscaped features.

Table 7.7: *Key components of enhanced swales for inspection and maintenance.*

Component	Description
Contributing Drainage Area	The area from which runoff directed to the BMP originates. CDAs include impervious and pervious areas draining to the BMP and the BMP itself. CDAs should be free of point sources of pollutants (e.g., leaking waste containers, spills, failing ESCs). Trash, sediment and debris should be removed regularly from pavements and other stormwater conveyances (e.g., gutters, catchbasins, eavestroughs) draining to the BMP.
Inlets	Inlets can be pavement edges (for BMP receiving sheet flow), curb-cuts, pipes or other engineered structures. Inlets must remain unobstructed to ensure that stormwater enters the BMP as designed. Scour protection features (e.g., stone cover, flow spreaders) may also be needed for curb-cut or pipe inlets to prevent erosion of the filter bed from concentrated flow.
Pretreatment	Pretreatment refers to techniques or devices used to slow down and spread out concentrated stormwater flow and retain coarse materials suspended in runoff, either through filtration or settling, before it enters the BMP. Proper pretreatment extends the operating life cycle of the BMP by reducing the rate of accumulation of coarse sediment in the BMP. Common pretreatment devices include vegetated filter strips, gravel diaphragms, forebays, eavestrough screens or filters, oil and grit separators (i.e., hydrodynamic separators) and manholes containing baffles or filters and sumps. Pretreatment devices require frequent (e.g., annual or bi-annual) trash, sediment and debris removal maintenance.

Perimeter	Side slopes of the BMP, covered by a mixture of vegetation, mulch and stone with slopes of 2.5:1 (H:V) or less that surround the filter bed and convey stormwater. Inspection of the perimeter is done to confirm the dimensions of the BMP are acceptable, ensure the structural integrity of side slopes is maintained and confirm that the BMP continues to provide the designed conveyance capacity. Periodic maintenance of side slopes may be needed to repair erosion rills or damage from vehicle or foot traffic.
Filter bed	The bottom of the open channel that has a gentle longitudinal slope (i.e., between 0.5 and 4%) and is composed of a minimum 0.3 metre deep uncompacted topsoil layer covered by a mixture of vegetation, mulch and stone where filtration, evaporation and limited surface ponding of runoff occurs. Enhanced swales are designed to infiltrate all ponded water within 24 hours after the end of a storm to prevent conditions supportive of mosquito breeding. Filter beds should be routinely checked for presence of standing water. Trash should be removed from the filter bed regularly. Mulch or stone cover should be maintained on non-vegetated areas to prevent weed growth and soil erosion. Accumulated sediment should be periodically removed to maintain infiltration function. Repair of animal burrows, sunken areas, erosion rills or damage from vehicle or foot traffic may also be needed to prevent excessive surface ponding. Maximum ponding depths (i.e., check dam heights) should be checked and maintained at design specifications to ensure they continue to function and that surface ponding depth is not excessive.
Vegetation	Enhanced swales rely on vegetation (i.e., grasses, herbs, shrubs, and trees in some cases) to intercept, uptake and evapotranspire stormwater and to provide habitat for soil organisms that break down pollutants. Plant roots also help to maintain soil structure and permeability. Routine maintenance of vegetation is the same as a conventional planting bed (i.e., weeding, mowing, pruning, irrigation during droughts). In the first 2 months of establishment, plantings need to be irrigated frequently (e.g., bi-weekly). As enhanced swales practices are intended to help retain nutrients from inflowing stormwater, applying fertilizer to the filter bed should not be a part of routine maintenance.
Outlet	Flows exceeding the storage capacity of the BMP are conveyed to an adjacent drainage system via an outlet structure (e.g., ditch inlet catchbasin, culvert/pipe). Outlet structures must be kept free of obstructions to ensure stormwater is safely conveyed during major storm events.

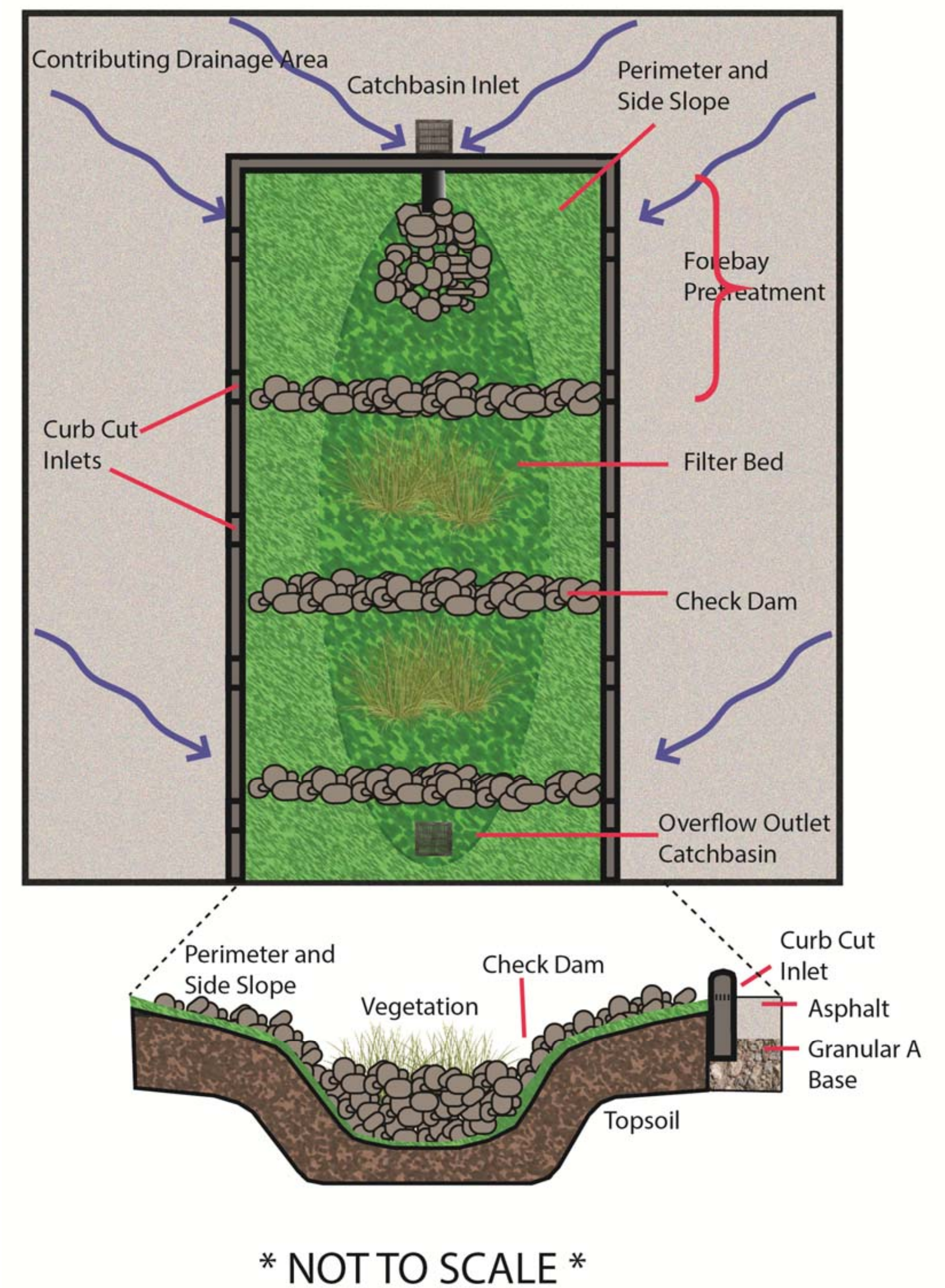


Figure 7.2: *Generalized plan and cross-section views of an enhanced swale showing key components.*

7.2.2 *Inspection and Testing Framework*

Table 7.8 describes what visual and testing indicators should be used during each type of inspection for enhanced swales and provides a basis for planning field work. Numbers in the first column refer to the section of Section 8.0 and Appendix C that provides detailed guidance on standard protocols and test methods for assessing the respective indicator.

7.2.3 *Critical Timing of Construction Inspections*

Construction inspections take place during several points in the construction sequence, specific to the type of LID BMP, but at a minimum should be done weekly and include the following:

1. During site preparation, prior to BMP excavation and grading to ensure the CDA is stabilized or that adequate ESCs or flow diversion devices are in place and confirm that construction materials meet design specifications;
2. At completion of excavation and grading, prior to planting to ensure depths, slopes and elevations are acceptable;
3. Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the storm sewer servicing, paving, building and landscaping contractors);
4. After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure ESCs and pretreatment or flow diversion devices are functioning and adequately maintained.

Table 7.9 describes critical points during the construction sequence when inspections should be performed prior to proceeding further. Table 7.9 can also be used as a checklist during Construction inspections, in addition to the Inspection Field Data Forms provided in Appendix C.

Table 7.8: *Inspection and testing indicators framework for enhanced swales.*

INSPECTION AND TESTING FRAMEWORK					
ENHANCED SWALES		Inspection Type			
Section	**Indicator**	**Construction**	**Assumption**	**Routine Operation**	**Verification**
Visual indicators					
C.1	CDA condition	x	x	x	x
C.2	Inlet//Flow spreader structural integrity		x	x	x
C.3	Inlet/Flow spreader obstruction	x	x	x	x
C.4	Pretreatment sediment accumulation	x	x	x	
C.5	Inlet erosion		x	x	
C.6	BMP dimensions	x	x		x
C.7	Side slope erosion		x	x	
C.8	Surface ponding area	x	x		x
C.9	Standing water		x	x	x
C.10	Trash		x	x	
C.11	Filter bed erosion		x	x	
C.13	Filter bed sediment accumulation		x	x	x
C.14	Surface ponding depth	x	x		x
C.15	Filter bed surface sinking		x	x	x
C.16	Check dams	x	x	x	x
C.17	Vegetation cover	x	x	x	x
C.18	Vegetation condition		x	x	
C.19	Vegetation composition	x	x	x	
C.22	Overflow outlet obstruction	x	x	x	x
Testing indicators					
8.2	Soil characterization testing	x	x		(x)
8.3	Sediment accumulation testing	x	x	x	x
8.4	Surface infiltration rate testing		x		(x)
8.5	Natural or simulated storm event testing		x		(x)

(x) denotes indicators to be used for Performance Verification inspections only (i.e., not for Maintenance Verification inspections)

Table 7.9: *Critical timing of construction inspections - enhanced swales.*

Construction Sequence Step and Timing	Inspection Item	Observations [1]
Site Preparation – after site clearing and grading, prior to BMP excavation and grading	Natural heritage system and tree protection areas remain fenced off	
	ESCs protecting BMP layout area are installed properly	
	CDA is stabilized or runoff is diverted around BMP layout area	
	BMP layout area has been cleared and is staked/delineated	
	Benchmark elevation(s) are established nearby	
	Construction materials have been confirmed to meet design specifications	
BMP Excavation and Grading - prior to landscaping	Excavation location, footprint, depth and slopes are acceptable	
	Excavated soil is stockpiled outside the CDA	
	Embankments/berms (elevations, slopes, compaction) are acceptable	
	Excavation bottom and sides roughened to reduce smearing and compaction	
Landscaping – after final grading, prior to planting	Topsoil depth, degree of compaction and surface elevations at inlets and outlets are acceptable	
	Maximum surface ponding depth is acceptable	
	Filter bed is free of ruts and local depressions	
	Planting material meets approved planting plan specifications (plant types and quantities)	

Notes:

1. S = Satisfactory; U= Unsatisfactory; NA = Not Applicable

7.2.4 Inspection Field Data Forms

Template forms for recording inspection observations, measurements, sampling location details and follow-up actions have been prepared for each LID BMP type and can be found in Appendix C.

7.2.5 Routine Maintenance

Table 7.10 describes routine maintenance tasks for enhanced swales, organized by BMP component, along with recommended minimum frequencies. It also suggests higher frequencies for certain tasks that may be warranted for BMPs located in highly visible locations or those receiving flow from large or high traffic (vehicle or pedestrian) drainage areas. Tasks involving removal of trash, debris and sediment and weeding/trimming of vegetation for BMPs in such contexts may need to be done more frequently (i.e., higher standards may be warranted).

Individuals conducting vegetation maintenance and in particular, weeding (i.e., removal of undesirable vegetation), should be familiar with the species of plants specified in the planting plan and experienced in plant identification and methods of removing/controlling noxious weeds. Key resources on these topics are provided below:

- Agriculture and Agri-food Canada's WeedInfo database, http://www.weedinfo.ca/en/
- Ontario Ministry of Agriculture, Food and Rural Affairs' Ontario Weed Gallery, http://www.omafra.gov.on.ca/english/crops/facts/ontweeds/weedgal.htm
- Ontario Ministry of Agriculture, Food and Rural Affairs' Noxious Weeds In Ontario list, http://www.omafra.gov.on.ca/english/crops/facts/noxious_weeds.htm
- Ontario Invasive Plant Council's Quick Reference Guide to Invasive Plant Species, http://www.ontarioinvasiveplants.ca/files/Invasives_booklet_2.pdf
- Oregon State University Stormwater Solutions, 2013, Field Guide: Maintaining Rain Gardens, Swales and Stormwater Planters, Corvallis, OR.
- Plants of Southern Ontario (book), 2014, by Richard Dickinson and France Royer, Lone Pine Publishing, 528 pgs.
- Weeds of North America (book), 2014, by Richard Dickinson and France Royer, University of Chicago Press, 656 pgs.

Table 7.10: *Routine maintenance tasks for enhanced swales.*

Component	Routine Maintenance Task	Frequency[1]	
		Minimum[2]	High[3]
Contributing Drainage Area	Remove trash, natural debris, clippings and sediment	BA	Q
	Re-plant or seed bare soil areas	A	BA
Inlets and Outlets	Remove trash, natural debris and clippings	BA	Q
	Remove accumulated sediment Remove woody vegetation at inflow points	A	BA
Pretreatment & Flow spreaders	Remove trash, natural debris, clippings and sediment	A	BA
	Re-grade and re-plant eroded areas when ≥30 cm in length	AN	AN
Perimeter	Replace dead/diseased plants to maintain a minimum of 80% vegetation cover[4]	A	BA
	Add mulch to maintain 5 to 10 cm depth on non-vegetated areas	Every 2 years	Every 2 years
	Re-grade and re-plant eroded areas when ≥30 cm in length	AN	AN
Filter bed	Remove trash	BA	Q
	Core aerate	Every 5 years	Every 3 years
	Remove accumulated sediment when ≥ 5 cm depth.	AN	AN

	◖ Re-grade and restore cover over any animal burrows, sunken areas when ≥ 10 cm in depth and erosion rills when ≥ 30 cm in length		
	◖ Add stone cover to maintain 5 to 10 cm depth where specified in the planting plan	AN	AN
Vegetation	◖ Watering during first two months after planting	BW	BW
	◖ Watering for the remainder of the first two (2) growing seasons (i.e., May to September) after planting or until vegetation is established	AN	AN
	◖ Watering for the remainder of the BMP lifespan	D	AN
	◖ Mow grass to maintain height between 10 to 15 cm.	M	BM
	◖ Remove undesirable vegetation (e.g., tree seedlings, invasives/weeds)	BA	Q
	◖ Replace dead/diseased plants to maintain a minimum of 80% vegetation cover[4]	A	BA
	◖ Prune shrubs and trees ◖ Cut back spent plants ◖ Divide or thin out overcrowded plants	A	A

Notes:

1. A = Annually; AN = As needed based on Routine Operation inspections; BA = Bi-annually or twice per year, ideally in the spring and late fall/early winter; BM = Bi-monthly; BW = Bi-weekly or twice per week; M = Monthly; D = During drought conditions classified by Agriculture and Agri-Food Canada's Canadian Drought Monitor as severe (D2) or higher (AAC, 2015); Q = Quarterly or four times per year, ideally in the spring, summer, early fall and late fall/early winter; W = Weekly.
2. These frequencies are recommended as the minimum necessary to ensure the BMP functions adequately over its expected lifespan.
3. High priority BMPs such as or those draining to a sensitive receiving waterbody, those receiving drainage from high traffic areas, or those designed with larger than recommended impervious drainage area to pervious BMP footprint area ratios (i.e., I:P ratios), may warrant a higher frequency of routine maintenance tasks involving removal of trash/debris/sediment and mowing/weeding/trimming of vegetation.
4. Aim to achieve 80% vegetation cover in planting areas by the end of the establishment/warranty period for the original plantings (e.g., two years after planting).

Tips to help preserve BMP function

- Because the risk of compaction is higher when topsoil is saturated, any maintenance tasks involving vehicle (e.g., ride mower) or foot traffic on the filter bed should not be performed during wet weather;
- Use push mower to maintain enhanced swales with grass as vegetation cover or the lightest ride mower equipment available to minimize compaction of the filter bed;

- Use a mulching mower to maintain enhanced swales with grass as vegetation cover or leave clippings on the surface to help replenish organic matter and nutrients in the topsoil;
- Pruning of mature trees should be performed under the guidance of a Certified Arborist;
- Woody vegetation should not be planted or allowed to become established where snow will be piled/stored during winter; and
- Removal of sediment accumulated on the filter bed surface should be performed by hand with rake and shovel, or vacuum equipment where feasible. If a small excavator is the chosen method, keep the excavator off the BMP footprint to avoid damage to side slopes/embankments and compaction of the topsoil.

7.2.6 Rehabilitation and Repair

Table 7.11 provides guidance on rehabilitation and repair work specific to enhanced swales organized according to BMP component.

Table 7.11: *Rehabilitation and repair guidance for enhanced swales.*

BMP Component	Problem	Task
Inlets	Inlet or flow spreading device is producing concentrated flow and causing filter bed erosion	Add flow spreading device or regrade existing device back to level to promote sheet flow to the filter bed. Regrade damaged portion of the filter bed and replant or restore mulch/stone cover. If problem persists consider adding turf reinforcement devices or replace filter bed vegetation/mulch cover with stone at inlets.
Filter bed	Topsoil is overly compacted	Core aerate; or remove stone and vegetation cover and till topsoil to a depth of 20 cm; or remove and replace with uncompacted topsoil that meets design specifications. Replace stone and vegetation cover (re-use/transplant where possible).
	Topsoil organic matter or phosphorus content too low AND vegetation not thriving	Remove stone and vegetation cover and uppermost 5 cm of topsoil, spread 5 cm compost, incorporate into topsoil to 20 cm depth by tilling. Replace stone and vegetation cover (re-use/transplant where possible).
	Topsoil pH is out of specification range (6.0 to 7.8) AND vegetation not thriving	If soil pH is lower than 6.0, amend with ground limestone to raise the pH back to neutrality. If soil pH is higher than 7.8, amend with compost or sulphur to lower the pH back to neutrality.
	Topsoil soluble salts content exceeds 2.0 mS/cm	Flush the affected area with fresh water.

	Surface ponding remains for > 24 hours or surface infiltration rate is out of acceptable range	Remove stone, accumulated sediment, and vegetation cover. Till the topsoil to a depth of 20 cm to eliminate surface crusting and reduce compaction; or remove and replace the uppermost 15 cm of material with topsoil that meets design specifications. Replace stone and vegetation cover (re-use/transplant where possible).
	Damage to filter bed or side slope is present (e.g., erosion rills, animal burrows, local sinking, ruts)	Re-grade damaged portion, replace stone, mulch and vegetation cover. Animal burrows, local sinking and compacted areas should be tilled to 20 cm depth prior to re-grading.

7.2.7 Life Cycle Costs of Inspection and Maintenance

Estimates of the life cycle costs of inspection and maintenance have been produced using the latest version of the LID Life Cycle Costing Tool (STEP, 2016; TRCA & U of T, 2013b) to assist stormwater infrastructure planners, designers and asset managers with planning and preparing budgets. For more details about the tool's assumption, see Section 7.1.7 and refer to the project report (TRCA & U of T ,2013a).

For enhanced swales, three design variations are presented – concrete check dams, filter sock check dams and rock check dams. For each design variation, life cycle cost estimates have been calculated for two level-of-service scenarios: the minimum recommended frequency of inspection and maintenance tasks (i.e., Table 7.8 and Table 7.10 "Minimum Frequency" column), and a high frequency scenario (i.e., Table 7.8 and Table 7.10 "High Frequency" column) to provide an indication of the potential range.

For enhanced swales it is assumed that some rehabilitation work to the filter bed surface will be needed once the BMP has been in service for 25 years in order to maintain functional drainage performance at an acceptable level. Included in the rehabilitation costs are (de)mobilization costs, as equipment would not have been present on site. Design costs were not included in the rehabilitation as it was assumed that the original LID practice design would be used to inform this work. The annual average maintenance cost does not include rehabilitation costs and therefore represents an average of routine maintenance tasks, as outlined in Table 7.10. All cost value estimates represent the NPV as the calculation takes into account average annual interest (2%) and discount (3%) rates over the evaluation time periods.

The CDA has been defined as 2,000 m^2 which drains to an enhanced grass swale that is 200 m^2 in area, 42.1 m long and 0.8 m deep and includes one driveway and culvert, one check dam and one ditch-inlet catchbasin. The side slopes are graded at a 2.5:1 (40%) slope, while the impervious area to pervious area ratio (I:P ratio) is 10:1. Flow enters the swale through curb inlets. The swale is longitudinally sloped at 25:1 (4%), planted with grass and includes one check dam that is 30 cm (12") in height. A ditch inlet catchbasin (DICB) at the furthest downstream end of the swale conveys water to a downstream BMP or the storm sewer system.

Estimates of the life cycle costs of enhanced swales in Canadian dollars per unit CDA ($\$/m^2$) are presented in Table 7.12. The LID Life Cycle Costing Tool allows users to select what BMP type and design variation applies, and to use the default assumptions to generate planning level cost estimates. Users can also input their own values relating to a site or area, design, unit costs, and inspection and maintenance task frequencies to generate customized cost estimates, specific to a certain project, context or stormwater infrastructure program.

For all BMP design variations and maintenance scenarios, it is assumed that rehabilitation of part or all of the filter bed surface (i.e., swale surface) will be necessary when the BMP reaches 25 and 50 years of age to maintain acceptable surface drainage performance (e.g., drainage time for surface ponding behind check dams) and vegetation cover. Filter bed rehabilitation for enhanced swales is assumed to typically involve the following tasks and associated costs:

- Remove stone and vegetation cover, separating and re-using existing materials and plants to greatest extent feasible (all stone is re-used, 2/3 of vegetation is transplanted);
- Spread 5 cm of compost on filter bed surface;
- Till the compost into the surface soil to 20 cm depth with a rototiller;
- Rake to restore final grading;
- Surface infiltration rate testing to determine if acceptable drainage performance has been restored;
- Restore stone cover and transplant/plant vegetation;
- Perform routine vegetation maintenance tasks (i.e., watering, weeding, trimming) at recommended frequencies over the two (2) year establishment period for the plantings; and,
- Replace plants that don’t survive the initial establishment period (assumes 10% and 20% of plant material does not survive the first year for Minimum Recommended and High Frequency maintenance scenarios respectively).

Table 7.12: *Life Cycle Costs for Enhanced Swales.*

Enhanced Swales	Minimum Frequency			High Frequency		
Design Variation	**Concrete check dam**	**Filter sock check dam**	**Rock check dam**	**Concrete check dam**	**Filter sock check dam**	**Rock check dam**
Construction Costs	$8.50	$8.32	$8.36	$8.50	$8.32	$8.36
Rehabilitation Costs	$2.34	$2.34	$2.34	$2.07	$2.07	$2.07
Rehabilitation Period (years in service)	25	25	25	25	25	25
50 YEAR EVALUATION PERIOD						
Average Annual Maintenance	$0.50	$0.45	$0.45	$0.73	$0.73	$0.73
Maintenance and Rehabilitation	$26.64	$26.64	$26.64	$39.41	$39.41	$39.41
25 YEAR EVALUATION PERIOD						
Average Annual Maintenance	$0.55	$0.55	$0.55	$0.82	$0.82	$0.82
Maintenance and Rehabilitation	$15.09	$15.09	$14.73	$22.14	$22.14	$22.14

Notes:

1. Estimated life cycle costs represent NPV of associated costs in Canadian dollars per square metre of CDA ($/m2).
2. Average annual maintenance cost estimates represent NPV of all costs incurred over the time period and do not include rehabilitation costs.
3. Rehabilitation cost estimates represent NPV of all costs related to repair work assumed to occur every 25 years including those associated with inspection and maintenance over a two (2) year establishment period for the plantings.
4. Life cycle costs are very similar but slightly lower for BMPs constructed with filter sock or rock check dams, than concrete ones due to differences in material and labor unit costs.
5. Rehabilitation costs are estimated to be between 24.4 to 28.1% of the original construction costs for High Frequency and Minimum Recommended maintenance program scenarios, respectively.
6. Maintenance and rehabilitation costs over a 25 year time period are estimated to be 1.77 to 2.66 times the original construction cost, for the Minimum Recommended and High Frequency maintenance scenarios respectively, depending on check dam construction material.
7. Maintenance and rehabilitation costs over a 50 year time period are estimated to be 3.13 and 4.74 times the original construction cost for the Minimum Recommended and High Frequency maintenance scenarios respectively, depending on check dam construction material.

7.3 Vegetated Filter Strips and Soil Amendment Areas

7.3.1 BMP Overview

Vegetated filter strips (a.k.a. buffer strips and grassed filter strips) are gently sloping, densely vegetated areas that treat runoff as sheet flow from adjacent impervious areas. Similarly, soil amendment areas are any landscaped area where the topsoil has been amended to enhance its water holding capacity. Typical types of soil amendments include application or restoration of 20 to 30 cm of uncompacted topsoil, rather than the standard 10 to 15 cm, and incorporation of compost to achieve between 5 and 15% organic matter content by dry weight. It is a good practice to implement such soil amendments on vegetated filter strips. Soil amendment areas that serve as SWM BMPs may receive runoff from adjacent impervious areas either by sheet flow or from a pipe (e.g., roof downspout) with a splash block or gravel diaphragm to help spread out and slow the flow of water onto the landscaped area.

In both of these types of LID BMPs vegetation slows the flow of water to enhance sedimentation, filtration/infiltration through the soil and root zones of plants and evaporation back to the atmosphere. Vegetation may be comprised of grass or a variety of trees, shrubs and native plants to add aesthetic value. Water not absorbed/infiltrated by, or evaporated from the filter bed is conveyed to an adjacent drainage system (e.g., municipal storm sewer or other BMP) at the lowest downstream point by an outlet structure (e.g., swale and ditch inlet catchbasin) or sheet flow onto an adjacent impervious surface. Key components of vegetated filter strips and soil amendment areas for inspection and maintenance are described in Table 7.13 and Figure 7.3.

Properly functioning vegetated filter strips and soil amendment areas reduce the quantity of pollutants and runoff being discharged to municipal storm sewers and receiving waters (i.e., rivers, lakes and wetlands). In addition to their SWM benefits, they provide aesthetic value as attractive landscaped features.

7.3.2 Inspection and Testing Framework

Table 7.14 describes what visual and testing indicators should be used during each type of inspection for vegetated filter strips and soil amendment areas and provides a basis for planning field work. Numbers in the first column refer to the section of Section 8.0 and Appendix C that provides detailed guidance on standard protocols and test methods for assessing the respective indicator.

Table 7.13: *Key components of vegetated filter strips and soil amendment areas for inspection and maintenance.*

Component	Description
Contributing Drainage Area	The area from which runoff directed to the BMP originates. CDAs include impervious and pervious areas draining to the BMP and the BMP itself. CDAs should be free of point sources of pollutants (e.g., leaking waste containers, spills, failing ESCs). Trash, sediment and debris should be removed regularly from pavements and other stormwater conveyances (e.g., gutters, eavestroughs) draining to the BMP.
Inlets	Inlets can be pavement edges (for BMPs receiving sheet flow) or pipes (e.g., roof downspouts). Inlets must remain unobstructed to ensure that stormwater enters the BMP as designed. Flow spreading devices (e.g., splash blocks, gravel diaphragms) are needed for pipe inlets to promote sheet flow and prevent filter bed erosion.
Perimeter	Inspection is done to confirm the dimensions and footprint area of the BMP are acceptable. For soil amendment areas, inspection involves confirming that topsoil depth and degree of compaction are acceptable in the specified areas.
Filter bed	A gently sloping (between 0.5 and 3%) vegetated area that receives runoff from adjacent impervious surfaces and is composed of a 0.2 to 0.3 metre deep uncompacted topsoil layer containing 5 to 15% organic matter by dry weight where filtration and evaporation of runoff occurs. Vegetated filter strips and soil amendment areas should not pond water on the surface during storm events. Areas should be routinely checked for presence of standing water. Trash should be removed from the filter bed regularly. Repair of animal burrows, sunken areas, erosion rills or damage from vehicle or foot traffic may also be needed to prevent surface ponding.
Vegetation	Healthy vegetation cover (i.e., grasses, herbs, shrubs, and trees) is relied upon to intercept, uptake and evapotranspire stormwater and to provide habitat for soil organisms that break down pollutants. Plant roots also help to maintain soil structure and permeability. Routine maintenance of vegetation is the same as a conventional lawn or planting bed (i.e., weeding, mowing, irrigation during droughts). In the first 2 months of establishment, plantings need to be irrigated frequently (e.g., bi-weekly). Where topsoil has been amended with compost, periodic top dressing with compost should be all that is needed to maintain healthy vegetation cover (i.e., application of chemical fertilizers should not be a part of routine maintenance).

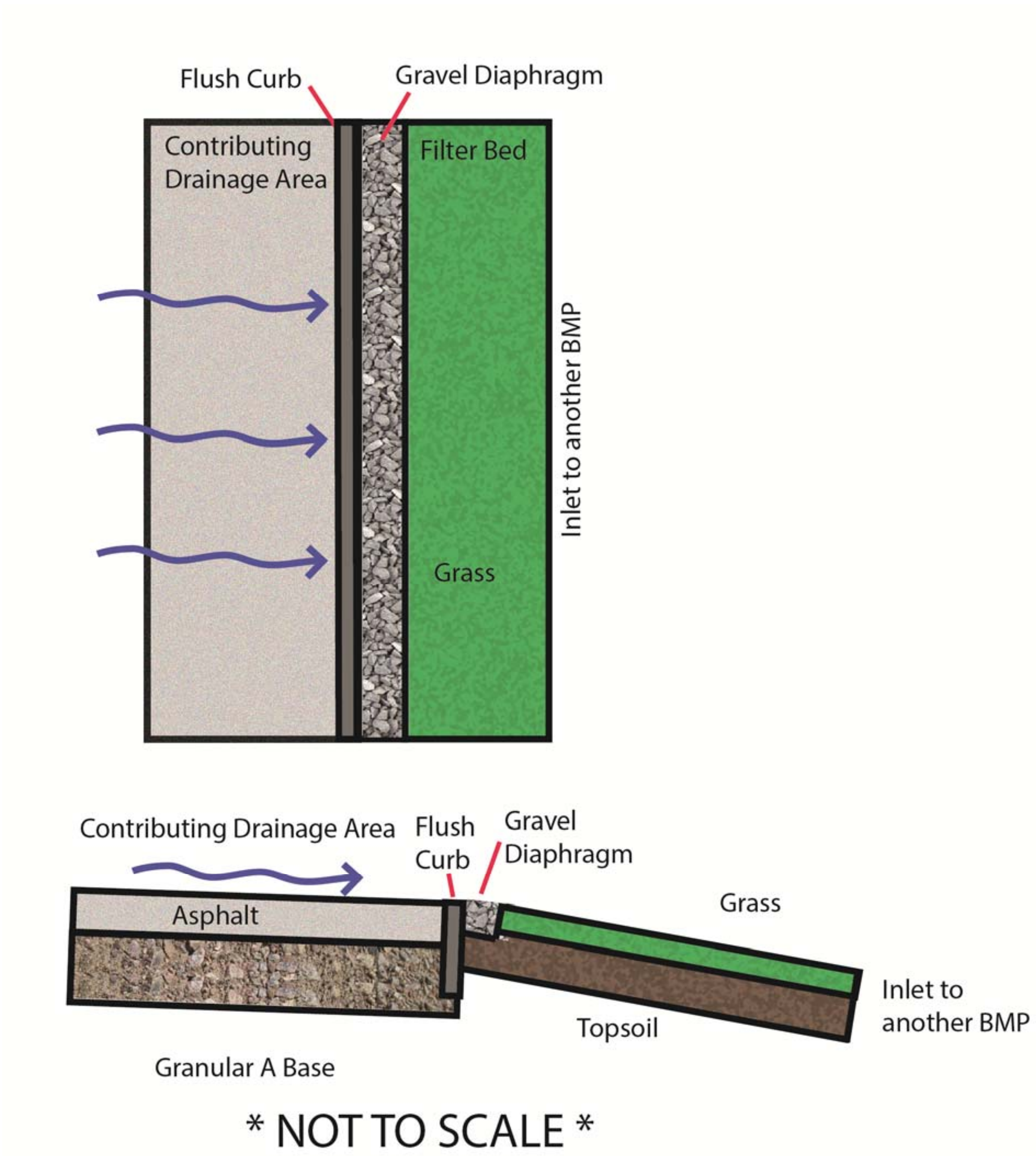


Figure 7.3: *Generalized plan and cross-section views of a vegetated filter strip showing key components.*

Table 7.14: *Inspection and testing indicators framework for vegetated filter strips and soil amendment areas.*

INSPECTION AND TESTING FRAMEWORK					
VEGETATED FILTER STRIPS & SOIL AMENDMENT AREAS		**Inspection Type**			
Section	**Indicator**	**Construction**	**Assumption**	**Routine Operation**	**Verification**
Visual indicators					
C.1	CDA condition	x	x	x	x
C.2	Inlet//Flow spreader structural integrity		x	x	x
C.3	Inlet/Flow spreader obstruction	x	x	x	x
C.6	BMP dimensions	x	x		x
C.9	Standing water		x	x	x
C.10	Trash		x	x	
C.11	Filter bed erosion		x	x	
C.15	Filter bed surface sinking		x	x	x
C.17	Vegetation cover	x	x	x	x
C.18	Vegetation condition		x	x	
C.19	Vegetation composition	x	x	x	
Testing indicators					
8.2	Soil characterization testing	x	x		(x)
8.4	Surface infiltration rate testing		x		(x)

(x) denotes indicators to be used for Performance Verification inspections only (i.e., not for Maintenance Verification inspections)

7.3.3 Critical Timing of Construction Inspections

Construction inspections take place during several points in the construction sequence, specific to the type of LID BMP, but at a minimum should be done weekly and include the following:

1. During site preparation, prior to BMP grading to ensure the CDA is stabilized or that adequate ESCs or flow diversion devices are in place and confirm that construction materials meet design specifications;
2. At completion of grading, prior to planting to ensure slopes and elevations are acceptable;
3. Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the storm sewer servicing, paving, building and landscaping contractors);
4. After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure ESCs and pretreatment or flow diversion devices are functioning and adequately maintained.

Table 7.15 describes critical points during the construction sequence when inspections should be performed prior to proceeding further. Table 7.15 can also be used as a checklist during Construction inspections, in addition to the Inspection Field Data Forms provided in Appendix C.

Table 7.15: *Critical timing of construction inspections - vegetated filter strips and soil amendment areas.*

Construction Sequence Step and Timing	Inspection Item	Observations [1]
Site Preparation – after site clearing and grading, prior to BMP grading	Natural heritage system and tree protection areas remain fenced off	
	ESCs protecting BMP layout area are installed properly	
	CDA is stabilized or runoff is diverted around BMP layout area	
	BMP layout area has been cleared and is staked/delineated	
	Benchmark elevation(s) are established nearby	
	Construction materials have been confirmed to meet design specifications	
BMP Grading - prior to landscaping	Excavation depth, footprint and slope are acceptable	
	Excavated soil is stockpiled outside the CDA	
Landscaping – after final grading, prior to planting	Topsoil depth, degree of compaction and surface elevations at inlets and outlets are acceptable	
	Area is free of ruts, local depressions	
	Planting material meets approved planting plan specifications (plant types and quantities)	

Notes:
1. S = Satisfactory; U= Unsatisfactory; NA = Not Applicable

7.3.4 Inspection Field Data Forms

Template forms for recording inspection observations, measurements, sampling location details and follow-up actions have been prepared for each LID BMP type and can be found in Appendix C.

7.3.5 Routine Maintenance

Table 7.16 describes routine maintenance tasks for vegetated filter strips and soil amendment areas, organized by BMP component, along with recommended minimum frequencies. It also suggests higher frequencies for certain tasks that may be warranted for BMPs located in highly visible locations or those receiving flow from large or high traffic (vehicle or pedestrian) drainage areas. Tasks involving removal of trash, debris and sediment and weeding/trimming of vegetation for BMPs in such contexts may need to be done more frequently (i.e., higher standards may be warranted).

Individuals conducting vegetation maintenance and in particular, weeding (i.e., removal of undesirable vegetation), should be familiar with the species of plants specified in the planting plan and experienced in plant identification and methods of removing/controlling noxious weeds. Key resources on these topics are provided below:

- Agriculture and Agri-food Canada's WeedInfo database, http://www.weedinfo.ca/en/
- Ontario Ministry of Agriculture, Food and Rural Affairs' Ontario Weed Gallery, http://www.omafra.gov.on.ca/english/crops/facts/ontweeds/weedgal.htm
- Ontario Ministry of Agriculture, Food and Rural Affairs' Noxious Weeds In Ontario list, http://www.omafra.gov.on.ca/english/crops/facts/noxious_weeds.htm
- Ontario Invasive Plant Council's Quick Reference Guide to Invasive Plant Species, http://www.ontarioinvasiveplants.ca/files/Invasives_booklet_2.pdf
- Plants of Southern Ontario (book), 2014, by Richard Dickinson and France Royer, Lone Pine Publishing, 528 pgs.
- Weeds of North America (book), 2014, by Richard Dickinson and France Royer, University of Chicago Press, 656 pgs.

Table 7.16: *Routine maintenance tasks for vegetated filter strips and soil amendment areas.*

Component	Routine Maintenance Task	Frequency[1]	
		Minimum[2]	High[3]
Contributing Drainage Area	◖ Remove trash, natural debris, clippings and sediment	BA	Q
	◖ Re-plant or seed bare soil areas	A	BA
Inlets and Outlets	◖ Remove trash, natural debris and clippings	BA	Q
	◖ Reconfigure splash block if displaced	BA	Q
	◖ Remove accumulated sediment	A	BA
Filter bed	◖ Remove trash	BA	Q
	◖ Core aerate	Every 5 years	Every 3 years
	◖ Remove accumulated sediment when ≥ 5 cm depth ◖ Re-grade and restore cover over any animal burrows, sunken areas when ≥ 10 cm in depth and erosion rills when ≥ 30 cm in length	AN	AN
	◖ Add stone cover to maintain 5 to 10 cm depth where specified in the planting plan	AN	AN
Vegetation	◖ Watering during first two months after planting	BW	BW
	◖ Watering for the remainder of the first two (2) growing seasons (i.e., May to September) after planting or until vegetation is established	AN	AN
	◖ Watering for the remainder of the BMP lifespan	D	AN
	◖ Mow grass to maintain height between 5 to 10 cm	M	BM
	◖ Remove undesirable vegetation (e.g., tree seedlings, invasives/weeds)	BA	Q
	◖ Replace dead/diseased plants to maintain a minimum of 80% vegetation cover[4]	A	BA
	◖ Prune shrubs and trees ◖ Cut back spent plants ◖ Divide or thin out overcrowded plants	A	A

Notes:

1. A = Annually; AN = As needed based on Routine Operation inspections; BA = Bi-annually or twice per year, ideally in the spring and late fall/early winter; BM = Bi-monthly; BW = Bi-weekly or twice per week; M = Monthly; D = During drought conditions classified by Agriculture and Agri-Food Canada's Canadian Drought Monitor as severe (D2) or higher (AAC, 2015); Q = Quarterly or four times per year, ideally in the spring, summer, early fall and late fall/early winter; W = Weekly.
2. These frequencies are recommended as the minimum necessary to ensure the BMP functions adequately over its expected lifespan.
3. High priority BMPs such as or those draining to a sensitive receiving waterbody, those receiving drainage from high traffic areas, or those designed with larger than recommended impervious drainage area to pervious BMP footprint area ratios (i.e., I:P ratios), may warrant a

higher frequency of routine maintenance tasks involving removal of trash/debris/sediment and mowing/weeding/trimming of vegetation.

4. Aim to achieve 80% vegetation cover in planting areas by the end of the establishment/warranty period for the original plantings (e.g., two years after planting).

Tips to help preserve BMP function

- Because the risk of compaction is higher when topsoil is saturated, any maintenance tasks involving vehicle (e.g., ride mower) or foot traffic on the filter bed should not be performed during wet weather;
- Use push mower to maintain grass cover or the lightest ride mower equipment available to minimize compaction of the topsoil;
- Use a mulching mower to maintain grass cover or leave clippings on the surface to help replenish organic matter and nutrients in the topsoil;
- Pruning of mature trees should be performed under the guidance of a Certified Arborist;
- Woody vegetation should not be planted or allowed to become established where snow will be piled/stored during winter; and
- Removal of sediment accumulated on the filter bed surface should be performed by hand with rake and shovel, or vacuum equipment where feasible. If a small excavator is the chosen method, keep the excavator off the BMP footprint to avoid rutting and compaction of the topsoil.

7.3.6 Rehabilitation and Repair

Table 7.17 provides guidance on rehabilitation and repair work specific to vegetated filter strips and soil amendment areas organized according to BMP component.

Table 7.17: *Rehabilitation and repair guidance for vegetated filter strips and soil amendments.*

BMP Component	Problem	Task
Inlets	Inlet or flow spreading device is producing concentrated flow and causing filter bed erosion	Add flow spreading device or regrade existing device back to level to promote sheet flow to the filter bed. Regrade damaged portion of the filter bed and replant. If problem persists, consider adding turf reinforcement devices or replace filter bed vegetation cover with stone at inlets.
Filter bed	Topsoil is overly compacted	Core aerate; or remove stone, mulch and vegetation cover and till topsoil to a depth of 20 cm; or remove and replace with uncompacted topsoil that meets design specifications. Replace stone, mulch and vegetation cover (re-use/transplant where possible).

	Topsoil organic matter or phosphorus content too low AND vegetation not thriving	Top dress with compost
	Topsoil pH is out of specification range (6.0 to 7.8) AND vegetation not thriving	If soil pH is lower than 6.0, amend with ground limestone to raise the pH back to neutrality. If soil pH is higher than 7.8, amend with compost or sulphur to lower the pH back to neutrality.
	Topsoil soluble salts content exceeds 2.0 mS/cm	Flush the affected area with fresh water.
	Surface ponding remains for > 24 hours or surface infiltration rate is out of acceptable range	Remove any accumulated sediment and core aerate. If problem persists, remove vegetation, till the topsoil to a depth of 20 cm to reduce compaction, or remove and replace the uppermost 15 cm of material with topsoil that meets design specifications. Replace vegetation cover (transplant where possible).
	Damage to filter bed is present (e.g., erosion rills, animal burrows, local sinking, ruts)	Re-grade damaged portion and restore vegetation cover. Animal burrows, local sinking and compacted areas should be tilled to 20 cm depth prior to re-grading and planting.

7.3.7 Life Cycle Costs of Inspection and Maintenance

Estimates of the life cycle costs of inspection and maintenance have been produced using the latest version of the LID Life Cycle Costing Tool (STEP, 2016; TRCA & U of T, 2013b) to assist stormwater infrastructure planners, designers and asset managers with planning and preparing budgetsFor more details of the tool's assumptions, see Section 7.1.7 and refer to the project report, TRCA and U of T (2013a).

For vegetated filter strips and soil amendment areas, life cycle cost estimates have been calculated for two level-of-service scenarios: the minimum recommended frequency of inspection and maintenance tasks (i.e., Table 7.14 and Table 7.16 "Minimum Frequency" column), and a high frequency scenario (i.e., Table 7.14 and Table 7.16 "High Frequency" column) to provide an indication of the potential range. Version 1.1 of the tool does not include the an option for generating life cycle cost estimates for vegetated filter strips and soil amendment areas, but Version 2.0 does, with assumptions based on an impervious to pervious area (I:P) ratio of 2.5:1 and inspection and maintenance recommendations for enhanced swales, for relevant components.

The annual average maintenance cost represents an average of routine maintenance tasks, as outlined in Table 7.10. All cost value estimates represent the NPV as the calculation takes into account average annual interest (2%) and discount (3%) rates over the evaluation time periods.

The CDA has been defined as 2,000 m^2 of impermeable pavement (e.g., road or parking area) which drains by sheet flow to a vegetated filter strip that is approximately 800 m^2 in area (I:P ratio of 2.5:1), 70 m long, 11.4 m wide and situated along the long edge of the paved area. The side slope is defined as

12.5:1 (8%). Water enters the BMP as sheet flow from a gravel diaphragm flow spreading device along the edge adjacent to the pavement. The BMP surface is planted with grass and does not include check dams, nor any pipes or culverts.

The life cycle cost estimates for vegetated filter strips and soil amendments are presented in Table 7.18. No design variations scenarios were examined, therefore the Minimum Recommended and High Frequency maintenance scenarios (Table 7.16) are the only two scenarios examined for this BMP. It is assumed that no rehabilitation work will be needed to maintain acceptable drainage performance over a 50 year time period.

Estimates of the life cycle costs of vegetated filter strips and soil amendment areas in Canadian dollars per unit CDA ($\$/m^2$) are presented in Table 7.18. The LID Life Cycle Costing Tool allows users to select what BMP type and design variation applies, and to use the default assumptions to generate planning level cost estimates. Users can also input their own values relating to a site or area, design, unit costs, and inspection and maintenance task frequencies to generate customized cost estimates, specific to a certain project, context or stormwater infrastructure program.

Table 7.18: *Life cycle costs for vegetated filter strips and soil amendment areas.*

Vegetated Filter Strips and Soil Amendment Areas	Minimum Frequency	High Frequency
Construction Costs	$8.18	$8.18
Rehabilitation Costs	$0.00	$0.00
Rehabilitation Period	n/a	n/a
50 YEAR EVALUATION PERIOD		
Average Annual Maintenance	$1.00	$1.57
Maintenance and Rehabilitation	$50.36	$78.32
25 YEAR EVALUATION PERIOD		
Average Annual Maintenance	$1.14	$1.79
Maintenance and Rehabilitation	$28.82	$44.32

Notes:

1. Estimated life cycle costs represent NPV of associated costs in Canadian dollars per square metre of contributing drainage area ($/m2).
2. Average annual maintenance cost estimates represent NPV of all costs incurred over the time period and do not include rehabilitation costs.
3. It is assumed that no rehabilitation is needed to maintain acceptable drainage performance over a 50 year evaluation period.
4. Maintenance costs over a 25 year time period are estimated to be between 3.52 to 5.42 times the original construction cost for the Minimum Recommended and High Frequency maintenance scenarios respectively.
5. Maintenance costs over a 50 year time period are estimated to be between 6.16 and 9.57 times the original construction cost for the Minimum Recommended and High Frequency maintenance scenarios respectively.

7.4 Permeable Pavements

7.4.1 BMP Overview

Permeable pavements contain many small openings (i.e., joints or pores) that allow rainfall and snowmelt to drain through them instead of running off the surface as it does on impervious pavements like conventional asphalt and concrete (Permeable Pavement Task Committee, 2015). Permeable pavements treat the precipitation that falls on them and may be designed to also receive runoff from adjacent impermeable surfaces (e.g., pavements and roofs) as either sheet flow or from a pipe (e.g., roof downspout) discharged to the pavement surface or connected to the aggregate base . Water that has infiltrated through the permeable pavement is temporarily stored in the clear stone (i.e., washed gravel) aggregate base. There it either percolates into the underlying native sub-soil and replenishes the groundwater system, or the filtered water is conveyed to a municipal storm sewer or another stormwater BMP by a perforated pipe sub-drain. An overflow outlet is necessary to safely convey flows from major storm events to a storm sewer or another BMP. Key components of permeable pavements for inspection and maintenance are described in Table 7.19 and Figure 7.4.

Properly functioning permeable pavements reduce the quantity of runoff and pollutants being discharged to municipal storm sewers and receiving waters (i.e., rivers, lakes and wetlands) and can help replenish groundwater resources. They can be used for low to medium traffic roads, parking spaces, driveways, pedestrian plazas and walkways.

There are a variety of types of permeable pavements that differ in terms of the surface layer:

- permeable interlocking pavers (i.e., block pavers) – Precast modular units made of concrete, pervious concrete or rubber/plastic composite designed to create open joints between pavers that are filled with fine, washed aggregate and installed on an open-graded aggregate (i.e., clear stone) base and sub-base.
- permeable interlocking grid systems (i.e., grid pavers) – Precast concrete or manufactured plastic grids with open cells that can be filled with aggregate or a mixture of sand, gravel and topsoil and planted with grass or low-growing ground covers and are installed on an open-graded aggregate base.
- pervious concrete – a rigid pavement installed on an open-graded aggregate base that uses a cementitious binder to adhere aggregate together, similar to conventional concrete, except that the fine aggregate component is minimized or eliminated which results in the formation of connected pores throughout.
- porous asphalt – a flexible pavement installed on an open-graded aggregate base that uses a bituminous binder to adhere aggregate together, similar to conventional asphalt, except that the fine aggregate component is minimized or eliminated which results in the formation of connected pores throughout.

Depending on the permeability of the underlying native sub-soil and other constraints, the pavement may be designed with no sub-drain for full infiltration, with a sub-drain for partial infiltration, or with an impermeable liner and sub-drain for a no infiltration or detention and filtration only practice. The sub-drain pipe may feature a flow restrictor (e.g., orificed cap, ball valve) for BMP designed to control the peak flow rate.

Table 7.19: *Key components of permeable pavements for inspection and maintenance.*

Component	Description
Contributing Drainage Area	The area from which runoff directed to the BMP originates. CDAs include impervious and pervious areas draining to the BMP and the BMP itself. CDAs should be free of point sources of pollutants (e.g., leaking waste containers, spills, failing ESCs). Trash, sediment and debris should be removed regularly from pavements and other stormwater conveyances (e.g., gutters, eavestroughs) draining to the BMP.
Pavement surface	The surface should be inspected to confirm dimensions are acceptable, check for damage, deformation (e.g. ruts), unevenness, open joints and sediment accumulation. Permeable pavements should not allow ponding of water on the surface to occur when functioning acceptably so any observation of surface ponding indicates that a problem exists. Trash and natural debris should be periodically removed. Permeable interlocking pavers, pervious concrete and porous asphalt need to be swept and vacuumed regularly to remove fine sediment from joints and pores, and plowed of snow and spread with deicing salt as needed during winter. Sand should not be spread as an anti-slip agent as it will clog the joints or pores. Grid systems with topsoil and grass fill are maintained like lawns.
Vegetation	Permeable interlocking grid systems may be filled with topsoil and planted with grass. Routine maintenance of grid system grass cover is the same as conventional lawns (i.e., weeding, mowing, watering during droughts). In the first 2 months of establishment, plantings need to be irrigated frequently (e.g., bi-weekly). Where compost amended topsoil is used to fill grid cells, periodic top dressing with compost should be all that is needed to maintain healthy vegetation cover (i.e., application of chemical fertilizers should not be a part of routine maintenance).
Overflow outlets	Flows exceeding the storage capacity of the BMP are conveyed to an adjacent drainage system via an overflow outlet structure (e.g., flush curb, curb-cut, catchbasin). Overflow outlet structures must be kept free of obstructions to ensure stormwater is safely conveyed during major storm events.
Sub-drain	Sub-drains are optional components that may be included where the permeability of the underlying native sub-soil is low or, due to other constraints, an impermeable liner is required. They are installed in the pavement base to collect and convey filtered water to an adjacent drainage system. Sub-drains are comprised of perforated pipes wrapped in a gravel blanket and in some cases geotextile filter fabric. The perforated pipe must be kept free of obstructions to ensure that the subsurface water storage capacity of the BMP drains within a specified time period. A maintenance port standpipe may be connected to the perforated pipe to provide a means of flushing and inspecting it. Perforated pipes should be routinely flushed with water to remove sediment. If the sub-drain is equipped with a flow-restrictor (e.g., orifice plate, ball valve) to attenuate flow rates, the flow restrictor must be inspected and cleaned regularly.

Monitoring well	Standpipes that extend from just below the surface of the pavement to the bottom of the excavation and contain perforations or slots to allow observation and measurement of subsurface water level in the BMP. Monitoring wells are needed to determine if the BMP drains within an acceptable time period and to track drainage performance over its operating lifespan. Standpipes should be securely capped on both ends and remain undamaged and free of sediment which may require periodic flushing.
Control structure	The manhole or catchbasin to which the sub-drain outlets that provides access to the sub-drain and flow restrictor device, if present. Inspect for damage and sediment.

7.4.2 Inspection and Testing Framework

Table 7.20 describes what visual and testing indicators should be used during each type of inspection for permeable pavements and provides a basis for planning field work. Numbers in the first column refer to the section of Chapter 8 that provides detailed guidance on standard protocols and test methods for assessing the respective indicator.

7.4.3 Critical Timing of Construction Inspections

Construction inspections take place during several points in the construction sequence, specific to the type of LID BMP, but at a minimum should be done weekly and include the following:

1. During site preparation, prior to BMP excavation and grading to ensure the CDA is stabilized and/or flow diversion devices are in place and confirm that construction materials meet design specifications;
2. At completion of excavation and grading, prior to backfilling and installation of pipes to ensure depths, slopes and elevations are acceptable;
3. At completion of installation of pipes, prior to completion of backfilling to ensure slopes and elevations are acceptable;
4. After final grading, prior to surface course installation to ensure depths, slopes and elevations are acceptable;
5. Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the storm sewer servicing, paving, building and landscaping contractors);
6. After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure flow diversion devices are functioning and adequately maintained.

Table 7.21 describes critical points during the construction sequence when inspections should be performed prior to proceeding further. Table 7.21 can also be used as a checklist during Construction inspections, in addition to the Inspection Field Data Forms provided in Appendix C.

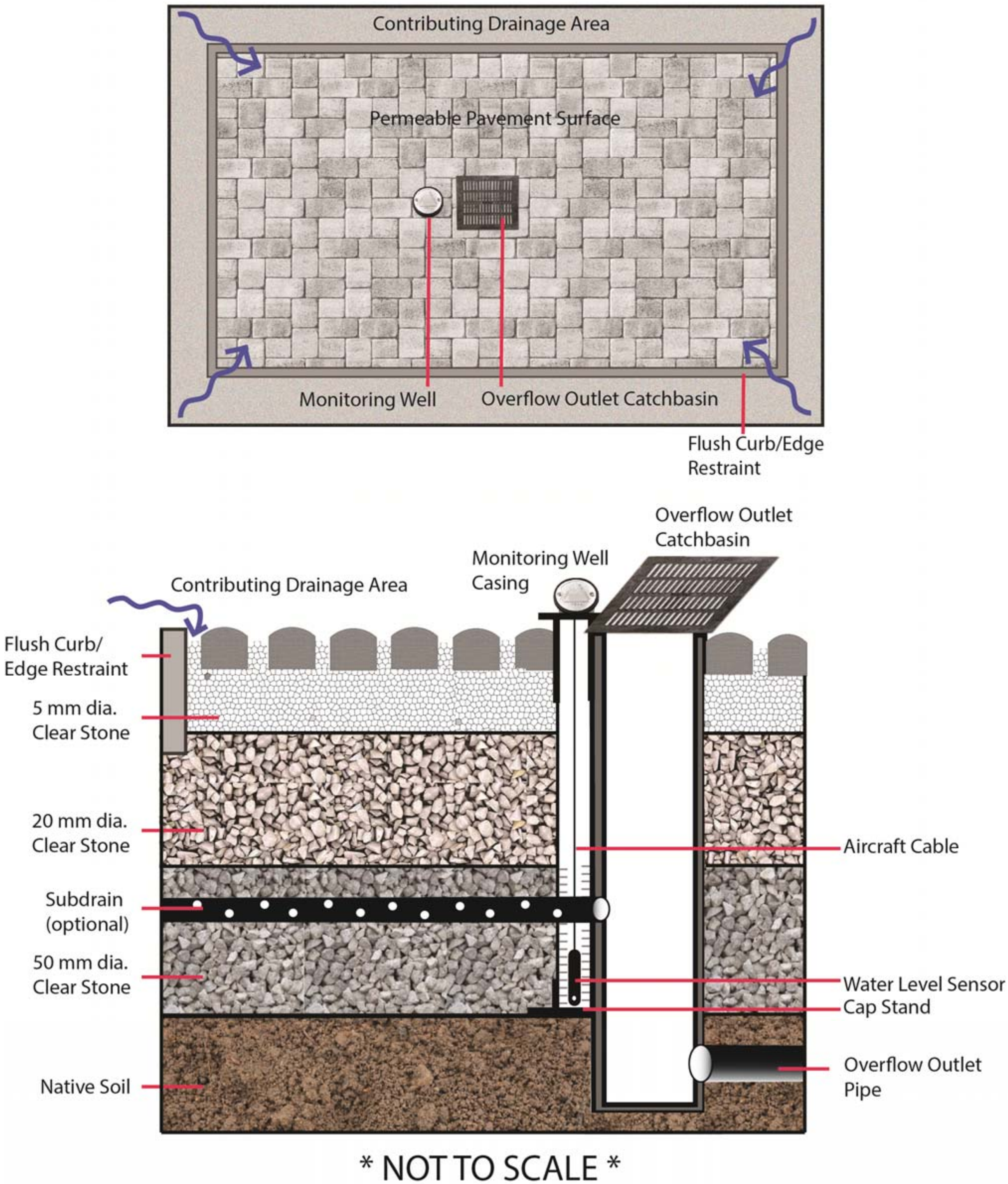


Figure 7.4: *Generalized plan and cross-section views of a permeable pavement showing key components.*

Table 7.20: *Inspection and testing indicators framework for permeable pavements.*

INSPECTION AND TESTING FRAMEWORK					
PERMEABLE PAVEMENTS		Inspection Type			
Section	**Indicator**	**Construction**	**Assumption**	**Routine Operation**	**Verification**
Visual indicators					
C.1	CDA condition	x	x	x	x
C.6	BMP dimensions	x	x		x
C.9	Standing water		x	x	x
C.10	Trash		x	x	
C.17	Vegetation cover	x	x	x	x
C.18	Vegetation condition		x	x	
C.19	Vegetation composition	x	x	x	
C.20	Monitoring well condition	x	x	x	x
C.21	Sub-drain/Perforated pipe obstruction		x		x
C.22	Overflow outlet obstruction	x	x	x	x
C.23	Pavement surface condition		x	x	
C.24	Pavement surface sediment accumulation	x	x	x	x
C.25	Control structure condition	x	x	x	x
C.26	Control structure sediment accumulation	x	x	x	x
Testing indicators					
8.4	Surface infiltration rate testing		x		(x)
8.5	Natural or simulated storm event testing		x		(x)
8.6	Continuous monitoring		x		(x)

(x) denotes indicators to be used for Performance Verification inspections only (i.e., not for Maintenance Verification inspections)

Table 7.21: *Critical timing of construction inspections - permeable pavements.*

Construction Sequence Step and Timing	Inspection Item	Observations [1]
Site Preparation – after site clearing and grading, prior to BMP excavation and grading	Natural heritage system and tree protection areas remain fenced off	
	ESCs protecting BMP layout area are installed properly	
	CDA is stabilized or runoff is diverted around BMP layout area	
	BMP layout area has been cleared and is staked/delineated	
	Benchmark elevation(s) are established nearby	
	Construction materials have been confirmed to meet design specifications	
BMP Excavation and Grading - prior to backfilling and installation of pipes/catchbasins	Excavation location, footprint, depth and slope are acceptable	
	Excavated soil is stockpiled outside the CDA	
BMP Installation – after installation of pipes/catchbasins, prior to completion of backfilling	Impermeable liner installed correctly, if applicable	
	Structural components (e.g., pavement base, curbs) installation is acceptable	
	Installations of sub-drain pipes (e.g., locations, elevations, slopes), standpipes/monitoring wells are acceptable	
	Sub-drain trench dams installed correctly (location, elevation)	
	Surface coarse installation (elevation, slope, monitoring wells) is acceptable	

Notes:

1. S = Satisfactory; U= Unsatisfactory; NA = Not Applicable

7.4.4 Inspection Field Data Forms

Template forms for recording inspection observations, measurements, sampling location details and follow-up actions have been prepared for each LID BMP type and can be found in Appendix C.

7.4.5 Routine Maintenance

Table 7.22 describes routine maintenance tasks for permeable pavements, organized by BMP component, along with recommended minimum frequencies. It also suggests higher frequencies for certain tasks that may be warranted for BMPs located in highly visible locations or those receiving flow from high traffic (vehicle or pedestrian) areas or those designed with higher than recommended impermeable drainage area to permeable BMP footprint area ratios (I:P ratios). Tasks involving removal of trash, debris and sediment and weeding/trimming of vegetation for BMPs in such contexts may need to be done more frequently (i.e., higher standards may be warranted).

Individuals conducting vegetation maintenance and in particular, weeding (i.e., removal of undesirable vegetation), should be familiar with the species of plants specified in the planting plan and experienced in plant identification and methods of removing/controlling noxious weeds. Key resources on these topics are provided below:

- Agriculture and Agri-food Canada's WeedInfo database, http://www.weedinfo.ca/en/
- Ontario Ministry of Agriculture, Food and Rural Affairs' Ontario Weed Gallery, http://www.omafra.gov.on.ca/english/crops/facts/ontweeds/weedgal.htm
- Ontario Ministry of Agriculture, Food and Rural Affairs' Noxious Weeds In Ontario list, http://www.omafra.gov.on.ca/english/crops/facts/noxious_weeds.htm
- Ontario Invasive Plant Council's Quick Reference Guide to Invasive Plant Species, http://www.ontarioinvasiveplants.ca/files/Invasives_booklet_2.pdf
- Plants of Southern Ontario (book), 2014, by Richard Dickinson and France Royer, Lone Pine Publishing, 528 pgs.
- Weeds of North America (book), 2014, by Richard Dickinson and France Royer, University of Chicago Press, 656 pgs.

Table 7.22: *Routine maintenance tasks for permeable pavements.*

Component	Routine Maintenance Task	Frequency[1]	
		Minimum[2]	High[3]
Contributing Drainage Area	Remove trash, natural debris, clippings and sediment	BA	Q
	Re-plant or seed bare soil areas	A	BA
Overflow outlets	Remove trash, natural debris and clippings	BA	Q
	Remove accumulated sediment	A	BA
Pavement surface	Remove trash, natural debris and clippings (rakes and leaf blowers)	BA	Q
	Remove accumulated sediment (sweep and vacuum)[4]	A	BA
	Replace/top up joint or grid fill material (if applicable)	A	BA
	Remove undesirable vegetation (e.g., tree seedlings, invasives/weeds)	A	BA
	Plow snow and apply de-icing salt during winter	AN	AN
	Re-paint lines/parking space divisions (if applicable)	Every 3 years	Every 3 years

Vegetation	◖ Watering during first two months after planting	BW	BW
	◖ Watering for the remainder of the first two (2) growing seasons (i.e., May to September) after planting or until vegetation is established	AN	AN
	◖ Watering for the remainder of the BMP lifespan	D	AN
	◖ Mow grass to maintain height between 5 to 10 cm.	M	BM
	◖ Remove undesirable vegetation (e.g., tree seedlings, invasives/weeds)	A	BA
	◖ Overseed and top dress bare areas with compost to maintain a minimum of 80% grass cover [5]	A	BA
Sub-drain & Monitoring well	◖ Flush out accumulated sediment with hose or pressure washer	A	A

Notes:

1. A = Annually; AN = As needed based on Routine Operation inspections; BA = Bi-annually or twice per year, ideally in the spring and late fall/early winter; BM = Bi-monthly; BW = Bi-weekly or twice per week; M = Monthly; D = During drought conditions classified by Agriculture and Agri-Food Canada's Canadian Drought Monitor as severe (D2) or higher (AAC, 2015); Q = Quarterly or four times per year, ideally in the spring, summer, early fall and late fall/early winter; W = Weekly.
2. These frequencies are recommended as the minimum necessary to ensure the BMP functions adequately over its expected lifespan.
3. High priority BMPs such as or those draining to a sensitive receiving waterbody, those receiving drainage from high traffic areas, or those designed with larger than recommended impervious drainage area to pervious BMP footprint area ratios (i.e., I:P ratios), may warrant a higher frequency of routine maintenance tasks involving removal of trash/debris/sediment and mowing/weeding/trimming of vegetation.
4. For permeable interlocking pavers, pervious concrete and porous asphalt, use regenerative air vacuum sweepers for routine maintenance and pure vacuum sweepers for rehabilitating slow draining/clogged pavements. Sweeping and vacuuming should be done during dry weather.
5. For grid systems where cells are filled with topsoil and grass, aim to achieve 80% grass cover by the end of the establishment/warranty period (e.g., two years after planting).

Tips to help preserve BMP function

- Never use sealants on porous asphalt nor pervious concrete;
- Prohibit access by construction vehicles to prevent tracking of sediment on to the surface;

- Prohibit storage of soil, compost, sand, salt or unwashed gravel on permeable pavements to prevent clogging of joints or pores, or protect the pavement surface with tarps or geotextile during temporary storage of such materials;
- Landscaped areas adjacent to permeable pavements should be covered with vegetation and not drain to the pavement where possible to prevent eroding soil from reaching the surface;
- Use a mulching mower to mow permeable interlocking grid systems with grass cover;
- Permeable pavements can be plowed for snow removal like conventional pavements. To reduce the risk of dislodging pavers or grids and minimize displacement of joint/cell fill material, the plow blade should be slightly raised off the pavement surface (e.g., 0.6 cm or 1/4") with a shoe attachment;
- Plowed snow piles should not be stored on permeable pavements to reduce the risk of clogging from sediment accumulation upon melting;
- Do not spread sand on permeable pavements as part of winter maintenance as it will quickly clog the joints or pores and impair drainage function. On permeable interlocking pavers and grid systems filled with gravel, if application of an anti-skid material is desirable, spread the same fine washed gravel material used to fill the paver joints or grid cells; and
- De-icers should be used sparingly, as needed during winter. Due to their freely draining design, ice will not form on permeable pavements as readily as it does on conventional impermeable pavements during winter thaw-freeze cycles.

7.4.6 Rehabilitation and Repair

Table 7.23 provides guidance on rehabilitation and repair work specific to permeable pavements organized according to BMP component.

Table 7.23: *Rehabilitation and repair guidance for permeable pavements.*

BMP Component	Problem	Task
Pavement surface	Major cracks, spalling or raveling of the porous asphalt or pervious concrete surface	Fill small potholes or cracks with patching mixes (consult with product vendor for further guidance). Large potholes or cracks may require cutting and replacement of a section of the surface layer. Replace with the same permeable material where possible. Conventional asphalt or concrete could be acceptable if the cumulative area remains below 15% of the total BMP footprint area.
	Paver or grid unit is missing, damaged or displaced	Replace or reset unit by hand and restore joint or grid cell fill material that meets design specification.

	Surface infiltration rate is < 250 mm/h	Sweep and thoroughly vacuum with a pure vacuum sweeper to remove accumulated sediment. Replace joint fill material removed through vacuuming. Pretreatment of the surface of slow draining pavements (e.g., water-assisted techniques, additional sweeping) prior to vacuuming may be warranted where surface clogging of joints or pores is visible. . If surface drainage performance remains unacceptable, remove all pavers, bedding and joint fill and top 5 cm (2") of base aggregate and replace with new materials that meet design specifications.
Vegetation	Poor grass cover on interlocking permeable grid system	Aerate or remove and replace growing medium in affected area with material that meets design specifications and replant.
Sub-drain	Sub-drain perforated pipe is obstructed by sediment	Schedule hydro-vac truck or drain-snaking service to remove the obstruction.

7.4.7 Life Cycle Costs of Inspection and Maintenance

Estimates of the life cycle costs of inspection and maintenance have been produced using the latest version of the LID Life Cycle Costing Tool (STEP, 2016) to assist stormwater infrastructure planners, designers and asset managers with planning and preparing budgets. For more details of the tool's assumption, see Section 7.1.7 and refer to the project report (TRCA and U of T, 2013a).

For permeable pavements it is assumed that rehabilitation of the pavement surface will be needed once the BMP reaches 30 years of age in order to maintain surface drainage performance at an acceptable level. Included in the rehabilitation costs are (de)mobilization costs, as equipment would not have been present on site. Design costs were not included in the rehabilitation as it was assumed that the original LID practice design would be used to inform this work. The annual average maintenance cost does not include rehabilitation costs and therefore represents an average of routine maintenance tasks, as outlined in Table 7.22. All cost value estimates represent the NPV as the calculation takes into account average annual interest (2%) and discount (3%) rates over the evaluation time periods.

Design variations for permeable pavements can be broken down into three main categories: Full Infiltration design, where the pavement drains through infiltration into the underlying subsoil alone (i.e., no sub-drain); Partial Infiltration design, where drainage is through the combination of a sub-drain and infiltration into the underlying subsoil (i.e., with a sub-drain); or No Infiltration (i.e., filtration-only design) that includes an impermeable liner between the base of the BMP and the underlying native sub-soil, where drainage is through a sub-drain alone (i.e., with a sub-drain and impermeable liner). For each design variation, life cycle cost estimates have been calculated for two level-of-service scenarios: the minimum recommended frequency of inspection and maintenance tasks (i.e., Table 7.20 and Table 7.22 "Minimum Frequency" column), and a high frequency scenario (i.e., Table 7.20 and Table 7.22 "High Frequency" column) to provide an indication of the potential range. A rehabilitation period of 30 years is assumed, at which point rehabilitative maintenance of the pavement surface is undertaken to maintain acceptable drainage performance.

The costing presented in this section is specific to permeable interlocking concrete pavers (PICP), as defined in the Tool. This product has been selected for costing due to its popularity and well-understood maintenance needs (Permeable Pavements Task Committee, 2015).

For all permeable pavement design variations, the CDA has been defined as 2,000 m^2 of which 1,000 m^2 is impermeable pavement draining to the pavers, and 1,000 m^2 is permeable pavement. The impervious area to pervious area ratio (I:P ratio) used to size the BMP footprint is 1:1, which is in accordance with recommendations in the LID SWM Planning and Design Guide (CVC & TRCA, 2010). The Full Infiltration design does not include a sub-drain and assumes a native sub-soil infiltration rate of 20 mm/h. The base granular reservoir is 350 mm deep and is capable of storing runoff from a 61 mm rain event over the CDA. A monitoring well is included for inspection purposes. The Partial Infiltration design includes a sub-drain and assumes a native sub-soil infiltration rate of 10 mm/h. The base granular reservoir is 350 mm deep and is capable of storing runoff from a 9 mm rain event before the stored volume reaches the perforated underdrain pipe located 50 mm above the native sub-soil. Although a flow restrictor is recommended to maximize infiltration, the cost of this feature is not included due to its relatively low cost. The No Infiltration design includes a sub-drain pipe installed on the bottom of the sub-surface water storage reservoir and an impermeable liner. All other features are the same as the Partial Infiltration design variation.

Estimates of the life cycle costs of PICP permeable pavement in Canadian dollars per unit CDA ($/m^2) are presented in Table 7.24. The LID Life Cycle Costing Tool allows users to select what BMP type and design variation applies, and to use the default assumptions to generate planning level cost estimates. Users can also input their own values relating to a site or area, design, unit costs, and inspection and maintenance task frequencies to generate customized cost estimates, specific to a certain project, context or stormwater infrastructure program.

For all BMP design variations and maintenance scenarios, it is assumed that rehabilitation of the pavement surface will be necessary when the BMP reaches 30 years of age to maintain acceptable surface drainage performance. Rehabilitation of PICP pavements is assumed to typically involve the following tasks and associated costs:

- Remove pavers, bedding and joint fill and top 5 cm (2") of base aggregate and replace with new material that meets design specifications;
- Construction and Assumption inspection and testing associated with rehabilitation work to confirm that materials meet design specifications and installation is acceptable, including compaction and surface infiltration rate testing.

Table 7.24: *Life cycle costs for permeable interlocking concrete pavers.*

Permeable Interlocking Concrete Pavers (PICP)	Minimum Frequency			High Frequency		
Design Variation	**Full Infiltr.**	**Partial Infiltr.**	**No Infiltr.**	**Full Infiltr.**	**Partial Infiltr.**	**No Infiltr.**
Construction Costs	$53.60	$54.85	$61.95	$53.60	$54.85	$61.95
Rehabilitation Costs	$29.80	$29.80	$29.80	$29.35	$29.35	$29.35
Rehabilitation Period (years in service)	30	30	30	30	30	30
50 YEAR EVALUATION PERIOD						
Average Annual Maintenance	$0.55	$0.55	$0.55	$0.95	$0.95	$0.95
Maintenance and Rehabilitation	$57.35	$58.20	$58.20	$76.75	$77.60	$77.60
25 YEAR EVALUATION PERIOD						
Average Annual Maintenance	$0.60	$0.60	$0.60	$1.05	$1.05	$1.05
Maintenance and Rehabilitation	$11.95	$12.40	$12.40	$20.90	$21.35	$21.35

Notes:

1. Estimated life cycle costs represent NPV of associated costs in Canadian dollars per square metre of CDA ($\$/m^2$).
2. Average annual maintenance cost estimates represent NPV of all costs incurred over the time period and do not include rehabilitation costs.
3. Rehabilitation cost estimates represent NPV of all costs related to rehabilitative maintenance work assumed to be needed after 30 years in service, including those associated with inspection.
4. Full Infiltration design life cycle costs are lower than Partial and No Infiltration designs due to the absence of a sub-drain to construct, inspect and routinely flush.
5. Rehabilitation costs for Full Infiltration designs are estimated to be 54.8% to 55.6% of the original construction costs for High and Minimum Recommended Frequency maintenance program scenarios, respectively.
6. Rehabilitation costs for Partial Infiltration designs are estimated to be 53.5% to 54.3% of the original construction costs for High and Minimum Recommended Frequency maintenance program scenarios, respectively.
7. Rehabilitation costs for No Infiltration designs are estimated to be 47.4% to 48.1% of the original construction costs for High and Minimum Recommended Frequency maintenance program scenarios, respectively.
8. Maintenance and rehabilitation costs over a 25 year time period for the Minimum Recommended maintenance scenario are estimated to be 22.3%, of the original construction costs for Full Infiltration design, 22.6% for Partial Infiltration design, and 20.0% for No Infiltration design.

9. Maintenance and rehabilitation costs over a 25 year time period for the High Frequency maintenance scenario are estimated to be 39.0% of the original construction costs for Full, 38.9% for Partial Infiltration designs, and 34.5% for No Infiltration designs.
10. Maintenance and rehabilitation costs over a 50 year time period for the Minimum Recommended Frequency maintenance scenario are estimated to be approximately1.07 times the original construction cost for Full, 1.06 times the original construction costs for Partial Infiltration designs, and 93.9.% the original construction cost for No Infiltration designs.
11. Maintenance and rehabilitation costs over a 50 year time period for the High Frequency maintenance scenario are estimated to be approximately 1.43 times the original construction cost for Full, 1.41 times the original construction costs for Partial Infiltration designs, and 1.25 times the original construction cost for No Infiltration designs.

7.5 Underground Infiltration Systems

7.5.1 BMP Overview

Underground infiltration systems is a general term that refers to stormwater treatment practices that temporarily store runoff below ground in geotextile-lined excavations filled with clear stone (i.e., washed gravel) or other void space forming structures and treat it by sedimentation and filtration through the geotextile and underlying sub-soil. Runoff water is delivered to the practice through inlets such as curb-cuts or other concrete structures and pipes connected to other stormwater conveyances (e.g., catchbasins, roof downspouts). They are most often installed to a depth below the maximum frost penetration depth to ensure they continue to drain year-round. Water that is in excess of the storage capacity overflows to an adjacent drainage system (e.g., municipal storm sewer or other BMP), typically via a manhole containing a control structure, to safely convey flows from major storm events. Depending on the permeability of the underlying native sub-soil, such practices may be designed without a sub-drain for full infiltration or with a sub-drain for partial infiltration. Captured water is either infiltrated or collected by the sub-drain and discharged to the municipal storm sewer system. The sub-drain pipe may feature a flow restrictor (e.g., orificed cap, ball valve) for BMPs designed to control the peak flow rate. Key components of underground infiltration systems for inspection and maintenance are described in Table 7.25 and Figure 7.5.

Properly functioning underground infiltration systems reduce the quantity of runoff and pollutants being discharged to municipal storm sewers and receiving waters (i.e., rivers, lakes and wetlands) and can help replenish groundwater resources. An advantage of underground infiltration systems is that they can be located below parking lots, roads, parkland or other landscaped areas. In densely developed urban areas, where the value of land is very high, this often makes them preferable to surface practices.

Underground infiltration systems include soakaways, infiltration trenches, infiltration chamber systems and perforated pipe storm sewer systems. Soakaways typically service individual lots and receive only roof and walkway runoff but can also be designed to receive overflows from other LID BMPs (e.g., rain barrels or cisterns). Soakaways can also be referred to as infiltration galleries, dry wells or soakaway pits. Infiltration trenches are linear oriented soakaways designed to fit into narrow strips of land between buildings or properties, or along road rights-of-way and can also receive road runoff with an adequate pretreatment device upstream. Infiltration chamber systems include a range of proprietary manufactured modular structures installed underground that create large void spaces for temporary storage of stormwater (CSA, 2011). Structures may be plastic or concrete and typically have an open bottom and are wrapped with clear stone and geotextile. They can be installed individually or in series in trench or bed configurations. They can also be referred to as infiltration tanks. Perforated pipe storm sewer systems can be thought of as long infiltration trenches or linear soakaways that are installed parallel with conventional storm sewer pipes that receive stormwater from them (i.e., roof, walkway and road runoff). Perforated pipe systems can also be referred to as exfiltration systems, percolation drainage systems, and clean water collector systems (i.e., those receiving flows from roofs and foundation drains only).

Requirements of the Ontario Occupational Health and Safety Act regulation for individuals working in confined spaces (O. Reg. 632/05) must be adhered to during any inspection or maintenance work on underground infiltration systems that involves entry into confined spaces (e.g., catchbasins, manholes, access hatches). Individuals working in such environments should be adequately trained on the use and maintenance of the necessary safety equipment and review hazards and safety plans regularly. Further information about Ontario's Confined Spaces Regulation and Guideline can be accessed at the following location:

- http://www.labour.gov.on.ca/english/hs/pubs/confined/cs_4.php

Table 7.25: *Key components of underground infiltration systems for inspection and maintenance.*

Component	Description
Contributing Drainage Area	The area from which runoff directed to the BMP originates. CDAs include impervious and pervious areas draining to the BMP. CDAs should be free of point sources of pollutants (e.g., leaking waste containers, spills, failing ESCs). Trash, sediment and debris should be removed regularly from pavements and other stormwater conveyances (e.g., gutters, eavestroughs) draining to the BMP.
Inlets	Inlets can be curb-cuts, pipes or other engineered structures. Inlets must remain unobstructed to ensure that stormwater enters the BMP as designed. Pipe inlets typically include a perforated section that distributes flow throughout the practice and may be wrapped with geotextile.
Pretreatment	Pretreatment refers to techniques or devices used to slow down concentrated stormwater flow and retain coarse materials suspended in runoff, either through filtration or settling, before it enters the BMP. Proper pretreatment extends the operating life cycle of the BMP by reducing the rate of accumulation of coarse sediment in the BMP. Common pretreatment devices include geotextile-lined stone inlets, eavestrough screens or filters, oil and grit separators (i.e., hydrodynamic separators), manholes containing baffles and sumps, in-line filters or chamber structures that are isolated from the main portion of infiltration chamber systems (a.k.a. isolator or containment row). Pretreatment devices require frequent (e.g., annual or bi-annual) trash, sediment and debris removal maintenance.
Filter bed	The clear stone bed on which infiltration chamber systems are installed. When accessible by a maintenance hatch or manhole, filter beds should be routinely checked for sediment accumulation which may require the use of a closed circuit camera. Accumulated sediment may need to be periodically removed by a hydro-vac truck to maintain infiltration function (e.g., once over a 50 year life cycle).
Overflow outlets	Flows exceeding the storage capacity of the BMP are conveyed to an adjacent drainage system via an overflow outlet structure (e.g., control manhole containing a weir wall and outlet pipe). Overflow outlet structures must be kept free of obstructions to ensure stormwater is safely conveyed during major storm events.

Sub-drain	Sub-drains are optional components that may be included where the permeabililty of the underlying native sub-soil is low. They are installed in the clear stone fill or bedding to collect and convey filtered water to an adjacent drainage system. Sub-drains are comprised of perforated pipes and may be wrapped in geotextile filter fabric. A maintenance port standpipe or manhole may be connected to the perforated pipe to provide a means of flushing and inspecting it. The perforated pipe must be kept free of obstructions to ensure that the subsurface water storage capacity of the BMP drains within a specified time period. Perforated pipes should be routinely flushed with water to remove sediment. If the sub-drain is equipped with a flow-restrictor (e.g., orifice plate, ball valve) to attenuate flow rates, the flow restrictor must be inspected and cleaned regularly.
Monitoring well	Standpipes that extend from the surface to the bottom of the excavation and contain perforations or slots to allow observation and measurement of subsurface water level in the BMP. Monitoring wells are needed to determine if the BMP drains within an acceptable time period and to track drainage performance over its operating lifespan. Standpipes should be securely capped on both ends and remain undamaged and free of sediment which may require periodic flushing.
Control structure	The manhole or catchbasin that contains the overflow control structure and outlet pipe and is connected to the sub-drain pipe that provides access to the outlet, sub-drain and flow restrictor device, if present. Inspect for damage, obstruction and sediment accumulation.

7.5.2 Inspection and Testing Framework

Table 7.26 describes what visual and testing indicators should be used during each type of inspection for underground infiltration systems and provides a basis for planning field work. Numbers in the first column refer to the section of Section 8.0 and Appendix C that provides detailed guidance on standard protocols and test methods for assessing the respective indicator.

7.5.3 Critical Timing of Construction Inspections

Construction inspections take place during several points in the construction sequence, specific to the type of LID BMP, but <u>at a minimum should be done weekly</u> and include the following:

1. During site preparation, prior to BMP excavation and grading to ensure the CDA is stabilized or that adequate ESCs or flow diversion devices are in place and confirm that construction materials meet design specifications;
2. At completion of excavation and grading, prior to backfilling and installation of geotextile/pipes to ensure depths, slopes and elevations are acceptable;
3. At completion of installation of geotextile/pipes, prior to completion of backfilling to ensure slopes and elevations are acceptable;
4. Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the storm sewer servicing, paving, building and landscaping contractors);

5. After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure ESCs and pretreatment or flow diversion devices are functioning and adequately maintained.

Table 7.27 describes critical points during the construction sequence when inspections should be performed prior to proceeding further. Table 7.27 can also be used as a checklist during Construction inspections, in addition to the Inspection Field Data Forms provided in Appendix C. Additional inspection points may be warranted for infiltration chamber systems. Refer to the installation instructions provided by the product vendor/manufacturer for further guidance on construction sequence and critical timing of inspections.

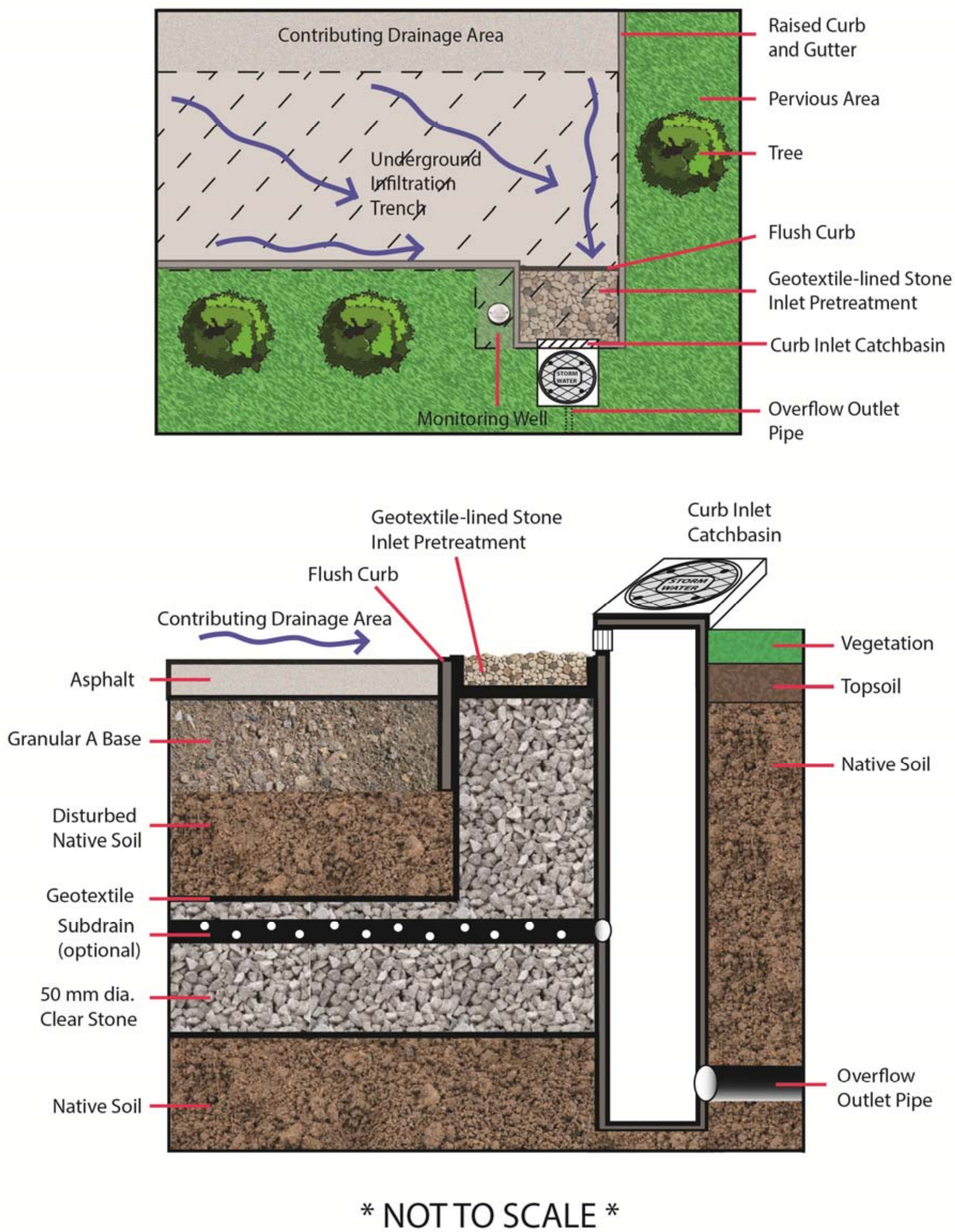


Figure 7.5: *Generalized cross-section view of an infiltration trench showing key components.*

Table 7.26: *Inspection and testing indicators framework for underground infiltration systems.*

INSPECTION AND TESTING FRAMEWORK					
UNDERGROUND INFILTRATION SYSTEMS		Inspection Type			
Section	**Indicator**	**Construction**	**Assumption**	**Routine Operation**	**Verification**
Visual indicators					
C.1	CDA condition	x	x	x	x
C.2	Inlet//Flow spreader structural integrity		x	x	x
C.3	Inlet/Flow spreader obstruction	x	x	x	x
C.4	Pretreatment sediment accumulation	x	x	x	
C.6	BMP dimensions	x	x		x
C.13	Filter bed sediment accumulation		x	x	x
C.20	Monitoring well condition	x	x	x	x
C.21	Sub-drain/Perforated pipe obstruction		x		x
C.22	Overflow outlet obstruction	x	x	x	x
C.25	Control structure condition	x	x	x	x
C.26	Control structure sediment accumulation	x	x	x	x
Testing indicators					
8.3	Sediment accumulation testing	x	x	x	x
8.5	Natural or simulated storm event testing		x		(x)
8.6	Continuous monitoring		x		(x)

(x) denotes indicators to be used for Performance Verification inspections only (i.e., not for Maintenance Verification inspections)

Table 7.27: *Critical timing of construction inspections - underground Infiltration Systems.*

Construction Sequence Step and Timing	Inspection Item	Observations [1]
Site Preparation – after site clearing and grading, prior to BMP excavation and grading	Natural heritage system and tree protection areas remain fenced off	
	ESCs protecting BMP layout area are installed properly	
	CDA is stabilized or runoff is diverted around BMP layout area	
	BMP layout area has been cleared and is staked/delineated	
	Benchmark elevation(s) are established nearby	
	Construction materials have been confirmed to meet design specifications	
BMP Excavation and Grading - prior to backfilling and installation of geotextile/pipes	Excavation location, footprint, depth and slope are acceptable	
	Excavated soil is stockpiled outside the CDA	
	Compaction of subsoil where load-bearing portions of the system will be installed is acceptable	
	Excavation bottom and sides roughened to reduce smearing and compaction	
BMP Installation – after installation of geotextile/ pipes/structures, prior to completion of backfilling	Installation of structural components (e.g., control manhole, maintenance hatches) is acceptable	
	Installations of sub-drain pipes (e.g., locations, elevations, slopes) & maintenance access hatches are acceptable	
	Sub-drain trench dams installed correctly (location, elevation)	

Notes:

1. S = Satisfactory; U= Unsatisfactory; NA = Not Applicable

7.5.4 Inspection Field Data Forms

Template forms for recording inspection observations, measurements, sampling location details and follow-up actions have been prepared for each LID BMP type and can be found in Appendix C.

7.5.5 Routine Maintenance

Table 7.28 describes routine maintenance tasks for underground infiltration systems, organized by BMP component, along with recommended minimum frequencies. It also suggests higher frequencies for certain tasks that may be warranted for BMPs located in highly visible locations or those receiving flow from large or high traffic (vehicle or pedestrian) drainage areas. Tasks involving removal of trash, debris and sediment for BMPs in such contexts may need to be done more frequently (i.e., higher standards may be warranted).

Table 7.28: *Routine maintenance tasks for underground infiltration systems.*

Component	Routine Maintenance Task	Frequency[1]	
		Minimum[2]	High[3]
Contributing Drainage Area	◖ Remove trash, natural debris, clippings and sediment	BA	Q
	◖ Re-plant or seed bare soil areas	A	BA
Inlets and Outlets	◖ Remove trash, natural debris and clippings	BA	Q
	◖ Remove accumulated sediment	A	BA
Pretreatment Devices	◖ Remove trash, natural debris, clippings and sediment	A	BA
Filter bed	◖ Remove accumulated sediment when ≥ 8 cm depth (requires BMP to be fully drained first)	AN	AN
Overflow Outlets	◖ Remove trash, natural debris and clippings	BA	Q
	◖ Remove accumulated sediment	A	BA
Sub-drain & Monitoring well	◖ Flush out accumulated sediment with hose or pressure washer	A	A
Control structure	◖ Remove accumulated sediment when ≥ 10 cm depth	AN	AN

Notes:

1. A = Annually; AN = As needed based on Routine Operation inspections; BA = Bi-annually or twice per year, ideally in the spring and late fall/early winter; BM = Bi-monthly; BW = Bi-weekly or twice per week; Q = Quarterly or four times per year, ideally in the spring, summer, early fall and late fall/early winter.
2. These frequencies are recommended as the minimum necessary to ensure the BMP functions adequately over its expected lifespan.
3. High priority BMPs such as or those draining to a sensitive receiving waterbody, those receiving drainage from high traffic areas, or those designed with larger than recommended impervious drainage area to pervious BMP footprint area ratios (i.e., I:P ratios), may warrant a higher frequency of routine maintenance tasks involving removal of trash/debris/sediment.

Tips to help preserve BMP function

- Prohibit stockpiling of soil, sand, compost or unwashed gravel within the CDA and inlets to prevent clogging with sediment;
- For BMPs with sub-drains and flow restrictors, pretreatment devices that prevent floating trash and debris from entering the practice should be used to prevent obstruction of the sub-drain pipe/flow restrictor;

- For BMPs equipped with pretreatment that detains floating contaminants (e.g., oil and grease, trash and debris), such as hydrodynamic separators or forebays with baffle walls, remove trash and debris first using a bucket strainer. Floating oils and grease should then be removed off the top of the water using a vacuum truck;
- Provide a means of draining infiltration chamber systems by gravity (e.g., pipe and valve through the control structure weir wall) to make inspection and maintenance work that requires drainage of the BMP (e.g., filter bed and control structure inspection and sediment removal, repairs to control structure) easier to perform; and
- To remove accumulated sediment from sub-drain pipes and chamber system units, a hydro-vac truck equipped with a JetVac nozzle should be employed that uses pressured jets of water to propel itself through the structure while scouring and directing suspending sediments to a collection point. As the nozzle is retrieved, the sediment is flushed into the manhole or catchbasin sump for removal by vacuuming. Selecting an appropriate JetVac nozzle will depend on the structure being cleaned. For chamber system units, fixed nozzles designed for culverts or large diameter pipe cleaning with rear-facing jets are preferable (consult product manufacturer for further guidance).

7.5.6 Rehabilitation and Repair

Table 7.29 provides guidance on rehabilitation and repair work specific to underground infiltration systems organized according to BMP component.

Table 7.29: *Rehabilitation and Repair Guidance for Underground Infiltration Systems.*

BMP Component	Problem	Task
Sub-drain	Sub-drain perforated pipe is obstructed by trash, debris, sediment or roots	Schedule hydro-vac truck or drain-snaking service to remove the obstruction.
	Pipe caps are missing or damaged	Replace missing or damaged caps.
Filter bed (for chamber systems only)	Average sediment accumulation ≥ 8 cm in depth or drainage performance is unacceptable	Schedule work to fully drain the system and remove accumulated sediment through use of a hydro-vac truck equipped with JetVac nozzle.
Control structure	Structure or pipe connection is leaking and impairing the water storage capacity or function of the BMP	Schedule work to repair cracks or seal leaking components. The BMP may need to be fully drained to make such repairs.

7.5.7 Life Cycle Costs of Inspection and Maintenance

Estimates of the life cycle costs of inspection and maintenance have been produced using the latest version of the LID Life Cycle Costing Tool (STEP, 2016) to assist stormwater infrastructure planners, designers and asset managers with planning and preparing budgets. For more details of the Tool's assumption, see Section 7.1.7 and refer to the project report (TRCA and U of T, 2013a).

For underground infiltration systems it is assumed that no rehabilitation work will be needed to maintain drainage performance at an acceptable level over a 50 year period of operation, given that pretreatment devices are in place upstream and are being adequately maintained. The annual average maintenance cost value represents an average of routine maintenance tasks, as outlined in Table 7.28. All cost value estimates represent the NPV as the calculation takes into account average annual interest (2%) and discount (3%) rates over the evaluation time periods.

Life cycle cost estimates have been generated for two types of underground infiltration systems: infiltration trenches and infiltration chamber systems. For each type, two design variations have been examined: BMPs designed to receive roof runoff only; and BMPs designed to receive a combination of roof and road runoff. For each system type and design variation, life cycle cost estimates have been calculated for two level-of-service scenarios: the minimum recommended frequency of inspection and maintenance tasks (i.e., Table 7.26 and Table 7.28 "Minimum Frequency" column), and a high frequency scenario (i.e., Table 7.26 and Table 7.28 "High Frequency" column) to provide an indication of the potential range.

For all design variations, the CDA is assumed to be composed of a 2,000 m^2 roof for the roof runoff only design variation, and a 500 m^2 roof and 1,500 m^2 impermeable pavement area for the roof and road runoff design. All are sized to retain runoff from a 34 mm rain event and assumed to have a native sub-soil infiltration rate of 34 mm/h. An impervious drainage area to pervious area ratio (I:P ratio) of 20:1 is used to size the BMP footprint area, in accordance with the LID SWM Planning and Design Guide recommendations (CVC & TRCA, 2010). The infiltration trench is assumed to be 1.630 m deep, 2.0 m wide and 50.0 m long. The infiltration chamber system is assumed to be 1.067 m deep, 8.0 m wide and 12.5 m long.

For all design variations, the invert of the overflow outlet pipe is located 1.2 m below the surface to protect against frost. Monitoring wells are provided to facilitate inspections. In the roof runoff only design, there is no pretreatment other than a sump in the control manhole which allows for some settling of coarse sediment and debris. In the roof and road runoff design, pretreatment is provided by a hydrodynamic (i.e., oil and grit) separator for the impermeable pavement portion of the CDA.

Estimates of the life cycle costs of infiltration trenches and chamber systems in Canadian dollars per unit CDA ($/$m^2$) are presented in Tables 7.30 and 7.31, respectively. The LID Life Cycle Costing Tool allows users to select what BMP type and design variation applies, and to use the default assumptions to generate planning level cost estimates. Users can also input their own values relating to a site or area, design, unit costs, and inspection and maintenance task frequencies to generate customized cost estimates, specific to a certain project, context or stormwater infrastructure program.

Table 7.30: *Life cycle cost estimates for infiltration trenches.*

Infiltration Trenches	Minimum Frequency		High Frequency	
Design Variation	**Roof only**	**Road & Roof**	**Roof only**	**Road & Roof**
Construction Costs	$18.25	$27.55	$18.25	$27.55
Rehabilitation Costs	$0.00	$0.00	$0.00	$0.00
Rehabilitation Period (years in service)	n/a	n/a	n/a	n/a
50 YEAR EVALUATION PERIOD				
Average Annual Maintenance	$0.20	$0.70	$0.25	$1.20
Maintenance and Rehabilitation	$10.75	$34.20	$13.50	$60.50
25 YEAR EVALUATION PERIOD				
Average Annual Maintenance	$0.20	$0.75	$0.30	$1.30
Maintenance and Rehabilitation	$5.55	$18.45	$7.10	$32.90

Notes:

1. Estimated life cycle costs represent NPV of associated costs in Canadian dollars per square metre of CDA ($/m2).
2. Average annual maintenance cost estimates represent NPV of all costs incurred over the time period and do not include rehabilitation costs.
3. Life cycle costs are higher for BMPs designed to receive roof and road runoff due to additional costs associated with the hydrodynamic (i.e., oil and grit) separator and associated inspection and routine maintenance.
4. Life cycle cost estimates are similar between infiltration trench and infiltration chamber system designs, and predicted to be slightly higher for infiltration trenches compared to chamber systems (construction and maintenance costs).
5. Maintenance costs over a 25 year time period for roof runoff only infiltration trenches are estimated to be 30.4% of the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 38.9% for the High Frequency maintenance scenario.
6. Maintenance costs over a 25 year time period for roof and road runoff infiltration trenches are estimated to be 67.0% of the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 1.19 times the original construction cost for the High Frequency maintenance scenario.
7. Maintenance costs over a 50 year time period for roof runoff only infiltration trenches are estimated to be 58.9% of the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 74.0% for the High Frequency maintenance scenario.
8. Maintenance costs over a 50 year time period for roof and road runoff infiltration trenches are estimated to be 1.24 times the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 2.20 times for the High Frequency maintenance scenario.

Table 7.31: *Life cycle cost estimates for infiltration chamber systems.*

Infiltration Chambers	MINIMUM RECOMMENDED FREQUENCY		HIGH FREQUENCY	
Design Variation	**Roof only**	**Road & Roof**	**Roof only**	**Road & Roof**
Construction Costs	$13.95	$23.80	$13.95	$23.80
Rehabilitation Costs	$0.00	$0.00	$0.00	$0.00
Rehabilitation Period (years in service)	n/a	n/a	n/a	n/a
50 YEAR EVALUATION PERIOD				
Average Annual Maintenance	$0.15	$0.65	$0.20	$1.15
Maintenance and Rehabilitation	$7.85	$32.10	$10.00	$58.50
25 YEAR EVALUATION PERIOD				
Average Annual Maintenance	$0.15	$0.70	$0.20	$1.25
Maintenance and Rehabilitation	$3.90	$16.70	$5.10	$30.75

Notes:

1. Estimated life cycle costs represent NPV of associated costs in Canadian dollars per square metre of CDA ($/m2).
2. Average annual maintenance cost estimates represent NPV of all costs incurred over the time period and do not include rehabilitation costs.
3. Life cycle costs are higher for BMPs designed to receive roof and road runoff due to additional costs associated with the hydrodynamic (i.e., oil and grit) separator and associated inspection and routine maintenance.
4. Maintenance costs over a 25 year time period for roof runoff only infiltration chamber system are estimated to be 28.0% of the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 36.6% for the High Frequency maintenance scenario.
5. Maintenance costs over a 25 year time period for roof and road runoff infiltration chamber system are estimated to be 70.2% of the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 1.29 times the original construction cost for the High Frequency maintenance scenario.
6. Maintenance costs over a 50 year time period for roof runoff only infiltration chamber system are estimated to be 56.3% of the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 71.7% for the High Frequency maintenance scenario.
7. Maintenance costs over a 50 year time period for roof and road runoff infiltration chamber system are estimated to be 1.35 times the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 2.46 times for the High Frequency maintenance scenario.

7.6 Green Roofs

7.6.1 BMP Overview

Green roofs are specially engineered rooftops designed to support the growth of vegetation while protecting the structural integrity of the roof. They can also be referred to as vegetated roofs, rooftop gardens or eco-roofs. A green roof acts like a lawn, meadow or garden by intercepting and absorbing a portion of the rain or snow that falls on it. The typical layers of a green roof (in order from the roof surface) include insulation layer, water-proofing membrane, root barrier, drainage layer, geotextile, lightweight growing medium layer and the vegetation. Excess water that is not absorbed by the vegetation, growing medium, or geotextile is collected by the underlying drainage layer, directed to outlet structures and conveyed via the roof drainage system to another stormwater BMP or the municipal storm sewer system. A large portion of the water absorbed by green roofs is returned to the atmosphere by evaporation and transpiration by plants. Green roofs are typically designed to retain precipitation from small to medium-sized storm events. Overflow outlets are necessary to safely convey flows from major storm events. Key components of green roofs for inspection and maintenance are described in Table 7.32 and Figure 7.6.

Properly functioning green roofs reduce the quantity of runoff and pollutants being discharged to municipal storm sewers and receiving waters (i.e., rivers, lakes and wetlands). The growing medium and plants retain pollutants deposited from the atmosphere and reduce metals and other pollutants from conventional roof materials transported by runoff. In addition to their SWM benefits, green roofs can improve the energy efficiency of the building due to their insulating properties, reduce the urban heat island effect, provide food and shelter for pollinators and have aesthetic value as attractive landscaped features.

There are two types of green roofs: intensive and extensive. Intensive green roofs contain greater than 15 cm depth of growing medium, can be planted with deeply rooted plants and can be designed to handle pedestrian traffic. Extensive green roofs consist of a thinner growing medium layer (15 cm depth or less) and are typically planted with drought-tolerant, shallow rooting, low maintenance herbaceous vegetation.

Ontario Occupational Health and Safety training standards for individuals working at heights must be adhered to during installation, inspection and maintenance of green roofs. Individuals working on rooftops should be adequately trained on the use and maintenance of fall prevention and arrest equipment and review hazards and safety plans regularly. Further information about Ontario's training standard for working at heights can be accessed at the following location:

- http://www.labour.gov.on.ca/english/hs/pubs/wah/

Table 7.32: *Key Components of Green Roofs for Inspection and Maintenance.*

Component	Description
Perimeter	Inspection of the perimeter is done to confirm the dimensions of the BMP are acceptable, check for wind uplift of green roof layers or other types of structural damage (e.g. failing edge restraint). A vegetation-free zone that separates the green roof perimeter from the roof perimeter and other structures on the roof (e.g., vents), that is kept devoid of vegetation and natural debris should be maintained as a fire prevention measure. Parapets or other wind break structures may also be present around the green roof perimeter to help prevent wind scour of growing medium, and should be routinely inspected for damage.
Filter bed/ Growing media area	The green roof surface that is composed of filter bed (i.e., growing medium area) covered by a mixture of vegetation and either flat or gently sloping. Growing media will vary according to the green roof system/product installed but is generally designed to be porous and lightweight with adequate fertility and drainage capacity to support plant growth and allow for absorption and infiltration of water. Growing media may be covered by matting or another erosion control measure to prevent surface erosion from rain or wind scour while plantings are becoming established. Green roofs are designed to drain all excess water within a few hours after the end of a storm. The filter bed should be routinely checked for presence of standing water. Trash should be removed from the filter bed regularly. Repair of animal burrows or damage from foot traffic, wind scour or uplift may also be needed periodically.
Vegetation	Green roofs rely on vegetation (i.e., sedums/succulents, grasses, herbs, wildflowers and for intensive green roofs, shrubs and trees) to intercept, absorb and evapo-transpire stormwater. Plantings should be adapted to the harsh conditions (i.e., minimal soil depth, seasonal drought, high winds and strong sun exposure) prevalent on rooftops. A wider variety of vegetation types may be used on intensive green roofs, but these typically require additional maintenance. In the first 2 months of establishment, plantings need to be irrigated frequently (e.g., bi-weekly). Routine maintenance of vegetation is similar to a conventional planting bed (i.e., weeding, pruning, watering during droughts, fertilization as needed).
Overflow outlets	Flows exceeding the storage capacity of the BMP are conveyed to an adjacent drainage system via an overflow outlet structure and the roof drainage system. Overflow outlet structures must be kept free of obstructions to ensure stormwater is safely conveyed during major storm events.
Irrigation system	Most green roofs will require periodic irrigation, especially during the first 2 months of the establishment period. Inspection and testing of the irrigation system should be done regularly to ensure it is functioning properly. Irrigation systems need to be disconnected from the water supply and drained prior to winter and re-connected in the spring.
Protective layers	Green roofs typically contain one or more layers designed to protect the roof deck and insulation from water damage, including a water-proofing membrane layer, a root barrier layer that protects the water-proofing membrane from root penetration and degradation by microbial activity, or a single protective layer that provides both functions. Inspection work should include checking for any portions of the green roof where protective layers are exposed and thereby at risk of damage.
Leak detection system	Where present, leak detection systems should be used to periodically check for the presence of leaks in the water-proofing membrane.

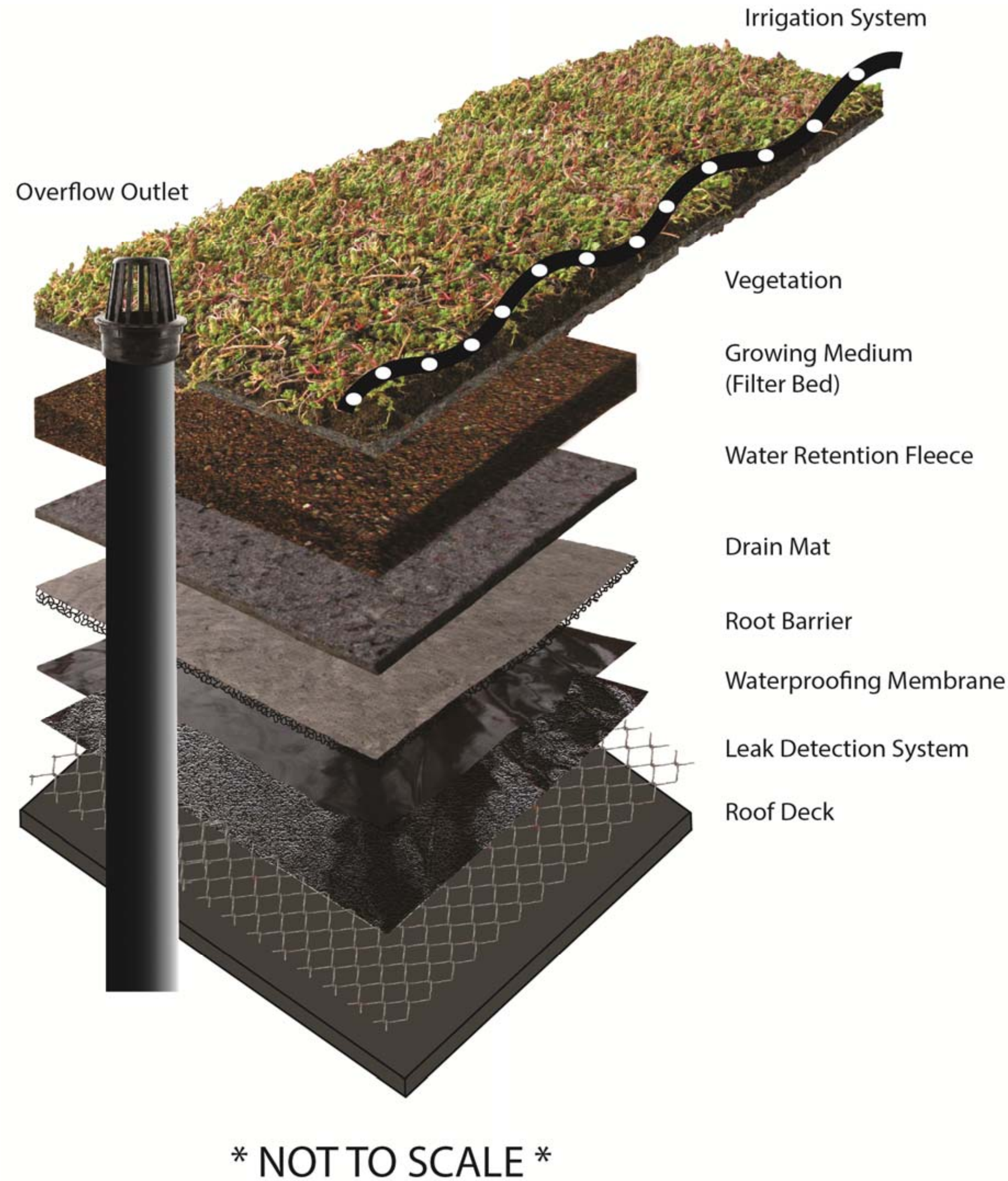


Figure 7.6: *Generalized plan and cross-section views of a green roof showing key components.*

7.6.2 Inspection and Testing Framework

Table 7.33 describes what visual and testing indicators should be used during each type of inspection for green roofs and provides a basis for planning field work. Numbers in the first column refer to the part of Section 8.0 and Appendix C that provides detailed guidance on standard protocols and test methods for assessing the respective indicator.

7.6.3 Critical Timing of Construction Inspections

Construction inspections take place during several points in the construction sequence, specific to the type of LID BMP, but at a minimum should be done weekly and include the following:

1. During site preparation, prior to BMP installation to ensure the roof structure is ready for green roof construction work and confirm that BMP layout area matches approved design drawings and that construction materials meet design specifications;
2. After installation of leak detection system (if applicable) to ensure it was done properly.
3. At installation of water-proofing membrane, prior to installation of root barrier, drainage layer and overflow outlets to ensure it was done properly and to confirm that slopes are acceptable;
4. After installation of root barrier, drainage layer (including filter fabric/layer) and overflow outlets, prior to installation of growing medium and plants to ensure it was done properly and confirm that depth and slopes are acceptable;
5. After installation of growing medium layer and plants to ensure it was done properly and to confirm depth, slopes and elevations at overflow outlets are acceptable;
6. After installation of irrigation system to confirm system is functioning;
7. Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the building and green roof installation contractors);
8. After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure roof drainage or flow diversion devices are functioning and adequately maintained.

Additional inspections may be needed depending on the number of layers in the green roof design (e.g., insulation, root barrier, and growing medium structural support layers) and may be required to comply with product warranty conditions. The green roof product vendor or designer should provide further guidance in this regard, specific to the system or product being installed.

Table 7.34 describes some critical points during the construction sequence when inspections should be performed prior to proceeding further. Table 7.34 can also be used as a checklist during Construction inspections, in addition to the Inspection Field Data Forms provided in Appendix C.

Table 7.33: *Inspection and testing indicators framework for green roofs.*

INSPECTION AND TESTING FRAMEWORK					
GREEN ROOFS		**Inspection Type**			
Section	Indicator	Construction	Assumption	Routine Operation	Verification
Visual indicators					
C.6	BMP dimensions	x	x		x
C.27	Green roof structural integrity		x	x	x
C.9	Standing water		x	x	x
C.10	Trash		x	x	
C.11	Filter bed erosion		x	x	
C.17	Vegetation cover	x	x	x	x
C.18	Vegetation condition		x	x	
C.19	Vegetation composition	x	x	x	
C.22	Overflow outlet obstruction	x	x	x	x
Testing indicators					
8.2	Soil characterization testing	x	x		(x)
8.7	Green roof irrigation system testing	x	x	x	
8.8	Green roof leak detection testing		x		x

(x) denotes indicators to be used for Performance Verification inspections only (i.e., not for Maintenance Verification inspections)

Table 7.34: *Critical timing of construction inspections - green roofs.*

Construction Sequence Step and Timing	Inspection Item	Observations [1]
During site preparation, prior to BMP installation	Ensure the roof structure is ready for green roof construction work	
	BMP layout area and dimensions match approved design drawings	
	Construction materials have been confirmed to meet design specifications	
After installation of leak detection system (if applicable), prior to installation of water-proofing membrane	Quality control check leak detection system installation	
After installation of water-proofing membrane, prior to installation of root barrier, drainage layer and overflow outlets	Quality control check membrane installation	
	Confirm that slopes conform with approved design drawings	
After installation of root barrier, drainage layer (including filter fabric) and overflow outlets, prior to installation of growing medium layer and plants	Quality control check root barrier and drainage layer installations	
	Installation of drainage layer (e.g., depth and slope) is acceptable	
	Installations of overflow outlets (e.g., elevation and slope) are acceptable	
After installation of filter bed (growing medium layer and plants)	Quality control check installation of any structural components of growing medium layer (if applicable)	
	Installation of growing medium (e.g., depth, elevations at overflow outlets) is acceptable	
	Growing medium is free of ruts, local depressions	
	Planting material meets approved planting plan specifications (plant types and quantities)	
	Quality control check installation of erosion matting/protection (if applicable)	
After installation of irrigation system	Confirm installation is acceptable and system is functioning (through testing)	

Notes:

1. S = Satisfactory; U= Unsatisfactory; NA = Not Applicable

7.6.4 Inspection Field Data Forms

Template forms for recording inspection observations, measurements, sampling location details and follow-up actions have been prepared for each LID BMP type and can be found in Appendix C.

7.6.5 Routine Maintenance

Table 7.35 describes routine maintenance tasks for green roofs, organized by BMP component, along with recommended minimum frequencies. It also suggests higher frequencies for certain tasks that may be warranted for BMPs located in highly visible or high pedestrian traffic locations or intensive green roofs featuring shrubs, trees and a wider variety of vegetation types. Tasks involving removal of trash, debris and weeding/trimming or replacement of dead plants may need to be done more frequently in such contexts. For further guidance on maintenance of vegetation cover on green roofs, refer to ASTM D2400/E2400M-06 Standard Guide for Selection, Installation and Maintenance of Plants for Green Roof Systems (ASTM International, 2015).

Individuals conducting vegetation maintenance and in particular, weeding (i.e., removal of undesirable vegetation), should be familiar with the species of plants specified in the planting plan and experienced in plant identification and methods of removing/controlling noxious weeds. Key resources on these topics are provided below:

- Agriculture and Agri-food Canada's WeedInfo database, http://www.weedinfo.ca/en/
- Ontario Ministry of Agriculture, Food and Rural Affairs' Ontario Weed Gallery, http://www.omafra.gov.on.ca/english/crops/facts/ontweeds/weedgal.htm
- Ontario Ministry of Agriculture, Food and Rural Affairs' Noxious Weeds In Ontario list, http://www.omafra.gov.on.ca/english/crops/facts/noxious_weeds.htm
- Ontario Invasive Plant Council's Quick Reference Guide to Invasive Plant Species, http://www.ontarioinvasiveplants.ca/files/Invasives_booklet_2.pdf
- Plants of Southern Ontario (book), 2014, by Richard Dickinson and France Royer, Lone Pine Publishing, 528 pgs.
- Weeds of North America (book), 2014, by Richard Dickinson and France Royer, University of Chicago Press, 656 pgs.

Table 7.35: *Routine maintenance tasks for green roofs.*

Component	Routine Maintenance Task	Frequency[1]	
		Minimum[2]	High[3]
Perimeter	◖ Remove any vegetation or natural debris from the vegetation-free zones between the green roof perimeter and the roof edge and other rooftop structures	A	BA
Filter bed	◖ Remove trash and natural debris	A	BA
Vegetation	◖ Watering during first two months after planting	BW	BW
	◖ Watering for the remainder of the first two (2) growing seasons (i.e., May to September) after planting or until vegetation is established	AN	AN
	◖ Watering for the remainder of the BMP lifespan	D	AN
	◖ Remove undesirable vegetation (e.g., weeds or invasive species, tree or shrub seedlings/saplings)	BA	Q
	◖ Replace dead/diseased plants to maintain a minimum of 80% vegetation cover[4] ◖ Prune shrubs and trees ◖ Cut back spent plants	A	BA
Overflow outlets	◖ Remove trash, natural debris and clippings	BA	Q
	◖ Flush out accumulated sediment with hose or pressure washer	A	BA
Irrigation system	◖ In the Spring, reconnect all parts to the water supply, flush lines to clear out any debris or sediment and test (i.e., run each zone for a few minutes) to confirm that the system is undamaged and functioning well ◖ In the late Fall/early Winter, disconnect the system from the water supply, connect it to an air compressor and blow air through it to remove water and ensure the lines and parts are dry, shut off water supply to the roof, and drain all hose bibs	A	A
	◖ Remove any debris or sediment accumulated on main assembly filter (if present)	BA	BA
Protective layers	◖ Repair isolated leaks in the water-proofing membrane through deconstruction of a small portion of the green roof, patching with new material, and reconstruction.	1 m^2 patch at 10 years & every 5 years thereafter	2 m^2 patch at 10 years & every 5 years thereafter

Notes:

1. A = Annually; AN = As needed based on Routine Operation inspections; BA = Bi-annually or twice per year, ideally in the spring and late fall/early winter; BM = Bi-monthly; BW = Bi-weekly or twice per week; M = Monthly; D = During drought conditions classified by

Agriculture and Agri-Food Canada's Canadian Drought Monitor as severe (D2) or higher (AAC, 2015); Q = Quarterly or four times per year, ideally in the spring, summer, early fall and late fall/early winter; W = Weekly.

2. These frequencies are recommended as the minimum necessary to ensure the BMP functions adequately over its expected lifespan.
3. High priority BMPs such as or those draining to a sensitive receiving waterbody or in highly visible locations, may warrant a higher frequency of routine maintenance tasks involving weeding and replacing dead plants.
4. Aim to achieve 80% vegetation cover in planting areas by the end of the establishment/warranty period for the original plantings (e.g., two years after planting).

Tips to help preserve BMP function

- Because the risk of compaction is higher when growing medium soil is saturated, any maintenance tasks involving foot traffic on the filter bed should not be performed during wet weather;
- Pavers or walkways should be placed at roof access locations and in primary paths to facilitate ease of access and help avoid having to walk on planted portions of the green roof during inspection and maintenance work.;
- During maintenance and any other type of installation or repair work over the green roof, use of sharp tools, lawn staples and stakes should be avoided to prevent damage to the drainage layer, root barrier and water-proofing membrane. All sharp pieces of metal and fasteners should be removed from the filter bed area with care;
- For green roofs with sedum as vegetation cover, trim off top stems annually in the spring during the first two years of establishment and leave on the growing medium surface to encourage colonization or purchase and spread fresh cuttings;
- Transplant vegetation that is established in the vegetation-free zone between the green roof perimeter and roof edge or other rooftop structures to supplement plantings on the filter bed if species are appropriate;
- Pruning of mature trees should be performed under the guidance of a Certified Arborist;
- Establish procedures and timing for irrigation system start-up and winterization to avoid damage to system components from freezing (e.g., start-up in the spring, once minimum air temperatures are above freezing and shutdown/winterize in late fall, prior to on-set of freezing weather);
- Routinely check that the irrigation system is free of damage and delivering water evenly to vegetated areas;
- For green roofs with automated irrigation systems using municipal/drinking water, schedule watering to occur at night or early in the morning to minimize the loss of water to evaporation; and
- For green roofs with automated irrigation systems using cistern water, irrigating during the day when evaporation rate is high will make greater use of stored rainwater between storm events, thereby freeing up more storage in the system for the next event and helping to reduce site runoff volume.

7.6.6 Rehabilitation and Repair

Table 7.36 provides guidance on rehabilitation and repair work specific to green roofs organized according to BMP component.

Table 7.36: *Rehabilitation and repair guidance for green roofs.*

BMP Component	Problem	Task
Filter bed/ Growing medium area	Eroded growing media area ≥ 30 cm in length or other damage is present	Restore growing media to required depth with material that meets design specifications, replant and irrigate bi-weekly or as needed until plantings are established. If problems persist, consider covering with matting or other erosion control measure until plantings are established or adding parapets or other wind break structures.
	Growing medium texture is out of specification range	Consult with medium manufacturer or product vendor to determine corrective actions.
	Growing medium organic matter or phosphorus content too low AND vegetation not thriving	Amendment or fertilizer application should be prescribed by the medium manufacturer or product vendor.
	Growing medium pH is out of specification range (6.0 to 7.8) AND vegetation not thriving	Consult with media manufacturer or product vendor to determine corrective actions.
	Growing medium soluble salts content exceeds 2.0 mS/cm AND vegetation not thriving	Consult with media manufacturer or product vendor to determine corrective actions.
	Surface ponding remains for > 3 hours after the end of a storm event because water does not infiltrate through the growing medium	Aerate (i.e., rake) or replace growing medium in problem areas taking care not to damage the drainage layer, root barrier or water-proofing membrane.
	Surface ponding remains for > 3 hours after the end of a storm event because water does not infiltrate through the drainage layer	Consult with green roof designer or product manufacturer/vendor to determine corrective actions.
Overflow outlets	Surface ponding remains for > 3 hours after the end of a storm event because overflow outlet is obstructed	Remove the obstruction which may require the use of a pressure washer or drain-snaking service.
Irrigation system	Distribution line, fitting or drip emitter/spray head is leaking, damaged or misaligned.	Identify the location of the damaged system component through testing (i.e., running the system in each zone while making observations). Turn off the system and schedule the repair work.

Protective layers	Water-proofing membrane has reached 40 years of age and is due for replacement.[1]	Deconstruct the green roof (re-using materials where possible), replace the water-proofing membrane with new material, and reconstruct with materials that meet design or product specifications.

Notes:

1. The expected lifespan of typical water-proofing membrane materials used below a green roof is estimated to be 40 years (TRCA & U of T, 2013a).

7.6.7 Life Cycle Costs of Inspection and Maintenance

Estimates of the life cycle costs of inspection and maintenance have been produced using the latest version of the LID Life Cycle Costing Tool (STEP, 2016; TRCA & U of T, 2013b) for four design variations to assist stormwater infrastructure planners, designers and asset managers with planning and preparing budgets. For more details of the tool's assumption, see Section 7.1.7 and refer to the project report (TRCA & U of T, 2013a).

For green roofs it is assumed that replacement of the water-proofing membrane protecting the roof structure will be needed once the roof has been in place for 40 years (TRCA & U of T, 2013a). Rehabilitation costs are those related to deconstruction, replacement of most materials (assumes 2/3 of cuttings needed to replant the 10 cm deep growing media bed design can be harvested from the previous roof), and reconstruction including (de)mobilization costs, as equipment would not have been present on site. Design costs were not included in the rehabilitation as it was assumed that the original LID practice design would be used to inform this work.

The annual average maintenance cost does not include rehabilitation costs and therefore represents an average of routine maintenance tasks, as outlined in Table 7.35. As part of these costs, it is assumed that a minor leak is detected in the waterproofing membrane when the roof reaches 10 years of age, and that the leak can be isolated through leak detection tests and repaired through patching. It is also assumed that one minor leak is detected and repaired every 5 years thereafter, until it reaches 40 years of age, when the entire membrane is replaced with new material.

All cost value estimates represent the NPV as the calculation takes into account average annual interest (2%) and discount (3%) rates over the evaluation time periods.

The design variations examined are as follows:

1. Extensive, 10 cm deep growing media bed, no irrigation system, no waterproof membrane;
2. Extensive, 10 cm deep growing media bed, no irrigation system, with waterproof membrane;
3. Extensive, 15 cm deep growing media bed with irrigation system, no waterproof membrane;
4. Extensive, 15 cm deep growing media bed with irrigation system and waterproof membrane;

The costing presented in this section is specific to extensive green roofs only, which are more common than intensive green roofs. Extensive green roofs support low growing plants and have substrate depths ranging from 5-15 cm, while intensive green roofs have growing media deeper than 15 cm (Permeable Pavement Task Committee, 2015). The no waterproof membrane scenarios assume that the membrane has already been installed as part of building roof construction and that waterproof membrane leak detection testing is performed by flood tests.

For each design variation, life cycle cost estimates have been calculated for two level-of-service scenarios: the minimum recommended frequency of inspection and maintenance tasks (i.e., Table 7.33 and Table 7.35 "Minimum Frequency" column), and a high frequency scenario (i.e., Table 7.33 and Table 7.35 "High Frequency" column) to provide an indication of the potential ranges.

For all scenarios, the CDA (i.e., green roof area) is 2,000 m^2 and cost estimates include crane mobilization and demobilization to install, deconstruct and reconstruct the green roof. The 10 cm deep growing media bed is planted with cuttings and the "with water-proofing membrane" design is installed with a thermoplastic polyolefin (TPO) membrane and no membrane leak detection system. The 15 cm deep growing media bed is planted with pre-grown sedum mats, includes an irrigation system, and the "with waterproof membrane" design is installed with a synthetic rubber, ethylene propylene diene terpolymer (EPDM) membrane and an Electric Field Vector Mapping (EFVM) leak detection system.

Estimates of the life cycle costs for all green roof design variations and maintenance scenarios in Canadian dollars per unit CDA ($/$m^2$) are presented in Table 7.37. The LID Life Cycle Costing Tool allows users to select what BMP type and design variation applies, and to use the default assumptions to generate planning level cost estimates. Users can also input their own values relating to a site or area, design, unit costs, and inspection and maintenance task frequencies to generate customized cost estimates, specific to a certain project, context or stormwater infrastructure program.

For all BMP design variations and maintenance scenarios, it is assumed that replacement of the water-proofing membrane is needed at 40 years of age (TRCA & U of T, 2013a). Where a green roof is in place, replacement of the water-proofing membrane is assumed to typically involve the following tasks and associated costs:

- Deconstruction of all green roof components and layers;
- For 10 cm growing media bed designs, harvesting 2/3 of the plant material needed to replant by cuttings;
- For 15 cm growing media bed designs planted with pre-grown sedum mats, it is assumed that all mats and associated growing media and plants are replaced with new ones;
- Replacement of the water-proofing membrane with new material that meets design specifications;
- Reconstruction of the green roof layers up to and including the growing media bed with new material that meets design specifications;

- Leak detection testing to confirm membrane installation is acceptable;
- Planting or installation of new plant material;
- Reconstruction of the irrigation system (where applicable) with new materials that meet design specifications;
- Green roof irrigation system testing to confirm installation is acceptable (where applicable);
- Construction and Assumption inspection work as part of reconstruction work at year 40;
- Routine inspection and vegetation maintenance work over a two (2) year establishment period for the plantings;
- Replace plants that don't survive the initial establishment period (assumes 10% and 20% of transplanted plant material does not survive the first year for Minimum Recommended and High Frequency maintenance scenarios, respectively).

Table 7.37: *Life cycle cost estimates for extensive green roofs.*

Green Roofs	**Minimum Frequency**				**High Frequency**			
Design Variation	**10 cm bed, no irrig., w membr.**	**10 cm bed, no irrig., w/o memb.**	**15 cm bed, w irrig. & memb.**	**15 cm bed, w irrig., w/o memb.**	**10 cm bed, no irrig., w membr.**	**10 cm bed, no irrig., w/o memb.**	**15 cm bed, w irrig. & memb.**	**15 cm bed, w irrig., w/o memb.**
Construction Costs	$126.40	$60.50	$244.75	$158.50	$126.40	$60.50	$244.75	$158.50
Rehabilitation Costs	$133.00	$84.45	$232.85	$169.35	$131.65	$83.10	$231.60	$168.10
Rehabilitation Period (years in service)	40	40	40	40	40	40	40	40
50 YEAR EVALUATION PERIOD								
Average Annual Maintenance	$2.50	$2.50	$2.60	$2.60	$4.65	$4.65	$4.65	$4.65
Maintenance and Rehabilitation	$257.55	$209.00	$362.45	$298.95	$363.00	$314.45	$464.25	$400.75
25 YEAR EVALUATION PERIOD								
Average Annual Maintenance	$2.80	$2.80	$2.85	$2.85	$5.15	$5.15	$5.15	$5.15
Maintenance and Rehabilitation	$69.55	$69.55	$71.85	$71.85	$128.70	$128.70	$129.05	$129.05

Notes:

1. Estimated life cycle costs represent NPV of associated costs in Canadian dollars per square metre of CDA ($\$/m^2$).
2. Average annual maintenance cost estimates represent NPV of all costs incurred over the time period and do not include rehabilitation costs.
3. Rehabilitation cost estimates represent NPV of all costs related to rehabilitative maintenance work assumed to be needed within the first 40 years of operation, including those associated with inspection and maintenance over a two (2) year establishment period for the plantings.

4. Average annual maintenance cost estimates for the High Frequency maintenance program scenario are approximately 1.82 times the costs for the Minimum Recommended Frequency scenario over the 50 year evaluation period.
5. Rehabilitation costs for the 10 cm deep filter bed, no irrigation system, with membrane are estimated to be between 1.04 and 1.05 times the original construction costs for High and Minimum Recommended Frequency maintenance program scenarios, respectively.
6. Rehabilitation costs for the 15 cm deep filter bed, with irrigation system, with membrane are estimated to be 95% of the original construction costs for both High and Minimum Recommended Frequency maintenance program scenarios.
7. Maintenance and rehabilitation costs over a 25 year time period for the High Frequency maintenance scenario are estimated to be 1.01 and 0.53 times the original construction costs for the 10 cm and 15 cm with membrane designs, respectively.
8. Maintenance and rehabilitation costs over a 25 year time period for the Minimum Frequency maintenance scenario are estimated to be 0.55 and 0.30 times the original construction costs for the 10 cm and 15 cm with membrane designs, respectively.
9. Maintenance and rehabilitation costs over a 50 year time period for the High Frequency maintenance scenario are estimated to be 2.87 and 1.90 times the original construction costs for the 10 cm and 15 cm with membrane designs, respectively.
10. Maintenance and rehabilitation costs over a 50 year time period for the Minimum Frequency maintenance scenario are estimated to be 2.04 and 1.48 times the original construction costs for the 10 cm and 15 cm with membrane designs, respectively.

7.7 Rainwater Cisterns

7.7.1 BMP Overview

Rainwater harvesting refers to the practice of collecting, storing and making use of rainwater and snowmelt from roofs. Roof runoff water is collected by eavestroughs or other types of roof drains, filtered to remove coarse debris, and conveyed to a structure where it is stored and drawn upon for purposes not requiring potable water such as landscape irrigation, outdoor washing, fire suppression, toilet flushing and even laundry. Storage structures may be cisterns installed below-ground or indoors that provide a year-round water source, or above-ground tanks or rain barrels that can only be used seasonally (spring, summer and fall) and must be taken off-line for the winter. Commercial-size rainwater cisterns can range in size from about 750 to 40,000 litres or larger and may be constructed from precast concrete, fiberglass, plastic or metal.

Underground cisterns are most often installed to a depth below the maximum frost penetration depth to ensure they can be used year-round. A pump is used to deliver the stored water to the fixtures where it is utilized. Water that is in excess of the storage capacity of the cistern overflows to an adjacent drainage system (e.g., municipal storm sewer or other BMP) via an overflow outlet pipe to safely convey flows from major storm events. Underground cisterns that are drawn upon for indoor water uses (e.g., toilet flushing, laundry) will also feature water level sensors and the means of adding municipal/potable water during extended periods of dry weather when stormwater does not meet the demand (i.e., make-up water supply system). They may also include in-line devices to filter stored cistern water prior to delivery at the fixtures. Key components of rainwater cisterns for inspection and maintenance are described in Table 7.38 and Figure 7.7.

Properly functioning rainwater cisterns reduce the quantity of runoff being discharged to municipal storm sewers and receiving waters (i.e., rivers, lakes and wetlands) and conserve potable water. An advantage of underground cisterns is that they can be used year-round and located below parking lots, roads, parkland or other landscaped areas. In densely developed urban areas, where the value of land is very high, this often makes them preferable to surface practices.

Requirements of the Ontario Occupational Health and Safety Act regulation for individuals working in confined spaces (O. Reg. 632/05) must be adhered to during any inspection or maintenance work on rainwater cisterns that involves entry into confined spaces (e.g., access hatches, cistern). Individuals working in such environments should be adequately trained on the use and maintenance of the necessary safety equipment and review hazards and safety plans regularly. Further information about Ontario's Confined Spaces Regulation and Guideline can be accessed at the following location:

- http://www.labour.gov.on.ca/english/hs/pubs/confined/cs_4.php

Table 7.38: *Key components of rainwater cisterns for inspection and maintenance.*

Component	Description
Contributing Drainage Area	The roof area from which runoff directed to the BMP originates. CDAs should be free of point sources of pollutants (e.g., leaking or badly corroded mechanical equipment, spills). Debris and trash should be removed regularly from the roof surface and eavestroughs/roof drains connected to the BMP.
Inlets	Inlets are pipes connected to eavestroughs or roof drains and must remain unobstructed to ensure that stormwater enters the BMP as designed. For outdoor above-ground cisterns, inlets need to be disconnected in the late fall/early winter, prior to the onset of freezing temperatures.
Pretreatment	Pretreatment refers to techniques or devices used to retain coarse materials suspended in runoff, either through filtration or settling, before it enters the BMP. Proper pretreatment reduces the risk of clogging conveyance pipes, intakes or overflow outlets and reduces the rate of accumulation of sediment in the cistern itself. Common pretreatment devices include eavestrough screens, first flush diverters or in-line filters on pipes leading to the cistern. Pretreatment devices require frequent (e.g., annual or bi-annual) debris removal maintenance.
Cistern	The water storage structure itself should be inspected during construction to ensure it has the correct dimensions and provides the intended water storage capacity. During construction and as part of routine operation it is also important to check for damage or leaks, that pump and make-up water supply system are installed properly and functioning, and to track the depth of accumulated sediment in relation to the water intake structure.
In-line Filters	The system may include in-line devices to filter the stored cistern water prior to delivery at fixtures. Sediment or debris captured by in-line filters needs to be periodically removed at the frequency recommended by the product manufacturer.
Overflow outlets	Flows exceeding the storage capacity of the BMP are conveyed to an adjacent drainage system via an overflow outlet structure (e.g., pipe connected from the cistern to the drainage system that features a backflow preventer valve). Overflow outlet structures must be kept free of obstructions to ensure stormwater is safely conveyed during major storm events.
Control structure	The manhole or hatch that provides access to the interior of the cistern. Inspect for damage and obstruction/accessibility.

7.7.2 Inspection and Testing Framework

Table 7.39 describes what visual and testing indicators should be used during each type of inspection for rainwater cisterns and provides a basis for planning field work. Numbers in the first column refer to the section of Chapter 8 that provides detailed guidance on standard protocols and test methods for assessing the respective indicator.

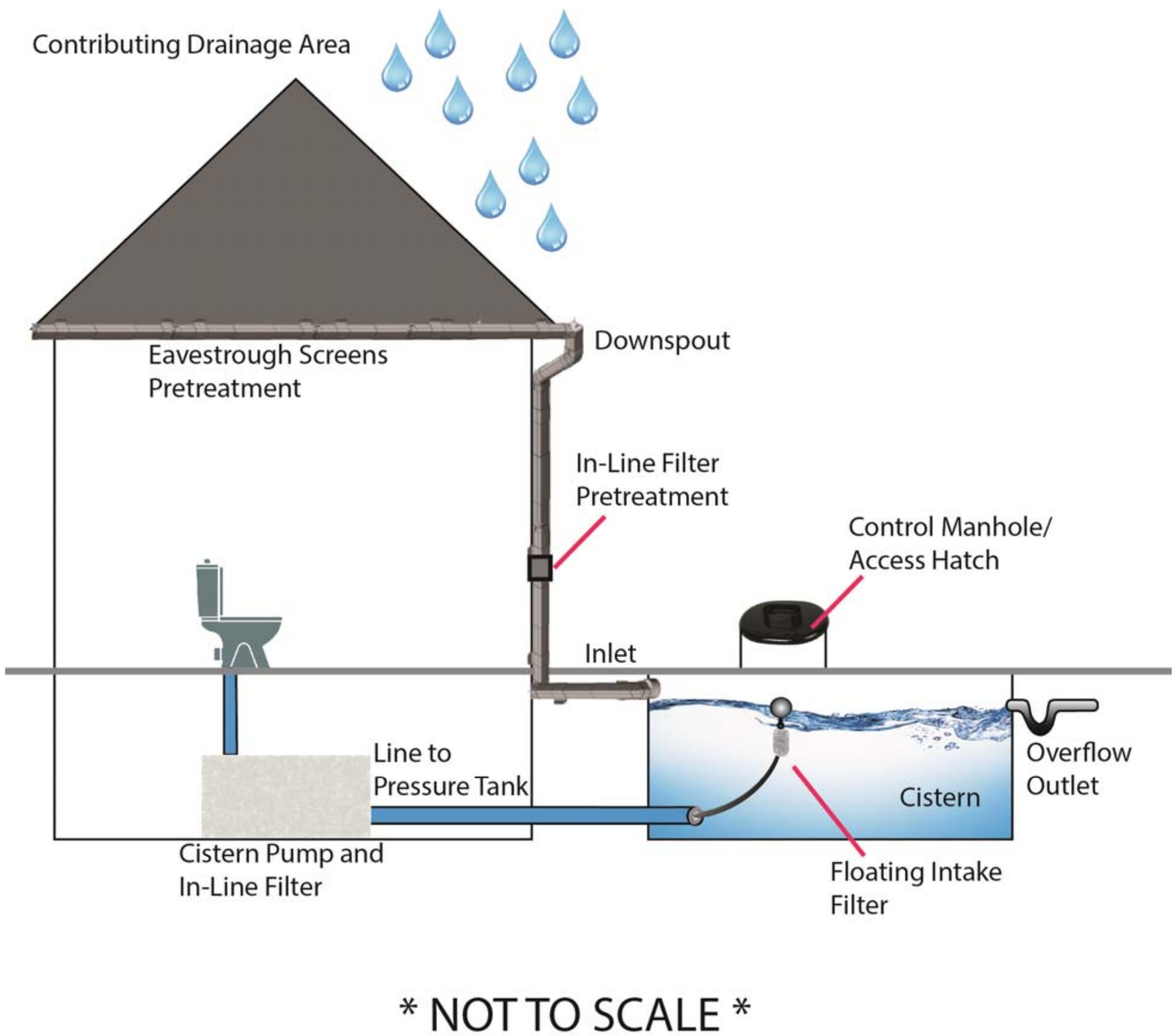


Figure 7.7: *Generalized plan and cross-section views of a rainwater cistern showing key components.*

Table 7.39: *Inspection and testing indicators framework for rainwater cisterns.*

INSPECTION AND TESTING FRAMEWORK					
RAINWATER CISTERNS		Inspection Type			
Section	Indicator	Construction	Assumption	Routine Operation	Verification
Visual indicators					
C.1	CDA condition	x	x	x	x
C.2	Inlet//Flow spreader structural integrity		x	x	x
C.3	Inlet/Flow spreader obstruction	x	x	x	x
C.4	Pretreatment sediment accumulation	x	x	x	
C.6	BMP dimensions	x	x		x
C.22	Overflow outlet obstruction	x	x	x	x
C.25	Control structure condition	x	x	x	x
C.28	Cistern structural integrity	x	x	x	x
C.29	Cistern sediment accumulation		x	x	x
Testing indicators					
8.3	Sediment accumulation testing	x	x	x	x
8.9	Cistern pump testing		x	x	(x)

(x) denotes indicators to be used for Performance Verification inspections only (i.e., not for Maintenance Verification inspections)

7.7.3 Critical Timing of Construction Inspections

Construction inspections take place during several points in the construction sequence, specific to the type of LID BMP, but at a minimum should be done weekly and include the following:

1. During site preparation, prior to BMP excavation and grading to ensure that adequate ESCs and flow diversion devices are in place and confirm that construction materials meet design specifications;
2. At completion of excavation and grading, prior to backfilling and installation of cistern and pipes to ensure depths, slopes and elevations are acceptable;
3. At completion of installation of cistern and pipes, prior to completion of backfilling to ensure slopes and elevations are acceptable;
4. Prior to hand-off points in the construction sequence when the contractor responsible for the work changes (i.e., hand-offs between the storm sewer servicing, paving, building and landscaping contractors);
5. After every large storm event (e.g., 15 mm rainfall depth or greater) to ensure ESCs and pretreatment or flow diversion devices are functioning and adequately maintained.

Table 7.40 describes critical points during the construction sequence when inspections should be performed prior to proceeding further. Table 7.40 can also be used as a checklist during Construction inspections, in addition to the Inspection Field Data Forms provided in Appendix C. For proprietary systems refer to the installation instructions provided by the product vendor/manufacturer for further guidance on construction sequence and critical timing of inspections.

Table 7.40: *Critical timing of construction inspections - rainwater cisterns.*

Construction Sequence Step and Timing	Inspection Item	Observations [1]
Site Preparation – after site clearing and grading, prior to BMP excavation and grading	Natural heritage system and tree protection areas remain fenced off	
	ESCs protecting BMP layout area are installed properly	
	CDA is stabilized or runoff is diverted around BMP layout area	
	BMP layout area has been cleared and is staked/delineated	
	Benchmark elevation(s) are established nearby	
	Construction materials have been confirmed to meet design specifications	
BMP Excavation and Grading - prior to backfilling and installation of cistern and conveyance pipes	Excavation location, footprint, depth and slope are acceptable	
	Installations of sub-drain pipes (location, elevation, slope) are acceptable	

BMP Installation – after installation of cistern/ pipes/structures and backfilling	Installation of structural components (i.e., pretreatment devices, inlets, cistern, overflow outlet, pump, make-up water supply and backflow preventer valve, control manhole/ access hatch) are acceptable and functioning	

Notes:

1. S = Satisfactory; U= Unsatisfactory; NA = Not Applicable

7.7.4 Inspection Field Data Forms

Template forms for recording inspection observations, measurements, sampling location details and follow-up actions have been prepared for each LID BMP type and can be found in Appendix C.

7.7.5 Routine Maintenance

Table 7.41 describes routine maintenance tasks for rainwater cisterns, organized by BMP component, along with recommended minimum frequencies. It also suggests higher frequencies for certain tasks that may be warranted for cisterns that receive flows from large roof drainage areas or roofs with mature trees near them. Tasks involving removal of debris, sediment and trash may need to be done more frequently in such contexts.

Table 7.41: *Routine maintenance tasks for rainwater cisterns.*

Component	Routine Maintenance Task	Frequency[1]	
		Minimum[2]	High[3]
Contributing Drainage Area	▪ Trim overhanging tree branches	A	A
	▪ Remove trash, natural debris and sediment	BA	Q
Pretreatment Devices	▪ Remove trash, natural debris and sediment	BA	Q
Inlets and Outlets	▪ For above-ground cisterns, reconnect the cistern to the roof drainage area in the spring once temperatures remain above freezing; disconnect the cistern from the roof drainage area (i.e., divert inlet pipes to grade or storm sewer connection) and fully drain it in the fall/late winter before the onset of freezing temperatures	A	A
	▪ Remove trash, natural debris and sediment	A	BA
Cistern	▪ Remove accumulated sediment when affecting aesthetics of water delivered to fixtures (requires BMP to be fully drained first)	AN	AN
In-line filters	▪ Remove debris and sediment	AN	AN
Overflow outlets	▪ Remove trash, natural debris and sediment	A	BA

Notes:

1. A = Annually; AN = As needed based on Routine Operation inspections; BA = Bi-annually or twice per year, ideally in the spring and late fall/early winter; BM = Bi-monthly; BW = Bi-weekly or twice per week; Q = Quarterly or four times per year, ideally in the spring, summer, early fall and late fall/early winter.
2. These frequencies are recommended as the minimum necessary to ensure the BMP functions adequately over its expected lifespan.
3. BMPs receiving flow from large CDAs may warrant a higher frequency of routine maintenance tasks involving removal of trash/debris/sediment.

Tips to help preserve BMP function

- Routinely check the water delivered to fixtures for excessive turbidity or discolouration which could be an indication of excessive sediment accumulation in the cistern or failure of pretreatment devices;
- Include a filtration device to treat stored water prior to delivery to fixtures as part of the intake/distribution system and clean filters at the same frequency as pretreatment devices;
- If the overflow outlet discharges at grade, the pipe opening should be covered with a coarse screen to prevent entry by insects and animals;
- Provide a means of draining the cistern by gravity to make inspection and maintenance work that requires drainage of the BMP (e.g., cistern sediment removal, repairs to cistern structures) easier to perform; and
- To remove accumulated sediment from a large cistern, a hydro-vac truck equipped with a JetVac nozzle may be employed that uses pressured jets of water to propel itself through the structure while scouring and directing suspended sediments to a collection point for removal by vacuuming; for small cisterns, a wet shop vacuum may be used.

7.7.6 Rehabilitation and Repair

Table 7.42 provides guidance on types of rehabilitation and repair work specific to rainwater cisterns organized according to BMP component. For more detailed guidance on troubleshooting rainwater harvesting systems refer to Ontario Guidelines for Residential Rainwater Harvesting Systems Handbook (Despins, 2010).

Table 7.42: *Rehabilitation and repair guidance for rainwater cisterns.*

BMP Component	Problem	Task
Inlets	Pipes or fittings are damaged or displaced	Schedule repairs
	Ice is accumulating and obstructing inflow to BMP	Schedule installation of heat trace wire along eavestroughs, around roof drains and in above-ground pipes, or disconnect the system during winter.
Cistern	Cracks are visible or seals between joints in the structure are leaking	Schedule repairs with oversight by the product manufacturer/vendor.
Overflow outlet	Overflow outlet pipe is obstructed by trash, debris or sediment	Schedule drain snaking service or pressure/vacuum truck to remove the obstruction.
Make-up water supply	System is malfunctioning (e.g., tops up cistern water level when unneccesary or fails to top up when needed).	Schedule FIT work to determine the cause of system malfunction with oversight by the product manufacturer/vendor or a licensed plumber and electrician.
Cistern pump	Pump is not delivering water to fixtures or not providing adequate water pressure.	Schedule FIT work to determine the cause of system malfunction with oversight by the product manufacturer/vendor or a licensed plumber and electrician.
Cistern	Cistern has reached 40 years of age and is due for replacement	Replace cistern with new one that meets design specifications.

7.7.7 Life Cycle Costs of Inspection and Maintenance

Estimates of the life cycle costs of inspection and maintenance have been produced using the latest version of the LID Life Cycle Costing Tool (STEP, 2016; TRCA & U of T, 2013b) to assist stormwater infrastructure planners, designers and asset managers with planning and preparing budgets. For more details of the tool's assumption, see Section 7.1.7 and refer to the project report (TRCA and U of T,2013a).

For rainwater cisterns it is assumed that no rehabilitation work will be needed to maintain acceptable storage and drainage performance over a 50 year period of operation, given that pretreatment devices are in place and are being adequately maintained. The annual average maintenance cost value represents an average of routine maintenance tasks, as outlined in Table 7.28. All cost value estimates represent the NPV as the calculation takes into account average annual interest (2%) and discount (3%) rates over the evaluation time periods.

Life cycle cost estimates have been generated for two design variations that can be used year-round: underground concrete cistern; and indoor plastic cistern systems. For each design variation, life cycle cost estimates have been calculated for two level-of-service scenarios: the minimum recommended frequency of inspection and maintenance tasks (i.e., Table 7.39 and Table 7.41 “Minimum Frequency” column), and a high frequency scenario (i.e., Table 7.39 and Table 7.41 “High Frequency” column) to provide an indication of the potential range. Only the indoor plastic cistern requires rehabilitation within the 50 year evaluation period. At year 40 it is assumed the plastic cistern is replaced with a new one.

For all scenarios, the roof area that drains into the rainwater harvesting cistern is 2,000 m^2. The water storage capacity of the cistern is assumed to be 23,000 L. Both cistern systems include a dual plumbing distribution system, an 81.2 LPM submersible pump and a 439 L expansion tank. The systems also include a float switch to prevent the pump from dry running, a top-up float switch and associated wring, a solenoid valve, air gap to prevent backflow, as well as backflow preventer at the premise boundary, a water meter and a water hammer arrestor. The rainwater is used for toilet flushing of 260 occupants. It is assumed that two hose bibs are used on average 14 minutes per day from April to September. The underground concrete cistern is installed adjacent to the building. The plastic cisternis stored inside the building, so no excavation is required to install/uninstall it.

Estimates of the life cycle costs for the two rainwater cistern system design variations in Canadian dollars per unit CDA ($\$/m^2$) are presented in Table 7.43. The LID Life Cycle Costing Tool allows users to select what BMP type and design variation applies, and to use the default assumptions to generate planning level cost estimates. Users can also input their own values relating to a site or area, design, unit costs, and inspection and maintenance task frequencies to generate customized cost estimates, specific to a certain project, context or stormwater infrastructure program.

For indoor plastic cistern systems it is assumed that replacement of the cistern itself is needed once it reaches 40 years of age (TRCA & U of T, 2013a). Replacement of the cistern is assumed to typically involve the following tasks and associated costs:

- Dismantle all portions of the system within or connected to the cistern;
- Replace the plastic cistern with a new one that meets design specifications;
- Reassemble the system, re-using existing components;
- Construction and Assumption inspection work associated with the rehabilitation work (including cistern pump testing).

Table 7.43: *Life cycle costs for rainwater harvesting.*

Rainwater Harvesting	Minimum Frequency		High Frequency	
Design Variation	**Buried concrete cistern**	**Indoor plastic cistern**	**Buried concrete cistern**	**Indoor plastic cistern**
Construction Costs	$26.30	$22.75	$26.30	$22.75
Rehabilitation Costs	$0.00	$2.20	$0.00	$2.20
Rehabilitation Period (years in service)	0	40	0	40
50 YEAR EVALUATION PERIOD				
Average Annual Maintenance	$0.50	$0.45	$0.85	$0.80
Maintenance and Rehabilitation	$24.15	$24.25	$41.85	$41.95
25 YEAR EVALUATION PERIOD				
Average Annual Maintenance	$0.50	$0.45	$0.95	$0.90
Maintenance and Rehabilitation	$12.05	$10.85	$23.50	$22.30

Notes:

1. Estimated life cycle costs represent NPV of associated costs in Canadian dollars per square metre of CDA ($/m2).
2. Average annual maintenance cost estimates represent NPV of all costs incurred over the time period and do not include rehabilitation costs.
3. Over a 50 year evaluation period, average annual maintenance cost estimates for the High Frequency maintenance scenario are 59% and 56% higher than the Minimum Recommended Frequency maintenance scenario for underground concrete cistern and indoor plastic cistern systems respectively.
4. Rehabilitation costs for the indoor plastic cistern system (i.e., replacing the cistern structure) are estimated to be 9.67% of the original construction costs, regardless of the maintenance frequency.
5. Maintenance costs over a 25 year time period for underground concrete cistern systems are estimated to be 45.8% of the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 89.4% for the High Frequency maintenance scenario.
6. Maintenance costs over a 25 year time period for indoor plastic cistern systems are estimated to be 47.7% of the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 98.0% for the High Frequency maintenance scenario.
7. Maintenance costs over a 50 year time period for underground concrete cistern systems are estimated to be 0.918 times the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 1.59 times for the High Frequency maintenance scenario.
8. Maintenance costs over a 50 year time period for indoor plastic cistern systems are estimated to be 1.07 times the original construction cost for the Minimum Recommended Frequency maintenance scenario, and 1.84 times for the High Frequency maintenance scenario.

8.0 INSPECTION AND TESTING PROTOCOLS

8.1 Visual Indicator Protocols

Appendix C describes protocols for assessing each of the twenty-nine (29) visual indicators for inspecting LID BMPs. Visual indicator protocols are organized according to the BMP component that they pertain to. The visual indicators approach allows for a rapid assessment of an LID BMP within a few hours by visually examining the condition of key features in a logical sequence (CSN, 2013). The observed condition for each indicator is recorded on an inspection field data form (Appendix D), documented by photographs and compared to quantitative or qualitative triggers to determine if follow-up tasks are warranted (e.g., routine maintenance, structural repair, further investigation).

Protocols for each visual indicator provide the following information for each relevant BMP type:

- Types of inspections that the indicator is used for;
- BMP component that it relates to;
- Brief description of what to look for or measure;
- Visual examples of passing and failing conditions;
- Conditions that trigger the need for follow-up tasks; and
- Typical follow-up tasks.

These protocols can be used to train inspectors about the visual indicators prior to conducting field visits to help ensure consistency in how the work is done. It is recommended that the components relevant to the BMP under inspection be examined in the order they appear in the following sections since they follow a logical progression that mirrors how water is delivered to and flows through the BMP. Following this sequence will reinforce the inspector's understanding of the function of the BMP while helping to hone in on the cause of any observed issues with its condition or function.

Inspection field data form templates have been provided for each type of LID BMP in Appendix C, and should be used to record observations, measurements and details about the locations where sampling, testing or measurements are undertaken, and follow-up tasks prescribed by the inspector along with timeframes for completing them.

The following equipment may be needed to complete visual indicator assessments:

- Camera;
- Small whiteboard and dry erase marker (to help keep track of what site or component is depicted in photographs);
- Safety apparel (hard hat, steel-toe boots, gloves, eye protection, safety vest);
- Safety cones (for restricting traffic from areas being inspected);
- Clipboard, pen and copies of blank inspection field data forms;

- Copies of as-built drawings and planting plans, BMP inspection and maintenance plan and results from the previous inspection;
- Shovel;
- Hand tools (e.g., screwdrivers, wrenches, pliers);
- Pick (for accessing manholes and catchbasins);
- Multi-gas detector, recently calibrated and bump tested (for entry into manhole/catchbasin/cisterns confined spaces);
- Tripod, winch and harness (for entry into manhole/catchbasin/cisterns confined spaces);
- Flashlight or headlamp;
- Measuring wheel;
- Measuring tape;
- Ruler or metre stick;
- Water level tape (for manual measurements of water level in monitoring wells);
- Stakes, string and hanging level (for estimating maximum ponding depth);
- Waterproof push camera (for inspecting sub-drains and outlet pipes).

8.2 Soil Characterization Testing

The soil component of an LID BMP contributes substantially to its stormwater treatment performance and overall function. If the soil is overly compacted or very finely textured, it may drain too slowly. If the soil is highly organic or contains excessive amounts of chemical fertilizer it may contribute to nutrient loads to receiving waters rather than reduce them. If the soil is too shallow it may not provide adequate treatment of contaminated stormwater or may not support healthy vegetation. Whether it be the engineered filter media of bioretention cells, the growing media of green roofs or the topsoil of enhanced swales, vegetated filter strips and soil amendment areas, it is important that the soil provide a healthy growing environment for plantings while being within design specifications for key parameters specific to the type of BMP.

It is most important to sample and test soil characteristics as a part of Construction and Assumption inspections, to confirm the BMP has been constructed with materials that meet design specifications and that installation of the soil component is acceptable. Testing to confirm that the material meets quality specifications (i.e., particle-size distribution, organic matter, pH, cationic exchange capacity, nutrients and soluble salts) needs to be completed prior to it being delivered to the construction site. Testing to confirm that installation of the soil component is acceptable (i.e., depth and compaction) should be performed after the installed material has been allowed to settle for at least two (2) weeks, and prior to planting.

Sampling and testing is also recommended as a part of Verification inspections, to determine if the BMP is being adequately maintained and if soil characteristics are still within acceptable ranges. It may also be done as part of Forensic inspection and Testing (FIT) work to help diagnose the cause of poor vegetation cover, drainage or treatment performance and decide on corrective actions.

Inspection field data forms provided in Appendix D can be used to record and document the sampling approach and results of tests performed in the field.

Table 8.1 describes the soil characteristics (i.e., parameters and specifications) that are critical to the performance and function of each type of LID BMP containing a soil component and the type of testing involved in determining if the soil is within an acceptable range. For Construction and Assumption inspections, the final design specifications relating to the soil component of the BMP or product specifications from the media supplier should be used as the Acceptance Criteria, which may be different ranges than those in Table 8.1. The values in Table 8.1 represent acceptable ranges for established BMPs (e.g., ones that have been operating for 3 years or more) and should be used during Verification inspections to determine if the BMP is being adequately maintained.

Table 8.1: *Critical soil characteristics, acceptance criteria and tests by LID BMP type.*

LID BMP Type	Soil Characteristic	Acceptance Criteria [1]	Test
Bioretention and Dry Swales (filter media)	Texture [2]	Loamy Sand or Sandy Loam; 70 to 88% sand-sized particles; 12 to 30% silt- and clay-sized particles; <20% clay-sized particles.	Particle-Size Distribution (PSD), or % Sand/Silt/Clay (i.e., Soil Texture) plus Sand Fraction
	Organic Matter (OM)	3 to 10% by dry weight [2]	Walkley-Black method when OM <7.5% or Loss On Ignition (LOI) method when OM ≥7.5% [3]
	Soil pH	6.0 to 7.8	pH of a Saturated Paste [3]
	Cationic Exchange Capacity	>10 meq/100 g	Cationic Exchange Capacity Test
	Phosphorus [4]	12 to 40 ppm	Extractable Phosphorus
	Soluble Salts [5]	≤2.0 mS/cm (0.2 S/m)	Electrical Conductivity of a Soil-Water Slurry (2:1 water to soil ratio by volume) [3]
	Depth	+/- 10% of design specification	Soil Cores, Test Pits or Cone Penetration Tests
	Compaction [6]	Surface Resistance: ≤110 PSI; Sub-surface Resistance: ≤260 PSI Bulk Density: ≤1.60 g/cm^3	Cone Penetration Tests or Bulk Density Tests
	Permeability	i ≥25 mm/h ($K_S \geq 1 \times 10^{-5}$ cm/s); and i ≤203 mm/h ($K_S \leq 0.02$ cm/s).	Surface Infiltration Rate Tests
Enhanced Swales (topsoil)	Texture	Same soil texture classification as specified in the final design or recorded on the as-built drawing	Particle-Size Distribution (PSD), or % Sand/Silt/Clay (i.e., Soil Texture) plus Sand Fraction
	Organic Matter (OM)[2]	5 to 10% by dry weight	Walkley-Black method when OM <7.5% or Loss On Ignition (LOI) method when OM ≥7.5% [3]
	Soil pH	6.0 to 7.8	pH of a Saturated Paste [3]
	Phosphorus [4]	12 to 40 ppm	Extractable Phosphorus
	Soluble Salts [5]	≤2.0 mS/cm (0.2 S/m)	Electrical Conductivity of a Soil-Water Slurry (2:1 water to soil ratio by volume) [3]
	Depth	+/- 10% of design specification	Soil Cores, Test Pits
	Compaction	Surface Resistance: ≤110 PSI; Sub-surface Resistance: Use soil texture class and Table 8.3 to determine maximum acceptable value; Bulk Density: Use PSD to interpolate maximum bulk density value from Figure 8.7.	Cone Penetration Tests or Bulk Density Tests
	Permeability	i ≥15 mm/h ($K_S \geq 1 \times 10^{-6}$ cm/s)	Surface Infiltration Rate Tests

Vegetated Filter Strips and Soil Amendment Areas (topsoil)	Texture	Same soil texture classification as specified in the final design or recorded on the as-built drawing	Particle-Size Distribution (PSD), or % Sand/Silt/Clay (i.e., Soil Texture) plus Sand Fraction
	Organic Matter (OM)	5 to 10% by dry weight [2]	Walkley-Black method when OM <7.5% or Loss On Ignition (LOI) method when OM ≥7.5% [3]
	Soil pH	6.0 to 7.8	pH of a Saturated Paste [3]
	Depth	+/- 10% of design specification	Soil Cores, Test Pits
	Phosphorus [4]	12 to 40 ppm	Extractable Phosphorus
	Soluble Salts [5]	≤2.0 mS/cm (0.2 S/m)	Electrical Conductivity of a Soil-Water Slurry (2:1 water to soil ratio by volume) [3]
	Compaction	Surface Resistance: ≤110 PSI; Sub-surface Resistance: Use soil texture class and Table 8.3 to determine maximum acceptable value; Bulk Density: Use PSD to interpolate maximum bulk density value from Figure 8.7.	Cone Penetration Tests or Bulk Density Tests
	Permeability	i ≥15 mm/h (K_S ≥1 x 10^{-6} cm/s)	Surface Infiltration Rate Tests
Green Roof (growing media)	Texture	See product vendor or BMP designer for specifications	Particle-Size Distribution (PSD), or % Sand/Silt/Clay (i.e., Soil Texture) plus Sand Fraction
	Maximum Media Density	See product vendor or BMP designer for specification	Maximum Media Density Test (ASTM E2399/E2399M-15)
	Water Storage Capacity [7]	Extensive: ≥35% by volume	Part of Maximum Media Density Test (ASTM E2399/E2399M-15)
		Intensive: ≥45% by volume	Part of Maximum Media Density Test (ASTM E2399/E2399M-15)
	Air-Filled Porosity [7]	≥10% by volume	Part of Maximum Media Density Test (ASTM E2399/E2399M-15)
	Permeability, Saturated Media	See product vendor or BMP designer for specification	Part of Maximum Media Density Test (ASTM E2399/E2399M-15)
	Organic Matter (OM)	See product vendor or BMP designer for specification	Walkley-Black method when OM <7.5% or Loss On Ignition (LOI) method when OM ≥7.5% [3]
	Soil pH [8]	6.5 to 7.8	pH of a Saturated Paste
	Soluble Salts [8]	≤0.85 mS/cm (0.085 S/m)	Electrical Conductivity of a Saturated Media Extract (SME) solution
	Phosphorus [9]	2.2 to 40.0 ppm	Extractable Phosphorus of a Saturated Media Extract (SME) solution

Notes:

1. Values represent acceptable ranges for established BMPs (i.e., in operation for 3 years or more). For Construction and Assumption inspections, final design and soil or media product specifications and permissible tolerance ranges should be used as the acceptance criteria, which may be smaller ranges than the values in this table.
2. Suggested range for diagnosing suspected problems with drainage function, vegetation cover or vegetation condition for established BMPs constructed with filter media that meets recommended guidelines (CVC & TRCA, 2010). For proprietary filter media products, different ranges may be acceptable. Product specifications should be provided by the media supplier. Test results should be compared to the media supplier's specifications and permissible tolerance ranges.
3. Based on Ontario Ministry of Food and Rural Affairs' Soil Fertility Handbook guidance on soil fertility testing for crop production (OMAFRA, 2006).
4. Based on Minnesota Pollution Control Agency (MPCA, 2015) for minimum to sustain plant growth and Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 2014) for a maximum to avoid unnecessary fertilization that would have low or no effect on plant health.
5. Based on the threshold for non-saline soils (Whitney, 2012).
6. Interpolated value from Figure 8.7 based on a sandy loam soil containing at least 70% sand-sized particles.
7. Based on German green roof standards (FLL 2008). Specifications will vary depending on the green roof growing media product. Product specifications should be provided by the media supplier. Test results should be compared to the media supplier's specifications and permissible tolerance ranges.
8. Based on Penn State University Center for Green Roof Research (Berghage et al. 2008).
9. Based on Penn State University Center for Green Roof Research (Berghage et al. 2008) for the minimum to sustain plant growth and Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 2014) for the maximum to avoid unnecessary fertilization that would have low or no effect on plant health.

The following sections describe sampling procedures and acceptable test methods associated with each soil characteristic (i.e., parameter) that should be tested to confirm the soil component of the LID BMP is within an acceptable range.

8.2.1 Soil Sampling Methods and Equipment

The approach to soil sampling will vary depending on what type of inspection is being performed.

As part of a Construction and Assumption inspections, the objective of soil sampling and testing is to confirm that the quality, depth and physical properties of the soil meets design specifications. In Verification inspections, the objectives are to determine if the BMP is being adequately maintained and if the soil properties are still within acceptable ranges for key parameters affecting BMP functional performance. As part of Forensic Investigation and Testing (FIT) work the objective is to help diagnose the cause of potential problems with functional performance detected through visual inspections or other types of testing and decide on appropriate corrective actions. Soil sampling is done to examine how the characteristics of the soil vary over the surface area and depth of the BMP (e.g., has the texture of bioretention filter media at the BMP surface and nearest the inlets become finer than Acceptance Criteria due to accumulation of fine sediment?). So FIT work requires a different approach to sampling that targets problem areas and specific depth ranges and produces multiple samples for laboratory testing.

In general, soil samples should be collected as per ASTM D6640-01 Standard Practice for Collection and Handling of Soils Obtained in Core Barrel Samplers for Environmental Investigations (ASTM International, 2015). Before sampling the soil, any mulch, natural debris (i.e., leaves and branches) and grass cover should be removed from the specific location to be sampled. While collecting samples, it is good practice to make a sketch of the BMP perimeter and sampling locations along with an indicator of orientation (e.g., a north arrow) and rough locations of inlets and outlets. Inspection field data forms provided in chapter 7 should be used to record sample numbers and locations (e.g., sketches) along with other information about the sampling approach (e.g., soil depth range each sample represents).

Equipment needed for soil sampling includes the following:

- Safety apparel (steel toed boots, gloves and eye protection)
- Clipboard, inspection field data forms, pens
- Shovels (e.g., spade and trowl)
- Pails (to contain bulk samples)
- Hand tools (e.g., hammer, screw driver, pliers, wrenches)
- Wooden stakes
- Soil core sampler
- Acrylic soil core sample tubes and caps,
- Plastic bags or containers, sealable
- Duct tape and markers (for sealing and labelling sample containers)
- Ruler or metre stick;
- Measuring tape (and measuring wheel for large BMPs)
- GPS or mobile device

Construction Inspections

The objective of soil sampling and testing as part of Construction inspections is to confirm that the physical and chemical properties of the soil to be used to construct the BMP meets design specifications. For all topsoil or media products to be used to construct LID BMPs, laboratory test results showing that the material meets design or product specifications (i.e., quality control/assurance documentation) should be provided to the designers and construction site supervisor or project manager prior to delivery to the construction site. Samples submitted for laboratory testing should be collected during the beginning, middle and end of the blending process or the top, middle and bottom of the pile. For proprietary media mixtures (e.g., bioretention filter media, green roof growing media) specifications and quality control/assurance documentation should be obtained from the media supplier prior to the material being delivered to the construction site.

After the material has been accepted for delivery and has been installed at the construction site, further sampling and laboratory testing should be done as part of the Assumption inspection to assure the product quality was not compromised during transport or installation (see below for guidance on sampling methods).

Assumption and Verification inspections

For Assumption and Verification inspections, the sampling approach should focus on producing a sample that is representative of the entire soil component of the BMP. To produce such a sample requires collecting material through the full depth of soil in multiple locations distributed evenly across the BMP surface, combining them into a bulk sample, homogenizing the bulk sample and deriving a composite sample from it. For very large BMP footprints (e.g., soil amendments), generating and testing multiple composite samples may be necessary.

Samples are most easily collected using a soil corer (Figure 8.3) to collect cores at approximately 30 cm depth intervals at each location, to the full depth of soil present. Samples can also be obtained by digging a test pit and collecting material from the full depth of the soil layer using a trowl and bucket. For enhanced swale, vegetated filter strip and soil amendment BMPs, soil cores or test pits must extend to the sub-soil layer in order to determine the depth of topsoil present. Topsoil depth can be determined by examining the colour of the soil, with the topsoil layer ending when dark brown coloured soil transitions to lighter coloured subsoil that is low in organic matter (Figures 8.1and 8.2). See section 8.2.2 for further guidance on sampling methods to determine soil depth.

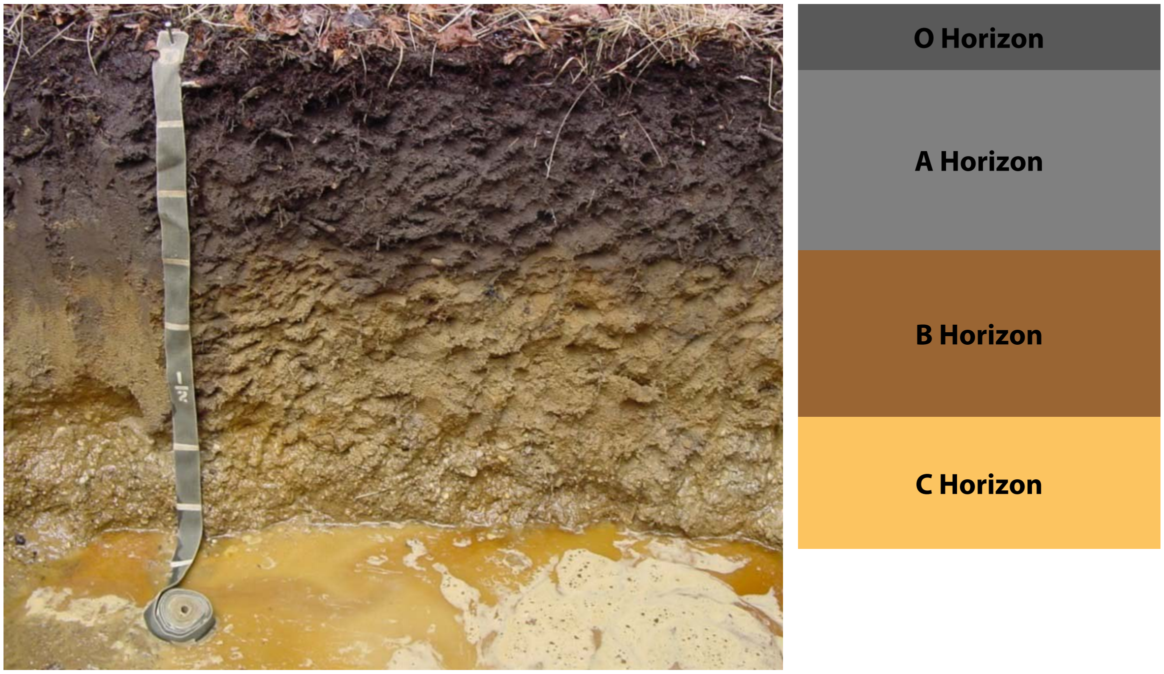
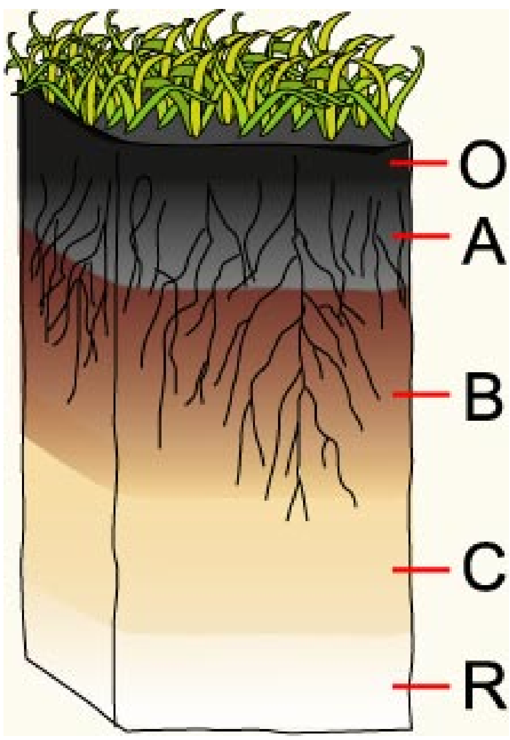


Figure 8.1: *Photograph of a test pit revealing O,A, B and C soil horizons(Source: Mount St. Mary`s University).*



O Horizon – contains organic materials in various stages of decomposition;

A Horizon – surface mineral layer containing some organic material and a mix of clay, sand and gravel, and is usually darker than lower layers;

B Horizon – Mix of clay, iron and aluminum and has lighter colour than the A horizon;

C Horizon – this layer contains partly weather or decomposed rock;

R Horizon – solid rock (bedrock) layer

Figure 8.2: *Schematic of soil horizons (Source: Sydney TAFE).*

For bioretention, enhanced swales and green roofs, samples of the full depth of soil in the BMP should be collected in at least five (5) locations or at a rate of one sample for every twenty-five (25) square metres (m^2) of vegetated BMP area, evenly distributed over the BMP surface, and combined to produce a bulk sample. For vegetated filter strips, soil amendment areas and grassed permeable pavements samples should be collected at a rate of one for every 250 m^2 of vegetated BMP area, evenly distributed over the BMP surface, and combined to produce a bulk sample. The bulk sample should then be stirred to homogenize the material as best as possible. A composite sample should then be derived from the homogenized bulk sample that is of sufficient quantity to allow all applicable laboratory tests to be done. Place at least one litre (L) of the material into a clean, sealable container (e.g., plastic bag or container) to produce the composite sample. Label the sample with the date and identifiers that describe the BMP and submit it to an accredited soil laboratory (see Appendix A for a list of accredited soil testing laboratories in Ontario) for testing of the parameters described in Table 8.1.

If Cone Penetration Tests are the chosen method for evaluating the degree of soil compaction (recommended), refer to section 8.2.3 for guidance on the sampling approach. If Bulk Density is the chosen method of evaluating the degree of compaction, soil core samples from each sampling location must be collected using a soil core sampler (Figure 8.3) and submitted to the laboratory intact, in properly labelled acrylic sample tubes capped on both ends, in addition to the composite sample.

Forensic Investigation and Testing

When potential problems with the drainage, vegetation cover or functional performance of a BMP are suspected based on findings from visual inspection or other types of testing (e.g., surface infiltration rate testing, natural or simulated storm event testing) more detailed soil sampling and testing may be warranted. The objective of soil characterization testing in such cases is to examine how the characteristics of the soil vary over the surface area and depth of the BMP to further diagnose the cause of poor drainage, vegetation cover or condition, or effluent quality, determine what portion of the BMP is in need of structural repair or rehabilitation, and to select the appropriate procedure.

The number and distribution of sampling locations will be determined by the nature of the functional performance problem, but in general, areas to focus on include the following:

- Locations of dead or dying vegetation or highly saturated soil;
- Differences in characteristics between the surface soil layer (e.g., top 15 cm) and deeper layers to determine if accumulation of fine sediment or organic matter on the filter bed surface is impairing the drainage rate, soil fertility or effluent quality.

Figure 8.3: *Images of a simple soil corer, core barrel sampler and acrylic sample tubes .Left: Soil core sampler (Source: Amazon); Centre: Split soil core sampler kit which preserves the soil sample for further testing (i.e., bulk density). (Source: Ereink); Right: Soil Core Sampler (Source: Ereink).*

Separate soil samples of at least 1 L in quantity should be collected for each sampling location and depth interval of interest.

To help diagnose the cause of poor drainage performance detected through visual indicators or other testing (e.g., surface infiltration rate testing, natural or simulated storm event testing) collect separate samples for 0 to 15 cm depth and 15 to 30 cm depth intervals from problem areas, test for particle-size distribution (PSD) and organic matter, and compare to design or product specifications or Acceptance Criteria (Table 8.1). If test results show the surface soil has a finer texture or greater organic matter content than acceptable, procedures to repair/rehabilitate the soil may include core aeration, removal of accumulated sediment and debris, tilling surface sediment, debris and soil to 20 cm depth or greater, or replacement of the surface soil with material that meets specifications.

To help diagnose the cause of poor vegetation cover or condition, collect separate samples for 0 to 15 cm depth and 15 to 30 cm depth intervals from problem areas, test for organic matter, nutrient concentrations and soluble salts, and compare to design or product specifications or Acceptance Criteria (Table 8.1). If test results show the soil is deficient in organic matter or nutrients, it may need to be amended with compost to improve fertility and sustain vegetation cover. If test results show the soil contains an excessive concentration of soluble salts, the problem area should be flushed with fresh water and consideration should be given to selecting plants that are more tolerant to salt.

To help diagnose the cause of poor effluent quality detected through natural or simulated storm event testing and continuous monitoring, collect a composite sample representative of the entire soil component of the BMP using the method described in the previous sub-section and test for Organic Matter, cationic exchange capacity (CEC) and nutrient concentrations, and compare to design or product specifications or Acceptance Criteria (Table 8.1). If the test results show the soil contains higher organic matter or nutrient concentrations or lower CEC than Acceptance Criteria (Table 8.1) or product specifications, repair procedures may include removal of accumulated sediment and debris, incorporation of amendment(s) to increase retention of soluble nutrients or cationic exchange capacity, or replacement with material that meets specifications.

8.2.2 Depth

Soil depth is an important parameter to be confirmed as part of Assumption and Verification inspections as it will affect the vitality of plantings and stormwater treatment performance in terms of water retention and effluent quality. Testing to confirm soil depths are acceptable should be performed after the installed material has been allowed to settle for at least two (2) weeks, and prior to planting. There are three methods that can be used to evaluate soil depth: test pits, soil cores and soil probes (e.g., cone penetrometer). Table 8.2 describes each method and which LID BMPs they are best suited for. It is important to note that using a soil corer to collect core samples results in some compaction of the sample produced, so the media or topsoil depth value measured from the core sample needs to be corrected before using the information to determine if installation of the soil component is acceptable. To correct for compaction of the soil core sample produced through the collection process, divide the value for media or topsoil depth measured from the soil core sample by the compaction correction factor obtained by dividing the total length of the soil core sample by the total depth of the borehole produced through sampling (Equation 8.1).

Equation 8.1: *Soil core sample compaction correction factor.*

$$C = Lc/Db$$

Where,

C = Compaction correction factor

Lc = Length of soil core sample, total

Db = Depth of borehole, total

To evaluate the soil depth for bioretention, dry swales and enhanced swales, measure depths using a method recommended in Table 8.2 in at least five (5) locations or at a rate of one sample for every twenty-five (25) square metres (m^2) of vegetated BMP area, evenly distributed over the BMP surface. For vegetated filter strips, soil amendment areas, permeable pavements with grass cover and green roofs, measurements should be made at a rate of one for every 250 m^2 of vegetated BMP area, evenly distributed over the BMP surface. Measurement locations should be recorded on the field data form, including a plan view sketch of the BMP showing the spatial distribution of measurements.

For a bioretention cell or dry swale with no sub-drain, enhanced swale, vegetated filter strip or soil amendment area, soil cores or test pits must extend to the top of the sub-soil (i.e., B horizon) in order to determine the depth of filter media or topsoil present. Soil depth can be determined by examining the colour of the soil, with the filter media or topsoil layer ending when darker coloured soil transitions to lighter coloured subsoil that is low in, or devoid of dark brown coloured organic matter (Figure 8.1).

To determine if the observed soil depths are acceptable, calculate the mean value and compare to design specifications. If the mean observed soil depth is less than the design specification by 10% or more (see Acceptance Criteria in Table 8.1), corrective actions are needed to address this deficiency. Corrective action involves addition of soil material until an acceptable average depth is achieved which may require regrading.

8.2.3 Compaction

Drainage, water holding capacity and fertility characteristics of a soil can be greatly affected by the degree to which the soil has been compacted. Compaction of soil decreases porosity (i.e., void spaces between soil particles) and increases density which reduces the capacity of the soil to infiltrate and absorb water and can inhibit penetration by the roots of plants at excessive levels. Excessive compaction can result from the soil being subjected to heavy vehicle or foot traffic, storage of heavy materials or mechanical compaction equipment.

An important part of Assumption and Verification inspections includes testing the soil component of LID BMPs to ensure it has not become overly compacted. There are two acceptable approaches to testing soil compaction; Cone Penetration Tests performed by the inspector using a soil cone penetrometer; or Bulk Density tests performed by a soil laboratory on intact core samples. The choice of method will depend on the type of BMP being examined, physical properties of the soil, equipment available to the inspector and turnaround time for receiving test results. The quickest and cheapest method is by performing Cone Penetration Tests on the soil in the field, which is suitable for all types of soil, but requires the use of a soil cone penetrometer that is in good working order and an inspector familiar with its proper use. A more time-consuming and costly, but potentially more accurate method is by collecting intact soil core samples with a Core Barrel Sampler and submitting them for Bulk Density testing by a soil laboratory. Using the Bulk Density method may be problematic for highly coarse, organic or friable soil which, because of their lack of cohesiveness, makes collecting intact core samples difficult. It also involves laboratory testing which typically requires a few weeks to produce test results, which makes it unsuitable for use as part of Construction inspections.

Table 8.2: *Recommended methods for testing soil depth by LID BMP type.*

Method	LID BMP Type Suitability	Description	Equipment Needed
Test pits	Bioretention and Dry Swales; Enhanced Swales Vegetated Filter Strips & Soil Amendment Areas; Green Roofs	1. Dig a small vertical walled excavation that is deep enough to reveal the full depth of topsoil present; 2. Estimate depth of topsoil present; 3. Measure topsoil depth with a ruler or measuring tape.	◖ Shovel ◖ Measuring tape
Soil cores	Bioretention and Dry Swales; Enhanced Swales; Vegetated Filter Strips & Soil Amendment Areas; Green Roofs	1. Collect soil core sample using a soil corer; 2. Measure the total length of the soil core sample (Lc); 3. Measure the length of the soil core sample that is media or topsoil; 4. Measure the total depth of the borehole produced by the corer (Db); 5. Calculate Compaction Factor (C) using Equation 8.1; 6. Divide the length of the soil core sample that is media or topsoil by the Correction Factor to produce the corrected value for media or topsoil depth.	◖ Soil corer ◖ Measuring tape
Soil probes	Bioretention and Dry Swales (with sub-drains)	1. Insert the probe or cone penetrometer into the soil until the sub-drain is reached (when probe cannot be inserted any further); 2. Mark the soil surface level on the probe; 3. Remove probe and measure the depth it reached using a measuring tape.	◖ Probe or soil cone penetrometer at least 1 m in length ◖ Measuring tape

Cone Penetration Test

A common method for evaluating soil compaction is by the Cone Penetration Test (CPT). It is an in-situ test that can be performed in the field by the inspector on all soil types with the results immediately available for use in determining if corrective actions are needed. Cone penetration tests involve measurements of the maximum resistance to pushing an instrument with a conical tip into the soil at a controlled rate (Figure 8.4). The instrument used to take the measurement is called a soil cone penetrometer (ASABE, 2004). Readings depend on cone properties (angle and size) and soil properties (e.g., bulk density, texture, and soil moisture) (ASAE,1999; Herrick and Jones, 2002). As cone penetrometer readings are strongly related to soil moisture, measurements should be taken within a day or two after a heavy rainfall event or when soils are at, or near field capacity (i.e., fully wetted but not saturated).

There are two general types of cone penetrometers: static penetrometers (Figure 8.5) and dynamic penetrometers (Figure 8.6). The distinction between the two penetrometers lies in how force is applied to the cone.

Static cone penetrometers (Figure 8.5) measure the force required to manually push a metal cone through the soil at a consistent rate. The force is usually measured by a load cell or strain gauge coupled with an analog dial or pressure transducer for readout (ASABE, 2004). As the operator pushes down on the penetrometer, an assistant (for mechanical static soil cone penetrometers) or the instrument itself (for electronic static soil cone penetrometers) records values for each depth increment to evaluate the degree, depth, and thickness of compacted layers. For performing a Cone Penetration Test using a hand-held soil cone penetrometer, the American Society of Agricultural Engineers (ASAE) standards require using a steel cylindrical cone with a 30-degree tip. The diameter of the cone is 20.27 mm for soft soils or 12.83 mm for hard soils (ASABE, 2004). The force is commonly expressed in kilopascals (kPa), or an index of soil strength referred to as the cone index, or as surface resistance in kilograms per square centimetre (kg/cm^2) or pounds per square inch (PSI). The cone should be inserted into the soil at a steady rate of about 3 cm/s (USDA, 2005).

Acceptable procedures for cone penetration testing of soils using static soil cone penetrometers and reporting of the results are provided in the American Society of Agricultural Engineers (ASAE) EP542 Procedures for Using and Reporting Data Obtained with the Soil Cone Penetrometer (ASAE, 1999). Acceptable procedures for cone penetration testing of soil using electronic static cone penetrometers are provided in the instrument operating instructions (e.g., Eijkelkamp Agrisearch Equipment, 2014).

Figure 8.4: *Cone penetration testing with mechanical static, electronic static and dynamic cone penetrometers (Source: DGSI (left) Eijkelkamp (middle), Hoskin Scientific (right)).*


Figure 8.5: *Examples of mechanical static and electronic static soil cone penetrometers. Left: Hand-held static soil cone penetrometer set, mechanical with analog dial display; Right: Hand-held static soil cone penetrometer set, electronic with data logger. (Source: ELE International).*

Dynamic cone penetrometers (Figure 8.6) apply a known amount of kinetic energy to the cone, which causes the penetrometer to move a distance through the soil (Herrick and Jones, 2002). Dynamic penetrometers do not rely on constant penetration velocity, as most use a slide hammer of fixed mass and drop height to apply consistent energy with each blow. Either the number of blows required to penetrate a specified depth, or the depth of penetration per blow are measured. Measurements can be converted into cone index values. Soil resistance for each soil depth interval is calculated using standard equations that account for differences in hammer drop distance, weight, and cone size. Acceptable test methods for cone penetration tests using a dynamic cone penetrometer include the most current version of ASTM D7380-15 Standard Test Method for Soil Compaction Determination at Shallow Depths Using 5-lb (2.3 kg) Dynamic Cone Penetrometer (ASTM International, 2015) and ASTM D6951/D6951M Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications (ASTM International, 2015).

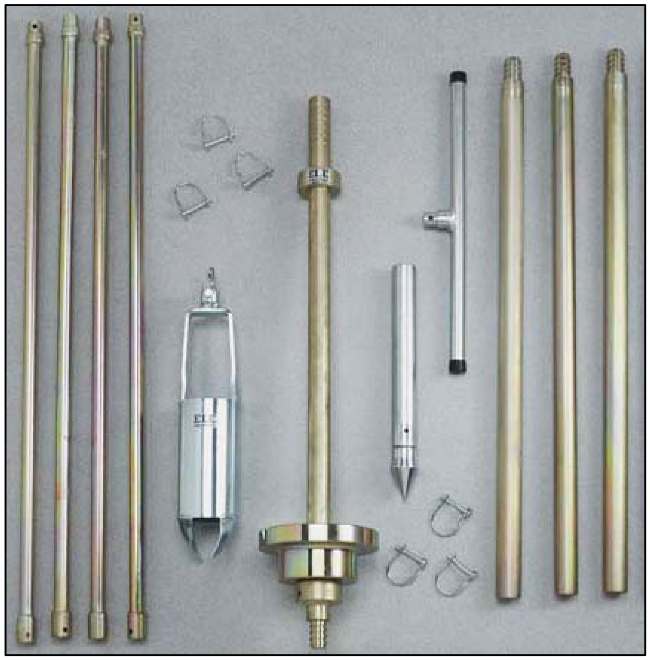


Figure 8.6: *Example of a dynamic soil cone penetrometer set with soil auger (Source: ELE International).*

The Cone Penetration Test using either a hand-held electronic static soil cone penetrometer or dynamic soil cone penetrometer is the recommended method for testing soil compaction in LID BMPs. For BMPs that cover extensive areas (e.g., enhanced swales, vegetated filter strips and soil amendments), assessing soil compaction by bulk density testing of core samples becomes impractical due to the large number of samples required and the considerable effort and cost involved in sampling, sample processing and laboratory testing. In bioretention and dry swales, which feature filter media (i.e., very sandy soil), collecting intact soil core samples is problematic, which makes measurement through bulk density testing of soil cores infeasible in most cases. While using a hand-held mechanical static cone penetrometer (i.e., hand penetrometer) provides a quick means of gauging soil strength (i.e., compaction) in the field (e.g., during construction), they are cited as being cumbersome to use (in terms of both effort and time) to assess extensive areas (USDA, 2005). The ease of use (single operator) and data management functionality provided by modern hand-held electronic static soil cone penetrometer sets make them preferable for testing large or multiple BMPs at one time over mechanical static and dynamic soil cone penetrometers.

Maximum soil cone penetrometer readings should be taken at each testing location at the soil surface (i.e., surface resistance) and through the full depth of soil present (i.e., sub-surface resistance), within a day or two after a heavy rainfall event. To evaluate soil compaction for bioretention, dry swales and enhanced swales, take measurements in at least five (5) locations or at a rate of one sample for every twenty-five (25) square metres (m^2) of vegetated BMP area, evenly distributed over the BMP surface. For vegetated filter strips, soil amendment areas, and grassed permeable pavements measurements should be made in at a rate of one for every 250 m^2 of vegetated BMP area, evenly distributed over the

BMP surface. Measurement locations should be recorded on the field data form, including a plan view sketch of the BMP showing the spatial distribution of measurements.

Maximum readings that exceed the values described in Table 8.3 indicate that the soil has been compacted to a degree that limits plant root growth. If any penetrometer maximum resistance reading exceeds the value corresponding to the relevant soil texture classification, as described in Table 8.3, steps should be taken to reverse compaction in that location. Compaction can be reversed through techniques such as tilling with a rototiller, scarifying with a subsoiler, chisel plow or backhoe, or excavation and replacement with uncompacted soil.

Table 8.3: *Acceptable soil cone penetrometer readings by soil texture class.*

Surface Resistance [1]	**Sub-surface Resistance** [1]		
All soil textures	Sandy *(includes loamy sand, sandy loam, sandy clay loam and sandy clay)*	Silty *(includes loam, silty loam, silty clay loam, and silty clay*	Clayey *(includes clay loam and clay)*
≤ 110 PSI	≤ 260 PSI	≤ 260 PSI	≤ 225 PSI
≤ 7.7 kg/cm²	≤ 18.3 kg/cm²	≤ 18.3 kg/cm²	≤ 15.8 kg/cm²
≤ 758 kPa	≤ 1793 kPa	≤ 1793 kPa	≤ 1551 kPa

Notes:

1. Adapted from Gugino et al. (2009).
2. PSI = pounds per square inch (lb/in^2)
3. kg/cm^2 = kilogram per square centimetre
4. kPa = kilopascals

Bulk Density

A more expensive and time-consuming, but potentially more accurate test of soil compaction is to collect soil cores and send them intact to a soil testing laboratory for analysis of bulk density and PSD (i.e., % sand, % silt, % clay). Bulk density is the ratio of the dry mass of a soil sample to the total soil volume and is expressed in units of mass per unit volume (e.g., g/cm^3). The bulk density of soil depends greatly on the mineral composition and degree of compaction. It is important to note that bulk density is not an intrinsic property of a soil as it can change depending on how the sample is handled. For example, if a soil core sample is disassociated through agitation during collection or transport, this changes the bulk density of the sample. Therefore, to accurately determine bulk density from soil sampling, soil cores must be delivered to the laboratory intact.

To determine if soil compaction is excessive using the laboratory test results for bulk density, the texture classification of the soil also needs to be known, which is determined through a PSD test (see Section 8.2.4). If soil texture is not known, a composite sample representative of the entire soil component of the BMP should be submitted for laboratory testing of PSD along with soil cores for bulk density testing.

Intact soil core samples should be collected through the full depth of soil present in at least five (5) locations, or at a rate of one reading for every twenty-five (25) square metres of vegetated BMP area, evenly distributed across the surface. Most soil corers can only sample approximately 30 cm of soil at a time so multiple core samples are needed at each testing location where soil depth exceeds 30 cm. As part of Assumption inspections, samples should be taken only after all grading operations have been completed and ideally before planting has occurred.

The acceptable laboratory method for determining soil bulk density is ASTM D7263-09 Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens (ASTM International, 2009). An acceptable field method for in-situ soil bulk density testing is provided in ASTM D2937-10 Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method (ASTM International, 2010). Although this method is the most simple to perform in the field, it is not suitable for use in organic, coarse or friable soils that are either prone to compaction during sampling or difficult to retain in soil core sample sleeves or cylinders. If the volume of extracted soil is not known, there are a number of other suitable methods, such as ASTM D2167-15 Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method (ASTM International, 2015), and ASTM D6938-15 Standard Test method for in Place Density and Water Content of Soil and Soil Aggregate by Nuclear Methods (ASTM International, 2015).

Once bulk density test results are available, which typically requires between 2 to 4 weeks turnaround time when done by laboratory testing, it is possible to use the bulk density values to determine if the soil is overly compacted. This is done by comparing measured results to recommended maximum allowable values. Figure 8.7 describes the relationship between soil texture and Maximum Allowable Bulk Density. Maximum Allowable Bulk Densities in Figure 8.7 are based on 95% of the bulk density value at which growth limitations are expected for an average range of plant material (Daddow and Warrington, 1983). To calculate the maximum allowable bulk density for a soil:

1. Obtain a laboratory analysis of the grain size distribution (% sand, silt and clay);
2. Sketch a parallel line for each percentage along the appropriate axis on Figure 8.7, and;
3. At the point of intersection, interpolate a value between the isodensity lines.

If any bulk density test results exceed the Maximum Allowable Bulk Density value for the corresponding soil texture classification (see Figure 8.7), steps should be taken to reverse soil compaction in that location. Compaction can be reversed through techniques such as tilling with a rototiller, scarifying with a subsoiler, chisel plow or backhoe, or excavation and replacement with uncompacted soil.

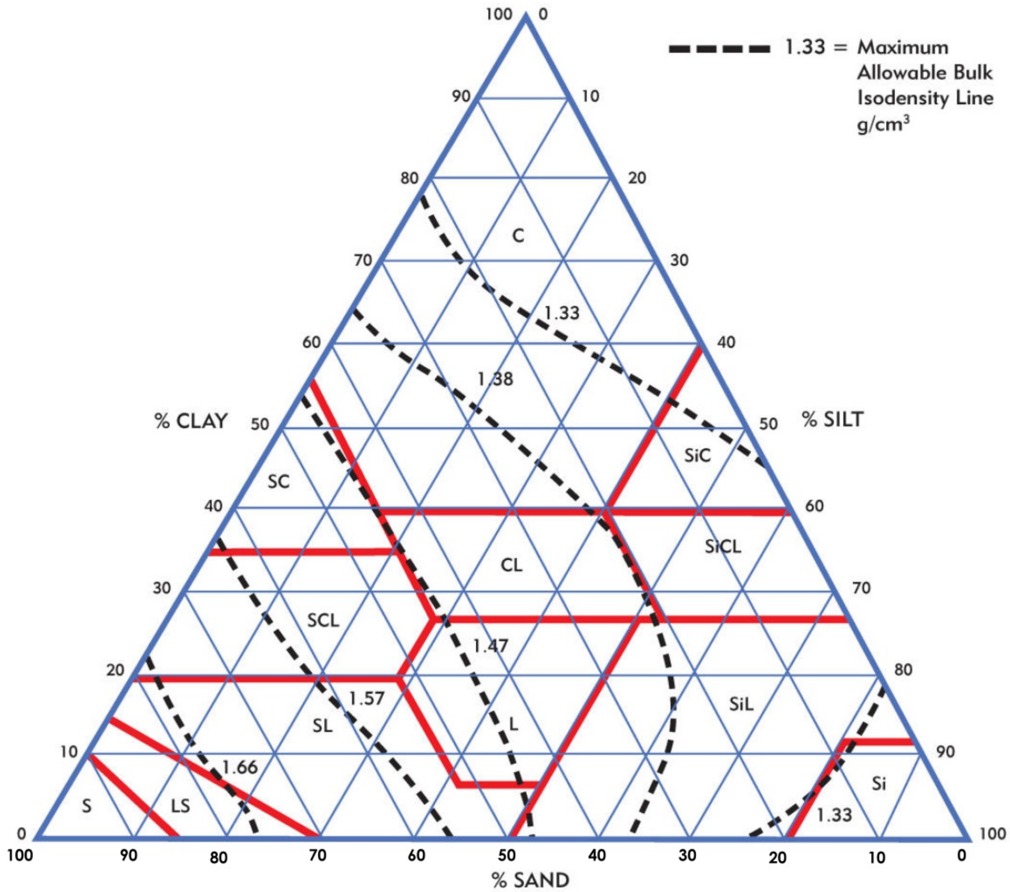


Figure 8.7: *Maximum allowable bulk density values by soil texture class (Source: The Sustainable Sites Initiative).*

8.2.4 Texture

Many of the physical and chemical properties of soil are affected by soil texture. The soil component of bioretention, dry swales and green roofs must meet very specific design specifications related to texture in order for the BMP to achieve drainage and water treatment performance targets. If the soil texture is too fine (i.e., contains more silt- and clay-sized particles than specified) it may have low permeability and drain too slowly or retain too much water for excessively long periods of time. If the soil texture is too coarse (i.e., contains more sand and gravel-sized particles than specified) it will have high permeability and may drain too quickly to provide adequate treatment of run-off, and may not retain enough water between storm events to sustain healthy vegetation cover. A critical part of Construction, Assumption and Verification inspections involves sampling and testing the soil component of BMPs to ensure it meets design specifications related to texture or is still within acceptable ranges for important gradations (e.g., percent silt- and clay-sized particles).

Soil texture is most accurately characterized by submitting a representative sample to a soil laboratory for a particle-size distribution (PSD) test. Other commonly used terms for the PSD test by soil laboratories are "Particle-Size Analysis", "Grain-Size Distribution" and "% Sand, % Silt, % Clay". For bioretention filter media and green roof growing media, "Sand Fraction Analysis" should also be requested. Acceptable methods for determining PSD of a soil sample are provided in ASTM D6913-04(2009)e1 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis (ASTM International, 2009) and ASTM D7928-16, Standard Test Methods for Particle Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis (ASTM International, 2016). These methods are recommended for use in inspection and testing of LID BMPs because they include assessment of the pebble-sized particles of the soil (i.e., particles that are greater than 2 mm in diameter). Training on these procedures is available in ASTM D422-63(2007)e2 Standard Test Method for Particle-Size Analysis (ASTM International, 2007).

Most soil laboratories will summarize PSD test results according to the proportions of the sample made up of pebble/gravel-, sand-, silt- and clay-sized particles. When Sand Fraction Analysis is requested, a more detailed breakdown of gradations of sand-sized particles is provided, which is important for evaluating the acceptability of filter media for bioretention and dry swales. Figure 8.8 describes the Wentworth soil particle-size classification system (Wentworth, 1922) that should be used to classify pebble, sand, silt and clay fractions of a soil sample.

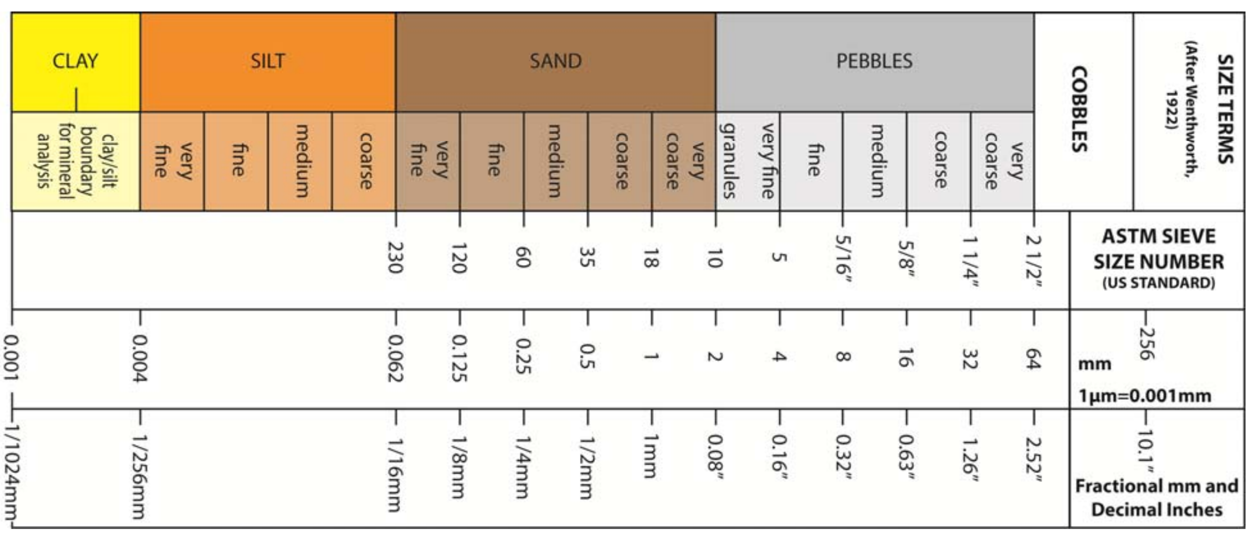


Figure 8.8: *Soil particle-size classification system (Adapted from Wentworth, 1922).*

As part of Construction inspections, <u>if laboratory testing indicates any soil texture-related parameter is not within the design or product specification ranges, notify the media or topsoil supplier, issue a "do not install" order to the construction site supervisor and contact the design professionals and property owner or project manager to determine corrective actions</u>.

As part of Assumption and Verification inspections, <u>if laboratory testing indicates any soil texture-related parameter is not within the design or product specification ranges, or the Acceptance Criteria ranges (Table 8.1), schedule FIT work to do further sampling and testing to determine the affected</u>

area and depth and decide on corrective actions. Corrective actions for bioretention and dry swale filter media where the proportion of silt- and clay-sized particles is too high may involve removal of mulch, stone cover and plantings and tilling the top 20 to 30 cm, or removal and replacement of part or all of the filter media with material that is within acceptable tolerance ranges of design specifications.

8.2.5 Organic Matter

Organic matter is matter that has come from a once-living organism (i.e., plants and animals), is capable of decay or the product of decay, or is composed of organic compounds. Once it has decayed to the point at which it is no longer recognizable it is called soil organic matter. When the organic matter has broken down into a stable substance that resists further decomposition it is called humus. Soil organic matter comprises all of the organic matter in the soil, exclusive of the material that has not yet decayed (i.e., surface litter). It can be divided into three general pools (Figure 8.9): living biomass of micro-organisms, fresh and partially decomposed residues (the active fraction), and the well-decomposed and highly stable humus (USDA, 2015).

The structure, drainage and fertility characteristics of soil are all highly affected by organic matter content. In LID BMPs, if the soil does not contain enough organic matter it will lack porosity, water holding capacity and be difficult to maintain healthy vegetation cover without addition of chemical fertilizers. When organic matter content is too high, the soil may leach nutrients into the water that infiltrates through it, potentially contributing to nutrient loads to receiving waters rather than reducing them. So an important part of Construction, Assumption and Verification inspections involves sampling and testing the soil component of BMPs to ensure it meets the design specification for organic matter, or determine if it is still within an acceptable range.

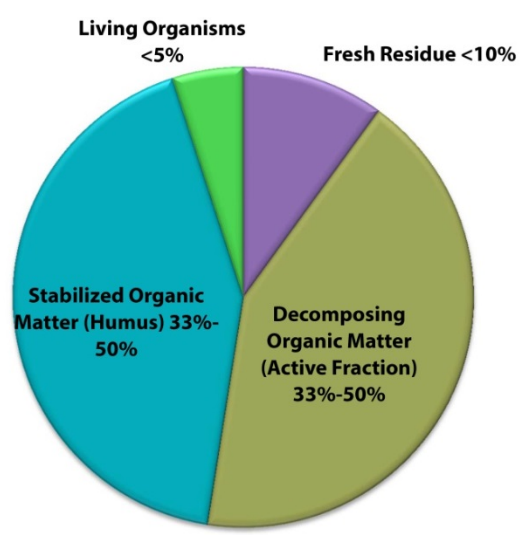


Figure 8.9: *Components of soil organic matter (Adapted from: USDA).*

To determine if the soil component of an LID BMP meets design specifications or is within an acceptable range for organic matter, representative samples must be collected and submitted to an accredited Ontario soil testing laboratory for soil organic matter analysis (see Appendix A for list). The recommended test method depends on the organic matter content of the soil sample. When organic matter is <7.5% by dry weight, the Walkley-Black method (Walkley, 1947) using a routine colorimetric determination procedure is acceptable. When organic matter is ≥7.5% testing must be done by a loss on ignition (LOI) method (OMAFRA, 2006). Testing soil organic matter by LOI method involves drying a sample, typically at 105 to 120 ◦C for 2 hours, measuring the dry weight, igniting and ashing the dry sample, typically at between 360 to 425 ◦C for 10 to 16 hours (OMAFRA, 2006; McLachlin, 2016; Wright, 2016) in a muffle furnace (Figure 8.10) and then reweighing the sample to determine the change in weight. The weight loss value (i.e., LOI value) is then used to calculate the organic matter content value based on the relationship between LOI and soil organic carbon established for the region through extensive testing of soil samples by the Walkley-Black method (McLachlin, 2016; Wright, 2016), with results reported as percent organic matter (%OM) by dry sample weight. Acceptable procedures for testing organic matter content of soils by both the Walkley-Black method and LOI method are provided by North Central Regional Research Publication No. 221 (Combs and Nathan, 2012). Acceptable procedures for testing organic matter content of compost or highly organic soils is provided by ASTM D2974-14, Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils (ASTM International, 2014) and United States Department of Agriculture (USDA, 2002).

Figure 8.10: *Crucibles filled with soil, prepared for a loss on ignition test (Source: Pitchcare.com).*

As part of Construction inspections, if laboratory testing indicates soil organic matter content is not within the design or product specification range, notify the media or topsoil supplier, issue a "do not install" order to the construction site supervisor and contact the design professionals and property owner or project manager to determine corrective actions.

As part of Assumption and Verification inspections, if laboratory testing indicates soil organic matter content is not within the design or product specification range, or the Acceptance Criteria range (Table 8.1), schedule FIT work to do further sampling and testing to determine the affected area and depth and decide on corrective actions. Corrective action where organic matter is lower than the design/product specification or Acceptance Criteria involves amending the soil with compost. Detailed guidance on implementing compost soil amendments can be found in *Preserving and Restoring Healthy Soil: Best Practices for Urban Construction* (TRCA 2012). Amendments to green roof growing media to address organic matter content deficiency should be prescribed by the designer, product vendor or media supplier. Where organic matter is higher than the design/product specification or Acceptance Criteria, natural or simulated storm event testing should be undertaken (Section 8.5) that includes sampling and testing of nutrient concentrations (i.e., Phosphorus, Nitrogen, Soluble Salts) in sub-drain or surface flows from the BMP to evaluate if the exceedance is negatively impacting effluent quality.

8.2.6 Soil pH

Soil pH is a measure of the hydrogen ion concentration of a mixture of soil and water. A neutral soil has a pH value of 7.0. An acidic soil has a pH less than 7 and a basic soil has a pH greater than 7.

Soil pH is an important parameter that affects soil fertility. It influences the availability of nutrients needed to sustain plants and soil micro-organisms. It also affects the solubility of some elements which, in extreme scenarios, can reach levels toxic to plants and soil micro-organisms and increases the mobility and the potential for leaching of pollutants such as metals into the groundwater system. In humid temperate regions, the optimum soil pH range for most plants is between 6.0 and 7.5 (Craul, 1999). More acidic soils inhibit the solubility of potassium, sulfur, calcium, magnesium and molybdenum, while increasing the solubility of iron, manganese, boron, copper and zinc (Figure 8.11). Additionally, the solubility of phosphorus and nitrogen are reduced in both acidic and basic (i.e., alkaline) soils.

Design specifications for the soil component of LID BMPs pertaining to pH are intended to ensure its fertility and suitability for maintaining healthy vegetation cover. Where soil pH deviates from design specification, vegetation cover may be spotty or uneven, growth may be stunted, or in extreme cases, plantings may not survive and vegetation cover becomes dominated by weeds. To ensure the soil will support the growth of plantings, which contributes to the drainage and water treatment performance of the BMP and adds aesthetic value, testing of soil pH should be done as part of Construction, Assumption and Verification inspections.

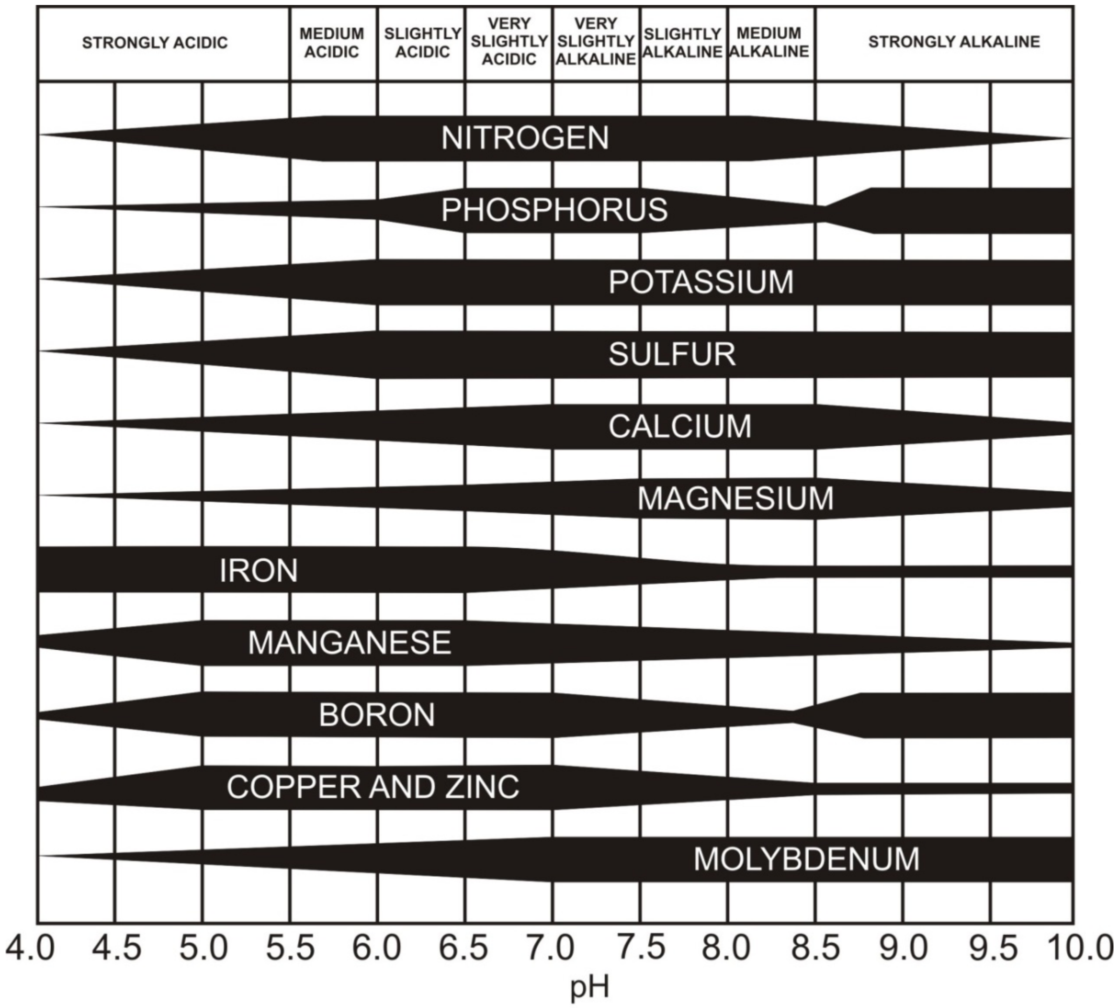


Figure 8.11: *Effects of soil pH on nutrient availability.*

Soil pH can be determined in the field using inexpensive soil pH testing kits (Figure 8.12) where a small sample of surface soil is mixed with water and reagents which change colour according to the acidity/alkalinity. The soil pH value is determined by comparing the colour and shade to calibrated scales. Soil pH can also be determined using a portable pH meter (Figure 8.12) which involves inserting a rod into a soil-water slurry mixture. Such soil pH tests should be conducted by creating a shallow (5 to 10 centimetre deep) hole in the soil, filling it up with distilled water, stirring to create a slurry mixture, inserting the pH meter rod into the slurry mixture and recording the value displayed on the meter. Alternatively, surface samples can be submitted to a soil testing laboratory accredited by the province of Ontario for testing by saturated paste method (OMAFRA, 2006). An acceptable procedure for testing soil pH is provided in ASTM D4972 - 13 Standard Test Method for pH of Soils (ASTM International, 2013).

Figure 8.12: *Examples of soil pH testing equipment. Left: Soil pH test kit (Source: Rapitest); Right: Soil pH meter (Source: Houston Gardening).*

<u>For soils found through testing to not be within the design or product specification range or Acceptance Criteria range (Table 8.1), corrective actions are only needed if problems with vegetation cover, condition or composition (i.e., dominance by weeds) are also detected through visual inspection.</u> Where vegetation cover is poor, unhealthy or dominated by weeds and soil pH is lower than the design/product specification or Acceptance Criteria ranges, corrective action involves amending the soil with ground limestone to raise the pH back to neutrality. Where soil pH is higher than the design/product specification or Acceptance Criteria ranges, corrective action involves amending the soil with sulphur or compost to lower the pH back to neutrality. Amendments to green roof growing media to address problems with soil pH and vegetation should be prescribed by the designer, product vendor or media supplier.

8.2.7 Cationic Exchange Capacity

Cationic exchange capacity (CEC) is an indicator of the capability of the soil to retain dissolved, positively charged elements such as metals, which are a common pollutant in stormwater runoff. Soil has the ability to retain dissolved metals due to the negative charge of clay and organic particles. Positively charged dissolved metals ions (i.e., cations) are attracted to the negatively charged soil particles which can cause them to be removed from solution and retained in the soil. CEC is influenced by soil texture (higher in fine textured soil), organic matter content (higher in organic soil), and pH (lower in acidic soil). Soils with high CEC are able to retain a larger proportion of dissolved metals and other positively charged pollutants, while soils with low CEC will retain less. The cationic exchange capacity of a soil sample is the sum of the exchangeable cations in the sample and expressed in milliequivalents of positive charge per 100 grams of soil.

Design specifications for the soil component of LID BMPs pertaining to CEC are intended to ensure the soil has adequate capacity to remove positively charged dissolved pollutants from the stormwater they receive. Where soil CEC is too low, dissolved metals and other positively charged pollutants may not be well retained and the BMP will not provide the targeted water treatment performance. Causes of low CEC in the soil component of LID BMPs can include excessively coarse texture, deficient organic matter content or that the soil has become saturated with positively charged ions (i.e., dissolved metal retention capacity has been exhausted). To ensure LID BMPs will provide the targeted water treatment performance, soil sampling and submission for laboratory testing of CEC by a soil testing laboratory accredited in the province of Ontario should be done as part of Construction, Assumption and Verification inspections.

A commonly used laboratory test method is to saturate a sample of the soil with a known quantity of cations and measure the amount retained by the soil. An acceptable test method is provided in ASTM D7503-10 Standard Test Method for Measuring the Exchange Complex and Cation Exchange Capacity of Inorganic Fine-Grained Soils (ASTM International, 2010). Descriptions of acceptable laboratory equipment for measuring CEC are described in the Soil Fertility Handbook (OMAFRA, 2006).

As part of Construction inspections, if laboratory testing indicates soil CEC is not within the design or product specification range, notify the media or topsoil supplier, issue a "do not install" order to the construction site supervisor and contact the design professionals and property owner or project manager to determine corrective actions.

As part of Assumption and Verification inspections, if laboratory testing indicates soil CEC is not within the design or product specification range, or Acceptance Criteria range (Table 8.1), schedule FIT work to do further sampling and testing to determine the affected area and depth and decide on corrective actions. Corrective action could involve amendment of the soil with compost or removal and replacement of an uppermost portion of the soil with material that is within the design or product specification range. Corrective actions to address CEC deficiency in green roof growing media should be prescribed by the designer, product vendor or media supplier.

8.2.8 Extractable Phosphorus

Phosphorus (P) is an essential soil nutrient that is necessary for sustaining plants and soil organisms. Sources of phosphorus in soil include minerals, organic matter, decomposing plant residues, manure and chemical fertilizers.

Too little phosphorus in soil reduces photosynthesis and respiration rates of plants, resulting in delayed maturity and reduced quality of foliage. Phosphorus is especially important in the early developmental stages of plants by stimulating seed germination, root formation, seedling growth, flowering, fruiting and seed development (Busman et al., 2009). Phosphorus utilized by plants becomes part of the foliage and roots. As foliage and roots decompose and becomes soil organic matter some of the P is converted to soluble, inorganic forms through mineralization. Phosphorus availability (i.e., solubility) is reduced at both high and low pH levels (Figure 8.11), so neutral soils are ideal for sustaining plants.

In natural systems like soil and water, phosphorus exists primarily as phosphate that is attached to soil particles or in the organic (i.e., solid) form as decaying organic matter and is not very soluble in water

(Busman et al., 2009). However, soil water and surface water usually contain low concentrations of inorganic, soluble (i.e., dissolved) phosphorus.

Although P is essential for plant growth and soil health, mismanagement can pose a threat to water quality in sensitive receiving waterbodies (i.e., lakes and rivers). When soil P is over abundant, it can be leached by infiltrating water and transported to surface waterbodies in its dissolved form by interflow or in its solid form (e.g., associated with soil particles) by surface runoff and erosion, thereby contributing to nutrient loading. When P concentration in a receiving waterbody becomes elevated, excessive growth of algae and aquatic plants often results. High levels of algae reduces water clarity and can lead to decreases in dissolved oxygen (i.e., eutrophication), conditions that can be very detrimental to fish populations and other beneficial uses of water resources.

Phosphorus is retained in soils by adsorption (i.e., attachment to soil particles) and chemical precipitation (Erickson et al. 2013). The presence of clay particles and organic matter increases the capacity of the soil to retain phosphorus, which reduces leaching and transport to receiving waters through interflow.

To help ensure LID BMPs sustain healthy vegetation cover while not contributing substantially to nutrient loading of receiving waters, the quantity of extractable (i.e., available) P in the soil component needs to be measured and compared to design specifications or acceptance criteria (Table 8.1).

For bioretention and dry swale, enhanced swale, vegetated filter strip and soil amendment BMPs, soil P should be measured as extractable phosphorus. Extractable phosphorus is a term referring to the portion that is easily available to organisms like plants and algae (i.e., available) that are present in a lake, river, stream or wetland and is the measure of immediate concern to water quality. The quantity of extractable P is determined through acid or base extraction of a sample and testing the concentration in solution by a soil testing laboratory. Commonly used extraction methods on soil samples are the Bray and Kurtz P-1 procedure for non-calcareous soil (Bray and Kurtz, 1945) or the Sodium Bicarbonate (Olsen) method for calcareous soil (Olsen *et al.,* 1954). The Sodium Bicarbonate (i.e., Olsen) method is recommended as the default to use for typical Ontario soils (OMAFRA, 2006). Calcareous soils are mostly or partly composed of calcium carbonate (i.e., lime or limestone). The Sodium Bicarbonate (Olsen) extraction method should be used if the soil contains more than 2% calcium carbonate (Frank et al., 2012). Modern and acceptable procedures for both types of extractions are provided by North Central Regional Research Publication No. 221 (Frank et al., 2012). Soil P results are typically reported in units of concentration as orthophosphate.

For green roof growing media, the Saturated Media Extract (SME) method should be used (Green Roofs for Healthy Cities, 2011). In this extraction procedure, a sample of the media is brought to saturation with deionized water containing a small amount of Pentetic acid (i.e., DTPA) to enhance extraction of micro-nutrients (Warnacke, 1995). The SME procedure should also be used to measure concentrations of soluble salts and nitrogen for green roof growing media (Green Roofs for Healthy Cities, 2011).

As part of Construction inspections, if laboratory testing indicates the extractable phosphorus concentration is not within the design or product specification range, notify the media or topsoil supplier, issue a “do not install” order to the construction site supervisor and contact the design professionals and property owner or project manager to determine corrective actions.

As part of Assumption and Verification inspections, for soils found through testing to be below the design or product specification range, or Acceptance Criteria range (Table 8.1), corrective actions are only needed if problems with vegetation cover, condition or composition (i.e., dominance by weeds) are also detected through visual inspection. Where vegetation cover is poor, unhealthy or dominated by weeds and soil P is lower than the design specification or Acceptance Criteria, schedule FIT work to do further sampling and testing to determine the affected area and depth and decide on corrective actions. Depending on the findings from FIT work, corrective action could involve amending the soil with compost or other fertilizer. Detailed guidance on implementing compost soil amendments can be found in *Preserving and Restoring Healthy Soil: Best Practices for Urban Construction* (TRCA 2012). Amendments to green roof growing media to address P deficiency should be prescribed by the media manufacturer or product vendor. Where soil P concentration is found to be higher than the Acceptance Criteria range (Table 8.1), and the BMP drains to a nutrient sensitive receiving water, continuous monitoring during natural or simulated storm events should be undertaken (Sections 8.5 & 8.6) that includes sampling and testing of nutrient concentrations (i.e., Phosphorus and Nitrogen) in sub-drain or surface flows from the BMP to evaluate if the exceedance is negatively impacting effluent quality and if corrective actions are warranted. Corrective action could involve incorporating a soil amendment that increases phosphorus retention, or replacement of part or all of the media or topsoil with material that is within the design or product specification.

8.2.9 Soluble Salts

All soils contain some water soluble salts which include essential nutrients for plant growth. When the concentration of water soluble salts exceeds a certain level, harmful effects on plant growth occur. A soil containing a high concentration of soluble salts is referred to as a saline soil. Salt-affected soils often result from the flow of salty water onto an area, either laterally (e.g., intentional infiltration of de-icing salt laden runoff in LID BMPs; de-icing salt laden runoff splashed onto roadside soils) or by artesian flow of salty groundwater onto topsoil.

The soluble salts design specification for the soil component of LID BMPs is intended to ensure its fertility and suitability for maintaining healthy vegetation cover. Where concentration of soluble salts deviates from design specification, vegetation cover may be spotty or uneven, growth may be stunted, or in extreme cases, plantings may not survive and vegetation cover becomes dominated by weeds. To ensure the soil will support the growth of plantings, which contributes to the drainage and water treatment performance of the BMP and adds aesthetic value, testing of soluble salts should be done as part of Construction, Assumption and Verification inspections.

Soluble salts concentration in soil can be assessed by measuring the ability of a soil and water mixture to conduct an electrical current, referred to as electrical conductivity (EC). The common unit for measurement of EC is milliSeimen per centimetre (mS/cm). The official international unit of measurement is Seimen per metre (S/m). One mS/cm is equal to one deciSiemen per metre (dS/m) or 0.1 Seimen per metre (S/m).

There are several methods available for preparing the soil and water mixture for EC testing. The method recommended for use in testing the soil component of LID BMPs for EC is using a 2:1 distilled water to soil ratio by volume slurry mixture based on OMAFRA recommendations for evaluating the fertility of cropland (OMAFRA, 2006). Other laboratory methods for measuring EC in engineered growing media (e.g., green roof growing media) include the Saturated Paste (SP) method (Whitley, 2012) or Saturated Media Extract (SME) method (Warnacke, 1995).

For green roof growing media, soluble salt concentration should also be measured using EC but with application of the SME method to prepare the soil and water mixture (Green Roofs for Healthy Cities, 2011). In this extraction procedure, a sample of the media is brought to saturation with deionized water containing a small amount of Pentetic acid (i.e., DTPA) to enhance extraction of micro-nutrients (Warnacke, 1995). The SME method should also be used to prepare soil water extraction solutions for measuring concentrations of extractable phosphorus and nitrogen for green roof growing media (Green Roofs for Healthy Cities, 2011).

As part of Construction inspections, if laboratory testing indicates soil soluble salts concentration is not within the design or product specification range, notify the media or topsoil supplier, issue a "do not install" order to the construction site supervisor and contact the design professionals and property owner or project manager to determine corrective actions.

As part of Assumption and Verification inspections, if laboratory testing indicates soil soluble salts concentration is higher than the design or product specification, or Acceptance Criteria (Table 8.1), corrective actions are only needed if problems with vegetation cover , condition or composition (i.e., dominance by weeds) are also detected through visual inspection. Where vegetation cover is poor, unhealthy or dominated by weeds and soluble salts are higher than the design or product specification or Acceptance Criteria, schedule FIT work to do further sampling and testing to determine the affected area and depth and decide on corrective actions. Depending on the findings from FIT work, corrective action could involve flushing the soil area with fresh water or removal and replacement of an uppermost portion of the soil with material that meets the design or product specification. Corrective actions to address soluble salts exceedance in green roof growing media should be prescribed by the designer, product vendor or media supplier.

8.2.10 Maximum Media Density

Maximum Media Density testing is only applicable to green roof growing media as part of a Construction inspection. Testing of this characteristic of growing media is important to green roof designers and approvers for load bearing capacity calculations for the roof structure the green roof will be installed on. If maximum media density is too high, the growing media may retain too much water or not drain quickly enough and could cause problems with the integrity of the roof structure.

To ensure the growing media is suitable for use on a given roof structure of set dead load bearing capacity, testing of maximum media density should be done as part of Construction inspections. Testing is typically done by the product manufacturer or vendor with results provided to approval authorities prior to delivery at the construction site. An acceptable method for assessing maximum media density is provided by ASTM E2399/E2399M-15 Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetated (Green) Roofing Systems (ASTM International, 2015). This method also includes acceptable procedures for assessing maximum water holding capacity, air-filled porosity and saturated media permeability. Table 8.1 provides Acceptance Criteria for maximum media density and all three of these related parameters.

As part of Construction inspections, if laboratory testing indicates maximum media density does not meet the design specification, notify the supplier, issue a "do not install" order to the construction site supervisor and contact the approval authorities (e.g., municipality and/or property owner/manager) to determine corrective actions. Corrective actions will depend on what factors are causing the exceedance, which can be diagnosed using the results for related parameters, maximum water holding capacity; air-filled porosity; and saturated media permeability. Corrective actions to address maximum media density exceedance in green roof growing media should be prescribed by the media manufacturer or product vendor.

8.3 Sediment Accumulation Testing

A primary function of LID BMPs is to capture and retain sediment, trash and debris that are suspended in stormwater runoff. Over time, sediment and natural debris accumulates in certain portions of a BMP, particularly in pretreatment devices (e.g., forebays, gravel diaphragms, hydrodynamic separators, filter strips, grass swales, catchbasin/manhole sumps) and at inlets, where inflowing runoff is slowed down and spread out, which promotes sedimentation of suspended materials by design. Without adequate inspection and maintenance (at least annually), accumulated sediment and debris in pretreatment devices and inlets can inhibit the flow of stormwater into the BMP or be transported onto the filter bed (Figure 8.13). Extensive sediment accumulation on the surface of a filter bed will eventually lead to drainage problems due to clogging of the filter media with fine-textured sediment. When sediment accumulation on the surface a filter strip or swale becomes excessive the BMPs begin to export sediment and associated pollutants to receiving waters rather than retain them.

Figure 8.13: *Example of excessive sediment accumulation at the inlet of a bioretention cell inhibiting flow of stormwater into the BMP.*

Therefore it is important to inspect LID BMPs for sediment accumulation as part of all types of inspections, which can be done visually (see Visual inspection Indicator sections C.3; C.4; C.13; C.29), but should also include periodic measurements of sediment depth in key components. As part of Construction inspections it helps to determine when pretreatment devices and construction site ESCs need sediment removal maintenance. As part of Assumption inspections it helps determine if the BMP is ready to be put into operation and assumed by the property owner/manager/municipality. As part of Routine Operation inspections it provides an indication of the volume of sediment removed and the means to estimate an accumulation rate, which can be used to optimize the frequency of routine maintenance work. As part of Verification inspections it provides an indication of whether or not the BMP is being adequately maintained and helps to diagnose the cause of any problems with drainage or vegetation detected through visual inspection or other types of testing.

8.3.1 Key Components, Test Methods and Equipment

Key components of LID BMPs that should be the subject of sediment accumulation testing (i.e., depth measurements) are described in Table 8.4 along with recommended test methods.

Depth measurements should be recorded on inspection field data forms provided in chapter 7 and used to determine if sediment removal maintenance is needed.

Specific to vaulted infiltration chamber systems, cisterns and pretreatment devices such as catchbasin or manhole sumps, measuring sediment depth by means that do not require entry into the structure are preferable from worker safety and level of effort perspectives. As described in Table 8.4, recommended methods for measuring sediment depth in such underground structures include using sludge samplers (e.g., a “sludge judge” sampler), probes from the surface or taking measurements from a pre-installed staff gauge (Figure 8.14) mounted on the structure wall and set to the bottom elevation. With knowledge of the dimensions of the structure, depth measurements can be used to estimate the volume of accumulated sediment and what portion of the retention capacity of the device this represents.

Measuring sediment depth in underground structures from surface access points is best done using the following "two prong" method (see Figure 8.15 for an illustration).

1. Vertically lower a rigid probe into the structure and press it through the sediment until the base elevation is reached
2. Mark the probe at a fixed reference point at the surface (e.g., rim of the access hatch, catchbasin or manhole).
3. Measure and record the length of probe inserted into the structure.
4. Attach a flat 20 to 30 cm diameter disc, like a secchi disk (Figure 8.16) to the probe or a length of rope and gently lower it into the structure, allowing it come to rest on the surface of the accumulated sediment.
5. Mark the probe or rope at the same fixed reference point used in step 2.
6. Measure and record the length of probe or rope inserted into the structure.
7. Subtract the value obtained in step 3 from the value obtained in step 6 to calculate the sediment depth.

It is important to note that Ontario Workplace Health and Safety regulations (O.Reg 632/05) require that any work involving entry into an underground structure (e.g., catchbasin, manhole, hydrodynamic separator, infiltration chamber system, cistern) can only be performed by staff trained in confined space entry and equipped with certified and recently tested safety equipment (i.e., harness, tripod, winch, multi-gas detector). Staff involved in sediment accumulation testing in underground structures must be adequately trained and equipped, even if "entry" only involves lowering equipment into the structure from the surface.

Table 8.4: *Key components and test methods for sediment accumulation testing by BMP type.*

LID BMP Type	Key Components	Recommended Test Method
Bioretention and dry swales; Enhanced swales; Vegetated filter strips	Inlets; Pretreatment devices	Use a tape measure or probe to measure the depth from the bottom elevation of the pretreatment device or surface of the filter bed (adjacent to the inlet structure), below any stone or mulch cover present, to the highest elevation of accumulated sediment present. For catchbasins, manholes and hydrodynamic separator pretreatment devices a sludge sampler (e.g., "sludge judge" sampler) should be used to sample the sediment and estimate depth accumulated in sumps. Record the measurement and remove the sediment if it exceeds trigger values for follow-up action.

	Filter bed	Use a tape measure or probe to measure sediment depth from the surface of the filter bed, below any stone or mulch cover present, to the elevation of accumulated sediment present in at least five (5) locations evenly distributed over the filter bed surface area. Record the measurements, calculate the mean sediment depth and compare to trigger values to determine if follow-up/corrective actions are needed.
Underground infiltration systems	Inlets; Pretreatment devices	Use tape measure or probe to measure the depth from the bottom elevation of the inlet pipe or pretreatment device, below any stone or mulch cover present, to the highest elevation of accumulated sediment present. For catchbasins, manholes and hydrodynamic separator pretreatment devices a sludge sampler (e.g., "sludge judge" sampler) should be used to sample the sediment and estimate depth accumulated in sumps. A measuring tape or staff gauge installed in the structure and set to the bottom elevation can provide another means of tracking sediment accumulation. Record the measurement and remove the sediment if it exceeds trigger values.
	Filter bed	(Applicable to vault-type infiltration chamber systems only) Use a tape measure or probe to measure sediment depth from the surface of the gravel bed to the elevation of accumulated sediment in at least five (5) locations evenly distributed over the bed surface area. Record the measurements, calculate the mean sediment depth and compare to trigger values to determine if follow-up/corrective actions are needed.
Cisterns	Cistern	From outside the cistern use a tape measure or probe to measure the depth from a fixed point (e.g., rim of the access hatch) to the bottom elevation of the cistern and to the highest elevation of accumulated sediment present. Subtract the two values to calculate the sediment depth. A sludge sampler (e.g., "sludge judge" sampler) may also be used to sample the sediment and estimate depth. A staff gauge installed on the cistern wall and set to the bottom elevation provides another means of measuring sediment depth that does not require entry into the confined space. Record the measurement and remove the sediment if it exceeds trigger values for follow-up action.

Figure 8.14: *Examples of staff gauges (Source: Hoskins Scientific Canada).*

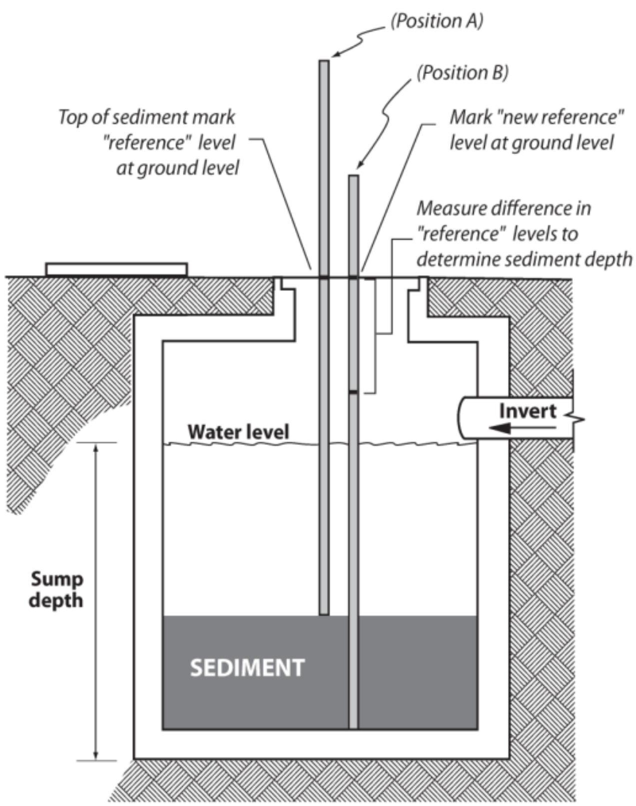


Figure 8.15: *Measuring sediment depth in a catchbasin by the two prong method (Source: King County, 2010).*

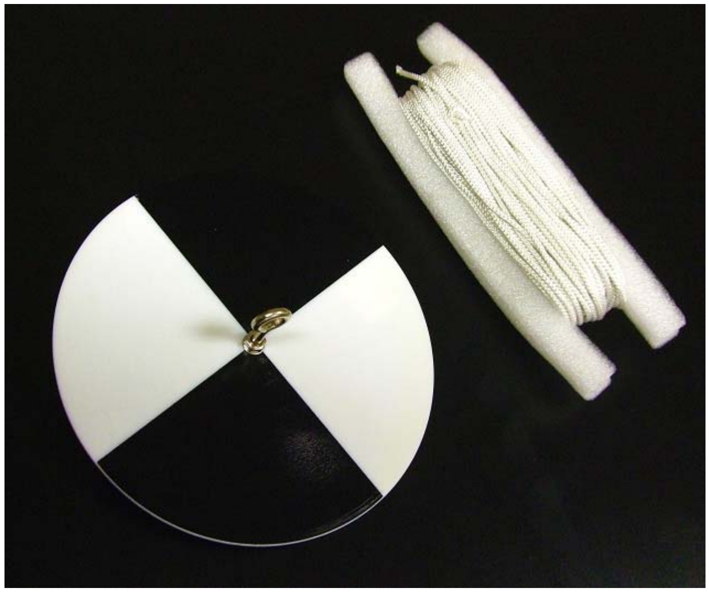


Figure 8.16: *Example of a secchi disk (Source: Wildco).*

Figure 8.17: *Example of a sludge sampler being used to inspect a hydrodynamic separator (Source: Minotaur Stormwater Services).*

Equipment needed for sediment accumulation testing can include the following:

- Safety apparel (hard hat, steel toed boots, gloves and eye protection)
- Safety cones or barriers (for restricting access around open hatches/grates/manhole covers)
- Clipboard, inspection field data forms, pens

- Pick shovel (for opening catchbasin grates or manhole covers)
- Measuring tape
- Probe (rigid)
- Secchi disk
- Sludge sampler (Figure 8.17)
- Rope
- Flashlight or headlamp
- Harness
- Tripod (certified and tested)
- Winch (certified and tested)
- Multi-gas detector (recently calibrated and tested)

Sediment accumulation testing should be conducted frequently during construction (e.g., weekly and after any storm event of 15 mm depth or greater), as part of Assumption inspection work, once construction is fully completed and sediment accumulated on the CDA, in conveyances (e.g., gutters, catchbasins, storm sewers) and pretreatment devices has been removed, and as part of Routine Operation and Verification inspections.

Sediment depth measurements collected at a BMP over the first few years of operation (e.g., at least 2 years) through Assumption and Routine Operation inspections provide the means of calculating a typical accumulation rate. This information provides an indication of the quantity of sediment retained over a given time period. It also provides an indication of whether or not the current frequency of routine sediment removal maintenance is adequate and the means of optimizing the frequency to provide adequate maintenance while minimizing effort and associated costs. To estimate the rate of sediment accumulation, at least two measurements are required. In most cases annual measurements taken over two or three years of routine operation (i.e., a fully stabilized and planted CDA) are all that is needed to estimate sediment accumulation rate.

8.3.2 Triggers for Follow-Up and Corrective Actions

The results of sediment accumulation testing can be used immediately to determine if sediment removal maintenance is needed or to determine other follow-up or corrective actions. Table 8.5 describes numerical triggers for follow-up and corrective actions and recommended tasks or actions, broken down by BMP component.

8.4 Surface Infiltration Rate Testing

For LID BMPs like bioretention and dry swales, enhanced swales, vegetated filter strips and permeable pavements, the rate at which stormwater infiltrates (i.e., percolates) through the BMP surface greatly affects its drainage performance. If the surface infiltration rate (i) is too low, inflowing stormwater will quickly begin to pond on the surface and, once the overflow outlet elevation is reached, will by-pass treatment by the BMP. In extreme cases the BMP may pond water on the surface for longer than 24 hours, creating nuisance conditions (e.g., poor vegetation cover, ice formation) and the potential for mosquito-breeding habitat. Causes of excessively low surface infiltration rates include use of soil during construction that does not meet design specifications, accumulation of fine sediment on the soil surface or in permeable pavement joints or pore spaces, and over-compaction of the soil, that can occur during construction or routine operation.

Therefore it is important to test the surface infiltration rate of LID BMPs as part of Assumption and Verification inspections. As part of Assumption inspections it helps determine if the BMP is ready to be assumed by the property owner. As part of Verification inspections it provides an indication of whether or not the surface drainage performance of the BMP is still within an acceptable range, if it is being adequately maintained, and to diagnose the cause of any problems with drainage or vegetation detected through visual inspection or other types of testing. Tests may also be done as part of FIT work to diagnose the cause of problems with drainage or vegetation, with the number and locations of test determined by the nature of the problem being investigated.

Table 8.5: *Sediment accumulation – triggers for follow-up and corrective actions.*

BMP Component	Trigger	Type of Structure	Follow-up and Corrective Actions [1]
Inlet	Sediment depth is ≥ 5 cm on the filter bed adjacent to the inlet (see Inlet Obstruction visual indicator protocol, section C.3)	Curb cut; Flush curb; Pavement edge; Pipe	Remove the accumulated sediment by shovel, vacuum or vacuum truck and estimate and record the quantity.
Pretreatment device	≥ 50% of retention capacity of the device is occupied by sediment and debris (see Pretreatment Sediment Accumulation visual indicator protocol, section C.4)	Forebay; Gravel diaphragm	Remove the accumulated sediment by shovel, vacuum or vacuum truck. Estimate and record the quantity.
		Vegetated filter strip; Grass swale	Remove the accumulated sediment by rake and shovel. Estimate and record the quantity.
		Catchbasin or manhole sump;	Schedule removal of accumulated sediment by vacuum or hydrovac truck.
		Hydrodynamic separator, in-line filter or isolator/ containment row	Schedule removal of accumulated sediment by hydrovac truck.
Filter bed	Mean sediment depth is ≥ 5 cm (see Filter Bed Sediment Accumulation visual indicator protocol, section C.13)	Filter media or swale surface	Remove the accumulated sediment by rake and shovel, vacuum , vacuum truck or small excavator. Estimate and record the quantity.
		Gravel bed surface (underground infiltration chambers)	Schedule removal of accumulated sediment by vacuum or hydrovac truck with JetVac pressure nozzle.
Cistern	Sediment depth is at the level of the distribution system intake when water level is at the lowest operating level (see visual indicator protocol section C.29)	Cistern	Schedule removal of accumulated sediment by vacuum or hydrovac truck with JetVac pressure nozzle.

Notes:

1. If standing water is present, the BMP component will need to be dewatered prior to or as part of the sediment removal procedure.

Surface infiltration rate testing involves estimating the saturated hydraulic conductivity (K_S) of the BMP surface through measurement at several locations and calculation of an average value. A single measurement can take anywhere from 15 minutes to several hours (Erickson et al., 2013) depending on soil or surface characteristics. Saturated hydraulic conductivity values can vary spatially by orders of magnitude depending on many factors, such as soil texture, plant root structure, compaction and soil moisture (Warrick and Nielsen, 1980; Asleson et al., 2009). So it is important to take several measurements for an individual BMP to represent the variation over the surface. Examination of individual measurements of K_S can also identify what portion of the BMP surface is draining too slowly or too quickly so that maintenance or rehabilitative efforts can be focused on only those areas to help minimize costs.

In bioretention practices with flat bottoms (e.g., cells, planters), a well installed at the surface of the filter media bed (Figure 8.18) can be used to measure surface ponding depth and duration using a pressure transducer water level logger. This provides the information needed to estimate filter bed surface infiltration rate, track it over time as the BMP ages and determine when rehabilitation is needed (when surface ponding drainage time exceeds 24 hours).

Time to drain water ponded on the surface of the filter media bed is derived from water level logger data. Conservative estimates of surface infiltration rate (i_S) of the filter media bed can be made by examining the time required to drain the last 50 mm (2") of surface ponded water and calculating the value (in mm/h) using Equation 8.2. Estimates are conservative because infiltration rates will be higher at greater ponding depths. To evaluate surface infiltration rate using a surface ponding well during a simulated storm event, the filter media bed should be thoroughly wetted prior to the test. Measurements of filter bed drainage rate and corresponding estimates of surface infiltration rate should be made following natural or simulated storm events that deliver enough water to the BMP to pond at least 75 mm of water on the surface of the filter media bed, in an effort to consistently approximate saturated soil flow conditions.

Equation 8.2: *Filter bed surface infiltration rate.*

Filter Bed Surface Infiltration Rate (i) = 50 mm / ΔT_{50}

Where;

ΔT_{50} = Time to drain last 50 mm of surface ponded water

$\Delta T_{50} = (T_2 - T_1)*24$

T_1 = Post-storm date and time (mm/dd/yyyy hh:mm:ss) when surface ponding water level reaches 50 mm in depth.

T_2 = Post-storm date and time (mm/dd/yyyy hh:mm:ss) when surface ponding is fully drained.

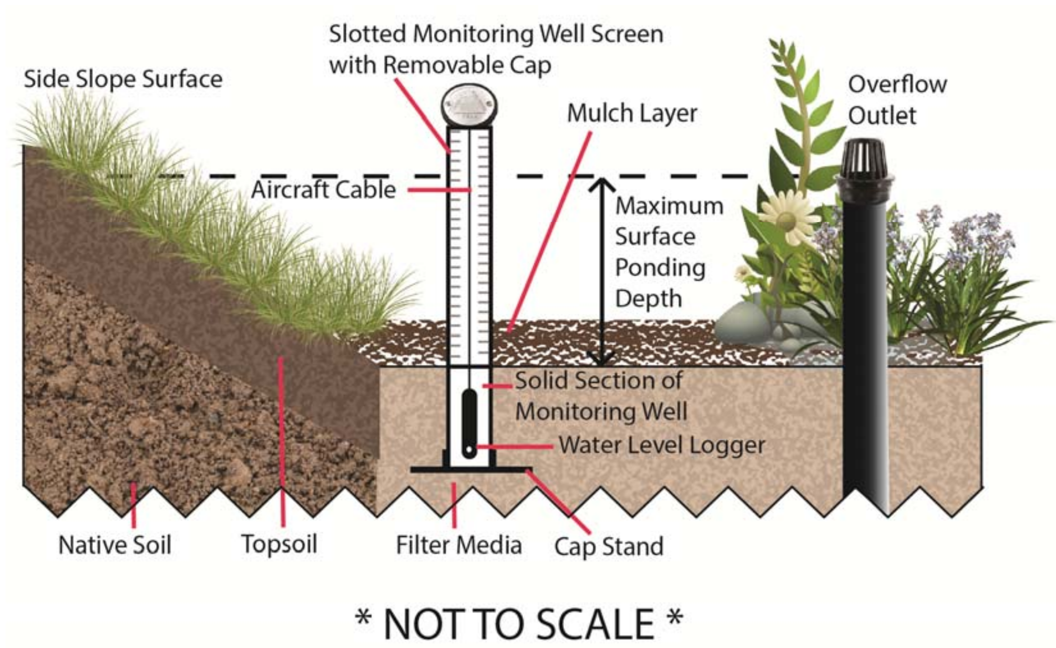


Figure 8.18: *Cross-section diagram of a surface ponding well installed in a bioretention cell.*

8.4.1 BMP Components and Test Methods

Key components of LID BMPs that should be the subject of surface infiltration rate testing are described in Table 8.6 along with recommended test methods.

Table 8.6: *Key components for surface infiltration rate testing by BMP type and test methods.*

LID BMP Type	Key Components	Recommended Test Methods
Bioretention and dry swales; Enhanced swales; Vegetated filter strips	Filter bed surface	Use an infiltrometer or permeameter to measure field saturated hydraulic conductivity (K_S) in at least 5 locations or at a rate of one measurement for every 25 m^2 of filter bed surface area, including inlet and lowest elevation areas. Compare mean and individual values to the design specification or trigger value (Table 8.9) to determine if follow-up tasks are needed.
Permeable pavements	Pavement surface	Use a single-ring infiltrometer to measure field saturated hydraulic conductivity (K_S) in at least 5 locations or at a rate of one measurement for every 250 m^2 of pavement surface area, evenly distributed. For permeable interlocking pavers, follow the procedure provided by ASTM C1781_C1781M – 15 (ASTM International, 2015). For pervious concrete or porous asphalt, follow the procedure provided by ASTM C1701_C1701M – 09 (ASTM International, 2009). Compare mean and individual values to the design specification or trigger value (Table 8.9) to determine if follow-up tasks are needed.

There are two major types of methods for testing surface infiltration rate; constant head and falling head methods (Table 8.7). A constant head test uses an instrument (permeameter or infiltrometer) to measure hydraulic conductivity until it approaches a steady state (i.e., field saturated conditions have be achieved). Double- and single-ring infiltrometers, Tension infiltrometer and the Guelph permeameter with tension disk are examples of constant head test methods for measuring saturated hydraulic conductivity (Ankeny, 1992). A falling head test uses an infiltrometer to measure the rate of water level decline over time. In-situ measurements of soil moisture should be taken before and after falling head tests to more accurately estimate saturated hydraulic conductivity values (Klute, 1986). The Modified Philip-Dunne infiltrometer (Ahmed et al., 2011) or single-ring infiltrometer are examples of falling head test methods.

An advantage of constant head test methods is that one does not need to measure soil moisture. Disadvantages are that they take longer to perform and require larger volumes of water than falling head tests. For comparison of various methods, refer to ASTM D5126/D5126M-90(2010)e1 Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in Vadose Zone (ASTM International, 2010). Details on standard test methods can also be found in Amoozegar and Warrick (1986).

Testing with an infiltrometer or permeameter produces a measurement of saturated hydraulic conductivity (K_S), which is typically reported in units of centimetres per second (cm/s). Infiltration rate (i) is typically reported in units of millimetres per hour (mm/h). <u>It is critically important to note that saturated hydraulic conductivity (K_S) and infiltration rate (i) are two different concepts and that conversion from one parameter to another cannot be done through unit conversion.</u> If the design specification is only available as an infiltration rate (e.g., ≥ 15 mm/h), the mean measured value for saturated hydraulic conductivity can be converted into an estimate of infiltration rate using the relationship described in Table 8.8 and Figure 8.20.

Field measurements of saturated hydraulic conductivity (K_S) are subject to considerable variation due to a variety of complicating factors (e.g., spatial variability, compaction, moisture content), so multiple measurements should be taken and used to calculate an average (mean) value. <u>For bioretention and dry swales, at least five (5) measurements should be taken, plus one for every 25 m^2 of filter bed surface area. For permeable pavements, at least five (5) measurements should be taken, plus one for every 250 m^2 of permeable pavement area</u>. Ideally, measurements should be taken soon after a storm event that thoroughly wets the full depth of soil.

Equipment needed for surface infiltration rate testing will vary depending on the chosen test method but can include the following:

- Safety apparel (steel toed boots)
- Safety cones or barriers (for restricting access when testing permeable pavements)
- Clipboard, inspection field data forms, pens
- Testing instrument (e.g., infiltrometer or permeameter) and instruction manual

- Stopwatch
- Water reservoir (e.g., truck mounted tank or cistern filled with water)
- Buckets or jugs (for filling the instrument)
- Plastic graduated cylinder (for measuring volume of water added during constant head infiltrometer tests)
- Soil moisture probe
- Fine sand (for even contact between Tension infiltrometer and soil surface)

Table 8.7: *Description of common methods for surface infiltration rate testing.*

Method	Description
Double Ring Infiltrometer (constant head)	The double-ring infiltrometer is made of two concentric tubes (Figure 8.19), typically of thin metal or hard plastic, that are both continuously filled with water such that a constant water level is maintained as water infiltrates into the soil (ASTM International, 2005). The rate at which water is added to the centre tube is measured to determine the infiltration rate. For detailed guidance on how to perform the testing, refer to ASTM D3385-09 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer (ASTM International, 2009) and ASTM D5093-15 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer with Sealed-Inner Ring. Accuracy is only moderate relative to permeameter methods (ASTM International, 2010) and results tend to be biased towards higher values due to lateral flow. Potentially requires large volume of water and significant length of time for each measurement to reach steady state.
Single Ring Infiltrometer (constant or falling head)	Similar to the double-ring infiltrometer, except with only one ring. Can be used to measure the vertical movement of water through a soil or permeable pavement. The standard design is a ring that is 30 cm in diameter and 20 cm tall, driven 5 cm into the soil or sealed to the surface of a permeable pavement and filled with water (Klute, 1986). For detailed guidance on how to perform the testing on permeable interlocking pavers, follow the procedure provided by ASTM C1781_C1781M – 15 (ASTM International, 2015). For pervious concrete or porous asphalt, follow the procedure provided by ASTM C1701_C1701M – 09 (ASTM International, 2009). Accuracy for soil testing is only moderate relative to permeameter methods (ASTM International, 2010) and results tend to be biased towards higher values due to lateral flow. Potentially requires large volume of water and significant length of time for each measurement to reach steady state when used for soil testing.
Modified Philip-Dunne Infiltrometer (falling head)	The Modified Philip-Dunne infiltrometer is falling head test device made of an open ended 50 cm long clear plastic cylinder with 2 mm thick walls, a 10 cm inner diameter and graduations, inserted into a machined metal base (Figure 8.19). Unlike the Philip-Dunne permeameter, which requires digging a borehole (i.e., not a surface infiltration test method), it is inserted 5 cm into the surface of the soil without the need for removing vegetation cover. Water level measurements in the tube can be obtained using the graduations on the side of the cylinder and a stopwatch, or continuously recorded through use of a data logger and pressure transducer installed in a piezometer tube.

	Measurements of soil moisture (e.g., using a handheld soil moisture probe) are needed before and after each test. Using relationships established by Ahmed and Gulliver (2011), the observed infiltration rate and initial and final soil moisture measurements are used to calculate a value for saturated hydraulic conductivity. A quicker test to perform than constant head tests. Superior to the single-ring infiltrometer falling head test as lateral flow is incorporated into the calculations.
Tension Infiltrometer (constant or falling head)	This test involves a porous disc of 10 or 20 cm diameter that is connected to a Marriotte bottle (water reservoir) and a bubbling tower where a negative pressure or tension is set (Figure 8.19). The porous disc must be placed in contact with the soil surface which usually requires removal of any vegetation and debris. In many cases it is necessary to place a thin layer of fine sand onto the soil surface to provide good contact between the disc and the soil. Infiltration rates are measured based on the water level drop in the water reservoir. The steady state infiltration rate into the soil is measured for two applied water pressures. To estimate saturated hydraulic conductivity the pressures need to be slightly negative (i.e., tensions) and it is recommended that successive pressures of -5 cm and -1 cm be used (Erickson et al., 2013). The measured steady state infiltration rates are used in equations derived by Reynolds and Elrick (1991) to calculate a value for saturated hydraulic conductivity. For detailed guidance on how to perform the testing, refer to Reynolds and Elrick (1991). The Mini-disc Tension infiltrometer (4.5 cm porous disc) uses a falling head method developed by Zhang (1997) to estimate saturated hydraulic conductivity. It is a quicker test to perform than the constant head method but potentially more difficult to achieve adequate contact with the soil surface.
Guelph Permeameter with Tension Disk (constant head)	The Guelph permeameter is another test device for measuring saturated hydraulic conductivity of a soil surface when used with a tension disc attachment (Figure 8.19). The method is similar to a Tension infiltrometer, but with water being directed to the tension disc from an inner or outer Mariotte reservoir, giving it the capacity to test low and high permeability soils (Soil Moisture Equipment Corp. 1986). Infiltration rates are calculated from monitoring the water level drop in the reservoir until a steady state is approached. Like the Tension infiltrometer method, tests are run with two applied tensions. Steady state infiltration rates from the two applied tensions are used to calculate a value for saturated hydraulic conductivity. Potentially requires large volume of water and significant length of time for each measurement to reach steady state.

Figure 8.19: *Examples of devices commonly used to test surface infiltration rate. Top left: Double-ring infiltrometer; Top right: Modified Philip-Dunne infiltrometer (Source: St. Anthony Falls Laboratory); Bottom left: Tension infiltrometer with data logger (Source: ICT International); Bottom right: Guelph permeameter tension disk attachment (Source: Hoskins Scientific).*

Table 8.8: *Approximate relationships between saturated hydraulic conductivity, percolation time and infiltration rate (*Source: OMMAH, 1997).

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

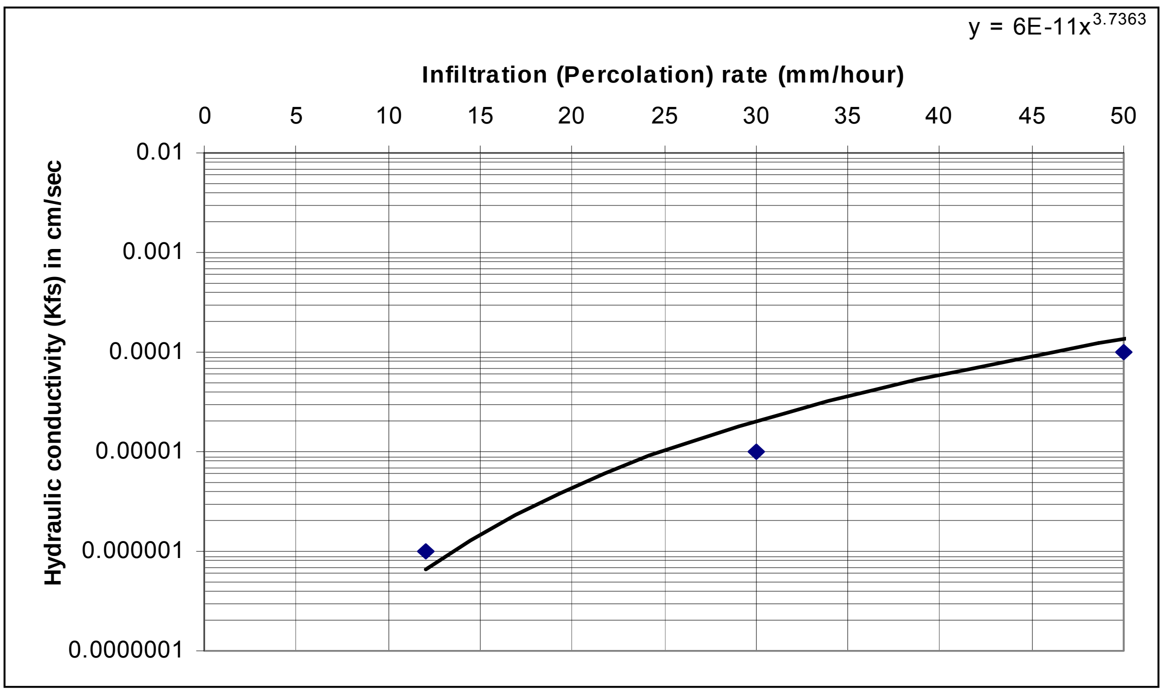


Figure 8.20: *Approximate relationship between infiltration rate and saturated hydraulic conductivity (Source: OMMAH, 1997).*

8.4.2 Triggers for Follow-Up and Corrective Actions

As part of Assumption inspections, the results of surface infiltration rate testing provide the means of confirming that the materials used to construct an LID BMP meet design specifications for permeability. As part of Verification inspections test results help to determine if the surface drainage performance of the BMP is still within an acceptable range. When combined with results from soil characterization and sediment accumulation testing and visual inspections, surface infiltration test results also help to determine when maintenance to address sediment accumulation on the surface of the BMP is needed. Accumulation of fine sediment at the BMP surface can cause a crust to form that greatly reduces the rate at which inflowing stormwater can infiltrate. Table 8.9 describes numerical triggers for follow-up by BMP type, and recommended corrective actions.

Table 8.9: *Surface infiltration rate – triggers for follow-up and corrective actions by BMP type.*

BMP Type	Trigger	Follow-up and Corrective Actions
Bioretention and Dry swales (filter media bed surface)	$i < 25$ mm/h; $K_S < 1 \times 10^{-5}$ cm/s $i > 203$ mm/h; $K_S > 0.02$ cm/s	When part of an Assumption inspection, issue a stop work order and contact the construction site supervisor, design professionals and property owner or project manager to determine follow-up tasks. Follow-up tasks involve scheduling FIT work to do further testing to determine the affected area and depth and decide on corrective actions. Corrective actions may involve removal of any accumulated sediment, mulch or stone cover and plantings and tilling of the top 20 to 30 cm of filter media to eliminate surface crusting or macropores and reduce compaction. Alternatively, removal and replacement of all or the uppermost 15 cm of filter media with material that meets design specifications may be necessary.
Enhanced Swales; Vegetated Filter Strips & Soil Amendment Areas (topsoil surface)	$i < 15$ mm/h; $K_S < 1.5 \times 10^{-6}$ cm/s	When part of an Assumption inspection, issue a stop work order and contact the construction site supervisor, design professionals and property owner or project manager to determine follow-up tasks. Follow-up tasks involve scheduling FIT work to do further testing to determine the affected area and depth and decide on corrective actions. Corrective actions may involve removal of any accumulated sediment and plantings and tilling of the topsoil to between 20 and 30 cm depth to eliminate surface crusting, increase porosity and reduce compaction. If testing indicates low organic matter content, topsoil should be amended with compost prior to tilling.
Permeable pavements (pavement surface)	$i < 250$ mm/h	When part of an Assumption inspection, issue a stop work order and contact the construction site supervisor, design professionals and property owner or project manager to determine follow-up tasks. Follow-up tasks involve scheduling FIT work to do further testing to determine the affected area and decide on corrective actions. Corrective action should first involve thoroughly sweeping and vacuuming the affected pavement area when dry in an attempt to remove sediment accumulated in the pavement joints or pore spaces. If vacuuming does not restore surface infiltration rate to an acceptable value (i.e., ≥ 250 mm/h) try manual or pressure washing means to remove surface crust and sediment from paver joints or pore spaces. In extreme cases, removal of the affected portion of the surface course and bedding and reinstallation with materials that meet design specifications may be necessary.

8.5 Natural or Simulated Storm Event Testing

For LID BMPs that receive stormwater via conveyances like gutters, concrete inlets and leader pipes from roofs or catchbasins (i.e., bioretention and dry swales, enhanced swales, underground infiltration systems) it is critically important to confirm that these conveyances have been designed and constructed properly. If the conveyances are obstructed or improperly graded or constructed, the BMP may not receive flows from their CDA or a significant quantity of stormwater may by-pass treatment. This is particularly important for underground BMPs where inlets are not visible from the surface. Therefore, confirming that these types of BMPs actually receive stormwater from their CDA should be a part of Assumption and Verification inspections.

The simplest approach to confirming that conveyances to LID BMPs are constructed properly and functioning well is through observation of the path of water flow and measuring water level in the BMP during a natural storm event. If timelines for completing inspections cannot be coordinated to coincide with a natural storm event, an alternative approach is to simulate a storm event over the CDA by directing water onto it through the use of a water tanker truck (Figure 8.21) or fire hydrant while observing conveyances and measuring water level in the BMP. Such testing not only confirms that conveyances to the BMP are functioning properly but also helps to confirm the size of the CDA (i.e., that site grading is correct) and that sub-drain systems are functioning properly. Use of fire hydrants as a source of water requires prior notice be provided to the fire department, a means of metering how much water is used (e.g., a magnetic flow meter), and a water taking permit from the municipality, including payment for the volume of water used. An example of a simulated storm event test design to confirm that conveyances are functioning properly for a hypothetical infiltration trench is provided in Section 8.5.1.

Natural or simulated storm event testing can also be undertaken to confirm that an LID BMP drains at an acceptable rate. Designing such tests is much more involved and requires the deployment of specialized field monitoring equipment like continuous water level loggers (i.e., pressure transducers) in monitoring wells, flow measurement apparatuses (e.g., area-velocity sensors) in sub-drain or outlet pipes and rain gauges, in addition to staff familiar with the use and calibration of such equipment and the processing and analysis of the data. Section 8.6 provides guidance on the utility and design of continuous monitoring programs along with key references for further reading. In many cases, testing to determine the drainage rate of a BMP is most easily done through continuous monitoring during natural storm events.

<u>For stormwater infiltration BMPs (i.e., bioretention and dry swales, permeable pavements, underground infiltration systems) it is recommended that natural storm event testing be undertaken in conjunction with continuous monitoring of BMP water level, outflow and rainfall depth at the site as part of Assumption and Verification inspections to evaluate the drainage rate (see Section 8.6).</u> Simulated storm event testing can be undertaken to evaluate the drainage rate of small infiltration BMPs such as rain gardens, permeable driveways, soakaways or small infiltration trenches (i.e., 50 m^2 in surface area or less). However, for larger BMPs like dry swales, permeable pavements and

underground infiltration chamber systems, the quantity of water needed for such testing often makes simulated storm event testing not feasible or requires use of a fire hydrant as the water source.

Figure 8.21: *Simulated storm event testing of a dry swale with a water truck.*

8.5.1 Test Methods, Equipment and Triggers for Corrective Action

If the primary objective of natural or simulated storm event testing is only to confirm that conveyances are delivering stormwater to the BMP, this is easily done by observing where water flows as it is delivered to the CDA. Prior to and after the release of water, measurements of water level in monitoring wells should be made and recorded to be able to detect whether or not flows are reaching the water storage portion of the BMP if it cannot be observed visually. Manual water levels measurements can be taken by lowering a rod, level tape or string with a weight on the end into the well until the bottom is reached and measuring the height of water present from the maximum water level indicated on the device. Water level can also be measured using a pressure transducer installed to just above the bottom of the well and set to continuously record water level at 1 minute intervals (see Section 8.6). For BMPs that contain sub-drains that can be accessed and visually inspected, observations should be made to determine if flow from the sub-drain pipe occurs following delivery of water to the BMP.

For simulated storm event testing, knowledge of the water storage capacity of the BMP, approximate infiltration rate of the native subsoil, and maximum flow rate of the water source is needed to design the test. If the BMP contains a sub-drain that can be accessed and visually inspected, observation of flow from the sub-drain pipe is enough to confirm water has been received and that the sub-drain is functioning properly. If no sub-drain is present and only monitoring wells are available to detect if flow is reaching the water storage portion of the BMP, calculations prior to testing are needed to determine the quantity of water needed for the test. Enough water should be available to raise water level in the water storage portion of the BMP by at least 2 cm in order to reliably detect change in water level through monitoring well depth measurements. An example test design is described below.

An underground infiltration trench with no sub-drain has been constructed that receives parking lot runoff via a catchbasin and leader pipe connected to the trench. The property owner or their consultant wishes to confirm the trench receives runoff from the parking lot drainage area through simulated storm event testing. The trench footprint surface area (SA) is 30 m^2 and is filled with clear ¾" diameter clear stone with an assumed porosity (p) of 40%. A monitoring well is installed with the well screened within the sub-surface water storage reservoir (i.e., bottom elevation of the trench).

The approximate infiltration rate of the underlying sandy clay loam subsoil is 25 mm/h. It is proposed that a water tanker truck be used as the water source, with a capacity of 13.0 m^3 and maximum flow rate (f) of 4.5 L/s (0.0045 m^3/s). The following calculation can be used to estimate the total volume of water (V) needed to register a 2 cm (0.2 m) change in water level reading in the monitoring well:

$V = (Vs + Vi) + (Vs + Vi) * 0.1$

where,
Vs = Volume to be stored
$Vs = SA * 0.2\ m * p$
$Vs = 30\ m^2 * 0.2\ m * 0.4$
$Vs = 2.4\ m^3$

and,
Vi = Volume infiltrated during the test (approximate)
$Vi = Vs/(f * 3600) * i/(1000*p) * SA$
$Vi = 2.4\ m^3/(0.0045\ m^3/s * 3600\ s/h) * 25\ mm/h/(1000\ mm/m * 0.4) * 30\ m^2$
$Vi = 0.28\ m^3$

and,
0.1 = estimated abstraction ratio to account for water loss by evaporation and retention on the parking lot surface and clear stone fill material (i.e., 10% loss)

Therefore,
$Vt = (2.4\ m^3 + 0.28\ m^3) + (2.4\ m^3 + 0.28\ m^3) * 0.1 = 2.95\ m^3$

So assuming that about 10% of the water delivered to the parking lot will be lost to evaporation and retention, 2.95 m^3 or about 3.0 m^3 (3,000 L) of water needs to be delivered to the BMP (i.e., releasing water at the maximum flow rate of 4.5 L/s for about 11 minutes) in order to register a 2 cm increase in water level in the 30 m^2 infiltration trench.

Equipment needed for natural or simulated storm event testing will vary depending on the BMP type, objectives of testing and the chosen method but can include the following:

- Water source of sufficient quantity (e.g., water truck, fire hydrant, truck mounted cistern)
- Safety apparel (steel toed boots)

- Safety cones or barriers (for restricting access when testing permeable pavements)
- Clipboard, inspection field data forms, pens
- Camera
- Water level tape or dip stick
- Measuring tape
- Surface ponding well (e.g., Figure 8.18)
- Sub-surface water storage reservoir monitoring well (e.g., Figure 7.1, 7.4 and Figure 7.5)
- Pressure transducers data logger (optional ,for detecting water level change in sub-drains)
- Hydrant coupling kit (for connecting to fire hydrant)
- Magnetic flow meter and data logger (for measuring quantity of water delivered to the BMP)
- Pipes (to distribute flow to the CDA or BMP itself)
- Pipe couplings (to connect water truck or fire hydrant hose/nozzle to flow meter and distribution pipes);
- Pick for opening manholes or catchbasin grates;
- Multi-gas sensor (for safe access of manholes or catchbasins);

Acceptance criteria for LID BMP drainage performance for both natural and simulated storm event testing are as follows:

1. Water flows into the BMP as intended;
2. For bioretention, dry swales and enhanced swales, the surface water storage reservoir (i.e., surface ponding) fully drains within 24 hours of the end of the storm;
3. For bioretention and dry swales, the filter bed surface infiltration rate ≥25 mm/h and ≤203 mm/h, or consult manufacturer or vendor for an acceptable range specific to the filter media product.
4. For enhanced swales, vegetated filter strips and soil amendment areas, the surface infiltration rate ≥15 mm/h and ≤203 mm/h, or consult manufacturer or vendor for an acceptable range specific to the topsoil product.
5. For newly constructed BMPs (i.e., Assumption inspection), the active sub-surface water storage reservoir volume drains within 48 to 72 hours of the end of the storm and sub-drain peak flow rate is within +/- 15% of design specification; and
6. For aged BMPs (i.e., Performance Verification inspections), active sub-surface water storage reservoir volume drains within 48 to 96 hours of the end of the storm and sub-drain peak flow rate is within +/- 15% of design specification.

<u>If through natural or simulated storm event testing it is observed that any of the above drainage performance criteria applicable to the BMP are not met, corrective actions are necessary. In an Assumption inspection of a new BMP, unacceptable test results indicate the need for FIT work or consultation with the designer to determine what portions of the BMP needs to be rehabilitated or reconstructed</u>. Depending on the nature of the problem, corrective actions may involve re-grading the CDA or inlets or unclogging or reinstalling obstructed inlets or pipes.

A drainage rate of less than 48 hours indicates that the sub-drain pipe or orifice may be oversized and that a flow restrictor should be added, or that the flow restrictor valve can be adjusted to a more restrictive setting.

In a Performance Verification inspection of an aged BMP, longer than acceptable drainage time results indicate the need to rehabilitate, reconstruct or replace part or all of the BMP and should trigger the planning of such work.

The time required to fully drain the surface and sub-surface water storage reservoirs can be determined directly from continuous monitoring by repeated manual water level measurements or the use of a water level logger. For infiltration BMPs, calculations of sub-surface storage reservoir drainage rate should be based on a drainage time observation over a set water level interval (e.g., between one half to one quarter full) to reduce systematic error associated with the estimation method and better enable examination of trends over time as the BMP ages (see Inspection Field Data Forms in Appendix C).

For bioretention cells and planters, it is recommended to calculate filter bed surface infiltration rate (i.e., surface water storage reservoir drainage rate) using surface ponding well data based on the time required to drain the last 50 mm of ponded water as a conservative estimate (see Section 8.4 and Bioretention and Dry Swales Inspection Field Data Form in Appendix C).

8.6 Continuous Monitoring

Continuous monitoring is the most comprehensive approach to inspection of stormwater BMPs that can provide quantitative information about drainage and water treatment performance during actual storm events, which can be directly compared to design specifications and regulatory criteria to determine if it is functioning and performing as intended. When it is conducted during natural storm events it involves deployment of specialized monitoring equipment at the BMP site for 6 months to two years, routine visits to download and maintain the equipment and statistical analyses of the monitoring data, all of which needs to be performed by skilled individuals trained in a variety of environmental monitoring techniques. When conducted during a simulated storm event it involves deployment of monitoring equipment at the BMP site for about 3 to 5 days and analysis of the monitoring data. Continuous monitoring is the most costly and time-consuming approach to inspection, but warranted in certain situations.

At a minimum, continuous monitoring should be undertaken as part of Assumption and Verification inspections in the following situations:

1. For infiltration BMPs designed without sub-drains to determine active sub-surface water storage reservoir volume drainage time and filter bed surface infiltration rate.

2. For infiltration BMPs designed with flow-restricted sub-drains, to determine sub-drain peak flow rate, active sub-surface water storage reservoir volume drainage time and filter bed surface infiltration rate.
3. As part of Forensic inspection and Testing (FIT) work to determine corrective actions for suspected problems with drainage or effluent quality detected through other inspection and testing work.
4. When little information is available about the effectiveness of a certain type of BMP in a certain environmental context, or when a new technology is being implemented for the first time in a certain context or geographic region.
5. Where the sensitivity of the receiving water warrants a high level of inspection and testing to determine if BMP effluent quality meets design specifications or regulatory criteria.

Continuous monitoring is also recommended for infiltration BMPs with unrestricted sub-drains to determine if drainage performance meets design specifications or regulatory criteria, to provide the information needed to evaluate groundwater recharge performance over time and to determine when rehabilitative action or replacement is needed.

Continuous monitoring can be performed during natural storm events by measuring rainfall depth, rate and volume of flow into and out of the BMP (where feasible) over entire events and, if water treatment performance is to be assessed, collecting water samples to determine event mean pollutant concentrations and loads in effluent from the BMP. To assess drainage performance (i.e., sub-drain peak flow rate, drainage time; surface infiltration rate) by continuous monitoring, the inflows and outflows must be measured or estimated along with continuous measurement of water level in the water storage portion(s) of the BMP (i.e., both surface and sub-drain storage). Where inflow to the BMP cannot be measured (e.g., BMP receives inflow as sheet flow or via multiple inlets) it is possible to estimate inflow volume based on event rainfall depth and the size and runoff coefficient of the CDA. Water treatment performance (i.e., pollutant removal efficiency ratios) can be evaluated through automated sampling of inflow and outflow and laboratory testing of flow-weighted composite water samples to determine event mean pollutant concentrations and loads. If sampling inflow to the BMP is not feasible, simultaneous sampling of flow from a nearby untreated drainage area is also necessary to calculate pollutant removal efficiency ratios by comparing outflows from the BMP to those from the untreated drainage area.

Continuous monitoring can also be performed to evaluate drainage performance during a simulated storm event test by directing a known quantity of clean water to the BMP using either a water tanker truck or fire hydrant and measuring water level change in the water storage reservoirs (i.e., surface and sub-surface) of the BMP along with the rate of outflow from the sub-drain. While it is possible to evaluate water treatment performance of a BMP through continuous monitoring during a simulated storm event test, it requires dosing the water source used with a known quantity of the pollutant of concern which is not feasible in most cases.
Design of the continuous monitoring program will depend on what parameters are relevant to the BMP being inspected and the objectives of the inspection work. As part of Assumption and

Verification inspections, it is recommended that continuous monitoring be conducted to determine if the drainage performance of the infiltration BMP meets design specifications or regulatory criteria. When included as part of Assumption inspection work, in addition to determining if the BMP is functioning as intended prior to acceptance, such inspection work provides a baseline of information to which subsequent monitoring (e.g., as part of Verification inspections) can be compared, to evaluate how performance changes over the routine operation of the facility and determine when the facility needs rehabilitation or replacement (i.e., the end of its lifespan). Drainage performance evaluation work should determine the time required for the BMP to fully drain runoff from a storm event that produces enough runoff to completely fill the sub-surface water storage reservoir of the BMP or between 15 and 25 mm depth over the CDA.

Evaluation of the water treatment performance can be included in program design, but it will greatly increase the cost of the work and length of the monitoring period required to produce meaningful results. Continuous monitoring to evaluate water treatment performance should be undertaken when the BMP is a new or hybrid technology for which little or no treatment performance evaluation results are available or where the sensitivity of the receiving water warrants a high level of inspection and testing to confirm that regulatory criteria are being met.

Some general guidance and tips on the design of continuous monitoring programs to evaluate drainage and water treatment performance of LID BMPs are provided in the following section along suggestions for the types of equipment that may be needed.

Recommended sources of in-depth guidance on monitoring the performance of stormwater BMPs, aimed at assisting stormwater infrastructure asset managers with understanding basic concepts and key considerations regarding program design and implementation are as follows:

- Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance (Erickson et al., 2013);
- Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies (Washington State Department of Ecology, 2011);
- Urban Stormwater BMP Performance Monitoring (Geosyntec Engineers and Wright Water Engineers, 2009);
- Center for Watershed Protection, Managing Stormwater Post-Construction Guide, BMP Performance Verification Tool (Tool 8) Appendix A (CWP, 2008);

Detailed standard operating procedures for conducting continuous water level monitoring and simulated storm event testing (i.e., simulated runoff testing) to evaluate BMP drainage performance are available in the City of Philadelphia's Green Cities, Clean Waters Comprehensive Monitoring Plan, Appendices C and D (City of Philadelphia, 2014).

8.6.1 Program Design and Equipment

Drainage Performance Evaluations

It is recommended that at a minimum, the drainage performance of stormwater infiltration BMPs be evaluated as part of Assumption and Verification inspections. Drainage performance, or the ability of the BMP to fully drain runoff from a certain size storm event within a certain time period, can be evaluated by continuous monitoring during natural or simulated storm events. Compared to simulated storm event testing, continuous monitoring over natural storm events provides the advantage of collecting data over a broader range of storm events (i.e., depth and intensity), and antecedent conditions (e.g., soil moisture, temperature), but requires longer durations of field monitoring in order to capture the targeted storm event size. When a water source of sufficient size to fill the sub-surface water storage reservoir is available, it is recommended that drainage performance evaluations be performed by simulated storm event testing as results can be produced within a much shorter time period (e.g., within a week) as opposed to natural storm event testing, which can require field monitoring activities over 6 months to 2 years in duration.

The general approach involves installing water level logger sensors (i.e., pressure transducers) in:

- a perforated standpipe on the BMP surface to measure the time required to drain water ponded on the surface (i.e., the surface water storage reservoir component) and estimate filter bed surface infiltration rate; and,
- a monitoring well screened within the sub-surface water storage reservoir component of the BMP.

The water level logger sensor should be installed such that it is slightly elevated off the bottom of the well (Figure 8.22). A rain gauge (e.g., tipping bucket rain gauge) and barometer (i.e., pressure transducer) are also needed within 2 kilometres of the BMP site. It is often best to install the barometer in the same monitoring well as the water level logger. The water level loggers, barometer and rain gauge should be programmed to record at 5 minute intervals. Water level readings in the BMP are made manually at the time of deployment in order to establish the vertical correction offset between sensor water level readings and the elevation reference, typically the top of the well. Rainfall depth, and water level logger data (pressure and temperature) are downloaded at regular intervals via a laptop computer. Water level logger data must be compensated for changes in barometric pressure using simultaneously logged data from the barometer prior to analysis. Manual water level readings are taken when downloading data and re-deploying sensors in order to calibrate water level readings and determine whether sensor drift occurred during the deployment.

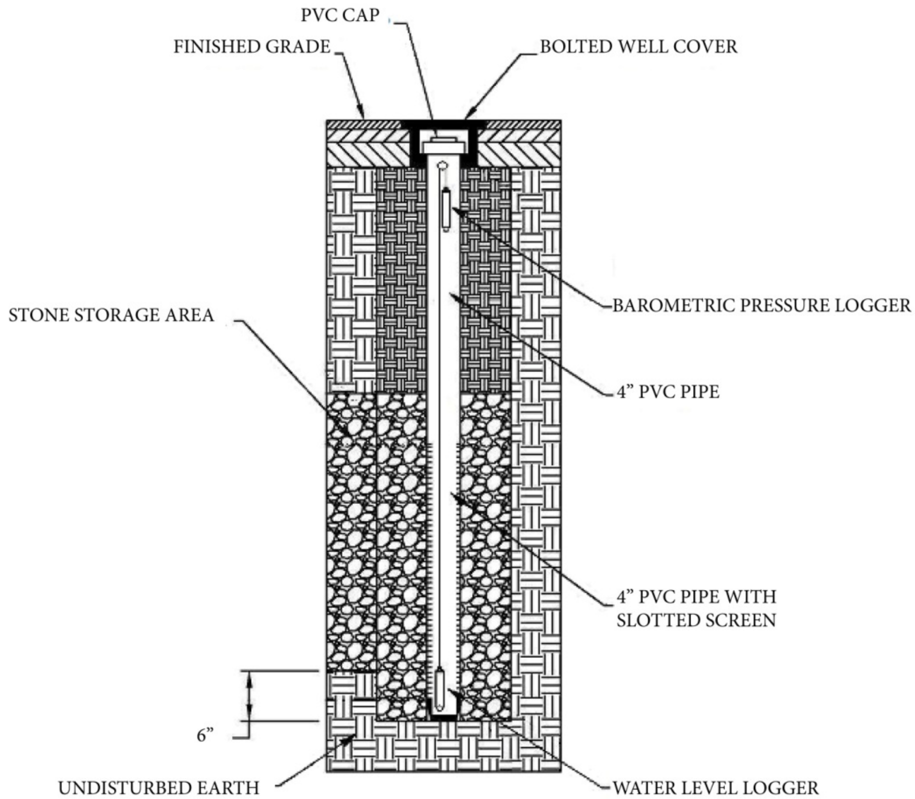


Figure 8.22: *Diagram of a typical water level logger installation in an infiltration BMP sub-surface water storage reservoir monitoring well (City of Philadelphia, 2014).*

For infiltration BMPs with no sub-drains, continuous monitoring to evaluate drainage performance should capture the full drainage period for at least one rain event large enough to fill the sub-surface water storage reservoir or at least 3 rain events between 15 and 25 mm in depth. Mean values for surface and sub-surface water storage reservoir drainage times and rates should be calculated and compared to design specifications or regulatory criteria to determine if the BMP is draining at an acceptable rate. Alternatively, a simulated storm event test can be performed, that involves directing enough water to completely fill the sub-surface water storage reservoir and monitoring decline in water level over time until the BMP is completely drained. Such a test should be timed to coincide when no rain is in the forecast for at least 4 days.

For infiltration BMPs designed with flow-restricted sub-drains to meet peak flow reduction/erosion control regulatory criteria, additional monitoring equipment is needed. In addition to a rain gauge, barometer, and water level loggers, a flow measurement apparatus needs to be installed in the sub-drain outlet pipe to monitor flow rate. Choice of flow measurement equipment will depend on the size and configuration of the pipe. Area-velocity sensors use water level and flow velocity measurements in conjunction with knowledge of the pipe size to produce measurements of flow rate. Magnetic flow meters can also be used to measure flow in full pipes with knowledge of the pipe size.

Alternatively, a tipping bucket flow gauge can be installed at the sub-drain pipe outlet that has the capacity to measure the expected maximum flow rate from the sub-drain pipe. Flow rate data produced by such instruments can be directly compared to design specifications and regulatory criteria to determine if the BMP is providing the intended level of peak flow control.

For infiltration BMP designed with flow-restricted sub-drains, continuous monitoring to evaluate drainage performance should be performed by conducting a simulated storm event test using the following stepwise procedure:

<u>Simulated storm event test procedure for evaluating drainage performance of infiltration BMPs</u>

1. Select a date for the test when no rainfall is forecast for at least 3 days.
2. Install flow monitoring apparatus downstream of the sub-drain flow restrictor device.
3. Temporarily plug the sub-drain pipe.
4. Direct enough water to the BMP to completely fill the sub-surface water storage reservoir.
5. Remove the sub-drain plug.
6. Allow the BMP to fully drain.
7. Determine the maximum flow rate from the sub-drain from flow measurements
8. Determine the drainage time from the water level measurements
9. Calculate the infiltration rate based on water level measurements once flow from the sub-drain has stopped as the change in storage volume over time divided by the infiltration area.

As mentioned in the previous section, to design a simulated storm event test, knowledge of the surface and sub-surface water storage capacity of the BMP is needed to determine the quantity of water needed, which will determine how the water will need to be delivered. If more than 13 m^3 of water (i.e., the typical capacity of water tanker trucks) is needed to fill the sub-surface water storage reservoir, a fire hydrant will need to be used as the water source.
The values obtained for maximum outflow rate from the sub-drain, drainage time and infiltration rate should be compared to design specifications or regulatory criteria to determine if the BMP drains at an acceptable rate.

For infiltration BMPs that contain unrestricted sub-drains, continuous monitoring to evaluate drainage performance should capture the full drainage periods for at least one storm event large enough to completely fill the sub-surface water storage reservoir to the elevation of the sub-drain pipe invert or at least 3 rain events between 15 and 25 mm in depth. Mean values for drainage time and infiltration rate should be calculated and compared to design specifications or regulatory criteria to determine if the BMP is draining at an acceptable rate. Alternatively, a simulated storm event test can be performed, using the stepwise procedure described above.

When continuous monitoring during natural storm events is the chosen approach to inspection, the site should be visited once every two weeks to ensure that all equipment remains functional and to download instruments and check on/replace batteries.

Water Treatment Performance Evaluations

When the objectives of BMP inspection include determining if the BMP is providing a minimum level of water treatment performance, design of the continuous monitoring program needs considerable thought. Table 8.10 describes some key considerations in program design.

When deciding if continuous monitoring to evaluate water treatment performance is to be part of Assumption and Verification inspections, it is important to consider budgetary constraints as such work typically involves having monitoring equipment deployed for 6 months to 2 years along with the costs associated with routine site visits (every two weeks), quality assurance checking of data, statistical analyses of results and staff training. Continuous monitoring must be performed by skilled individuals trained in a variety of environmental monitoring techniques and, in many cases, with confined space entry training and equipped with certified and recently calibrated safety equipment (i.e., tripod, winch, harnesses, multi-gas detectors).

A typical continuous monitoring program to evaluate water treatment performance is conducted between April and November, as water sampling during freezing winter temperatures is often difficult or not feasible. To evaluate BMPs that only produce outflow during large storm events (e.g., 15 mm depth or more), monitoring work should begin in the spring and continue through the summer as these months tend to be the wettest of the year. Rainfall depth should be continuously monitored within 3 kilometres of the BMP location and ideally, at more than one location. Storm events sampled should represent a range of conditions with respect to rainfall depth and intensity. Dry periods of 3 hours or greater should be used to define the beginning and end of storm events. A minimum of ten (10) equal-volume samples (i.e., aliquots) should be collected during each storm event. To adequately characterize variability in BMP water treatment performance, laboratory test results from a minimum of fifteen (15) storm events should be obtained. The evaluation period should also include at least one routine maintenance cycle (e.g., cleaning of inlets and pretreatment devices) to capture any variability in water treatment performance of the BMP over this time period.

Table 8.10: *Key considerations in designing continuous monitoring programs for water treatment evaluation.*

Variable	Key Considerations	Recommendations
BMP water storage capacity	Many LID BMPs contain sub-drains that only flow during large storm events which will limit the number of events that produce water samples in a given year.	Focus on BMPs that generate outflow during storm events of 25 mm depth or less. Budget for continuous monitoring periods of 6 months to 2 years to capture samples from enough storm events to produce meaningful results (at least 15) with site visits every 2 weeks to check on equipment and download and QA/QC check data.
Inlet configuration	Measuring and sampling inflow is often not feasible for BMPs that receive sheet flow or have multiple inlets.	Parallel measurement and sampling of outflow from a nearby, untreated drainage area is needed to evaluate water treatment performance of BMPs where inlet monitoring is not feasible.

Storm event size and duration	To adequately characterize water treatment performance, monitoring results from a range of storm event sizes is needed which requires that the programming of automated water samplers should be capable of capturing flow from a range of storm event depths and durations.	Start with collecting 500 mL aliquots every 10 minutes after flow is initiated. For an automated water sampler that contains 24 one litre bottles, this allows sampling over an 8 hour period. Sampling frequency should be adjusted to optimize between filling all the bottles in the sampler with capturing as much of the period of flow as possible. Alternatively, automated samplers can be coupled with flow measurement apparatuses to alter sampling frequency as flow rate changes.
Flow-weighted sampling method	How individual water samples are combined to produce the composite sample for laboratory testing will greatly affect results.	Composite samples should be generated by examining flow rate over the period each sample was taken, calculating what proportion of the total flow during the event that represents, and using this relationship to measure the quantity taken from each sample bottle to produce the composite sample.
Water quality parameters of interest	The cost of laboratory testing of water samples increases with the number of parameters to be tested. Water treatment performance evaluations should focus on the parameters of greatest concern from regulatory or receiving water sensitivity perspectives.	As most pollutants common to urban stormwater runoff are associated with suspended solids, focus on evaluating Total Suspended Solids removal efficiency. For nutrient-limited receiving waters, add nutrient testing (Total Phosphorus and Phosphate, Total Nitrogen, Nitrate and Nitrite). For bacteria-limited receiving waters add bacteria testing. When bacteria removal performance is to be evaluated, samples must be submitted for laboratory testing within 48 hours of the end of the storm event or refrigerated samplers are needed.
Security of monitoring equipment	In some cases, monitoring equipment will need to be installed at the ground surface, and require means of preventing tampering or sabotage.	House automated water samplers in protective structures that are securely locked and inaccessible or in manholes where possible.
Confined space entry	Installing and checking flow monitoring and sampling equipment often requires entry into confined spaces.	Monitoring that involves confined space entry requires adequately trained staff equipped with certified and recently calibrated safety equipment.

The choice of what water quality parameters are to be evaluated will depend on the objectives of the work but typically include one or more of the following: total suspended solids, nutrients (total phosphorus, orthophosphate, total nitrogen, nitrate, nitrite), metals, pH, chloride, conductivity, oil and grease, turbidity and PAHs. Bacteria (e.g., *E.Coli* or total coliforms) can also be evaluated but requires that samples be laboratory tested within 48 hours of being collected, which means samples need to be submitted for testing soon after the end of the storm event or that refrigerated auto sampler units be used.

Whenever water treatment performance is being evaluated, proper handling and storage of water samples is essential to prevent contamination and produce representative samples and accurate laboratory test results. Prior to sampling, bottles must be cleaned with phosphate-free detergents and rinsed with acid. Samples submitted for metals testing should be preserved with nitric acid. Samples submitted for bacteria testing should be contained in sterile bottles provided by the analytical laboratory and refrigerated immediately after collection and during transport to the laboratory.

Testing of water samples must be done by an accredited analytical laboratory. A list of accredited analytical water testing laboratories in Ontario is provided in Appendix B.

Interim results from such continuous monitoring work should be peer-reviewed before being used to trigger any corrective actions and final results should be made available to the stormwater management practitioner and research community to help foster continuous improvement of BMP designs and understanding of their effectiveness. Ideally, results from such work should be suitable for inclusion in the International Stormwater BMP Database. Information about the database and detailed guidance on standards for reporting stormwater BMP performance results is provided on the project website (www.bmpdatabase.org).

8.7 Green Roof Irrigation System Testing

In dry or temperate climates, an irrigation system can be crucial for establishing and maintaining green roofs. Extensive green roofs planted with drought tolerant plants do not always need an irrigation system, but intensive green roofs planted with a wider variety of plants would not be able survive without one. Most green roofs will require supplemental water either to enhance or speed up the establishment process or to protect the plantings during times of sustained drought. This can be accomplished by hand watering or installing an automated irrigation system.

Irrigation systems vary greatly in level of complexity. They can be simple hand watering systems using hose bibs on the roof and manual sprayers, or installed automated systems that are activated by timers, or more sophisticated “smart irrigation” systems that can be remotely controlled and coupled with rain sensors or sources of local weather data to only operate during extended dry periods (i.e., droughts). Drip irrigation is the most common type of irrigation system for green roofs (Green Roof for Healthy Cities, 2011) because it transfers the water directly to the growing medium via drip emitters installed at or near the surface with relatively little loss to evaporation. Other types of irrigation systems use handheld or installed spray nozzles to distribute water to the plants.

If an automatic irrigation system is in place, individuals performing inspection testing, maintenance and repairs on it should refer to the operator's manual from the product vendor or installer for instructions specific to that product.

Regardless of the type of irrigation system installed, it should be regularly inspected and tested to ensure it is free of damage and functioning properly. Such testing should be done annually in the spring as part of reconnecting the system to the water supply after having been disconnected and blown dry for the winter (see Section 7.6.5, Table 7.35 for guidance on spring start-up and winterization of green roof irrigation systems).

A green roof irrigation system test involves inspecting the supply lines, fittings and distribution points (e.g., drip emitters or spray heads) while the system is running to check for leaking, damaged, obstructed or misaligned components and dry or saturated portions of the filter bed/growing medium. A leaking or damaged supply line will often wash out or saturate a small area. An obstructed drip emitter or spray nozzle will create dry spots. If visual assessments of vegetation cover and condition reveal locations where plantings have died or are not thriving, make sure it is not due to irrigation system malfunction or damage.

Green roof irrigation system testing also provides a means of confirming that the drainage system is functioning properly. If the irrigation system test results in ponding on the filter bed/growing medium surface or in/around overflow outlets, repair or routine maintenance of those components may be necessary.

8.8 Green Roof Leak Detection Testing

On buildings featuring a green roof, a waterproofing membrane layer that covers the whole roof is essential to prevent water damage to the building. In some cases, a root barrier layer is also a part of the green roof design that protects the waterproofing membrane from being penetrated by roots and degraded by soil microbial activity. On top of these protective layers are the water retention and drainage layer, filter cloth, growing media and plants, making it impossible to visually inspect them for damage or leaks. There are two main approaches to leak detection for green roofs – flood tests and low-voltage leak detection tests.

Flood tests for detection of green roof leaks can be conducted as part of Construction inspections, prior to planting. The test requires an experienced professional to narrow down a small area where the leak may be originating from. The suspected area is isolated from the rest of the roof, the roof drains are plugged, 10 cm of water depth is introduced and observations are made. Once the leak is found, the area is opened up and the waterproofing membrane is repaired. This process is time-consuming and costly, as the leak is not always found during the first round of patch flooding (US GSA, 2011).

The low-voltage leak detection test utilizes electricity to locate water penetrations through the waterproofing membrane. Such leak detection systems can also be referred to as Electric Field Vector Mapping (EFVM®) systems. They require a grounded, conductive material be directly below the waterproofing membrane, such as reinforced concrete or metal, and that the membrane be a non-conductive material. During roof construction and prior to green roof installation, a conductive wire is looped around the surface of the waterproofing membrane and connected to an impulse generator. Testing involves the inspector or leak detection technician introducing a low-voltage, pulsating electric charge onto the surface of the waterproofing membrane which should be moist at the time. A watertight membrane will isolate the potential difference between the wetted surface and the underlying grounded conductive material layer, while breaches in the membrane will cause an electrical connection to occur. The inspector or leak detection technician reads the directional flow of current with a potentiometer to locate the point of entry with pinpoint accuracy. Low-voltage leak detection tests can be performed before and after a green roof is installed. As such, the location of leaks can be very precisely located and repaired with minimal disturbance to the rest of the roof (US GSA, 2011).

It is important to test green roofs for leaks as part of Construction, Assumption and Verification inspections. As part of Construction inspections, testing confirms that the roof layers have been installed correctly and that it is ready for planting. As part of Assumption inspections it helps determine if the green roof is ready to be assumed by the property owner/manager/municipality. Tests may also be done as part of Verification inspections (i.e., every five years) to check for leaks, and as part of FIT work to locate and repair leaks discovered through visual inspection work.

8.9 Cistern Pump Testing

Most rainwater cisterns are placed in basements or outdoors, and require a pump to distribute the water to service its designated locations throughout the property, generally located at higher elevations. Typically, a pump is arranged with a pressure tank, which includes a centrifugal pump that draws the water out of the storage tank and into the pressure tank, where it is stored and ready for distribution. As part of this distribution system, an appropriately sized pump is required to produce a sufficient flow to efficiently transport water that feeds into the pressure tank. With prolonged usage, the pump capacity may decline, which would be reflected by a reduction in flow rate. A simple flow rate measurement using a bucket, stopwatch and volume measurement device (e.g., graduated cylinder) at the outlet location can reveal whether the pump is functioning. Once the flow rate is measured the value can be compared to the design flow rate. If the pump is not creating sufficient pressure, then the flow rate will be inadequate. If the flow rate is below the design specification, servicing of the pump by a skilled technician should be scheduled.

In addition to confirming that the pump is functioning and checking on the flow rate, routinely conducting cistern pump tests also provides the opportunity to visually inspect the water produced by the system. If the water delivered from the cistern is discoloured or highly turbid (i.e., murky), it indicates that the pretreatment device or filtration system is malfunctioning or needs maintenance.

9.0 REFERENCES

Agriculture and Agri-food Canada (AAC). 2015. Canadian Drought Monitor. http://www5.agr.gc.ca/eng/?id=1430766471261, Date accessed: November 5, 2015.

Ahmed, F. and Gulliver, J.S. 2011. User's manual for the MPD infiltrometer. St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN.

Ahmed, F., Gulliver, J.S., and Nieber, J.L. 2011. A New Technique to Measure Infiltration Rate For Assessing Infiltration of BMPs. 12th International Conference on Urban Drainage, Porto Alegre, Brazil, September 11 to 16, 2011.

Ankeny, M.D. 1992. Methods and theory for unconfined infiltration measurements. In Advances in measurement of soil physical properties, Spec. Publ.30. G. C. Topp, W. D. Reynold. and R. E. Green (eds.). Soil Science Society of America, Madison, WI. pp. 123-141

Amoozegar, A. and Warrick, A.W. 1986. Hydraulic conductivity of saturated soils: field methods. In, A. Klute (ed.) Methods of Soil Analysis. 2nd edition. No. 9 Agronomy. American Society of Agronomy, Madison, WI.

American Society of Agricultural Engineers (ASAE). 1999. Procedures for Using and Reporting Data with the Soil Cone Penetrometer. ASAE Standard EP542. American Society of Agricultural Engineers: St. Joseph, MI.

American Society of Agricultural and Biological Engineers (ASABE). 2004. Soil Cone Penetrometer. ASAE Standard S313.3. American Society of Agricultural Engineers: St. Joseph, MI.

Asleson, B.C., Nestingen, R.S., Gulliver, J.S., Hozalski, R.M., Nieber, J.L. 2009. Performance assessment of rain gardens. *Journal of the American Water Resources Association*. 45(4): 1019-1031.

ASTM International. 2007. ASTM D422-63(2007)e2, Standard Test Method for Particle-Size Analysis of Soils, West Conshohocken, PA. Withdrawn in 2016.

ASTM International. 2009. ASTM C1701 / C1701M-09, Standard Test Method for Infiltration Rate of In Place Pervious Concrete, West Conshohocken, PA. .

ASTM International. 2009. ASTM D3385-09, Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer, West Conshohocken, PA.

ASTM International. 2009. ASTM D6913-04(2009)e1, Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis, West Conshohocken, PA.

ASTM International. 2009. ASTM D7263-09, Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens, West Conshohocken, PA.

ASTM International. 2010. ASTM D2937-10, Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method, West Conshohocken, PA.

ASTM International. 2010. ASTM D5126 / D5126M-90(2010)e1, Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in Vadose Zone, West Conshohocken, PA.

ASTM International. 2010. ASTM D7503-10, Standard Test Method for Measuring the Exchange Complex and Cation Exchange Capacity of Inorganic Fine-Grained Soils, West Conshohocken, PA.

ASTM International. 2013. ASTM D4972-13, Standard Test Method for pH of Soils, West Conshohocken, PA.

ASTM International. 2014. ASTM D2974-14, Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils, West Conshohocken, PA.

ASTM International. 2015. ASTM C1781/C1781M-15, Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems, West Conshohocken, PA

ASTM International. 2015. ASTM D2167-15, Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method, West Conshohocken, PA.

ASTM International. 2015. ASTM E2399/E2399M-15, Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetated (Green) Roof Systems, West Conshohocken, PA.

ASTM International. 2015. ASTM E2400/E2400M-06 (2015)e1, Standard Guide for Selection, Installation and Maintenance of Plants for Green Roof Systems. West Conshohocken, PA.

ASTM International. 2015. ASTM D5093-15, Standard Test Method for Field Measurement of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring, West Conshohocken, PA.

ASTM International. 2015. ASTM D6640-01(2015), Standard Practice for Collection and Handling of Soils Obtained in Core Barrel Samplers for Environmental Investigations, West Conshohocken, PA.

ASTM International. 2015. ASTM D6938-15, Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth), West Conshohocken, PA.

ASTM International. 2015. ASTM D6951/D6951M-09(2015) Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications, West Conshohocken, PA.

ASTM International. 2015. ASTM D7380-15, Standard Test Methods for Soil Compaction Determination at Shallow Depths Using a 5 lb (2.3 kg) Dynamic Cone Penetrometer, West Conshohocken, PA.

ASTM International. 2016. ASTM D7928-16, Standard Test Methods for Particle Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis, West Conshohocken, PA.

Berghage, R., Wolf. A., Miller, C. 2008. *Testing Green Roof Media for Nutrient Content*. Presented at Greening Rooftops for Sustainable Communities, held in Baltimore, MD from April 30 to May 2, 2008.

Bray, R.H. and Kurtz, L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59: 39-45.

Busman, L., Nalepa, P., Dobryniewska, M. 2009. The nature of phosphorous in soils, University of Minnesota Extension (2009) WW-06795- 576

Canadian Standards Association (CSA). 2011. CSA Standards B184 Series-11 Polymeric subsurface stormwater management structures. Mississauga, ON.

Center for Watershed Protection (CWP). 2008. Managing Stormwater in Your Community – A Guide for Building and Effective Post-Construction Program. U.S. EPA Publication No: 833-R08-001. Ellicott City, MD.

Center for Watershed Protection (CWP). 2009. Stormwater BMPs in Virginia's James River Basin: An Assessment of Field Conditions & Programs. Ellicott City, MD.

Chesapeake Stormwater Network (CSN). 2013. Bioretention Illustrated: A Visual Guide for Constructing, Inspecting, Maintaining and Verifying the Bioretention Practice. CSN Technical Bulletin No. 10. Version 2.0. Ellicott City, MD.

City of Edmonton. 2011. Low Impact Development Best Management Practices Design Guide. Edition1.0. Edmonton, AB.

City of Philadelphia. 2014. Green City, Clean Waters: Comprehensive Monitoring Plan. The Philadelphia Water Department. Philadephia, PA.

City of Toronto. 2010. Toronto Green Roof Construction Standard Supplementary Guidelines. Toronto, ON.

Combs, S.M. and Nathan,M.V. 2012. "Soil Organic Matter." In Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Research Publication No. 221. Missouri Agricultural Experimental Station.

Craul, P.J. 1999. Urban Soils: Applications and Practices. John Wiley & Sons, New York.

Credit Valley Conservation and Toronto and Region Conservation (CVC & TRCA). 2010. Low Impact Development Stormwater Management Planning and Design Guide. Toronto, ON.

Credit Valley Conservation (CVC). 2010. Policies and Administrative Approaches to Overcoming Institutional Barriers to Low Impact Development. Mississauga, ON.

Credit Valley Conservation (CVC). 2012. Low Impact Development Construction Guide. Mississauga, ON.

Credit Valley Conservation (CVC). 2014a. Grey to Green Business & Multi-Residential Retrofits: Optimizing Your Infrastructure Assets Through Low Impact Development. Mississauga, ON.

Credit Valley Conservation (CVC). 2014b. Grey to Green Road Retrofits: Optimizing Your Infrastructure Assets Through Low Impact Development. Mississauga, ON.

Daddow, R.L. and Warrington, G.E. 1983. Growth-limiting bulk densities as influenced by soil texture. WSDG Report WSDG-TN-00005 Watershed Systems Development Group, USDA Forest Service.

Despins, C. 2010. Ontario Guidelines for Residential Rainwater Harvesting Systems Handbook. University of Guelph. Guelph, ON.

Drake, J. Guo, Y. 2008. Maintenance of Wet Stormwater Ponds in Ontario. *Canadian Water Resources Journal*. 33 (4): 351-368.

Eijkelkamp Agrisearch Equipment. 2014. Penetrologger Operation Instructions. Giesbeek, the Netherlands. October 2014.

Erickson, A.J., Weiss, P.T., Gulliver, J.S. 2013. Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance. New York: Springer.

Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL). 2008. *Guidelines for the Planning, Execution and Upkeep of Green-roof Sites*. The Landscaping and Landscape Development Research Society E.V., Bonn, Germany.

Frank, K., Beegle, D., Denning, J. 2012. "Phosphorus" In Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Research Publication No. 221. Missouri Agricultural Experimental Station.

Geosyntec Consultants and Wright Water Engineers. 2009.Urban Stormwater BMP Performance Monitoring.

Green Roofs for Healthy Cities. 2011. Advanced Green Roof Maintenance: Participant's Manual. Toronto, ON.

Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., van Es, H.M., Wolfe, D.W., Moebius, B.N., Thies, J.E., Abawi, G.S. 2009. Cornell Soil Health Assessment Training Manual, Edition 2.0, 2009, Cornell University, College of Agriculture and Life Sciences, New York State Agricultural Experiment Station(NYSAES), Geneva, New York. ISBN 0-9676507-4-7.

Herrera Environmental Consultants and Washington Stormwater Center. 2013. Western Washington Low Impact Development (LID) Operation and Maintenance (O&M). Washington State Department of Ecology. Olympia, WA.

Herrick, J.E. and Jones, T.L. 2002. A dynamic cone penetrometer for measuring soil penetration resistance. *Soil Science Society of America Journal* **66**: 1320-1324.

King County. 2010. King County Drainage Maintenance Standards Booklet. Seattle, WA.

Klute, A. 1986. Methods of soil analysis, Part I. Physical and mineralogical methods, 2nd edition. Soil Science Society of America. Madison, WI.

Lake Simcoe Region Conservation Authority (LSRCA). 2011. Stormwater Pond Maintenance and Anoxic Conditions Investigation. Final Report. Newmarket, ON.

McLachlin, I. 2016. Personal communication. June 29, 2016.

Minnesota Pollution Control Agency (MPCA). 2015. Minnesota Stormwater Manual. http://stormwater.pca.state.mn.us/index.php/Main_Page. Accessed April 15, 2015.

Olsen, S.R., Cole, C.V., Watanabe, F.S., and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939:1-19. Gov. Printing Office Washington D.C.

Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). 2006. Soil Fertility Handbook. Publication #611. Toronto, Ontario.

Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). 2014. Guide to Nursery and Landscape Plant Production and IPM. Publication #841. Toronto, Ontario.

Ontario Ministry of the Environment (OMOE). 2011. Soil, Ground Water and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act. PIBS # 7382e01. Toronto, Ontario.

Ontario Ministry of Municipal Affairs and Housing (OMMAH). 1997. Supplementary Guidelines to the Ontario Building Code 1997. SG-6 Percolation Time and Soil Descriptions. Toronto, Ontario.

Oregon State University Stormwater Solutions. 2013. Field Guide: Maintaining Rain Gardens, Swales and Stormwater Planters. Corvallis, OR.

Permeable Pavements Task Committee. 2015. Permeable Pavements. Edited by Eisenberg, B., Collins Lindow, K., and Smith, D.R., American Society of Civil Engineers (ASCE), Reston, VA.

Reynolds, W.D. and Elrick, D.E. 1991. Determination of hydraulic conductivity using a tension infiltrometer. Soil Science Society of America Journal. 55(3):633-639.

Seattle Public Utilities. 2009. Stormwater Manual Volume 3 – Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual. Seattle, WA.

Soil Moisture Equipment Corporation. 1986. Guelph permeameter 2800ki operating instructions. Revision 8/86. Santa Barbara, CA.

Sustainable Technologies Evaluation Program (STEP). 2016. Low Impact Development Costing Tool Version 2.0. <http://www.sustainabletechnologies.ca/wp/home/urban-runoff-green-infrastructure/low-impact-development/low-impact-development-life-cycle-costs/>. Accessed July, 2016.

Toronto and Region Conservation Authority (TRCA). 2012. Preserving and Restoring Healthy Soil: Best Practices for Urban Construction. Toronto, ON.

Toronto and Region Conservation Authority and University of Toronto (TRCA & U of T). 2013a. Assessment of Life Cycle Costs for Low Impact Development Stormwater Management Practices. Toronto, ON.

Toronto and Region Conservation Authority and CH2M (TRCA & CH2M). 2016. Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands. Toronto, ON.

Toronto and Region Conservation Authority and University of Toronto (TRCA & U of T). 2013b. Low Impact Development Costing Tool. Version 1.1. Toronto, ON.

United States Department of Agriculture (USDA). 2002. 05.07A *Test Methods for the Examination of Composts and Composting*. Holbrook, NY: Composting Council Research and Education Foundation.

United States Department of Agriculture (USDA). 2005. Hand-Held Electronic Cone Penetrometers for Measuring Soil Strength. 2E22E60—Soil Strength Tester. USDA Forest Service Technology and Development Program. Missoula, MT.

United States Department of Agriculture (USDA). 2015. Glossary of Terms. http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/?cid=nrcs142p2_053848. Accessed February, 2015.

United States General Services Administration (US GSA). 2011. The Benefits and Challenges of Green Roofs on Public and Commercial Buildings. 140 pp.

Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils—effect of variations in digestion conditions and of inorganic soil constituents. Soil Science. 63:251-264.

Warnacke, D. 1995. "Recommended Test Procedures for Greenhouse Growth Media." In J. Thomas Sims and A. Wolf, eds., Recommended Soil Testing Procedures for the Northeastern United States. Northeast Regional Bulletin #493. Newark: Agricultural Experiment Station, University of Delaware.

Warrick, A.W., Nielsen, D.R. 1980. Spatial variability of soil physical properties in the field. In: Hillel, D. (ed) Applications of soil physics. Academic Press, New York, pp 319-344.

Washington State Department of Ecology (WS DOE). 2011. Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies. Publication No. 11-10-061. Technology Assessment Protocol – Ecology. Water Quality Program. Olympia, WA.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology* **30**: 377–392.

Whitney, D.A. 2012. "Soil Salinity." In Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Research Publication No. 221. Missouri Agricultural Experimental Station.

Wright, T. 2016, Personal communication. June 28, 2016.

Zhang, R. 1997. Determination of soil sorptivity and hydraulic conductivity form the disk infiltrometer. Soil Science Society of America Journal. 61: 1024-1030.

Zizzo, L.L., Allan, T., Kocherga, A. 2014. Stormwater Management in Ontario: Legal Issues In a Changing Climate – A Report for the Credit Valley Conservation Authority. Toronto, ON.

LOW IMPACT DEVELOPMENT
STORMWATER MANAGEMENT PRACTICE
INSPECTION AND MAINTENANCE GUIDE

VERSION 1.0

2016

Sustainable Technologies Evaluation Program
www.sustainabletechnologies.ca

Toronto and Region Conservation for The Living City

APPENDIX A

ACCREDITED SOIL TESTING LABORATORIES IN ONTARIO

Laboratory Name	**Address**	**Telephone/Fax**
A & L Canada Laboratories Inc.	2136 Jetstream Road, London, Ont. N5V 3P5	tel: (519) 457-2575 fax: (519) 457-2664 aginfo@alcanada.com
Activation Laboratories Ltd.	1480 Sandhill Dr., Unit 9, Ancaster, ON, L9G 4V5	tel: 289-204-0515 ext. 102/104 fax: 289-204-0514 Laboratory@ActLabsAg.com
Brookside Laboratories, Inc.	200 White Mountain Drive, New Bremen, OH 45869	tel: (419) 977-2766 fax: (419) 977-2767 jbrackman@blinc.com
Exova Accutest Laboratory	8-146 Colonnade Road, Ottawa, Ont., K2E 7Y1	tel: (613) 727-5692, x.317 fax: (613) 727-5222 lorna.wilson@exova.com
FoReST Laboratory	955 Oliver Road, BB1005D, Thunder Bay, ON P7B 5E1	tel: (807) 343-8639 fax: (807) 343-8116 forestlab@lakeheadu.ca
SGS Agrifood Laboratories	503 Imperial Road, Unit #1, Guelph, Ont. N1H 6T9	tel: (519) 837-1600 or 1-800-265-7175 fax: (519) 837-1242 lab@agtest.com
Stratford Agri-Analysis	1131 Erie St., Box 760, Stratford, Ont., N5A 6W1	tel: (519) 273-4411 or 1-800-323-9089 fax: (519) 273-2163 info@stratfordagri.ca
University of Guelph, Laboratory Services	University of Guelph, P.O. Box 3650, 95 Stone Rd., West, Guelph, Ont. N1H 8J7	tel: (519) 767-6299 fax: (519) 767-6240 aflinfo@uoguelph.ca

APPENDIX B

ACCREDITED WATER TESTING LABORATORIES IN ONTARIO

Laboratory Name	**Address**	**Telephone/Fax**	**Accept Outside Clients?**
Accuracy Environmental Laboratories Ltd.	1470 Government Road W, Kirkland Lake, ON P2N 3J1	Hannah Hill Phone: 705-642-3361 Fax: 705-642-3222 Customer.service@aelabs.com	Yes
AGAT Laboratories Ltd.	535 Coopers Ave., Mississauga, ON L4Z 1Y2	Mary Katalayi Phone: 905-712-5100 Fax: 905-712-5122 katalayi@agatlabs.com	Yes
ALS Laboratory Group (Environmental Division) – Burlington	1435 Norjohn Crt, Unit 1 Burlington, ON L7L 0E6	Ron Mcleod Phone: 905-331-3111 Fax: 905-311-4567 Ron.mcleod@alsglobal.com	Yes
ALS Laboratory Group (Environmental Division) – Thunder Bay	1081 Barton St., Thunder Bay, ON P7B 5N3	Tricia Sampson Phone: 807-623-6463 Fax: 807-623-7598 Tricia.sampson@alsglobal.com	Yes
ALS Laboratory Group (Environmental Division) – Waterloo	60 Northland Rd, Unit 1, Waterloo, ON N2V 2B8	Glenna Pike Phone: 519-886-6910 Fax: 519-886-9047 Glenna.pike@alsglobal.com	Yes
Caduceon Environmental Laboratories – Kingston	285 Dalton Avenue, Kingston, ON K7M 6Z1	Michelle Dubien Phone: 613-544-2001 Fax: 613-544-2770 mdubien@caduceonlabs.com	Yes
Caduceon Environmental Laboratories – Ottawa	2378 Holly Lane, Ottawa, ON K1V 7P1	Greg Clarkin Phone: 613-526-0123 Fax: 613-526-1244 gclarkin@caduceonlabs.com	Yes

Laboratory Name	Address	Telephone/Fax	Accept Outside Clients?
Caduceon Environmental Laboratories – Richmond Hill	110 West Beaver Creek Rd, Suite 14, Richmond Hill, ON L4B 1J9	Christine Burke Phone: 289-475-5442 Fax: 866-562-1963 cburke@caduceonlabs.com	Yes
City of Hamilton Environmental Laboratory	700 Woodward Ave, Hamilton, ON L8H 6P4	Lien Dang Phone: 905-546-2424 ext 1145 Fax : 905-545-0234 Lien.dang@hamilton.ca	No
City of Ottawa Laboratory Services	800 Green Creek Drive, Gloucester, ON K1J 1A6	Michael Ziebell Phone:613-580-2424 x 22836 Fax: 613-745-2030 Michael.ziebell@ottawa.ca	No
Exova Canada Ltd. – Ottawa	146 Colonnade Rd, Suite 8, Ottawa, ON K2E 7Y1	Krista Quantrill Phone : 613-727-5692 ext 325 Fax : 613-727-5222 Krista.quantill@exova.ca	Yes
Maxxam Analytics Inc.	6740 Campobello Road, Mississauga, ON L5N 2L8	James Aspin Phone: 905-817-5771 Fax: 905-817-5777 jaspin@maxxam.ca	Yes
Ontario Ministry of the Environment and Climate Change	125 Resources Road, Etobicoke, ON M9P 3V6	Janet Mills Phone: 416-235-5831 Janet.mills@ontario.ca	No
Paracel Laboratories Ltd.	#300-2319 St. Laurent Blvd. Ottawa, ON K1G 4J8	Dale Roberston Phone: 613-731-9577 Fax: 613-731-9064 drobertson@paracellabs.com	Yes

Laboratory Name	Address	Telephone/Fax	Accept Outside Clients?
Regional Municipality of Waterloo, Environmental Laboratory	100 Maple Grove Road, Cambridge, ON N3H 4R6	AnnMarie Wright Phone: 519-650-8266 Fax: 519-650-8270 awright@regionofwaterloo.ca	No
SGS Environmental Services - Lakefield	185 Concession Street, Lakefield, ON L0L 2H0	Joanne Williams Phone: 705-652-2000 Fax: 705-652-6365 Joanne.williams@sgs.com	Yes
Testmark Laboratories Ltd. – Sudbury	7 Margaret Street, Garson, ON P3L 1E1	Customer Service Phone: 705-693-1121 Fax: 705-693-1124 Customer.service@testmark.ca	Yes
Testmark Laboratories Ltd. – Mississauga	6820 Kitimat Road, Unit 4, Mississauga, ON L5N 5M3	Customer Service Phone: 905-821-1112 Fax: 905-821-2095 Barrett.beaudoin@testmark.ca	Yes
Toronto Water Laboratory – Central Laboratory	545 Commissioners Street, Toronto, ON M4M 1A5	Water Quality Inquiries Phone: 311 Fax: 416-392-9134	No
York-Durham Regional Environmental Laboratory	901 McKay Road, Pickering, ON L1W 3A3	Renu Joshi Phone:905-686-0041 ext 4325 Fax: 905-686-0664 Renu.joshi@durham.ca	Yes

APPENDIX C

VISUAL INDICATOR PROTOCOLS

C.1 CONTRIBUTING DRAINAGE AREA CONDITION

Construction Inspection ✓ Assumption ✓ Routine Maintenance and Inspection ✓ Maintenance Verification ✓ **CONTRIBUTING DRAINAGE AREA**

Contributing drainage area is the total area that drains to the BMP. Compare conditions with design or as-built drawings to look for changes in size or land cover. Also look for evidence of surface ponding, accumulation of sediment and debris and point sources of contaminants (e.g. absent or failing ESCs, leaking waste containers, spills).

Bioretention and Dry Swales

PASS: CDA has not changed in size or land cover. Sediment, trash or debris is not accumulating and point sources of contaminants are not visible.

FAIL: Size of the CDA has changed from design assumptions. A point source for contaminants is visible (i.e. lack of sediment controls on adjacent construction site). (Source: NCCE)

MAINTENANCE TRIGGER: Excessive sediment, trash, debris or other pollutant load is impairing the function of the BMP or point sources are visible. The size of the CDA differs from design or as-built drawings by 10% or more, or land cover has changed.

FOLLOW-UP TASKS: Sweep paved areas to remove accumulated sediment, trash and debris or clean out roof eavestroughs. Revegetate or mulch bare soil areas. Improve or install erosion and sediment control or flow diversion practices to address sediment load from destabilized areas. Address any point sources of contaminants. Consider increasing frequency of routine maintenance.

Enhanced Swales

PASS: CDA has not changed in size or land cover. Sediment, trash or debris is not accumulating and point sources of contaminants are not visible.

FAIL: Ponding and sediment accumulation on the CDA is visible indicating runoff is not freely entering the BMP and that the pavement has not been swept recently.

MAINTENANCE TRIGGER: Excessive sediment, trash, debris or other pollutant load is impairing the function of the BMP or point sources are visible. The size of the CDA differs from design or as-built drawings by 10% or more, or land cover has changed.

FOLLOW-UP TASKS: Sweep paved areas to remove accumulated sediment, trash and debris or clean out roof eavestroughs. Revegetate or mulch bare soil areas. Address any point sources of contaminants. Improve or install erosion and sediment control or flow diversion practices to address sediment load from destabilized areas. Consider increasing frequency of routine maintenance.

Vegetated Filter Strips/Soil Amendment Areas

PASS: CDA has not changed in size or land cover. Sediment, trash or debris is not accumulating and point sources of contaminants are not visible. (Source: CSN)

FAIL: Size of the CDA or land cover within it has changed from design assumptions. Accumulation of sediment on the CDA is visible.

MAINTENANCE TRIGGER: Excessive sediment, trash, debris or other pollutant load is impairing the function of the BMP or point sources are visible. The size of the CDA differs from design or as-built drawings by 10% or more, or land cover has changed.

FOLLOW-UP TASKS: Sweep paved areas to remove accumulated sediment, trash and debris or clean out roof eavestroughs. Revegetate or mulch bare soil areas. Address any point sources of contaminants. Improve or install erosion and sediment control or flow diversion practices to address sediment load from destabilized areas. Consider increasing frequency of routine maintenance.

Permeable Pavements

PASS: CDA has not changed in size or land cover. Sediment, trash or debris is not accumulating and point sources of contaminants are not visible.

FAIL: Size of the CDA has changed from design assumptions (i.e. large asphalt area drains to a small portion of the permeable pavement). Evidence of surface ponding is visible.

MAINTENANCE TRIGGER: Excessive sediment, trash, debris or other pollutant load is impairing the function of the BMP or point sources are visible. The size of the CDA differs from design or as-built drawings by 10% or more, or land cover has changed.

FOLLOW-UP TASKS: Sweep paved areas to remove accumulated sediment, trash and debris or clean out roof eavestroughs. Revegetate or mulch bare soil areas. Address any point sources of contaminants. Improve or install erosion and sediment control or flow diversion practices to address sediment load from destabilized areas. Consider increasing frequency of routine maintenance.

Underground Infiltration Systems

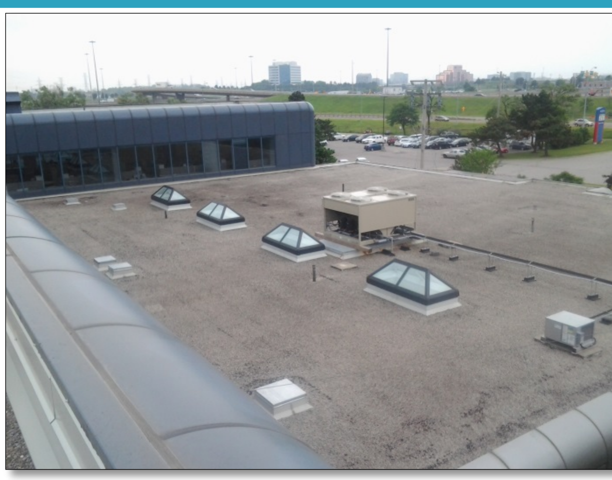
PASS: CDA has not changed in size or land cover. Sediment, trash or debris is not accumulating and point sources of contaminants are not visible.

FAIL: Point sources of contamination are present (i.e. accumulated sediment and debris from melted snow piles).

MAINTENANCE TRIGGER: Excessive sediment, trash, debris or other pollutant load is impairing the function of the BMP or point sources are visible. The size of the CDA differs from design or as-built drawings by 10% or more, or land cover has changed.

FOLLOW-UP TASKS: Sweep paved areas to remove accumulated sediment, trash and debris or clean out roof eavestroughs. Revegetate or mulch bare soil areas. Address any point sources of contaminants. Improve or install erosion and sediment control or flow diversion practices to address sediment load from destabilized areas. Consider increasing frequency of routine maintenance.

Rainwater Cisterns



PASS: CDA has not changed in size from design assumptions. Sediment, trash or debris is not accumulating and point sources of contaminants are not visible.

FAIL: Sediment and debris is accumulating on the CDA due to deteriorating roof shingles. Eavestroughs need cleaning.

MAINTENANCE TRIGGER: Excessive sediment, trash, debris or other pollutant load is impairing the function of the BMP or point sources are visible. The size of the CDA differs from design or as-built drawings by 10% or more.

FOLLOW-UP TASKS: Remove accumulated sediment, trash and debris from roof area and clean out eavestroughs or roof drain covers. Address any point sources of contaminants. Trim back any tree branches hanging over the roof area. Consider increasing frequency of routine maintenance.

C.2 INLET STRUCTURAL INTEGRITY

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓ | **INLET**

Look for signs of damage to, or displacement of the structure(s), missing or broken catchbasin grates or trash racks, or excessive filter bed erosion at the inlets. Confirm pavement and curb elevations are acceptable

Bioretention and Dry Swales

PASS: There is no evidence of damage or displacement of the inlet structure that would prevent runoff from freely entering the BMP.

FAIL: The inlet structure has been damaged or displaced and requires repair. (Source: CSN)

MAINTENANCE TRIGGER: Damage to, or displacement of the structure(s) prevents or impairs the flow of stormwater into the BMP. Catchbasin grate(s) or trash rack(s) are missing or damaged. Erosion gullies ≥ 30 cm in length are visible on the filter bed.

FOLLOW-UP TASKS: Replace catchbasin grate(s) or trash rack(s). Repair damaged or displaced structure(s) and erosion gullies. If excessive erosion persists, consider adding flow spreader (e.g. gravel diaphragm, check dam) or forebay (e.g. geotextile and stone) at inlet(s) to help spread and slow the flow of water before it reaches the filter bed.

Enhanced Swales

PASS: There is no evidence of damage or displacement of the inlet structure and no erosion gullies on the filter bed.

FAIL: Excessive erosion at the inlet is visible and undermining the integrity of the adjacent pavement. (Source: CSN)

MAINTENANCE TRIGGER: Damage to, or displacement of the structure(s) prevents or impairs the flow of stormwater into the BMP. Catchbasin grate(s) or trash rack(s) are missing or damaged. Erosion gullies ≥ 30 cm in length are visible on the filter bed.

FOLLOW-UP TASKS: Replace catchbasin grate(s) or trash rack(s). Repair damaged or displaced structure(s) and erosion gullies. If excessive erosion persists, consider adding flow spreader (e.g. gravel diaphragm, check dam) or forebay (e.g. geotextile and stone) at inlet(s) to help spread and slow the flow of water before it reaches the filter bed.

Vegetated Filter Strips/Soil Amendment Areas

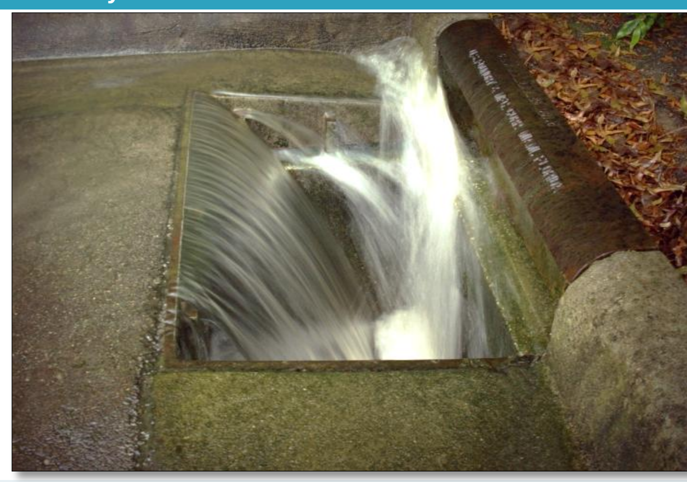
PASS: There is no evidence of damage to the gravel diaphragm inlet that would prevent runoff from entering the BMP nor excessive erosion of the filter bed. (Source: Aquafor Beech)

FAIL: Splash pad has been displaced and could lead to excessive erosion of the filter bed.

MAINTENANCE TRIGGER: Damage to, or displacement of the structure(s) prevents or impairs the flow of stormwater into the BMP. Flow spreading/energy dissipating structures (e.g. splash pads, gravel diaphragms) are missing or displaced.

FOLLOW-UP TASKS: Repair damaged or displaced structures (e.g. sunken pavement, damaged curb or flow spreader) and erosion gullies. If excessive erosion persists, consider adding flow spreader (e.g. gravel diaphragm) if not already present or re-grading the CDA to distribute flow to the BMP more evenly.

Underground Infiltration Systems



PASS: There is no evidence of damage or displacement of the inlet that would prevent runoff from freely entering the BMP.

FAIL: The catchbasin cover is missing, creating dangerous conditions and allowing large debris to enter the BMP. (Flickr Hive Mind).

MAINTENANCE TRIGGER: Damage to, or displacement of the structure(s) prevents or impairs the flow of stormwater into the BMP. Catchbasin grate(s) or trash rack(s) are missing or damaged.

FOLLOW-UP TASKS: Replace catchbasin grate(s) or trash rack(s). Repair damaged or displaced structure(s).

Rainwater Cisterns

PASS: Inlet pipe and couplings are securely connected to the CDA and cistern. (Source: Lake County SMC)

FAIL: The roof downspout is disconnected from the eavestrough, preventing runoff from entering the cistern.

MAINTENANCE TRIGGER: Damage to, or displacement of the structure(s) prevents or impairs the flow of stormwater into the BMP.

FOLLOW-UP TASKS: Repair damaged or displaced structures (e.g. eavestroughs, pipes, overflow diverters).

C.3 INLET OBSTRUCTION

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓ | INLET

Check inlets to ensure nothing is obstructing flow of stormwater into the BMP. An obstruction can be due to damaged or displaced structures (e.g. heaved or sunken curb or pavement) or accumulated sediment, trash, debris or vegetation in the inlet, pretreatment device or on the filter bed. Measure sediment depth.

Bioretention and Dry Swales

PASS: There are no obstructions at the inlet and stormwater can freely flow into the BMP.

FAIL: Accumulated sediment and vegetation is preventing stormwater from entering the BMP. Sediment on the pavement surface in front of the inlet indicates ponding is occurring.

MAINTENANCE TRIGGER: Sediment, trash, debris is ≥ 5 cm deep. Sediment, trash, debris or vegetation is blocking inflow over one third (33%) of the inlet width or area.

FOLLOW-UP TASKS: Remove or repair the obstruction. Re-grade at the inlet to provide a 5 cm drop in elevation between pavement edge and pretreatment device or filter bed surface.

Enhanced Swales

PASS: There are no obstructions at the inlet and stormwater can freely flow into the BMP.

FAIL: Accumulated sediment and vegetation is preventing stormwater from entering the BMP. Sediment on the pavement surface in front of the inlet indicates ponding is occurring.

MAINTENANCE TRIGGER: Sediment, trash, debris is ≥ 5 cm deep. Sediment, trash, debris or vegetation is blocking inflow over one third (33%) of the inlet width or area.

FOLLOW-UP TASKS: Remove or repair the obstruction. Regrade at the inlet to provide a 5 cm drop in elevation between pavement edge and pretreatment device or BMP surface.

Vegetated Filter Strips/Soil Amendment Areas

PASS: There are no obstructions at the inlet and stormwater can freely flow into the BMP as sheet flow from the pavement and gravel diaphragm. (Source: CSN).

FAIL: Concrete barriers are preventing stormwater from entering the BMP as sheet flow from the pavement. Sediment has accumulated at the inlet edge of the BMP.

MAINTENANCE TRIGGER: Sediment, trash, debris is ≥ 5 cm deep. Sediment, trash, debris or vegetation is blocking inflow over one third (33%) of the width edge.

FOLLOW-UP TASKS: Remove or repair the obstruction. Re-grade the width edge to provide a 5 cm drop in elevation between pavement edge and top of the flow spreader or BMP surface.

Underground Infiltration Systems

PASS: There are no obstructions at the inlet and stormwater can freely flow into the BMP.

FAIL: Sediment has accumulated in the inlet pipe to the infiltration trench and is fully obstructing flow of stormwater into the BMP.

MAINTENANCE TRIGGER: Sediment, trash, debris is ≥ 5 cm deep. Sediment, trash, debris or vegetation is blocking inflow over one third (33%) of the inlet width or area.

FOLLOW-UP TASKS: Remove or repair the obstruction. A vacuum truck service will be needed to clear obstructed inlet pipes.

Rainwater Cisterns

PASS: There are no obstructions at the inlet and stormwater can freely flow into the BMP	**FAIL:** Accumulated sediment and debris is blocking inflow over greater than one third of the inlet width and preventing stormwater from freely entering the BMP.

MAINTENANCE TRIGGER: Sediment, trash, debris is ≥ 5 cm deep. Sediment, trash or debris is blocking inflow over one third (33%) of the inlet width or area.

FOLLOW-UP TASKS: Remove or repair the obstruction.

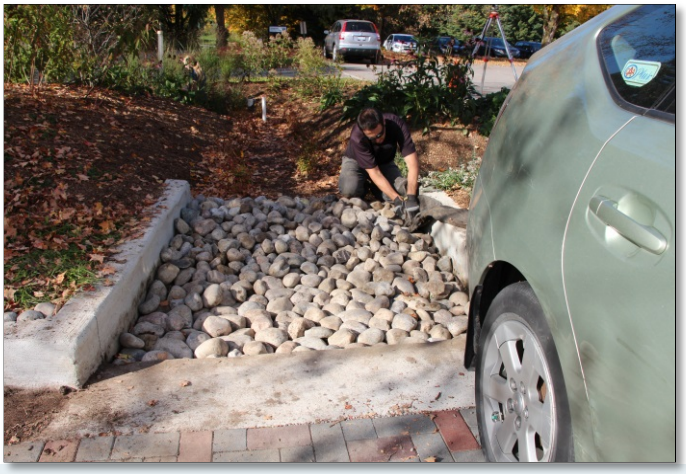
C.4 PRETREATMENT SEDIMENT ACCUMULATION

Construction Inspection ✓ Assumption ✓ Routine Maintenance and Inspection ✓ Maintenance Verification

INLET

Pretreatment devices (e.g. filter strips, forebays, gravel diaphragms, check dams, catchbasin baffles/sumps, filters) slow down and spread out inflowing water and retain coarse sediment, trash and debris. Confirm the device still exists and whether it needs to be cleaned out. Measure sediment depth and compare to last inspection

Bioretention and Dry Swales



PASS: Forebay is free of sediment , trash and debris. Stones to slow down and spread out inflowing water remain in place.

FAIL: Forebay has accumulated sediment and vegetation is growing in it which is impairing its function and preventing stormwater from freely entering the BMP.

MAINTENANCE TRIGGER: Pretreatment device is ≥ 50% full of sediment, trash or debris. Accumulation of sediment is preventing or impairing flow of water into the BMP.

FOLLOW-UP TASKS: Remove sediment, trash and debris. Check for signs of oil or grease contamination (e.g. sheen on surface of water when submerged). If oil or grease contamination is suspected, submit a sediment sample for contaminant testing by an accredited laboratory to determine the proper disposal method. Replace geotextile in forebays every 3 years. If ≥50% full, consider increasing the frequency of CDA sweeping or pretreatment device cleaning.

Enhanced Swales

PASS: The grass filter strip pretreatment is free of sediment, trash and debris. (Source: Abbey and Associates).

FAIL: Sediment and debris has accumulated in the forebay and is preventing stormwater from flowing into the BMP.

MAINTENANCE TRIGGER: Pretreatment device is ≥ 50% full of sediment, trash or debris. Accumulation of sediment is preventing or impairing flow of water into the BMP.

FOLLOW-UP TASKS: Remove sediment, trash and debris. Replace geotextile in forebays every 3 years. If ≥ 50% full, consider increasing the frequency of CDA sweeping or pretreatment device cleaning.

Underground Infiltration Systems

PASS: Geotextile-lined stone inlet is free of sediment , trash and debris. Stones to slow down and spread out inflowing water remain in place.

FAIL: Accumulated sediment, trash and debris in the hydrodynamic (i.e., oil and grit) separator is occupying greater than 50% of its storage capacity. (Source: SWC Canada)

MAINTENANCE TRIGGER: Pretreatment device is ≥ 50% full of sediment, trash or debris. Accumulation of sediment is preventing or impairing flow of water into the BMP.

FOLLOW-UP TASKS: Remove sediment, trash and debris. If ≥ 50% full, consider increasing the frequency of CDA sweeping or pretreatment device cleaning.

Rainwater Cisterns

PASS: The pretreatment filter of the cistern is free of sediment and debris.

FAIL: The pretreatment filter on the roof downspout is partially covered by debris which could prevent stormwater from freely entering the BMP (Source: DMR).

MAINTENANCE TRIGGER: Pretreatment device is ≥ 50% full of sediment, trash or debris. Accumulation of sediment is preventing or impairing flow of water into the BMP.

FOLLOW-UP TASKS: Remove sediment, trash and debris. If ≥ 50% full, consider increasing the frequency of eavestrough or pretreatment device cleaning.

C.5 INLET EROSION

Construction Inspection ✓ Assumption ✓ Routine Maintenance and Inspection ✓ Maintenance Verification

INLET

Look for bare soil areas and signs of excessive soil erosion (e.g. rills or gullies) or mulch/stone displacement at the inlet(s)

Bioretention and Dry Swales

PASS: No signs of soil erosion are visible on the filter bed immediately downstream of the inlet and no stones have been displaced from the forebay.

FAIL: Erosion gully and bare soil is visible on the grass filter strip pretreatment at the inlet indicating it is not sufficiently slowing and spreading out the inflow of stormwater to the BMP.

MAINTENANCE TRIGGER: Erosion gullies or bare soil areas ≥ 30 cm in length are visible. There are clear signs of frequent surface ponding on the filter bed surface at the inlet (e.g. dying vegetation, sediment accumulation). Mulch depth is <7.5 cm.

FOLLOW-UP TASKS: Repair erosion gullies. Restore vegetation and mulch cover or replace with stone cover. Redistribute or replenish mulch cover where missing or displaced. Where problems persist, consider adding a flow spreading device (e.g. check dam, gravel diaphragm), turf reinforcement.

Enhanced Swales

PASS: No erosion gullies or bare soil present at the inlet.

FAIL: Erosion gullies and bare soil areas are visible on the swale surface at the inlet.

MAINTENANCE TRIGGER: Erosion gullies or bare soil areas ≥ 30 cm in length are visible. There are clear signs of frequent surface ponding on the filter bed surface at the inlet (e.g. dying vegetation, sediment accumulation).

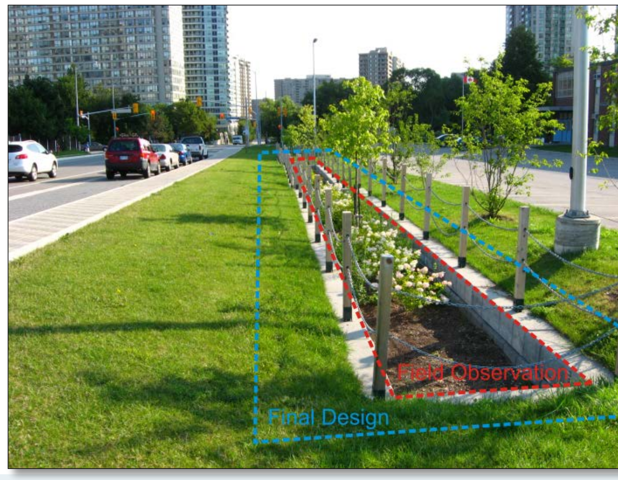
FOLLOW-UP TASKS: Repair erosion gullies. Restore vegetation or mulch cover or replace with stone cover. Where problems persist, consider adding a flow spreading device (e.g. check dam, gravel diaphragm) or turf reinforcement.

C.6 BMP DIMENSIONS

Construction Inspection ✓ | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓ | **PERIMETER**

Confirm that the dimensions of the BMP are acceptable. Undersized BMP's may not meet SWM criteria or may require more maintenance. For underground practices, this indicator can only be assessed during construction and prior to backfilling. Measure dimensions (i.e. length, width, depth) with a measuring tape or wheel and compare to final design, as-built drawings or the last inspection. For soil amendments, estimate the depth of uncompacted topsoil present with a soil corer and cone penetrometer to confirm areas where the BMP was implemented.

Bioretention and Dry Swales



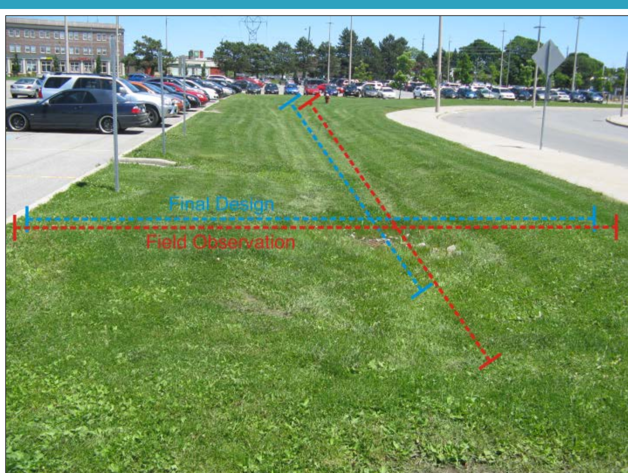
PASS: The footprint area of the BMP does not significantly deviate from the final design and should not negatively affect its stormwater management treatment performance.

FAIL: The footprint area of the BMP is significantly smaller than what was specified in the final design.

MAINTENANCE TRIGGER: Dimensions differ from design or as-built drawing by >10%.

FOLLOW-UP TASKS: Check if a maintenance easement exists or a performance bond is still active. If the facility is within limits of a maintenance easement or the performance bond is still active and space is available, restore the dimensions to final design size.

Enhanced Swales



PASS: The footprint area of the BMP does not significantly deviate from the final design and should not negatively affect its stormwater management treatment performance.

FAIL: The footprint area of the swale is significantly smaller than what was specified in the final design due to half the width having been paved over.

MAINTENANCE TRIGGER: Dimensions differ from design or as-built drawing by >10%.

FOLLOW-UP TASKS: Check if a maintenance easement exists or performance bond is still active. If the facility is within limits of a maintenance easement or the performance bond is still active and space is available, restore the BMP footprint area to final design size.

Vegetated Filter Strips/Soil Amendment Areas

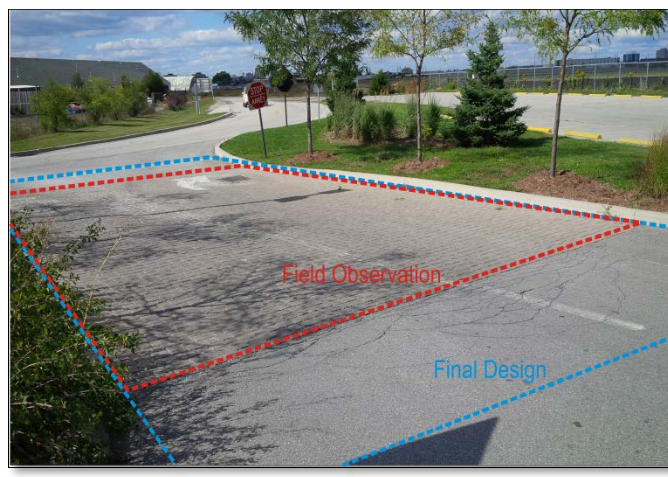
PASS: The footprint area where soil amendments have been implemented does not significantly deviate from the final design and should not negatively affect its stormwater management treatment performance.

FAIL: The footprint area where soil amendments have been implemented is significantly smaller than what was specified in the final design.

MAINTENANCE TRIGGER: Dimensions differ from design or as-built drawing by >10%.

FOLLOW-UP TASKS: Check if a maintenance easement exists or performance bond is still active. If the BMP is within limits of a maintenance easement or the performance bond is still active and space is available, restore the footprint area to final design size.

Permeable Pavements



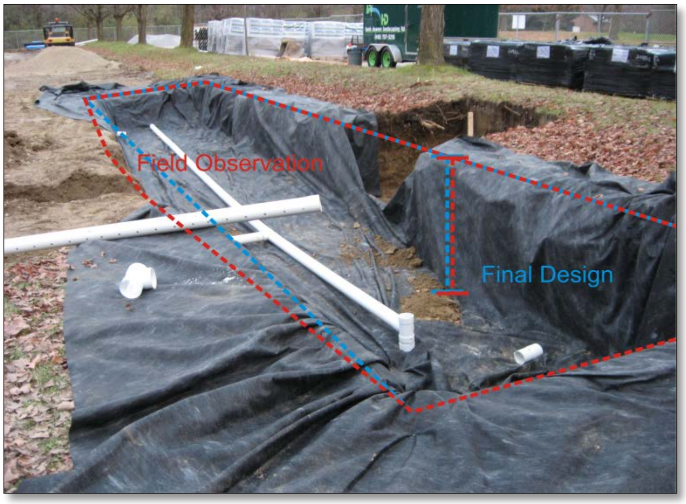
PASS: The footprint area of the BMP does not significantly deviate from the final design and should not negatively affect its stormwater management treatment performance.

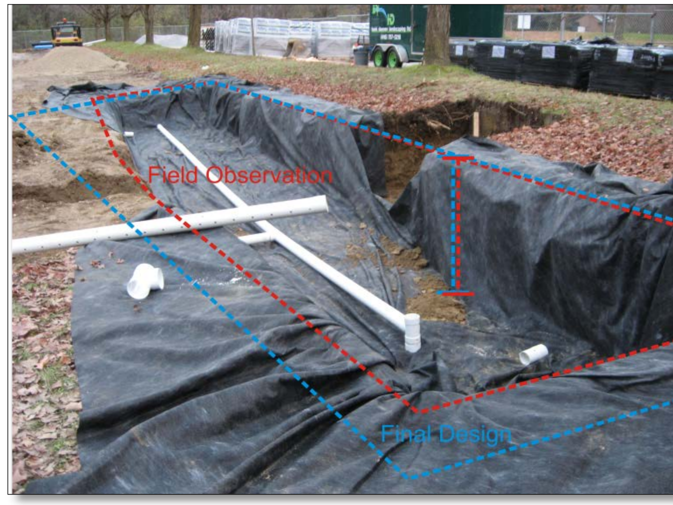
FAIL: The footprint area of the BMP is significantly smaller than what was specified in the final design.

MAINTENANCE TRIGGER: Dimensions differ from design or as-built drawing by >10%.

FOLLOW-UP TASKS: Check if a maintenance easement exists or performance bond is still active. If the facility is within limits of a maintenance easement or the performance bond is still active and space is available, restore the BMP footprint area to final design size.

Underground Infiltration Systems





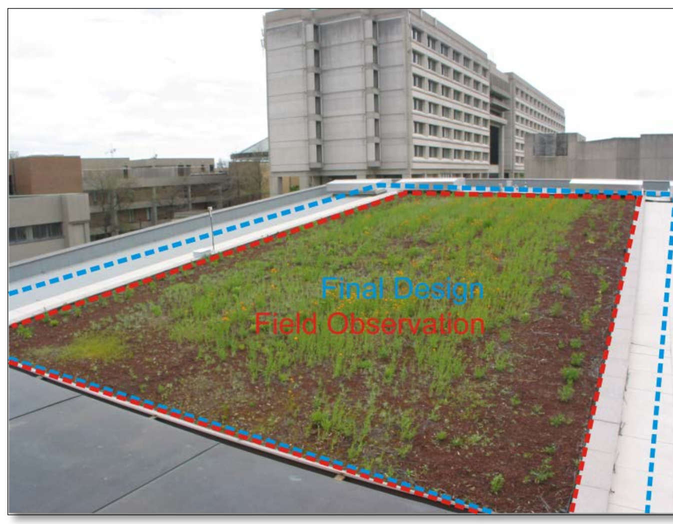
PASS: The footprint area and depth of the bioretention cell does not significantly deviate from the final design and should not negatively affect its stormwater management treatment performance.

FAIL: The footprint area of the bioretention cell deviates significantly from the final design.

MAINTENANCE TRIGGER: Dimensions differ from design or as-built drawing by >10%.

FOLLOW-UP TASKS: (During construction) Issue stop work order to construction contractor. Contact construction site manager and approval authority to decide on corrective actions.

Green Roofs



PASS: The footprint area of the green roof matches what was specified in the final design.

FAIL: The footprint area of the green roof is significantly smaller than what was specified in the final design.

MAINTENANCE TRIGGER: Dimensions differ from design or as-built drawing by >10%.

FOLLOW-UP TASKS: (During construction) Issue stop work order to construction contractor. Contact construction site manager and approval authority to decide on corrective actions.

Rainwater Cisterns

PASS: The size of the cistern matches what was specified in the final design.	**FAIL:** The size of the cistern being installed is much smaller than what was specified in the final design.

MAINTENANCE TRIGGER: Dimensions differ from design or as-built drawing by >10%.

FOLLOW-UP TASKS: (During construction) Issue stop work order to construction contractor. Contact construction site manager and approval authority to decide on corrective actions.

C.7 SIDE SLOPE EROSION

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification | **PERIMETER**

Assess the condition of the slopes along the perimeter of the BMP. Erosion rill or gullies, bare soil areas or ruts indicate slope may be too steep, plantings have not survived, or damage from foot or vehicle traffic. Erosion could also be due to water entering the facility as concentrated flow instead of sheet flow or in an unintended location.

Bioretention and Dry Swales

PASS: No erosion gullies, bare soil areas or ruts are visible on the side slopes. (Source: City of Maplewood)

FAIL: The side slopes of the BMP contain bare soil areas and show clear signs of erosion. (Source: CSN)

MAINTENANCE TRIGGER: Erosion gullies, bare soil areas or ruts ≥ 30 cm in length are visible. Foot or vehicular traffic has damaged the side slope or is preventing vegetation from becoming established.

FOLLOW-UP TASKS: Repair erosion gullies or ruts, replant bare soil areas and restore mulch or stone cover. If water is entering the BMP in an unintended area, install flow diversion device or re-grade the CDA to prevent it. If problems persist, consider adding soil or turf reinforcement, re-grading to reduce the slope or installing barriers to discourage foot or vehicular traffic.

Enhanced Swales

PASS: No erosion gullies, bare soil areas or ruts are visible on the side slopes. (Source: Thomas Engineering).

FAIL: Erosion gullies and bare soil areas exist on a portion of the side slopes due to steep slope.

MAINTENANCE TRIGGER: Erosion gullies or bare soil areas ≥ 30 cm in length are visible. Foot or vehicle traffic has damaged the side slope or is preventing vegetation from becoming established.

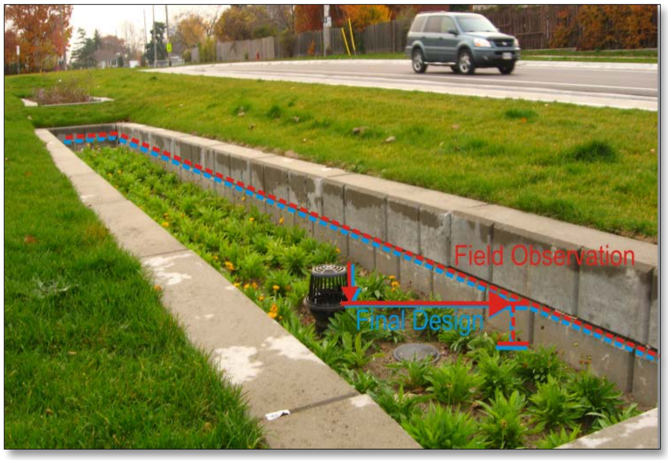
FOLLOW-UP TASKS: Repair erosion gullies or ruts, replant bare soil areas and restore mulch or stone cover. If water is entering the BMP in an unintended area, install flow diversion device or re-grade the CDA to prevent it. If problems persist, consider adding soil or turf reinforcement or re-grading to reduce the slope.

C.8 SURFACE PONDING AREA

Construction Inspection ✔ | Assumption ✔ | Routine Maintenance and Inspection ✔ | Maintenance Verification ✔ | **PERIMETER**

Assess maximum surface ponding area to confirm it is acceptable, determine if it has changed, and estimate the difference. Confirm the overflow outlet elevation is acceptable. Use a level to relate the elevation of the overflow outlet to the perimeter of the BMP to delineate the maximum surface ponding area. Use a measuring tape or wheel to estimate maximum surface ponding area and compare to design, as-built drawing or last inspection.

Bioretention and Dry Swales



PASS: The overflow outlet elevation and maximum surface ponding area match what was specified in the final design.

FAIL: The elevation of the overflow outlet is lower than what was specified in the design, producing a much smaller surface ponding area than intended and reducing the stormwater treatment capacity of the bioretention cell.

MAINTENANCE TRIGGER: Maximum surface ponding area differs from design or as-built drawing by ≥ 25%. Elevation of overflow outlet does not match final design. There are visible signs that the facility overflows at an unintended location (e.g. mulch displacement, soil erosion).

FOLLOW-UP TASKS: Re-grade or alter the overflow outlet elevation to match the final design. Re-grade the BMP surface or perimeter to achieve the maximum surface ponding area intended in the final design.

Enhanced Swales

PASS: The overflow outlet elevation and maximum surface ponding area closely match what was specified in the final design.

FAIL: The elevation of the overflow outlet is higher than what was specified in the design, producing a much larger surface ponding area than intended which could produce standing water for prolonged periods and cause vegetation to die off.

MAINTENANCE TRIGGER: Maximum surface ponding area differs from final design by ≥ 25%. Elevation of overflow outlet(s) does not match final design. There are visible signs that the facility overflows at an unintended location (e.g. mulch displacement, soil erosion).

FOLLOW-UP TASKS: Re-grade or alter the overflow outlet elevation to match the final design. Re-grade the BMP surface or perimeter to achieve the maximum surface ponding area intended in the final design.

C.9 STANDING WATER

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓

FILTER BED

This indicator should be assessed during, or within 24 hours after a storm event. Look for standing (i.e. ponded) water on the BMP surface. Check if ponded water drains within an acceptable time period (i.e., 24 hours). Standing water can indicate problems with the surface infiltration rate, the sub-drain system, overflow outlet, or that the maximum surface ponding depth is excessive.

Bioretention and Dry Swales

PASS: There is no standing water on the surface of this bioretention cell.

FAIL: There is standing water and highly saturated soils on the surface of this dry swale. Presence of algae indicates the swale does not drain between storms. (Source: James Urban).

MAINTENANCE TRIGGER: There is standing water on the BMP surface > 24 hours after the end of a storm event. Presence of highly saturated soil and bare soil areas.

FOLLOW-UP TASKS: Flush the sub-drain if present. Confirm maximum surface ponding depth matches final design. Schedule Forensic Inspection and Testing (FIT) to assess the cause of slow surface drainage. The FIT involves inspecting the sub-drain for obstructions, draining the BMP, checking for sediment accumulation on BMP surface, measuring surface infiltration rate, and testing of the surface soil/filter media for compaction, texture and organic matter content.

Enhanced Swales

PASS: There is no standing water on the surface of the swale and no bare soil areas around the outlet that would indicate surface ponding occurs regularly.

FAIL: There is standing water and highly saturated soils on the surface of swale. Dead vegetation and bare soil areas indicate that surface ponding occurs regularly. (Source: CSN).

MAINTENANCE TRIGGER: There is standing water on the BMP surface > 24 hours after the end of a storm event. Presence of highly saturated soil and bare soil areas.

FOLLOW-UP TASKS: Confirm maximum surface ponding depth matches final design. Schedule Forensic Inspection and Testing (FIT) to assess the cause of slow surface drainage. A FIT involves draining the BMP, checking for sediment accumulation on BMP surface, measuring surface infiltration rate and testing of the surface soil/filter media for compaction, texture and organic matter content.

Vegetated Filter Strips/Soil Amendment Areas

PASS: There is no standing water on the vegetated filter strip and no bare soil areas that would indicate surface ponding occurs regularly. (Source: Washington State DOT)

FAIL: Presence of large patches of dying vegetation and bare soil indicate that surface ponding occurs regularly and that the vegetated filter strip does not drain well.

MAINTENANCE TRIGGER: There is standing water on the BMP surface > 24 hours after the end of a storm event. Presence of highly saturated soil and bare soil areas.

FOLLOW-UP TASKS: Schedule Forensic Inspection and Testing (FIT) to assess the cause of slow surface drainage. A FIT involves draining the BMP, checking for sediment accumulation on BMP surface, measuring surface infiltration rate and testing of the surface soil/filter media for compaction, texture and organic matter content.

Permeable Pavement

PASS: There is no standing water on the surface of the permeable pavement shortly after a storm event and no signs of sediment accumulation to suggest that surface ponding occurs regularly.

FAIL: There is standing water on the permeable pavement surface during a storm event. Sediment accumulation on the pavement surface indicates that surface ponding occurs regularly.

MAINTENANCE TRIGGER: There is standing water on the BMP surface.

FOLLOW-UP TASKS: Flush the sub-drain if present. Schedule Forensic Inspection and Testing (FIT) to assess the cause of slow surface drainage. A FIT involves inspecting the sub-drain for obstructions, draining the BMP, checking for sediment accumulation on BMP surface and measuring surface infiltration rate.

Green Roofs

PASS: There is no standing water on the green roof surface shortly after a storm event.

FAIL: Standing water is present on the green roof surface and in the sub-drain system and bare soil areas are visible. (Source: J.V. Heidler)

MAINTENANCE TRIGGER: There is standing water on the green roof surface or in the overflow outlet > 3 hours after the end of a storm event.

FOLLOW-UP TASKS: If the overflow outlet is draining slowly, flush the pipe with a hose or schedule drain snaking service to unclog it. If the green roof surface is draining slowly, schedule Forensic Inspection and Testing (FIT) with an agent of the green roof system provider to assess the cause of slow drainage and determine corrective actions. A FIT could involve draining the BMP, checking for sediment accumulation on BMP surface, measuring surface infiltration rate and testing the growing media for compaction, texture and organic matter content. It may also involve excavation of portions of the green roof to inspect the drainage layer.

C.10 TRASH

Construction Inspection | Assumption | ✔ Routine Maintenance and Inspection | ✔ Maintenance Verification

FILTER BED

Check if the BMP contains trash or recyclables, which impair aesthetic value and could block inlets or outlets.

Bioretention and Dry Swales

PASS: There is no trash in or around the bioretention area that could possibly block inlets and outlets.

FAIL: The bioretention cell contains trash which could block the overflow outlet and is impairing aesthetic value. (Source: CVC).

MAINTENANCE TRIGGER: Presence of trash is impairing aesthetic value or function of the BMP.

FOLLOW-UP TASKS: Pick up the trash, sort out recycleables and properly dispose of any remaining items. Assess the CDA for point sources such as overflowing trash cans. If problems persist, consider providing recycling bin/trash can nearby.

Enhanced Swales

PASS: There is no trash in or around the swale that could possibly block inlets and outlets.

FAIL: The swale contains trash which could block the overflow outlet and is impairing aesthetic value.

MAINTENANCE TRIGGER: Presence of trash is impairing aesthetic value or function of the BMP.

FOLLOW-UP TASKS: Pick up the trash, sort out recycleables and properly dispose of any remaining items. Assess the CDA for point sources such as overflowing trash cans. If problems persist, consider providing recycling bin/trash can nearby.

C.11 FILTER BED EROSION

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification | FILTER BED

Look for signs of excessive soil erosion on the surface of the filter media/growing media bed, caused by concentrated flow of water or wind scour. Check for damage from foot or vehicle traffic.

Bioretention and Dry Swales

PASS: There are no erosion gullies or bare soil areas on the filter bed surface and mulch cover remains in place.

FAIL: Erosion gullies and bare soil areas are present on the filter bed surface, indicating that concentrated flow occurs regularly. (Source: CVC)

MAINTENANCE TRIGGER: Erosion gullies or bare soil areas ≥ 30 cm in length are visible. Foot or vehicle traffic has damaged the filter bed surface or is preventing vegetation from becoming established.

FOLLOW-UP TASKS: Repair erosion gullies, replant bare soil areas and irrigate as needed until vegetation cover is established or restore mulch or stone cover. If water is entering the BMP in an unintended area, install a flow diversion device or re-grade the CDA to prevent it. If problems persist, consider adding inlets, check dams, stone cover, soil/turf reinforcements or re-grading to reduce slope and spread out the flow of water.

Enhanced Swales

PASS: There are no erosion gullies or bare soil areas on the swale surface.

FAIL: Large erosion gully is present on the swale surface indicating that concentrated flow occurs regularly.

MAINTENANCE TRIGGER: Erosion gullies or bare soil areas ≥ 30 cm in length are visible. Foot or vehicle traffic has damaged the filter bed surface or is preventing vegetation from becoming established.

FOLLOW-UP TASKS: Repair erosion gullies, replant bare soil areas and irrigate as needed until vegetation cover is established or restore mulch or stone cover. If water is entering the BMP in an unintended area, install a flow diversion device or re-grade the CDA to prevent it. If problems persist, consider adding inlets, check dams, stone cover, soil/turf reinforcements or re-grading to reduce slope and spread out the flow of water.

Vegetated Filter Strips/Soil Amendment Areas

PASS: There are no erosion rills, gullies or bare soil areas on the filter strip surface. (Source: CIRIA)

FAIL: Scour erosion along the inlet edge is visible. Bare soil areas and bright green biofilm on the filter strip surface indicate that concentrated flow and surface ponding occurs regularly.

MAINTENANCE TRIGGER: Erosion gullies or bare soil areas ≥ 30 cm in length are visible. Foot or vehicle traffic has damaged the filter bed surface or is preventing vegetation from becoming established.

FOLLOW-UP TASKS: Repair erosion gullies, replant bare soil areas and irrigate as needed until vegetation cover is established or restore mulch or stone cover. If water is entering the BMP in an unintended area, install a flow diversion device or re-grade the CDA to prevent it. If problems persist, consider adding gravel diaphragms, check dams, soil/turf reinforcements, splash pads at roof downspouts or re-grading to reduce slope and spread out the flow of water.

Green Roofs

PASS: There are no bare areas or signs of erosion of growing media from concentrated flowing water or wind scour on the green roof (i.e. filter bed) surface.

FAIL: Wind scour of protective matting and growing media on the green roof (i.e. filter bed) surface is visible in several locations. (Source: Recover Green Roofs)

MAINTENANCE TRIGGER: Erosion gullies or bare areas ≥ 30 cm in length are visible. Foot traffic has damaged the filter bed surface or is preventing vegetation from becoming established.

FOLLOW-UP TASKS: Repair erosion gullies or wind scoured areas, replant and irrigate as needed until vegetation cover is established. If water is entering the BMP in an unintended area, install a flow diversion device or re-grade the CDA to prevent it. If problems persist, consider adding matting to protect growing media from scour until vegetation is established and/or wind barriers along the perimeter (e.g. stone, brick or paved parapets).

C.12 MULCH DEPTH

Construction Inspection ✓ | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓

FILTER BED

Check that the depth of mulch is adequate to protect the soil, surpress weeds and is not impeding the flow of water into the BMP.

Bioretention and Dry Swales

PASS: Mulch depth is within the range specified in the final design (i.e. 5 to 10 cm) and covers all non-vegetated portions of the filter bed.

FAIL: Mulch depth is greater than what was specified in the final design and is blocking the inlet to the bioretention cell. (Source: CSN).

MAINTENANCE TRIGGER: Average depth is less than 5 cm or greater than 15 cm. Bare soil areas are present. Mulch depth is impeding the flow of water into the BMP.

FOLLOW-UP TASKS: Add or redistribute mulch to maintain depth between 5 and 10 cm and not impede flow of water into the BMP.

Enhanced Swales

PASS: Mulch depth is within the range specified in the final design (i.e. 5 to 10 cm) and covers all portions of the BMP not covered by stone or vegetation. (Source: Blade Runners)

FAIL: Mulch depth is greater than what was specified in the final design and is blocking the inlet to the swale.

MAINTENANCE TRIGGER: Average depth is less than 5 cm or greater than 15 cm. Bare soil areas are present. Mulch depth is impairing flow of water into the BMP.

FOLLOW-UP TASKS: Add or redistribute mulch to maintain depth between 5 and 10 cm and not impede flow of water into the BMP.

C.13 FILTER BED SEDIMENT ACCUMULATION

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓ | FILTER BED

Assess the depth of sediment that has accumulated on the filter bed surface, which could be affecting the surface infiltration rate, vegetation cover or aesthetic value. Measure the depth in at least five (5) locations by digging test holes or examining soil core samples and compare to last inspection

Bioretention and Dry Swales

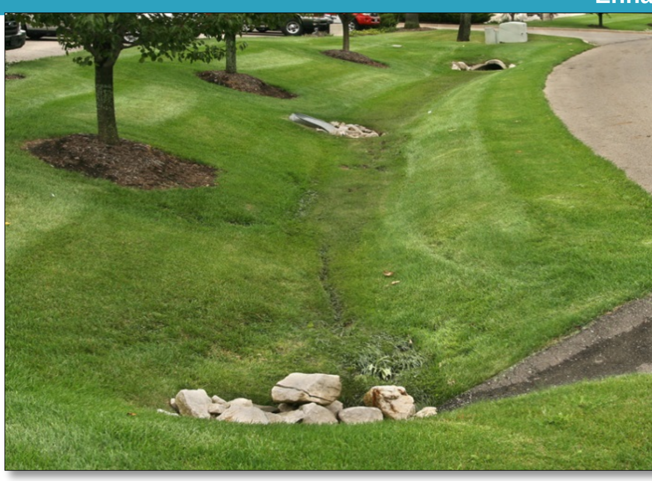
PASS: Depth of accumulated sediment below the stone cover on the filter bed surface is less than 5 cm.

FAIL: Sediment accumulation is visible on the filter bed surface and stone covering it and is greater than 5 cm deep.

MAINTENANCE TRIGGER: Mean or local sediment depth is 5 cm or greater.

FOLLOW-UP TASKS: Remove accumulated sediment and the top 15 cm of filter media by rake/shovel or small excavator, keeping heavy equipment off the filter bed surface. Check for signs of oil or grease contamination (e.g. sheen on surface of water when sediment is submerged). If oil or grease contamination is suspected, submit a sediment sample for contaminant testing by an accredited laboratory to determine the proper disposal method. Restore filter bed surface grading to match final design. Replant and replace mulch/stone cover. Assess the CDA for changes in land cover or point sources of sediment. Inspect and remove sediment from pretreatment devices. If problems persist, consider increasing frequency of routine maintenance.

Enhanced Swales



PASS: There are no signs of excessive sediment accumulation on the surface of the swale. (Source: DAA)

FAIL: Sediment is visible on top of the stone cover on the swale surface near the inlet and is greater than 2.5 cm deep .

MAINTENANCE TRIGGER: Mean or local sediment depth is 5 cm or greater.

FOLLOW-UP TASKS: Remove accumulated sediment by rake/shovel or small excavator, keeping heavy equipment off the filter bed surface. Check for signs of oil or grease contamination (e.g. sheen on surface of water when sediment is submerged). If oil or grease contamination is suspected, submit a sediment sample for contaminant testing by an accredited laboratory to determine the proper disposal method. Restore filter bed surface grading to match final design. Replant and replace mulch cover. Assess the CDA for changes in land cover or point sources of sediment. Inspect and remove sediment from pretreatment devices. If problems persist, consider adding pretreatment devices or increasing frequency of routine maintenance.

Underground Infiltration Systems

PASS: The coarse gravel filter bed of this infiltration chamber system has very little sediment accumulated on the surface indicating pretreatment devices are working well and that sediment removal from the gravel filter bed is not needed.

FAIL: A substantial amount of sediment has accumulated on the coarse gravel filter bed of the infiltration chamber system which could be impairing the drainage function of the BMP. (Source: Stormwater Maintenance)

MAINTENANCE TRIGGER: Mean or local sediment depth is 8 cm or greater on the gravel bed surface.

FOLLOW-UP TASKS: Removal of accumulated sediment from infiltration chamber systems requires entry into the chambers themselves by staff trained in confined space entry and equipped with recently certified safety equipment (i.e. tripod, winch, harness) and recently calibrated and tested multi-gas detector. Sediment removal involves the use of a pressure sprayer and shovels to consolidate sediment at the nearest access hatches and a vacuum truck to remove it. Flush inlet and outlet pipes with a hose. Check the removed material for signs of oil or grease contamination (e.g. sheen on surface of water when submerged). If oil or grease contamination is suspected, submit a sediment sample for contaminant testing by an accredited laboratory to determine the proper disposal method. Assess the CDA for changes in land cover or point sources of sediment. Inspect and remove sediment from pretreatment devices. If problems persist, consider adding pretreatment devices or increasing frequency of routine maintenance.

C.14 SURFACE PONDING DEPTH

Construction Inspection ✓ | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓ | **FILTER BED**

Measure maximum surface ponding depth to confirm it is acceptable, determine if it has changed, and estimate the difference. Use a level to measure the elevation difference between the overflow outlet and the lowest point on the filter bed surface.

Bioretention and Dry Swales

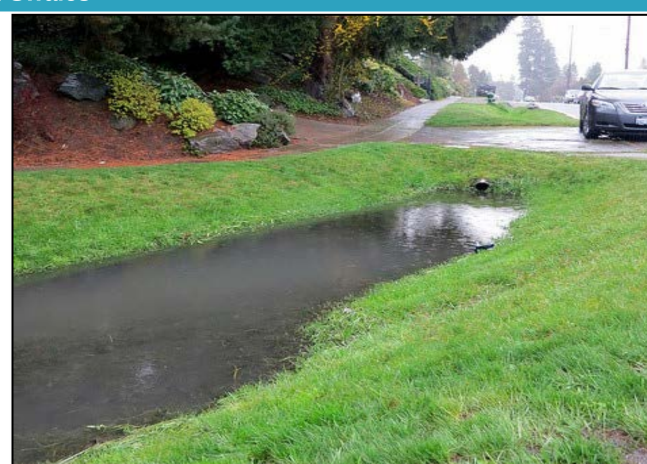
PASS: The maximum surface ponding depth of the bioretention cell matches what was specified in the final design.

FAIL: The maximum ponding depth of the bioretention cell is significantly shallower than intended as the overflow outlet is at the same elevation as the lowest point on the filter bed. (Source: CSN)

MAINTENANCE TRIGGER: Maximum surface ponding depth differs from design or as built drawing by >10%.

FOLLOW-UP TASKS: Measure filter media depth using a cone penetrometer or soil corer and check if it matches final design specification. Add, remove or redistribute filter media, or adjust the elevation of the overflow outlet to make the maximum surface ponding depth match the final design specification.

Enhanced Swales



PASS: The maximum surface ponding depth behind check dams matches what was specified in the final design. (Source: NEOSWTC)

FAIL: The maximum ponding depth of the swale is significantly deeper than intended as the elevation of the check dam or overflow outlet is too high. (Source: CSN)

MAINTENANCE TRIGGER: Maximum surface ponding depth differs from design or as built drawing by >10%.

FOLLOW-UP TASKS: Measure filter media depth using a cone penetrometer or soil corer and check if it matches final design specification. Add, remove or redistribute filter media, or adjust the elevation of the overflow outlet to make the maximum surface ponding depth match the final design specification.

C.15 FILTER BED SURFACE SINKING

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓ | **FILTER BED**

Look for local depressions or holes on the filter bed surface. Surface depressions can indicate problems with uneven settling of filter media/soil, a damaged sub-drain, heavy traffic (e.g. tire ruts) or the presence of animal burrows, all of which can affect the function of the BMP.

Bioretention and Dry Swales

PASS: The filter bed is nearly flat and there are no signs of localized bed sinking. (Source: CSN).

FAIL: Clear evidence of bed sinking is visible, creating a preferential ponding area where vegetation has died off.

MAINTENANCE TRIGGER: Local surface depressions 10 cm in depth or greater or animal burrows are visible on the filter bed surface.

FOLLOW-UP TASKS: Repair the depressions or fill animal burrows with filter media/soil. Inspect the sub-drain to ensure it has not been damaged. If problems with damage from heavy traffic persist, consider adding barriers.

Enhanced Swales

PASS: The filter bed has retained its original grading without any sharp depressions that would indicate surface bed sinking. (Source: SVR Design).

FAIL: Clear evidence of bed sinking is visible, creating a preferential ponding area where vegetation has died off.

MAINTENANCE TRIGGER: Local surface depressions 10 cm in depth or greater or animal burrows are visible on the filter bed surface.

FOLLOW-UP TASKS: Repair the depressions or fill animal burrows with filter media/soil. If problems with damage from heavy traffic persist, consider adding barriers.

Vegetated Filter Strips/Soil Amendment Areas

PASS: The lawn where soil amendments have been implemented is well graded with no signs of localized bed sinking , animal burrows or ruts.

FAIL: Clear evidence of bed sinking on the lawn, creating preferential ponding areas which could cause vegetation to die off (Source: The Anxious Gardener).

MAINTENANCE TRIGGER: Local surface depressions 10 cm in depth or greater or animal burrows are visible on the filter bed surface.

FOLLOW-UP TASKS: Repair the depressions or fill animal burrows with filter media/soil. If problems with damage from heavy traffic persist, consider adding barriers.

C.16 CHECK DAMS

Construction Inspection ✓ | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓

FILTER BED

Ensure that the check dam structures are still visible (i.e. not buried in sediment) and continue to help retain sediment and spread the flow of water across the BMP surface.

Bioretention and Dry Swales

PASS: The check dam is visible and continues to help retain sediment and spread the flow of water across the BMP surface. (Source: Green Girl PDX)

FAIL: Sediment has accumulated on the upstream side of the check dam and is affecting its function. (Source: James Urban).

MAINTENANCE TRIGGER: Check dam structures are missing or buried in sediment.

FOLLOW-UP TASKS: Remove accumulated sediment by rake/shovel. Check for signs of oil or grease contamination (e.g. sheen on surface of water when submerged). If oil or grease contamination is suspected, submit a sediment sample for contaminant testing by an accredited laboratory to determine the proper disposal method. Install check dams where specified in the final design. Assess the CDA for changes in land cover or point sources of sediment. Inspect and remove sediment from pretreatment devices. If problems persist, consider adding pretreatment devices or increasing frequency of routine maintenance.

Enhanced Swales

PASS: The check dams are visible and continue to help retain sediment and spread the flow of water across the BMP surface. (Source: CSN).

FAIL: Sediment has accumulated on the upstream side of the check dam and is affecting its function. (Source: Tennessee EPSC).

MAINTENANCE TRIGGER: Check dam structures are missing or buried in sediment.

FOLLOW-UP TASKS: Remove accumulated sediment by rake/shovel. Check for signs of oil or grease contamination (e.g. sheen on surface of water when sediment is submerged). If oil or grease contamination is suspected, submit a sediment sample for contaminant testing by an accredited laboratory to determine the proper disposal method. Install check dams where specified in the final design. Assess the CDA for changes in land cover or point sources of sediment. Inspect and remove sediment from pretreatment devices. If problems persist, consider adding pretreatment devices or increasing frequency of routine maintenance.

C.17 VEGETATION COVER

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓

PLANTING AREA

This indicator can only be assessed during the growing season. Estimate what portion of the planting area is covered by living vegetation. Inadequate vegetation cover can impair the water and pollutant retention functions and aesthetic value of the BMP and can contribute to filter bed erosion.

Bioretention and Dry Swales

PASS: The planted portion of the bioretention cell is completely covered with dense, attractive vegetation which helps to maintain its stormwater treatment function and aesthetic value.

FAIL: A larger portion of the bioretention cell has no vegetation cover which reduces its aesthetic value and could be negatively affecting its stormwater treatment function.

MAINTENANCE TRIGGER: Less than 80% of the planting area is covered by living vegetation.

FOLLOW-UP TASKS: Aerate bare spots and replant or reseed with plants specified in the final design (i.e. planting plan) and water as needed until cover is established. If bare spots persist, consider watering during extended dry periods, planting more tolerant species, amending the filter media/topsoil with compost or initiating a FIT to investigate the cause of plant mortality.

Enhanced Swales

PASS: The planted portion of the swale is well covered with dense, attractive vegetation which helps to maintain its stormwater treatment function and aesthetic value.

FAIL: Major portions of the swale surface contains dead or dying vegetation which reduces its aesthetic value and could be negatively affecting its stormwater treatment function.

MAINTENANCE TRIGGER: Less than 80% of the planting area is covered by living vegetation.

FOLLOW-UP TASKS: Aerate bare spots and replant or reseed with plants specified in the final design (i.e. planting plan) and water as needed until cover is established. If bare spots persist, consider watering during extended dry periods, planting more tolerant species, amending the filter media/topsoil with compost or initiating a FIT to investigate the cause of plant mortality.

Vegetated Filter Strips/Soil Amendment Areas

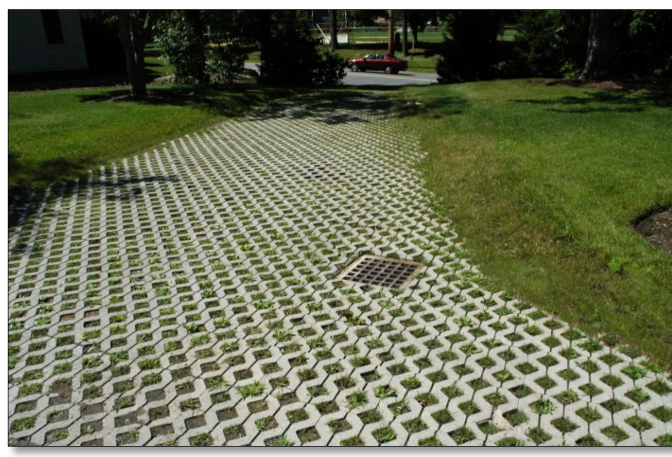
PASS: The vegetated filter strip is evenly covered with dense turf grass which helps to maintain its stormwater treatment function and aesthetic value. (Source: Trinkaus Engineering)

FAIL: Major portions of the filter strip contain bare soil or dead vegetation which reduces its aesthetic value and could be negatively affecting its stormwater treatment function.

MAINTENANCE TRIGGER: Less than 80% of the planting area is covered by living vegetation.

FOLLOW-UP TASKS: Aerate bare spots and replant or reseed with plants specified in the final design (i.e. planting plan) and water as needed until cover is established. If bare spots persist, consider watering during extended dry periods, planting more tolerant species, amending the filter media/topsoil with compost or initiating a FIT to investigate the cause of plant mortality.

Permeable Pavement



PASS: The permeable driveway is completely covered by dense turf grass which helps to maintain its stormwater treatment function and aesthetic value. (Source: Matthew Hague)

FAIL: Much of the permeable driveway contains bare soil which reduces its aesthetic value and could be affecting its stormwater treatment function. (Source: Dallas Metropolis)

MAINTENANCE TRIGGER: Less than 80% of the planting area is covered by living vegetation.

FOLLOW-UP TASKS: Reseed bare spots with the grass seed mixture specified in the final design and water as needed until grass cover is established. If bare spots persist, consider watering during extended dry periods, reseeding with more tolerant species, amending the filter media/topsoil with compost, or initiating a FIT to investigate the cause of grass mortality.

Green Roofs

PASS: The green roof is well covered by dense, attractive vegetation which helps maintain its stormwater treatment function and aesthetic value. (Source: Earth Rangers)

FAIL: A major portion of the green roof contains no living vegetation cover (Source: Kevin Songer).

MAINTENANCE TRIGGER: Less than 80% of the planting area is covered by living vegetation.

FOLLOW-UP TASKS: Replant or reseed with plants specified in the final design (i.e. planting plan) and water as needed until established. Check the irrigation system (if present) to ensure it is functioning. If the planting area is receiving regular foot traffic install pedestrian barriers to discourage it. If bare spots persist, consider watering during extended dry periods, planting more tolerant species, amending the soil/filter media or initiating a FIT to investigate the cause of plant mortality.

C.18 VEGETATION CONDITION

PLANTING AREA

Construction Inspection | Assumption | Routine Maintenance and Inspection ✔ | Maintenance Verification ✔

This indicator can only be assessed during the growing season. Assess the condition of vegetation growing in the planting area with regard to its health and aesthetic value. Look for plants that are not thriving or over-grown, or planting areas that are over-crowded.

Bioretention and Dry Swales

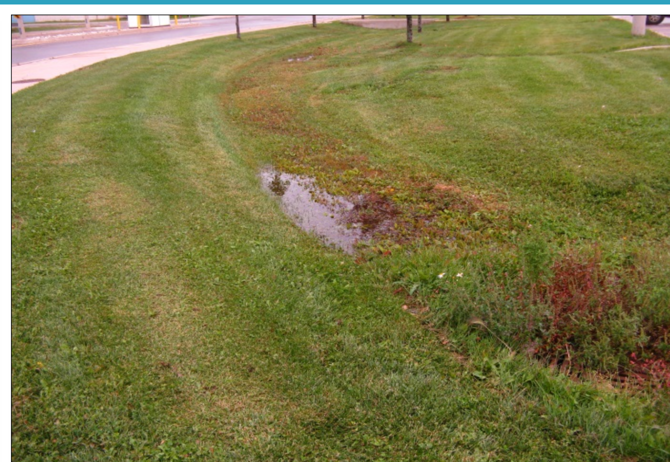
PASS: The vegetation looks healthy and well maintained.

FAIL: The vegetation looks healthy but is overcrowded and overgrown.

MAINTENANCE TRIGGER: Plants are not thriving and impairing the aesthetic value of the BMP. Plants are over-grown or over-crowded and obstructing sight lines need for safe driving or walking.

FOLLOW-UP TASKS: Trim over-grown shrubs to maintain clear sight lines for safety. Thin out vegetation cover in over-crowded plant areas to improve aesthetic value. If plants are not well established after the second growing season consider watering during extended dry periods, planting more tolerant species, amending the filter media/topsoil with compost or initiating a FIT to investigate the cause.

Enhanced Swales



PASS: The turf grass cover looks very healthy and well-maintained. (Source: CSN).

FAIL: Portions of the turf grass looks like it is dying or not flourishing, likely due to frequent surface ponding.

MAINTENANCE TRIGGER: Plants are not thriving and impairing the aesthetic value of the BMP. Plants are over-grown or over-crowded and obstructing sight lines need for safe driving or walking.

FOLLOW-UP TASKS: Trim over-grown shrubs to maintain clear sight lines for safety. Thin out vegetation cover in over-crowded plant areas to improve aesthetic value. If plants are not well established after the second growing season consider watering during extended dry periods, planting more tolerant species, amending the filter media/topsoil with compost or initiating a FIT to investigate the cause.

Vegetated Filter Strips/Soil Amendment Areas

PASS: The turf grass cover on the vegetated filter strip looks healthy and well maintained. (Source: VWRRC)

FAIL: The turf grass cover is patchy and not yet thriving. (Source: Washington State DOT).

MAINTENANCE TRIGGER: Plants are not thriving and impairing the aesthetic value of the BMP. Plants are over-grown or over-crowded and obstructing sight lines need for safe driving or walking.

FOLLOW-UP TASKS: Trim over-grown shrubs to maintain clear sight lines for safety. Thin out vegetation cover in over-crowded plant areas to improve aesthetic value. If plants are not well established after the second growing season consider watering during extended dry periods, planting more tolerant species, amending the filter media/topsoil with compost or initiating a FIT to investigate the cause.

Permeable Pavement

PASS: The turf grass cover on the permeable pavement looks healthy and well maintained. (Source: Herrerra Consulting).

FAIL: The turf grass cover on the permeable walkway is not thriving in some areas and needs cutting in others.

MAINTENANCE TRIGGER: Grass is not thriving or over-grown and impairing the aesthetic value of the BMP.

FOLLOW-UP TASKS: Mow grass more frequently to improve aesthetic value. If grass is not well established after the second growing season consider watering during extended dry periods, planting more tolerant species, amending the filter media/topsoil with compost or initiating a FIT to investigate the cause.

Green Roofs	
	
PASS: The green roof vegetation looks healthy and well maintained.	**FAIL:** A portion of the vegetation on the green roof is dying or not thriving.

MAINTENANCE TRIGGER: Plants are not thriving, over-grown or over-crowded and impairing the aesthetic value of the BMP.

FOLLOW-UP TASKS: Check the irrigation system (if present) to ensure it is functioning. Thin out vegetation cover where it is over-crowded to improve aesthetic value. If the planting area is receiving regular foot traffic install pedestrian barriers to discourage it. If plants are not well established after the second growing season consider watering during extended dry periods, planting more tolerant species, amending the growing media or initiating a FIT to investigate the cause.

C.19 VEGETATION COMPOSITION

PLANTING AREA

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification

This indicator can only be assessed during the growing season. Compare the types of plants present to those specified in the final design (i.e. planting plan). Look for species that did not survive or are not thriving. Estimate the portion of vegetation cover that is invasive or unwanted (i.e. weeds). Look for volunteer tree seedlings in unsuitable locations (e.g. where soil depth is less than 60 cm).

Bioretention and Dry Swales

PASS: The species of plants in the bioretention cell matches what was specified in the final design with few weeds and no volunteer tree seedlings present.

FAIL: Vegetation in the bioretention cell is dominated by invasive species (i.e. weeds) and includes volunteer tree saplings, indicating it is in need of routine maintenance.

MAINTENANCE TRIGGER: More than 50% of the vegetation cover is invasive or unwanted species (i.e. weeds) or not the species specified in the final design and is impairing the aesthetic value of the BMP. Volunteer tree seedlings or saplings are present in inappropriate locations.

FOLLOW-UP TASKS: Remove invasive, unwanted or inappropriate species and replant with species specified in the final design (i.e. planting plan). If problems persist, consider increasing the frequency of routine maintenance (i.e. mulching and weeding) or replanting with more tolerant species.

Enhanced Swales

PASS: The species of plants growing in the swale closely matches what was specified in the final design with few weeds.

FAIL: Vegetation in the swale is dominated by grasses and invasive species (i.e. weeds) rather than the shrubs and flowers specified in the final design .

MAINTENANCE TRIGGER: More than 50% of the vegetation cover is invasive or unwanted species (i.e. weeds) or not the species specified in the final design and is impairing the aesthetic value of the BMP. Volunteer tree seedlings or saplings are present in inappropriate locations.

FOLLOW-UP TASKS: Remove invasive, unwanted or inappropriate species and replant with species specified in the final design (i.e. planting plan). If problems persist, consider increasing the frequency of routine maintenance (i.e. mulching and weeding) or replanting with more tolerant species.

Permeable Pavement

PASS: The vegetation cover on the permeable pavement is turf grass as specified in the final design and contains very few weeds. (Source: WEF)

FAIL: The vegetation cover on the permeable pavement is a mixture of turf grass and invasive species (i.e. weeds). (Source: Immanuel Giel)

MAINTENANCE TRIGGER: More than 50% of the vegetation cover is invasive or unwanted species (i.e. weeds) or not the species specified in the final design and is impairing the aesthetic value of the BMP. Volunteer tree seedlings or saplings are present in inappropriate locations.

FOLLOW-UP TASKS: Remove invasive, unwanted or inappropriate species and replant with species specified in the final design (i.e. planting plan). If problems persist, consider increasing the frequency of routine maintenance (i.e. mulching and weeding) or replanting with more tolerant species.

Green Roofs

PASS: The green roof contains only the species specified in the final design with few weeds and no volunteer tree seedlings or saplings present. (Source: Earth Rangers)

FAIL: Vegetation on the green roof is a mixture of the species specified in the final design and invasive species (i.e. weeds) and needs maintenance.

MAINTENANCE TRIGGER: More than 50% of the vegetation cover is invasive or unwanted species (i.e. weeds) or not the species specified in the final design and is impairing the aesthetic value of the BMP. Volunteer tree or shrub seedlings or saplings are present in inappropriate locations.

FOLLOW-UP TASKS: Remove invasive, unwanted or inappropriate species and replant with species specified in the final design (i.e. planting plan). If problems persist, consider increasing the frequency of routine maintenance (i.e. mulching and weeding) or replanting with more tolerant species.

C.20 MONITORING WELL CONDITION

Construction Inspection ✔ | Assumption ✔ | Routine Maintenance and Inspection ✔ | Maintenance Verification ✔ | OUTLET

Ensure the monitoring well remains accessible. Look for damage to the well structure and missing or insecure cap. A damaged well can allow untreated runoff, sediment and debris to flow into it and potentially clog the screen. Check for obstructions or sediment in the casing. Measure and record water level in the BMP in centimetres by dip method.

Bioretention and Dry Swales

PASS: The well is undamaged and accessible and the cap is in place and secured to prevent unauthorized access.

FAIL: The well standpipe has been damaged by snow plowing which impairs its use for monitoring and is a safety hazard.

MAINTENANCE TRIGGER: Damage to the well structure is visible and impairing the function of the BMP. The cap is missing or not secured to prevent unauthorized access. An obstruction in the well casing is visible.

FOLLOW-UP TASKS: Repair damaged well structure, and firmly tamp around the casing to prevent short circuiting of water flow through the BMP. Replace and secure well cap. Remove well casing obstruction (e.g. flush with water or remove with a vacuum).

Permeable Pavements

PASS: The well is undamaged and accessible and the cap is in place and secured to prevent unauthorized access.

FAIL: The well cap is missing and the casing is clogged by sediment, preventing access for monitoring and allowing sediment to flow into the sub-drain system.

MAINTENANCE TRIGGER: Damage to the well structure is visible and impairing the function of the BMP. The cap is missing or not secured to prevent unauthorized access. An obstruction in the well casing is visible.

FOLLOW-UP TASKS: Repair damaged well structure, and firmly tamp around the casing to prevent short circuiting of water flow through the BMP. Replace and secure well cap. Remove well casing obstruction (e.g. flush with water or remove with a vacuum).

Underground Infiltration Systems

PASS: The well is undamaged and accessible and the cap is in place and secured to prevent unauthorized access.

FAIL: The well was buried during landscaping and found covered only by filter cloth (i.e. cap missing).

PASS: The well is undamaged and accessible and the cap is in place and secured to prevent unauthorized access.

FAIL: The well has been left uncapped and unprotected from erosion and sediment during construction.

MAINTENANCE TRIGGER: Damage to the well structure is visible and impairing the function of the BMP. The cap is missing or not secured to prevent unauthorized access. An obstruction in the well casing is visible.

FOLLOW-UP TASKS: Repair damaged well structure, and firmly tamp around the casing to prevent short circuiting of water flow through the BMP. Replace and secure well cap. Remove well casing obstruction (e.g. flush with water or remove with a vacuum).

C.21 SUBDRAIN/PERFORATED PIPE OBSTRUCTION

Construction Inspection ✔ Assumption ✔ Routine Maintenance and Inspection ✔ Maintenance Verification ✔ **OUTLET**

This indicator is best assessed using a waterproof snake camera or push camera system specifically designed for inspecting pipes. Assess if the sub-drain pipe is damaged or clogged with sediment, vegetation roots or otherwise obstructed. An obstructed sub-drain pipe impairs the drainage function of the BMP.

Bioretention and Dry Swales

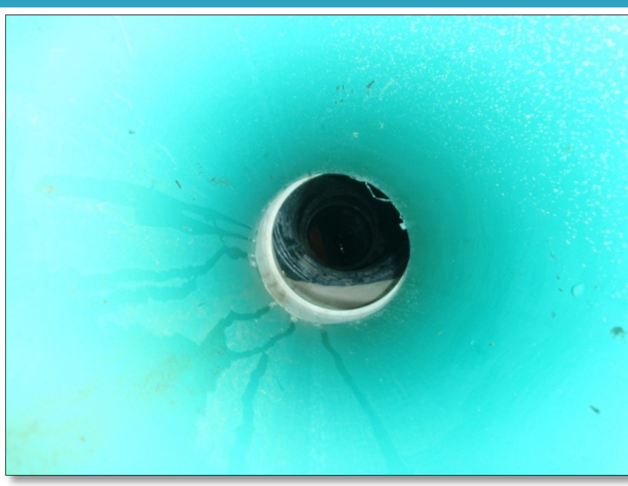
PASS: The perforated sub-drain pipe is not obstructed by sediment, debris or roots and shows no signs of damage.

FAIL: Roots have penetrated the sub-drain pipe and are substantially reducing its conveyance capacity. (Source: Pipelining Denver)

MAINTENANCE TRIGGER: Structural damage, sediment/debris clogs or vegetation roots are visible and are reducing the conveyance capacity of the pipe by one third (33%) or more.

FOLLOW-UP TASKS: Flush the full length of perforated pipe with a hose inserted into the upstream clean-out standpipe or monitoring well to remove accumulated sediment. Schedule drain snaking service to trim vegetation roots in the perforated pipe or vaccuum truck service to address other types of obstructions (e.g. trash/debris). Collapsed or broken perforated pipes or clogged geotextile requires structural repairs involving excavation and replacement.

Permeable Pavements



PASS: The solid section of the sub-drain pipe is not obstructed by sediment, debris or roots and shows no signs of damage.

FAIL: A section of the sub-drain pipe has been crushed which substantially reduces its conveyance capacity.

MAINTENANCE TRIGGER: Structural damage, sediment/debris clogs or vegetation roots are visible and are reducing the conveyance capacity of the pipe by one third (33%) or more.

FOLLOW-UP TASKS: Flush the full length of perforated pipe with a hose inserted into the upstream clean-out standpipe or monitoring well to remove accumulated sediment. Schedule vacuum truck or drain snaking service to address other types of obstructions (e.g. roots/trash/debris). Collapsed or broken pipes or clogged geotextile around pipes requires structural repairs involving excavation and replacement.

Underground Infiltration Systems

PASS: The sub-drain outlet pipe from the infiltration chamber system is not obstructed by sediment, debris or roots and shows no signs of damage.	**FAIL:** A perforated pipe in an exfiltration storm sewer system is clogged by sediment and debris which inhibits its drainage function.

MAINTENANCE TRIGGER: Structural damage, sediment/debris clogs or vegetation roots are visible and are reducing the conveyance capacity of the pipe by one third (33%) or more.

FOLLOW-UP TASKS: Remove downstream plug (if present) and flush the full length of the perforated pipe with a hose inserted into the upstream clean-out standpipe or monitoring well to remove accumulated sediment. Schedule drain snaking service to trim vegetation roots in the perforated pipe or vacuum truck service to address other types of obstructions (e.g. trash/debris). Collapsed or broken perforated pipes or clogged geotextile around pipes requires structural repairs involving excavation and replacement.

C.22 OVERFLOW OUTLET OBSTRUCTION

Construction Inspection ✔ Assumption ✔ Routine Maintenance and Inspection ✔ Maintenance Verification ✔ **OUTLET**

Check the overflow outlet structure to ensure it is not damaged and free of obstructions. Look for trash, debris, mulch or sediment on the structure that would impede the flow of water out of the BMP. Ensure that the structure is not full of standing water. A damaged or obstructed overflow outlet structure impairs the drainage function of the BMP and could lead to flooding during extreme storm events.

Bioretention and Dry Swales

PASS: The overflow outlet is free of damage and obstruction and functions as designed. (Source: Dylan Passmore)

FAIL: The overflow outlet is partially obstructed with trash and debris which reduces its capacity to safely convey excess water from the BMP.

MAINTENANCE TRIGGER: Structural damage or sediment/trash/debris is obstructing outflow and impairing the drainage function of the BMP. The structure is full of standing water. Standpipe or catchbasin grates are damaged or not in place and allow trash and debris to enter the outlet pipe or storm sewer.

FOLLOW-UP TASKS: Repair or replace any damaged or missing grates. Remove trash, debris and mulch from the overflow outlet structure. If the overflow outlet structure is not draining, schedule a drain snaking and vacuum truck service to address obstructions in the pipe.

Enhanced Swales

PASS: The overflow outlet of this vegetated swale is free of damage and obstruction and functions as designed to safely convey excess water from the BMP.

FAIL: Vegetation and debris is partially obstructing the overflow outlet structure which impairs its drainage function .

MAINTENANCE TRIGGER: Structural damage or sediment/trash/debris is obstructing outflow and impairing the drainage function of the BMP. The structure is full of standing water. Standpipe or catchbasin grates are damaged or not in place and allow trash and debris to enter the outlet pipe or storm sewer.

FOLLOW-UP TASKS: Repair or replace any damaged or missing grates. Remove trash, debris and mulch from the overflow outlet structure. If the overflow outlet structure is not draining, schedule a drain snaking and vacuum truck service to address obstructions in the pipe.

Permeable Pavements

PASS: The overflow outlet is free of damage and obstruction and functions as designed to safely convey excess water from the BMP.

FAIL: The overflow outlet is obstructed with sediment which impairs its function to convey excess water from the BMP.

MAINTENANCE TRIGGER: Structural damage or sediment/trash/debris is obstructing outflow and impairing the drainage function of the BMP. The structure is full of standing water. Standpipe or catchbasin grates are damaged or not in place and allow trash and debris to enter the outlet pipe or storm sewer.

FOLLOW-UP TASKS: Repair or replace any damaged or missing grates. Remove trash, debris and mulch from the overflow outlet structure. If the overflow outlet structure is not draining, schedule a drain snaking and vacuum truck service to address obstructions in the pipe.

Underground Infiltration Systems

PASS: The overflow outlet weir wall and storm sewer pipe in the control manhole of this infiltration chamber system is free of damage and obstruction and functions as designed to safely convey excess water from the BMP.

FAIL: Sediment and debris has accumulated in the overflow outlet pipe which impairs its function to convey excess water from the BMP.

MAINTENANCE TRIGGER: Structural damage or sediment/trash/debris is obstructing outflow and impairing the drainage function of the BMP. The structure is full of standing water. Standpipe or catchbasin grates are damaged or not in place and allow trash and debris to enter the outlet pipe or storm sewer.

FOLLOW-UP TASKS: Remove trash, debris and sediment from the overflow outlet structure. If the overflow outlet structure is not draining, schedule a drain snaking and vacuum truck service to address obstructions in the pipe.

Green Roofs

PASS: The overflow outlets of this green roof are free of damage and obstruction and function as designed to safely convey excess water from the BMP. (Source: Vegetal I.D.)

FAIL: Sediment is accumulating at the overflow outlet which could impair its drainage function and cause surface ponding and vegetation die-off. (Source: Jorg Breuning)

MAINTENANCE TRIGGER: Structural damage or sediment/trash/debris is obstructing outflow and impairing the drainage function of the BMP. The structure is full of standing water. Standpipe or catchbasin grates are damaged or not in place and allow trash and debris to enter the outlet pipe.

FOLLOW-UP TASKS: Remove any trash or debris from the overflow outlet structure. If the overflow outlet structure is not draining, schedule FIT to investigate the cause.

Rainwater Cisterns

PASS: The overflow outlet pipe diameter matches what was specified in the final design and is free of damage and obstruction.

FAIL: The overflow outlet pipe on this rain barrel is undersized and obstructed which impairs its function to safely convey excess water from the BMP. (Source: Melinda Webb)

MAINTENANCE TRIGGER: Structural damage or sediment/trash/debris is obstructing outflow and impairing the drainage function of the BMP. The structure is undersized or full of standing water and not draining.

FOLLOW-UP TASKS: Remove any trash or debris from the overflow outlet structure. If the overflow outlet structure is not draining, schedule FIT to investigate the cause. Undersized outlets should be replaced with structures that meet design specifications.

C.23 PAVEMENT SURFACE CONDITION

Construction Inspection	✓	Assumption	✓	Routine Maintenance and Inspection	✓	Maintenance Verification	✓

PERMEABLE PAVEMENT

Check for damage, displacement or deformation of the surface that impairs its function as a pavement and could be a hazard. Look for displaced or missing pavers, ruts, cracks or gaps on the pavement surface. Check if aggregate fill in paver joints or grid cells needs topping up. Also look for excessive or unsightly weed growth between pavers.

Permeable Pavement

PASS: No damage, displacement or sinking of the permeable surface is visible and there are no weeds growing between paver joints.

FAIL: The pavement surface has sunk in local areas, creating a trip hazard and the potential for further damage from snow plowing. (Source: Basalite)

PASS: No damage, displacement or sinking of the permeable surface is visible. Some grass and weeds are growing in the joints between pavers but the affected area is not extensive.

FAIL: A sink hole has formed in one location on the permeable pavement surface, requiring structural repair.

MAINTENANCE TRIGGER: Potholes or sinkholes are present or pavers are missing or displaced. Edge restraints are no longer functioning. Ruts or local sinking of 13 mm or greater over a 3 metre length. Adjacent pavers or cracks in pervious concrete or porous asphalt are vertically offset by 6 mm or greater. Aggregate between paver joints is missing or below 17 mm from the paver surface. Weed growth between pavers is extensive and impairing aesthetic value.

FOLLOW-UP TASKS: Remove weeds. Spread joint fill material and sweep in until the pavement surface is clean. Repair damaged or displaced portions of the pavement surface. Repairs could involve adding joint fill material into small gaps or cracks, re-installing broken, displaced or sunken pavers or patching to stabilize large cracks or gaps. If problems persist, consider adding or reinforcing edge restraints.

C.24 PAVEMENT SEDIMENT ACCUMULATION

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓

PERMEABLE PAVEMENT

Check for sediment accumulation on the pavement surface. Look for areas where fine sediment or sand has collected or completely fills the joints between interlocking pavers or the cells of interlocking grids. Sediment accumulation impairs the drainage function of the pavement and can lead to surface ponding.

Permeable Pavement

PASS: The fine gravel that fills the joints between pavers is clearly visible and there is no sediment accumulated on the surface of the pavers.

FAIL: The joints between pavers are completely filled with fine sediment and sand.

PASS: No portion of the pavement is covered in sediment and fine gravel fill material within the joints between pavers is still visible.

FAIL: The joints between pavers are completely filled with fine sediment in local areas and sediment is accumulating on the surface of the pavers.

MAINTENANCE TRIGGER: The joints between pavers or grid cells are completely filled with fine sediment. Any portion of the pavement surface is completely covered with sediment.

FOLLOW-UP TASKS: Sweep the pavement to remove coarse debris, loosen sediment accumulated in pavement joints or pores and vacuum the pavement surface. For interlocking pavers and grids, replacement of gravel fill in the joints between pavers or grid cells will be necessary. If surface ponding is observed, schedule FIT to determine the cause and corrective actions. A FIT could involve inspection of the sub-drain, measurement of the surface infiltration rate of the pavement, or natural or simulated storm event testing.

C.25 CONTROL STRUCTURE CONDITION

Construction Inspection	Assumption	Routine Maintenance and Inspection	Maintenance Verification	MANHOLE
✓	✓	✓	✓	

This indicator assesses the structure (e.g. manhole, catchbasin, access hatch) that controls flow of stormwater in and/or out of the BMP for accessibility, safe entry and visual signs of damage or malfunction. Look for obstructions to entry, missing ladder rungs, cracks or other damage in the concrete structure or evidence of leakage (e.g. pipe connections, valves, weir walls).

Underground Infiltration Systems

PASS: The control manhole of this infiltration chamber system is accessible with ladder rungs in place and no signs of leaking around the weir wall and pipe connections.

FAIL: The lid of the access hatch is missing which is a safety hazard and the concrete risers are displaced which prevents safe entry for inspection and maintenance tasks.

MAINTENANCE TRIGGER: The manhole is inaccessible or ladder rungs are missing. Damage to the concrete structure or evidence of leaking is visible and may be impairing the function of the BMP.

FOLLOW-UP TASKS: Schedule repairs to fix accessibility issues. Schedule a FIT to determine if the damage or suspected leak is impairing function of the BMP. A FIT could involve draining the BMP, continuous water level monitoring and natural or simulated storm event testing.

Rainwater Cisterns

PASS: The access hatch of this cistern is accessible with ladder rungs in place.

FAIL: The access hatch of this cistern was paved over with concrete and ladder rungs are missing which prevents safe entry for inspection and maintenance tasks. (Source: Miles Golding).

MAINTENANCE TRIGGER: The access hatch is inaccessible or ladder rungs are missing.

FOLLOW-UP TASKS: Schedule repairs to fix accessibility issues.

C.26 CONTROL STRUCTURE SEDIMENT ACCUMULATION

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓ | **MANHOLE**

Check if accumulated sediment or debris in the manhole or catchbasin sump is obstructing stormwater flow into or out of the BMP. Measure and record the depth of sediment accumulated since the last inspection.

Underground Infiltration Systems

PASS: There is some sediment accumulated in the manhole but it is not impairing the flow of stormwater into or out of the BMP. (Source: SWC Canada)

FAIL: The manhole sump is full of sediment and debris and it is beginning to impair flow of stormwater into a perforated pipe of the exfiltration storm sewer system.

MAINTENANCE TRIGGER: Depth of sediment is 10 cm or greater, or is obstructing the flow of stormwater into or out of the BMP.

FOLLOW-UP TASKS: Removal of accumulated sediment from underground control structures (i.e. manholes, catchbasins, access hatches) requires entry into the structures themselves by staff trained in confined space entry and equipped with recently certified safety equipment (i.e. tripod, winch, harness) and recently calibrated and tested multi-gas detector. Sediment removal involves the use of a pressure sprayer and shovel to consolidate the sediment and a vacuum truck to remove it. Flush inlet and outlet pipes with a hose. Check the removed material for signs of oil or grease contamination (e.g. sheen on surface of water when submerged). If oil or grease contamination is suspected, submit a sediment sample for contaminant testing by an accredited laboratory to determine the proper disposal method. Assess the CDA for changes in land cover or point sources of sediment. Inspect and remove sediment from pretreatment devices. If problems persist, consider adding pretreatment devices or increasing frequency of routine maintenance.

C.27 GREEN ROOF STRUCTURAL INTEGRITY

Construction Inspection ✔ Assumption ✔ Routine Maintenance and Inspection ✔ Maintenance Verification ✔ GREEN ROOF

Check for visible signs of damage to components or exposed root barrier or waterproofing membrane. Look at the perimeter for instances of uplifting of green roof layers from wind scour. Wind scour can be a problem in coastal environments, open areas with few obstructions and urban areas where adjacent structures cause turbulence.

Green Roofs

PASS: There are no signs of damage to the concrete parapets along the perimeter and no uplift of green roof layers.

FAIL: One of the green roof growing media structures has been displaced and requires replacement and repair. (Source: Kevin Songer)

MAINTENANCE TRIGGER: Signs of damage to green roof structures are visible or protective membranes are exposed.

FOLLOW-UP TASKS: Repair damaged green roof structures. Secure any uplifted areas. If wind uplift problems persist, consider installing wind barriers along the perimeter (e.g. stone, interlocking pavers or grids, parapets). Restore cover over exposed protective membranes.

C.28 CISTERN STRUCTURAL INTEGRITY

Construction Inspection ✓ | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓

CISTERN

Assessing this indicator may require entry into the confined space of the cistern structure so inspectors (minimum of two) must be adequately trained and equipped with recently certified safety equipment (e.g. multi-gas detector, harness, tripod and winch). Check the cistern structure for signs of damage or leakage. Look for large cracks or damaged seals that could be impairing the water storage function of the cistern.

Rainwater Cisterns

PASS: There are no cracks or leaks visible in the cistern structure.

FAIL: A section of sealing tape over two pieces of the concrete cistern structure is displaced, raising the potential for leaks in the future.

MAINTENANCE TRIGGER: There are one or more cracks or leaks visible in the cistern. Water level in the cistern is declining when no rainwater use is occurring or never fills completely.

FOLLOW-UP TASKS: Schedule a FIT to determine if the crack or leak is impairing the water storage function of the cistern and to decide on corrective actions/repairs.

C.29 CISTERN SEDIMENT ACCUMULATION

Construction Inspection | Assumption ✓ | Routine Maintenance and Inspection ✓ | Maintenance Verification ✓ | **CISTERN**

Assess the degree to which sediment and debris has accumulated in the cistern. Accumulation of sediment or debris can lead to elevated levels of turbidity in the water delivered from the cistern which impairs the aesthetics of the BMP (e.g., turbid water in toilets). Measure sediment depth in the cistern. Ensure that the intake for the distribution system is set above the level of accumulated sediment or that the float is in place.

Rainwater Cisterns

PASS: Very little sediment and no coarse debris has accumulated on the bottom of the cistern and the sediment is not at the level of the distribution system intake structure.

FAIL: Enough sediment has accumulated in the cistern to cause water delivered from the distribution system to be turbid and discoloured when cistern water levels are low.

MAINTENANCE TRIGGER: Levels of turbidity or discolouration of water drawn from the cistern are aesthetically unpleasing. The depth of accumulated sediment in the cistern is at the level of the distribution system intake structure when cistern water levels are at their lowest operating level.

FOLLOW-UP TASKS: Drain the cistern and use a wet shop vacuum or hydro-vac truck to remove accumulated sediment and debris. Check pretreatment devices for damage or malfunction and clean out captured sediment and debris. If problems persist, consider adding or improving pretreatment devices.

APPENDIX D

INSPECTION FIELD DATA FORMS

GENERAL INFORMATION:

BMP Identifier:	**Inspection type:**
Address :	**Location:**
BMP construction date:	**BMP assumption date:**

VISUAL INDICATORS:

Inspection date and time:	**Weather (24 hours prior to inspection):**
Inspected by:	**Inspection duration (minutes):**

ZONE	INDICATOR & TRIGGER FOR FOLLOW-UP	CONDITION		FOLLOW-UP
CDA	**Contributing drainage area condition:** Area differs by >10% from design or as-built drawing; Excessive trash, debris, sediment or other pollutant load is present or impairing function of the BMP; Land cover has changed	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
INLET	**Inlet structural integrity:** Damage to inlet or flow spreader structure is impairing function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Inlet obstruction: Sediment/trash/debris/vegetation ≥5 cm deep or blocking inflow over one third (33%) of the width	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Pretreatment sediment accumulation: Device is ≥50% full of sediment/trash/debris or inflow of water to the BMP is impaired	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Inlet erosion: Gullies or bare soil areas ≥ 30 cm in length are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

PERIMETER	**BMP dimensions:** Differ from design or as-built drawing by >10%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Side slope erosion: Gullies, ruts or bare soil areas ≥30 cm in length are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Surface ponding area: Maximum surface ponding area differs from design by >25%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
FILTER BED	**Standing water:** Standing water ponded on filter bed surface >24 hours after the end of a storm event	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Trash: Trash is visible and impairing aesthetics or function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Filter bed erosion: Gullies, ruts or bare soil areas ≥30 cm in length are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Mulch depth: Average depth is less than 5 cm or greater than 15 cm or bare soil areas are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Filter bed sediment accumulation: Mean or local accumulation of sediment is ≥5 cm in depth	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Surface ponding depth: Maximum differs from design or as-built drawing by >10%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

FILTER BED	**Filter bed surface sinking:** Local surface depressions are ≥10 cm in depth or animal burrows are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Check dams: Structures are missing or buried in sediment	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
PLANTING AREA	**Vegetation cover:** Less than 80% of planting area is covered by living vegetation	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation condition: Vegetation is over-grown or over-crowded and is impairing aesthetics or obstructing sight lines needed for safety	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation composition: More than 50% of the vegetation is undesirable (e.g. weeds, invasive) or not the species specified in the planting plan	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
OUTLET	**Monitoring well condition:** Structural damage or sediment clog is visible and impairing its function or cap is missing	**Comments/Measurements:** **Water level (cm):**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Sub-drain obstruction: Structural damage, sediment clog or vegetation roots are visible and reducing conveyance capacity of the pipe by ≥ 33%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Overflow outlet obstruction: Structural damage, sediment/trash/debris is obstructing outflow, structure is full of water or grate is missing	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

Codes

Inspection type: C = Construction; A = Assumption; RO = Routine Operation; MV = Maintenance Verification; PV = Performance Verification

Comments: NA = not applicable; NI = not inspected.

Actions: 0 = no action necessary; 1 = routine maintenance needed; 2 = structural repair needed; 3 = further investigation needed.

Photographs:
Notes and Sketches:

SOIL CHARACTERIZATION TESTING:

BMP Identifier	**Inspection Type:**
Sampling date and time:	**Weather (24 hours prior to sampling):**
Sampled by:	**Sampling duration (minutes):**

Sampling Location	**Sample Collected? (Y/N)**	**Filter Media Depth (cm)**	**Maximum Penetrometer Reading (PSI, kg/cm^2 or kPa)**	**Sample Location**	**Sample Collected? (Y/N)**	**Filter Media Depth (cm)**	**Maximum Penetrometer Reading (PSI, kg/cm^2 or kPa)**

Notes and Sketches:

NATURAL OR SIMULATED STORM EVENT TESTING:

BMP Identifier:	**Inspection Type:**
Testing date and time:	**Sub-surface water storage reservoir depth (mm):**
Tested by:	**Test duration (hours):**

Term	Parameter	Test 1	Test 2	Test 3	Mean
A	**Volume of water directed to the BMP (L or m^3, estimated from CDA and rainfall depth for natural storm events, measured by magnetic flow meter for simulated storm events):**				
B	Maximum post-storm filter bed surface water level (mm, at end of rainfall or delivery of water to the BMP):				
C	Date/time (mm/dd/yyyy hh:mm:ss) of maximum post-storm filter bed surface water level:				
D	Date/time (mm/dd/yyyy hh:mm:ss) when filter bed surface water level reaches 50 mm:				
E	Minimum post-storm filter bed surface water level (mm, zero or static reading or level just prior to onset of next rain storm):				
F	Date/time (mm/dd/yyyy hh:mm:ss) of minimum post-storm filter bed surface water level (zero or static reading or level just prior to onset of next rain storm):				
G	Date/time (mm/dd/yyyy hh:mm:ss) when filter bed surface is fully drained (zero or static water level reading):				
H	**Filter bed surface ponding event duration (h, (G-C)*24):**				
I	**Filter bed surface infiltration rate estimate (mm/h, (F-D)*24):**				
J	Maximum post-storm sub-surface storage reservoir water level (mm, at end of rainfall or delivery of water to the BMP):				
K	Date/time (mm/dd/yyyy hh:mm:ss) of maximum post-storm sub-surface storage reservoir water level:				
L	Sub-surface storage reservoir starting water level (mm, half full water level):				
M	Date/time (mm/dd/yyyy hh:mm:ss) of sub-surface storage reservoir starting water level (half full):				

N	Sub-surface storage reservoir ending water level (mm, one quarter full water level):				
O	Date/time (mm/dd/yyyy hh:mm:ss) of sub-surface storage reservoir ending water level (one quarter full):				
P	Date/time (mm/dd/yyyy hh:mm:ss) when sub-surface storage reservoir is fully drained (zero or static water level reading):				
Q	**Sub-surface water storage reservoir drainage period duration (h, (P-K)*24):**				
R	**Sub-surface water storage reservoir drainage rate (mm/h, (L-N)/(M-O)*24):**				

Acceptance Criteria:	
Water flows into BMP as intended; Filter bed surface infiltration rate ≥25 mm/h and ≤203 mm/h, or consult manufacturer or vendor for an acceptable range specific to the product; Surface water storage reservoir (i.e., surface ponding) fully drains within 24 hours of the end of the storm;	Sub-drain peak flow rate is within +/- 15% of design specification; Active sub-surface water storage reservoir volume drains within 48 to 72 hours of the end of the storm for newly constructed BMPs, and within 48 to 96 hours for in-service BMPs.

Notes and Sketches:

GENERAL INFORMATION:

BMP Identifier:	**Inspection type:**
Address :	**Location:**
BMP construction date:	**BMP assumption date:**

VISUAL INDICATORS:

Inspection date and time:	**Weather (24 hours prior to inspection):**
Inspected by:	**Inspection duration (minutes):**

ZONE	INDICATOR & TRIGGER FOR FOLLOW-UP	CONDITION		FOLLOW-UP
CDA	**Contributing drainage area condition:** Area differs by >10% from design or as-built drawing; Excessive trash, debris, sediment or other pollutant load is present or impairing function of the BMP; Land cover has changed	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
INLET	**Inlet structural integrity:** Damage to inlet or flow spreader structure is impairing function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Inlet obstruction: Sediment/trash/debris/vegetation ≥5 cm deep or blocking inflow over one third (33%) of the width	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Pretreatment sediment accumulation: Device is ≥50% full of sediment/trash/debris or inflow of water to the BMP is impaired	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Inlet erosion: Gullies or bare soil areas ≥ 30 cm in length are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

PERIMETER	**BMP dimensions:** Differ from design or as-built drawing by >10%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Side slope erosion: Gullies, ruts or bare soil areas ≥30 cm in length are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Surface ponding area: Effective surface ponding area differs from design by >25%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
FILTER BED	**Standing water:** Standing water ponded on filter bed surface >24 hours after the end of a storm event	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Trash: Trash is visible and impairing aesthetics or function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Filter bed erosion: Gullies, ruts or bare soil areas ≥30 cm in length are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Mulch depth: Average depth is less than 5 cm or greater than 15 cm or bare soil areas are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Filter bed sediment accumulation: Mean or local accumulation of sediment is ≥5 cm in depth	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Surface ponding depth: Maximum differs from design by ≥10 cm	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

FILTER BED	**Filter bed surface sinking:** Local surface depressions are ≥10 cm in depth or animal burrows are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Check dams: Structures are missing or buried in sediment	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
PLANTING AREA	**Vegetation cover:** Less than 80% of planting area is covered by living vegetation	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation condition: Vegetation is over-grown or over-crowded and is impairing aesthetics or obstructing sight lines needed for safety	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation composition: More than 50% of the vegetation is undesirable (e.g. weeds, invasive) or not the species specified in the planting plan	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
OUTLET	**Overflow outlet obstruction:** Structural damage, sediment/trash/debris is obstructing outflow, structure is full of water or grate is missing	**Comments/Measurements:** **Water level (cm):**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

<u>Codes</u>
Inspection type: C = Construction; A = Assumption; RO = Routine Operation; MV = Maintenance Verification; PV = Performance Verification
Comments: NA = not applicable; NI = not inspected.
Actions: 0 = no action necessary; 1 = routine maintenance needed; 2 = structural repair needed; 3 = further investigation needed.

Photographs:
Notes and Sketches:

SOIL CHARACTERIZATION TESTING:

BMP Identifier	**Inspection Type:**
Sampling date and time:	**Weather (24 hours prior to sampling):**
Sampled by:	**Sampling duration (minutes):**

Sampling Location	Sample Collected? (Y/N)	Topsoil Depth (cm)	Maximum Penetrometer Reading (PSI, kg/cm^2 or kPa)	Sample Location	Sample Collected? (Y/N)	Topsoil Depth (cm)	Maximum Penetrometer Reading (PSI, kg/cm^2 or kPa)

Notes and Sketches:

NATURAL OR SIMULATED STORM EVENT TESTING:

BMP Identifier:	**Inspection Type:**
Testing date and time:	**Check dam invert height (cm, between check dam invert and the soil or sediment surface on the upstream side):**
Tested by:	**Test duration (hours):**

Term	Parameter	Test 1	Test 2	Test 3	Mean
A	**Volume of water directed to the BMP (L or m^3, estimated from CDA and rainfall depth for natural storm events, measured by magnetic flow meter for simulated storm events):**				
B	Maximum post-storm filter bed surface water level (mm, at end of rainfall or delivery of water to the BMP):				
C	Date/time (mm/dd/yyyy hh:mm:ss) of maximum post-storm filter bed surface water level:				
D	Date/time (mm/dd/yyyy hh:mm:ss) when filter bed surface water level reaches 50 mm:				
E	Minimum post-storm filter bed surface water level (mm, zero or static reading or level just prior to onset of next rain storm):				
F	Date/time (mm/dd/yyyy hh:mm:ss) of minimum post-storm filter bed surface water level (zero or static reading or level just prior to onset of next rain storm):				
G	Date/time (mm/dd/yyyy hh:mm:ss) when filter bed surface is fully drained (zero or static water level reading):				
H	**Filter bed surface ponding event duration (h, (G-C)*24):**				
I	**Filter bed surface infiltration rate estimate (mm/h, (F-D)*24):**				

Acceptance Criteria:	
Water flows into BMP as intended; Filter bed (i.e., swale) surface infiltration rate ≥15 mm/h and ≤203 mm/h, or consult manufacturer orvendor for an acceptable range specific to the product;	Surface water storage reservoir (i.e., surface ponding behind check dams) fully drains within 24 hours of the end of the storm.

GENERAL INFORMATION:

BMP Identifier:	**Inspection type:**
Address :	**Location:**
BMP construction date:	**BMP assumption date:**

VISUAL INDICATORS:

Inspection date and time:	**Weather (24 hours prior to inspection):**
Inspected by:	**Inspection duration (minutes):**

ZONE	INDICATOR & TRIGGER FOR FOLLOW-UP	CONDITION		FOLLOW-UP
CDA	**Contributing drainage area condition:** Area differs by >10% from design or as-built drawing; Excessive trash, debris, sediment or other pollutant load is present or impairing function of the BMP; Land cover has changed	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
INLET	**Inlet structural integrity:** Damage to inlet or flow spreader structure is impairing function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Inlet obstruction: Sediment/trash/debris/vegetation ≥5 cm deep or blocking inflow over one third (33%) of the width	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Inlet erosion: Gullies or bare soil areas ≥ 30 cm in length are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

PERIMETER	**BMP dimensions:** Differ from design or as-built drawing by >10%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
FILTER BED	**Standing water:** Standing water ponded on filter bed surface >24 hours after the end of a storm event	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Trash: Trash is visible and impairing aesthetics or function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Filter bed erosion: Gullies, ruts or bare soil areas ≥30 cm in length are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Mulch depth: Average depth is less than 5 cm or greater than 15 cm or bare soil areas are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Filter bed sediment accumulation: Mean or local accumulation of sediment is ≥5 cm in depth	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Filter bed surface sinking: Local surface depressions are ≥10 cm in depth or animal burrows are visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
PLANTING AREA	**Vegetation cover:** Less than 80% of planting area is covered by living vegetation	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation condition: Vegetation is over-grown or over-crowded and is impairing aesthetics or obstructing	**Comments/Measurements:**		**Action:**

	sight lines needed for safety	**Pass:**	**Fail:**	**Timeframe:**
	Vegetation composition: More than 50% of the vegetation is undesirable (e.g. weeds, invasive) or not the species specified in the planting plan	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
OUTLET	**Overflow outlet obstruction:** Structural damage, sediment/trash/debris is obstructing outflow, structure is full of water or grate is missing	**Comments/Measurements:** **Water level (cm):**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

<u>**Codes**</u>

Inspection type: C = Construction; A = Assumption; RO = Routine Operation; MV = Maintenance Verification; PV = Performance Verification

Comments: NA = not applicable; NI = not inspected.

Actions: 0 = no action necessary; 1 = routine maintenance needed; 2 = structural repair needed; 3 = further investigation needed.

Photographs:

Notes and Sketches:

SOIL CHARACTERIZATION TESTING:

BMP Identifier	**Inspection Type:**
Sampling date and time:	**Weather (24 hours prior to sampling):**
Sampled by:	**Sampling duration (minutes):**

Sampling Location	Sample Collected? (Y/N)	Topsoil Depth (cm)	Maximum Penetrometer Reading (PSI, kg/cm^2 or kPa)	Sample Location	Sample Collected? (Y/N)	Topsoil Depth (cm)	Maximum Penetrometer Reading (PSI, kg/cm^2 or kPa)

Notes and Sketches:

GENERAL INFORMATION:

BMP Identifier:	**Inspection type:**
Address :	**Location:**
BMP construction date:	**BMP assumption date:**

VISUAL INDICATORS:

Inspection date and time:	**Weather (24 hours prior to inspection):**
Inspected by:	**Inspection duration (minutes):**

ZONE	INDICATOR & TRIGGER FOR FOLLOW-UP	CONDITION		FOLLOW-UP
CDA	**Contributing drainage area condition:** Area differs by >10% from design or as-built drawing; Excessive trash, debris, sediment or other pollutant load is present or impairing function of the BMP; Land cover has changed	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
PAVEMENT SURFACE	**BMP dimensions:** Differ from design or as-built drawing by >10%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Standing water: Standing water ponded on pavement surface is present	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Trash: Trash is visible and impairing aesthetics or function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Pavement surface condition: Damage, missing or displaced pavers, ruts or local sinking present, paver joint fill is missing	**Comments/Measurements:**		**Action:**

	or low, weed growth between pavers is extensive and impairing aesthetic value	**Pass:**	**Fail:**	**Timeframe:**
	Pavement surface sediment accumulation: Joints between pavers or grid cells are completely filled with fine sediment, any portion is covered with sediment	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
PLANTING AREA	**Vegetation cover:** Less than 80% of planting area is covered by living vegetation	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation condition: Grass is not thriving or over-grown and impairing the aesthetic value of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation composition: More than 50% of the vegetation is undesirable (e.g. weeds, invasive) or not the species specified in the planting plan	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
OUTLET	**Monitoring well condition:** Structural damage or sediment clog is visible and impairing its function or cap is missing	**Comments/Measurements:** **Water level (cm):**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Sub-drain obstruction: Structural damage, sediment clog or vegetation roots are visible and reducing conveyance capacity of the pipe by ≥ 33%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Overflow outlet obstruction: Structural damage, sediment/trash/debris is obstructing outflow, structure is full of water or grate is missing	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
CONTROL STRUCTURE	**Control structure condition:** Structure is inaccessible or ladder rungs are missing, damage or evidence of leaking is visible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

	Control structure sediment accumulation: Sediment depth ≥ 10 cm, or is obstructing flow out of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

Codes

Inspection type: C = Construction; A = Assumption; RO = Routine Operation; MV = Maintenance Verification; PV = Performance Verification

Comments: NA = not applicable; NI = not inspected.

Actions: 0 = no action necessary; 1 = routine maintenance needed; 2 = structural repair needed; 3 = further investigation needed.

Photographs:

Notes and Sketches:

NATURAL OR SIMULATED STORM EVENT TESTING:

BMP Identifier:	**Inspection Type:**
Testing date and time:	**Sub-surface water storage reservoir depth (mm):**
Tested by:	**Test duration (hours):**

Term	Parameter	Test 1	Test 2	Test 3	Mean
A	**Volume of water directed to the BMP (L or m^3, measured or estimated from CDA and rainfall depth for natural storm events; measured by flow meter for simulated storm events):**				
B	Maximum post-storm sub-surface storage reservoir water level (mm, at end of rainfall or delivery of water to the BMP):				
C	Date/time (mm/dd/yyyy hh:mm:ss) of maximum post-storm sub-surface storage reservoir water level:				
D	Sub-surface storage reservoir starting water level (mm, half full water level):				
E	Date/time (mm/dd/yyyy hh:mm:ss) of sub-surface storage reservoir starting water level (half full):				
F	Sub-surface storage reservoir ending water level (mm, one quarter full water level):				
G	Date/time (mm/dd/yyyy hh:mm:ss) of sub-surface storage reservoir ending water level (one quarter full):				
H	Date/time (mm/dd/yyyy hh:mm:ss) when sub-surface storage reservoir is fully drained (zero or static water level reading):				
I	**Sub-surface water storage reservoir drainage period duration (h, (H-C)*24):**				
J	**Sub-surface water storage reservoir drainage rate (mm/h, (D-F)/(G-E)*24):**				

Acceptance Criteria:	
Water flows into BMP as intended; Sub-drain peak flow rate is within +/- 15% of design specification;	Active sub-surface water storage reservoir volume drains within 48 to 72 hours of the end of the storm for newly constructed BMPs, and within 48 to 96 hours for in-service BMPs.

GENERAL INFORMATION:

BMP Identifier:	**Inspection type:**
Address :	**Location:**
BMP construction date:	**BMP assumption date:**

VISUAL INDICATORS:

Inspection date and time:	**Weather (24 hours prior to inspection):**
Inspected by:	**Inspection duration (minutes):**

ZONE	INDICATOR & TRIGGER FOR FOLLOW-UP	CONDITION		FOLLOW-UP
CDA	**Contributing drainage area condition:** Area differs by >10% from design or as-built drawing; Excessive trash, debris, sediment or other pollutant load is present or impairing function of the BMP; Land cover has changed	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
INLET	**Inlet structural integrity:** Damage to inlet or structure is impairing function of the BMP or catchbasin grate or trash rack is missing or damaged.	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Inlet obstruction: Sediment/trash/debris ≥5 cm deep or blocking inflow over one third (33%) of the inlet width or area	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Pretreatment sediment accumulation: Device is ≥50% full of sediment/trash/debris or inflow of water to the BMP is impaired	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

Component	Item	Comments/Measurements		Action
PERIMETER	**BMP dimensions:** Differ from design or as-built drawing by >10%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
FILTER BED	**Filter bed sediment accumulation:** Mean or local accumulation of sediment is ≥ 8 cm in depth	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	
OUTLET	**Monitoring well condition:** Structural damage or sediment clog is visible and impairing its function or cap is missing	**Comments/Measurements:** **Water level (cm):**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Sub-drain obstruction: Structural damage, sediment clog or vegetation roots are visible and reducing conveyance capacity of the pipe by ≥ 33%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Overflow outlet obstruction: Structural damage, sediment/trash/debris is obstructing outflow, structure is full of water or grate is missing	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
CONTROL STRUCTURE	**Control structure condition:** Structure is inaccessible or ladder rungs are missing. Damage to the concrete structure or evidence of leaking is visible and may be impairing the function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Control structure sediment accumulation: Depth of sediment ≥ 10 cm, or is obstructing flow of stormwater into or out of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

<u>**Codes**</u>
Inspection type: C = Construction; A = Assumption; RO = Routine Operation; MV = Maintenance Verification; PV = Performance Verification
Comments: NA = not applicable; NI = not inspected.
Actions: 0 = no action necessary; 1 = routine maintenance needed; 2 = structural repair needed; 3 = further investigation needed.

Photographs:
Notes and Sketches:

NATURAL OR SIMULATED STORM EVENT TESTING:

BMP Identifier:	**Inspection Type:**
Testing date and time:	**Sub-surface water storage reservoir depth (mm):**
Tested by:	**Test duration (hours):**

Term	Parameter	Test 1	Test 2	Test 3	Mean
A	**Volume of water directed to the BMP (L or m^3, measured or estimated from CDA and rainfall depth for natural storm events; measured by flow meter for simulated storm events):**				
B	Maximum post-storm sub-surface storage reservoir water level (mm, at end of rainfall or delivery of water to the BMP):				
C	Date/time (mm/dd/yyyy hh:mm:ss) of maximum post-storm sub-surface storage reservoir water level:				
D	Sub-surface storage reservoir starting water level (mm, half full water level):				
E	Date/time (mm/dd/yyyy hh:mm:ss) of sub-surface storage reservoir starting water level (half full):				
F	Sub-surface storage reservoir ending water level (mm, one quarter full water level):				
G	Date/time (mm/dd/yyyy hh:mm:ss) of sub-surface storage reservoir ending water level (one quarter full):				
H	Date/time (mm/dd/yyyy hh:mm:ss) when sub-surface storage reservoir is fully drained (zero or static water level reading):				
I	**Sub-surface water storage reservoir drainage period duration (h, (H-C)*24):**				
J	**Sub-surface water storage reservoir drainage rate (mm/h, (D-F)/(G-E)*24):**				

Acceptance Criteria:	
Water flows into BMP as intended; Sub-drain peak flow rate is within +/- 15% of design specification;	Active sub-surface water storage reservoir volume drains within 48 to 72 hours of the end of the storm for newly constructed BMPs, and within 48 to 96 hours for in-service BMPs.

INSPECTION FIELD DATA FORMS: Green Roofs

GENERAL INFORMATION:

BMP Identifier:	**Inspection type:**
Address :	**Location:**
BMP construction date:	**BMP assumption date:**

VISUAL INDICATORS:

Inspection date and time:	**Weather (24 hours prior to inspection):**
Inspected by:	**Inspection duration (minutes):**

ZONE	INDICATOR & TRIGGER FOR FOLLOW-UP	CONDITION		FOLLOW-UP
PERIMETER	**Access point:** Site remains safely and easily accessible	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Unvegetated borders: Free of vegetation and natural debris	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	BMP dimensions: Differ from design or as-built drawing by >10%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Green roof structural integrity: Signs of damage to green roof structures (including wind breaks if present) are visible or protective membranes are exposed	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
FILTER BED	**Standing water:** Standing water ponded on filter bed surface >3 hours after the end of a storm event	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

Section	Item	Comments/Measurements		Action
FILTER BED	**Trash:** Trash is visible and impairing aesthetics or function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Filter bed erosion: Erosion gullies or bare areas ≥ 30 cm in length are visible. Foot traffic has damaged the filter bed surface or is preventing vegetation from becoming established. Animal burrows are visible.	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Growing medium depth: Average depth matches design specification	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
PLANTING AREA	**Vegetation cover:** Less than 80% of planting area is covered by living vegetation	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation condition: Plants are not thriving, over-grown or over-crowded and impairing the aesthetic value of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Vegetation composition: More than 50% of the vegetation is undesirable (e.g. weeds) or not the species specified in the planting plan. Volunteer tree or shrub seedlings are present where inappropriate	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
OUTLET	**Overflow outlet obstruction:** Structural damage, sediment/trash/debris is obstructing outflow, structure is full of water or grate is missing	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

<u>**Codes**</u>

Inspection type: C = Construction; A = Assumption; RO = Routine Operation; MV = Maintenance Verification; PV = Performance Verification

Comments: NA = not applicable; NI = not inspected.

Actions: 0 = no action necessary; 1 = routine maintenance needed; 2 = structural repair needed; 3 = further investigation needed.

Photographs:
Notes and Sketches:

IRRIGATION SYSTEM TESTING:

Inspection date and time:			**Inspected by:**
TRIGGER FOR FOLLOW-UP	**CONDITION**		**FOLLOW-UP**
Components are damaged or leaking and impairing function of the irrigation system	**Comments/Measurements:**		**Action:**
	Pass:	**Fail:**	**Timeframe:**
Components are obstructed or misconfigured, causing uneven distribution of water to green roof vegetation	**Comments/Measurements:**		**Action:**
	Pass:	**Fail:**	**Timeframe:**

SOIL CHARACTERIZATION TESTING:

BMP Identifier	**Inspection Type:**
Sampling date and time:	**Weather (24 hours prior to sampling):**
Sampled by:	**Sampling duration (minutes):**

Sampling Location	Sample Collected? (Y/N)	Growing Medium Depth (cm)	Sample Location	Sample Collected? (Y/N)	Growing Medium Depth (cm)

Notes and Sketches:

GENERAL INFORMATION:

BMP Identifier:	**Inspection type:**
Address :	**Location:**
BMP construction date:	**BMP assumption date:**

VISUAL INDICATORS:

Inspection date and time:	**Weather (24 hours prior to inspection):**
Inspected by:	**Inspection duration (minutes):**

ZONE	INDICATOR & TRIGGER FOR FOLLOW-UP	CONDITION		FOLLOW-UP
CDA	**Contributing drainage area condition:** Area differs by >10% from design or as-built drawing; Excessive trash, debris, sediment or other pollutant load is present or impairing function of the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
INLET	**Inlet structural integrity:** Damage to, or displacement of the structures prevents or impairs the flow of stormwater into the BMP	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Inlet obstruction: Sediment/trash/debris ≥5 cm deep or blocking inflow over one third (33%) of the inlet width or area	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Pretreatment sediment accumulation: Device is ≥50% full of sediment/trash/debris or inflow of water to the BMP is impaired	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
CISTERN	**BMP dimensions:** Differ from design or as-built drawing by >10%	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

	Cistern structural integrity: Cracks or leaks are visible in the cistern. Water level in the cistern is declining when no rainwater use is occurring or never fills completely	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
	Cistern sediment accumulation: Level of turbidity or discolouration of water drawn from the cistern is aesthetically unacceptable. Sediment depth is at the level of the distribution system intake structure when cistern water levels are at a minimum	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	
OUTLET	**Overflow outlet obstruction:** Structural damage, sediment/trash/debris is obstructing outflow, structure is full of water or undersized.	**Comments/Measurements:** **Water level (cm):**		**Action:**
		Pass:	**Fail:**	**Timeframe:**
CONTROL STRUCTURE	**Control structure condition:** Structure is inaccessible or ladder rungs are missing.	**Comments/Measurements:**		**Action:**
		Pass:	**Fail:**	**Timeframe:**

Codes

Inspection type: C = Construction; A = Assumption; RO = Routine Operation; MV = Maintenance Verification; PV = Performance Verification

Comments: NA = not applicable; NI = not inspected.

Actions: 0 = no action necessary; 1 = routine maintenance needed; 2 = structural repair needed; 3 = further investigation needed.

Photographs:

Notes and Sketches:

CISTERN PUMP TESTING:

Inspection date and time:		**Inspected by:**	
TRIGGER FOR FOLLOW-UP	**CONDITION**		**FOLLOW-UP**
Pump or distribution system components are damaged or leaking and not delivering water to fixtures	**Comments/Measurements:**		**Action:**
	Pass:	**Fail:**	**Timeframe:**
Pump is not delivering adequate water pressure to fixtures	**Comments/Measurements:**		**Action:**
	Pass:	**Fail:**	**Timeframe:**