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.

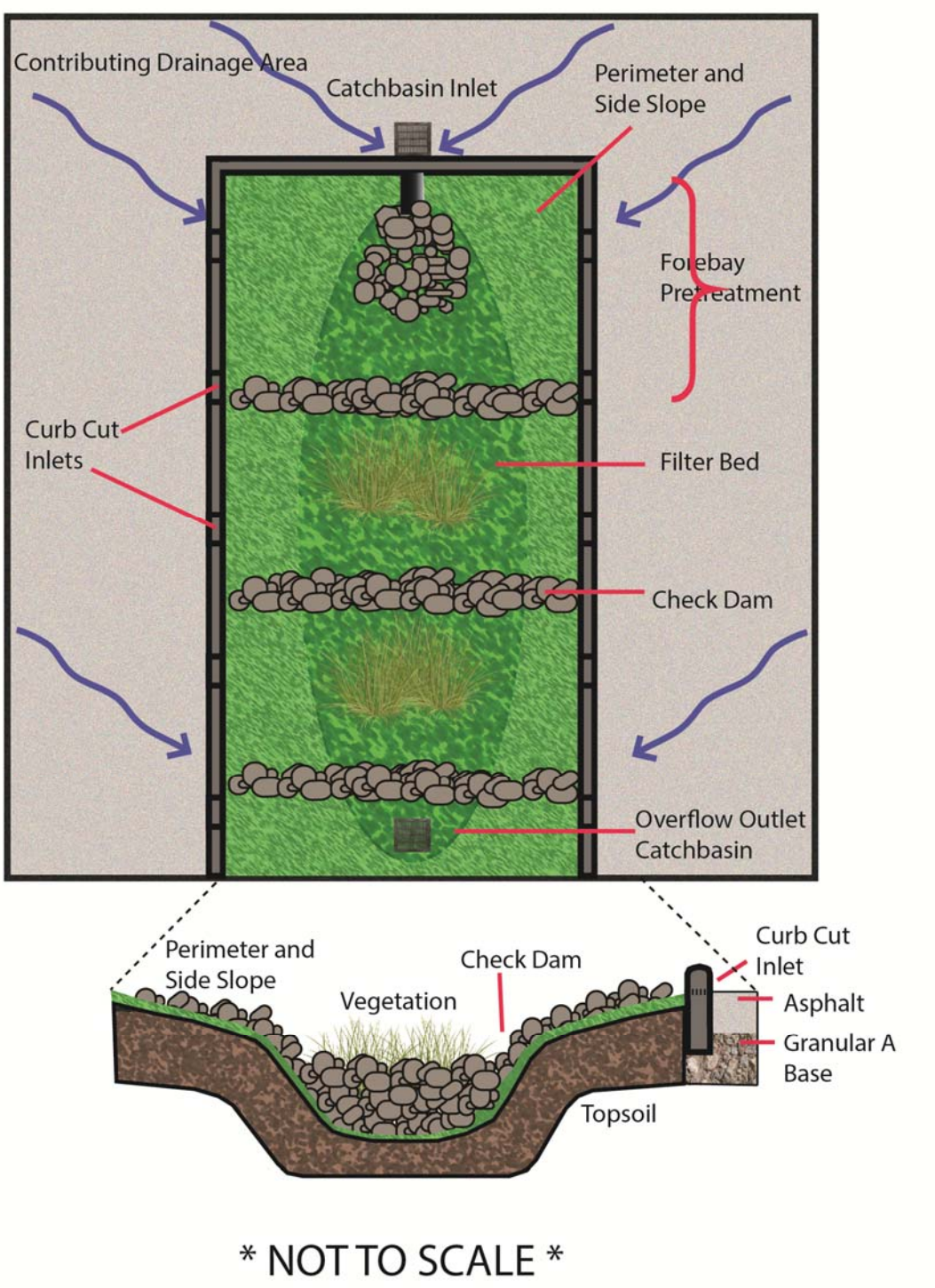

Figure 7.2: *Generalized plan and cross-section views of an enhanced swale showing key components.*

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.