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.

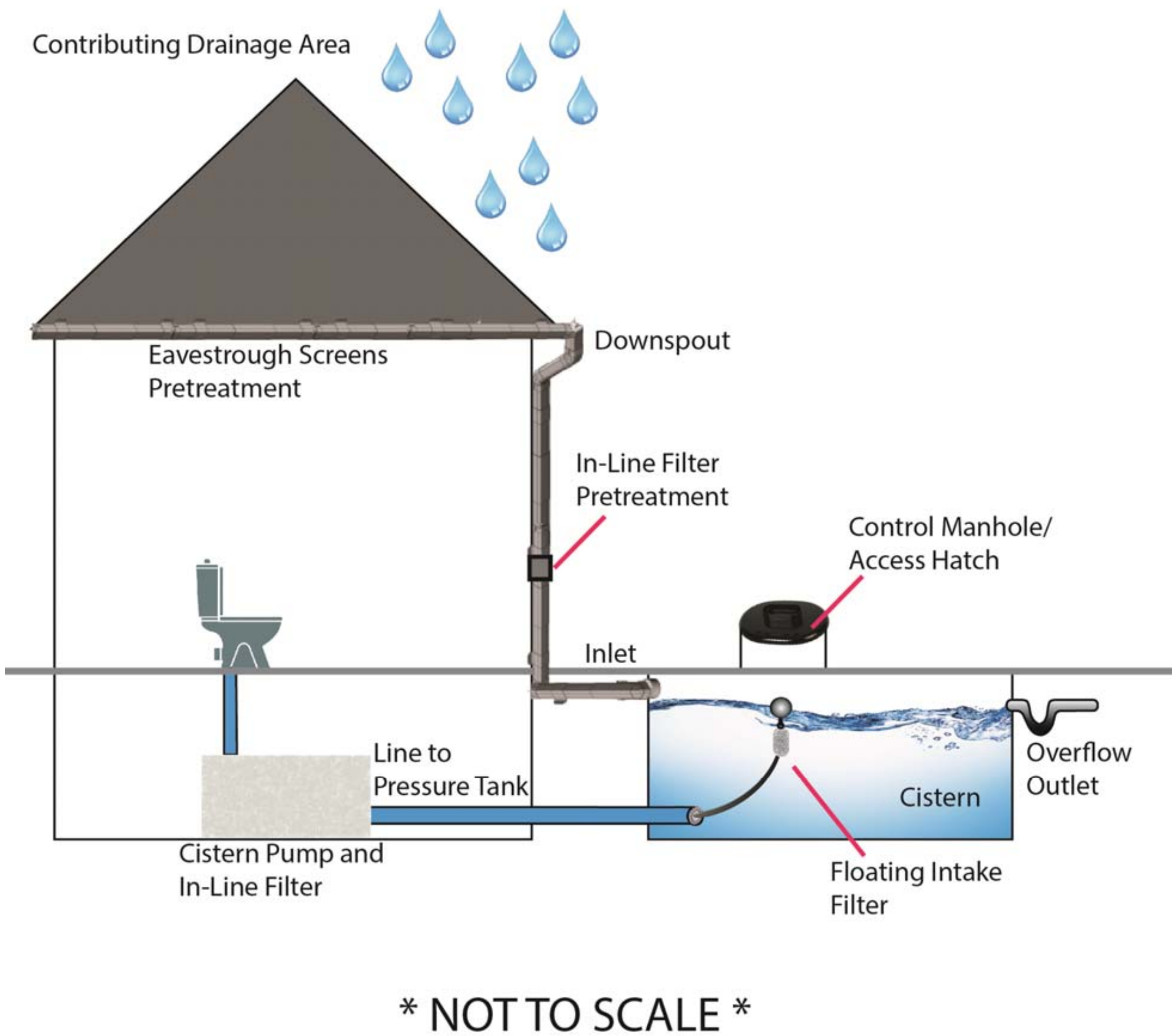

Figure 7.7: *Generalized plan and cross-section views of a rainwater cistern showing key components.*

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.