4.2 Green Roofs

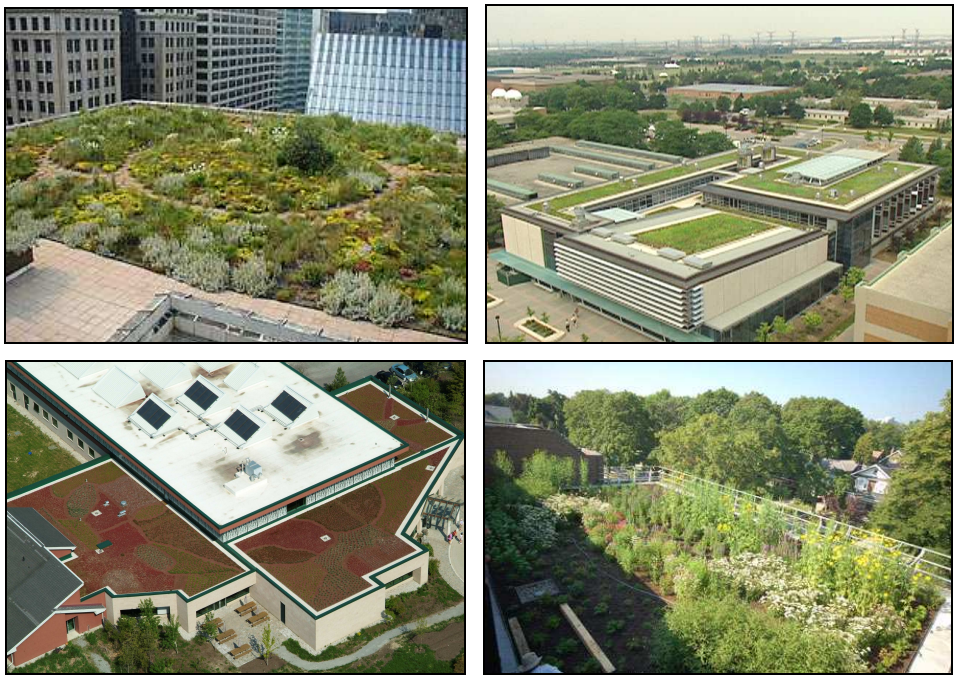
4.2.1 Overview

Description

Green roofs, also known as “living roofs” or “rooftop gardens”, consist of a thin layer of vegetation and growing medium installed on top of a conventional flat or sloped roof (Figure 4.2.1). Green roofs are touted for their benefits to cities, as they improve energy efficiency, reduce urban heat island effects, and create greenspace for passive recreation or aesthetic enjoyment. To a water resources manager, they are attractive for their water quality, water balance, and peak flow control benefits. From a hydrologic perspective, the green roof acts like a lawn or meadow by storing rainwater in the growing medium and ponding areas. Excess rainfall enters underdrains and overflow points and is conveyed in the building drainage system. After the storm, a large portion of the stored water is evapotranspired by the plants, evaporates or slowly drains away.

There are two types of green roofs: intensive and extensive. Intensive green roofs contain greater than 15 centimetres depth of growing medium, can be planted with deeply rooted plants and are designed to handle pedestrian traffic. Roof structures supporting intensive green roofs require significantly greater load bearing capacity, thereby increasing their overall cost and complexity of design. Guidance in this guide focuses on extensive green roof design. Extensive green roofs consist of a thin layer of growing medium (15 centimetre depth or less) with a herbaceous vegetative cover. Two installation options are discussed: conventional and modular construction.

Figure 4.2.1 Examples of green roofs



Clockwise from top left: Chicago City Hall (Source: Roofscapes, 2005); York University in Toronto, Jackman Public School in Toronto; and Earth Rangers Building in Vaughan (Source: TRCA)

Common Concerns

Green roofs have multiple benefits including improved aesthetics in urban areas, reduction of the urban heat island effect, improved air quality, and insulation of buildings. However, there are some common concerns that should be addressed through design:

- *Water Damage to Roof:* Ponding water on roofs with drain restrictions is a practice already in use in the Greater Toronto Area. While failure of waterproofing elements may present a risk of water damage, a warranty can ensure that any damage to the waterproofing system will be repaired, similar to traditional roof installations. Leak detection systems can also be installed to minimize or prevent water damage.

- *Vegetation Maintenance:* Extreme weather conditions can have an impact on plant survival. Appropriate plant selection will help to ensure plant survival during weather extremes (see Appendix B for guidance on plant selection). Irrigation during the first year may be necessary in order to establish vegetation. Vegetation maintenance costs decrease substantially after the first two years of operation, once plants become established.

- *Cost:* An analysis to determine cost effectiveness for a given site should include the roofing lifespan, energy savings, stormwater management requirements, aesthetics, market value, tax and other municipal incentives. It is estimated that green roofs can extend the life of a roof by as long as 20 years by reducing exposure of the roofing materials to sun and precipitation (Velazquez, 2005). They can also reduce energy demand by as much as 75% (TRCA, 2006). Some municipalities, such as the City of Toronto, offer green roof incentive programs that should be considered in the cost assessment. A study of the life cycle costs and savings of building and owning a green roof in the Greater Toronto Area was undertaken by TRCA (2007a).

- *Cold Climate:* Green roofs are a feasible BMP for cold climates (Figure 4.2.2). Snow can protect the vegetation layer and once thawed, will percolate into the growing medium and is either absorbed or drained away just as it would during a rain event. No seasonal adjustments in operation are needed.

- *On Private Property*: Property owners or managers will need to be educated on their routine operation and maintenance needs, understand the long-term maintenance plan, and may be subject to a legally binding maintenance agreement. An incentive program such as a storm sewer user fee based on the area of impervious cover on a property that is directly connected to a storm sewer (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices.

Figure 4.2.2 A green roof during winter

Source: National Research Council Canada, 2006

Physical Suitability and Constraints

Green roofs are physically feasible in most development situations, but should be planned at the time of building design. Some key constraints are addressed below.

- *Structural Requirements:* Load bearing capacity of the building structure and selected roof deck need to be sufficient to support the weight of the soil, vegetation and accumulated water or snow, and may also need to support pedestrians, concrete pavers, etc. Standards for dead and live design loads are available from ASTM International. Although the Ontario Building Code (2006) does not specifically address the construction of green roofs, requirements from the *Building Code Act* and Division B may apply to components of the construction. Further requirements from sections 2.4 and 2.11 of the 1997 Ontario Fire Code also require consideration.

- *Roof Slope:* Green roofs may be installed on roofs with slopes up to 10%.

- *Drainage Area and Runoff Volume:* Green roofs are designed to capture precipitation falling directly onto the roof surface. They are not designed to receive runoff diverted from other source areas.

Typical Performance

The ability of green roofs to help meet stormwater management objectives is summarized in Table 4.2.1.

Table 4.2.1 Ability of green roofs to meet SWM objectives

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Green Roofs	Yes	Yes	Yes

Water Balance

Green roofs help achieve water balance objectives by reducing total annual runoff volumes. Considerable research has been conducted in recent years to define the runoff reduction capacity of extensive green roofs. Reported rates for runoff reduction have been shown to be a function of media depth, roof slope, annual rainfall and cold season effects. Based on the prevailing climate for the region, a conservative runoff reduction rate for green roofs of 45 to 55% is recommended for initial screening of LID practices. Results from select monitoring studies are provided in Table 4.2.2.

Table 4.2.2 Monitoring results – green roof runoff reduction

Location	Monitoring Period	Substrate Depth (cm)	Runoff Reduction[1]	Reference
Toronto, Ontario	May '03 – Aug.'05 excluding winters	14	63%[2]	Van Seters *et al.* (2009)
Toronto, Ontario	Mar.'03 – Nov.'04 excluding winters	7.5 and 10	57%[2]	Liu and Minor (2005)
Ottawa, Ontario	Nov.'00 – Nov.'01	15	54%[2]	Liu (2002)
East Lansing, Michigan	Apr.'05 – Nov.'05 & Apr.'06 – Sep.'06	6	75 to 85%	Getter *et al.* (2007)
East Lansing, Michigan	Aug.'02 – Oct.'03 excluding winter	5.5	61%	VanWoert *et al.* (2005)
Portland, Oregon	May – Oct.'02	11	69%	Hutchinson *et al.* (2003)
Germany	Between 1987 and 2003[3]	10[4]	50%[5]	Mentens *et al.* (2005)
Kinston, North Carolina	July – Aug & Nov.-Dec.'03	10	64%	Hathaway *et al.* (2008)
Athens, Georgia	Nov.'03 – Nov.'04	11	78%	Carter and Rasmussen (2006)
Runoff Reduction Estimate[6]		**45 to 55%**		

Notes:

1. Values represent total precipitation retained by the green roof over the monitoring period unless otherwise noted.
2. Value represents reduction in runoff from the green roof relative to a reference roof, not relative to precipitation.
3. Based on summary of 18 different studies examining 121 extensive green roofs.
4. Value represents the median substrate depth from 121 extensive green roofs.
5. Value represents the average runoff reduction as % of total annual precipitation, based on studies of 121 extensive green roofs.
6. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Water Quality – Pollutant Removal Capacity

Only a handful of monitoring studies have measured the pollutant removal performance of green roofs. A TRCA study comparing conventional black roof runoff to green roof runoff in Toronto was completed in 2006. The study conducted a water quality analysis for a total of 21 events during 2003 and 2004**.** Table 4.2.3 summarizes the water quality results. The loading 'percent difference' values shown in the right column represent the difference in loading, expressed as a percentage, between unit area loads from the conventional roof and the green roof. Designers should regard the pollutant load reductions shown below as an initial estimate until more performance monitoring becomes available.

Table 4.2.3 Comparative pollutant load reductions for a green roof

Pollutant	Loading % Difference* (Conventional Roof vs. Green Roof)
Total Suspended Solids	89
Total Phosphorus	-248
Nitrate	91
Aluminum	69
Zinc	69
Copper	86
E. Coli	11
*Positive values indicate lower pollutant loadings from the green roof. Negative values indicate higher pollutant loadings from the green roof.	

Source: Van Seters et al, 2009

Other studies have also found higher concentrations of nutrients in green roof runoff that can be attributed to leaching from the growing medium (Hathaway *et al*., 2008; Berndtsson *et al.,* 2006; Long *et al.,* 2007). Leaching may be reduced by using less organic matter and coated, controlled release fertilizer in the growing medium (Emilsson *et al.*, 2007). Further reductions in phosphorus may be achieved by filtering runoff through media that are specially engineered to bind phosphorus through sorption processes (Ma and Sansalone, 2007).

Stream Channel Erosion Control

The use of a green roof will reduce the channel erosion control driven detention requirement by decreasing the impervious cover area. If the total detention requirements can't be met by the green roof alone, flow restrictors on roof downspouts may also be used.

Other Benefits

The benefits of green roofs reach beyond the specific stormwater management goals to other social and environmental benefits, including:

- *Energy Conservation:* The layers of growing medium and vegetation on the roof moderate interior building temperatures and provide insulation from the heat and cold. As a result the amount of energy required to heat and cool the building is reduced, providing energy savings to the owner. To illustrate, a recent study by

Environment Canada and the National Research Council of Canada (NRC) planted a green roof with juniper shrubs growing in thick soil. The purpose of the design was to reduce the effect of wind speed (which draws heat from the building) and to increase the building's resistance to heat loss. Indoor temperature variations and energy consumption was compared with a traditional roof building. Measurements showed that heat flow from the building with the green roof was reduced by more than 10 percent (Bass, 2005). At the NRC Ottawa green roof, energy demand for air conditioning was reduced by 75% (Liu, 2002).

- *Acoustic Insulation*: Green roofs can also be designed to insulate the building interior from outside noise, and sound-absorbing properties of green roof infrastructure can make surrounding areas quieter.

- *Urban Heat Island Effect:* Green roofs can reduce the urban heat island effect by cooling and humidifying the surrounding air. Temperature of runoff from the roof will also be lower, which is a benefit to temperature-sensitive aquatic life.

- *Aesthetics and Habitat:* With thoughtful design, green roofs can be aesthetically pleasing and can improve views from neighboring buildings. Additionally, the rooftop vegetation creates habitat for birds and butterflies.

- *Reduced Demand on Downstream Infrastructure*: The reduction in runoff volumes associated with green roofs can lessen the demand on existing downstream stormwater infrastructure, and, in the case of combined sewers, lower the frequency of overflows.

- Increased Longevity of Roof Structure: The green roof mitigates extreme temperatures and exposure to storms and extends the longevity of the roof structure.

4.2.2 Design Template

Applications

Green roofs can be installed on many types of roofs (Figure 4.2.3), from small slanting residential roofs to large commercial roofs. Sometimes only a portion of the roof is dedicated to a green roof. This best management practice is particularly useful in ultra urban sites where space for surface BMPs is limited.

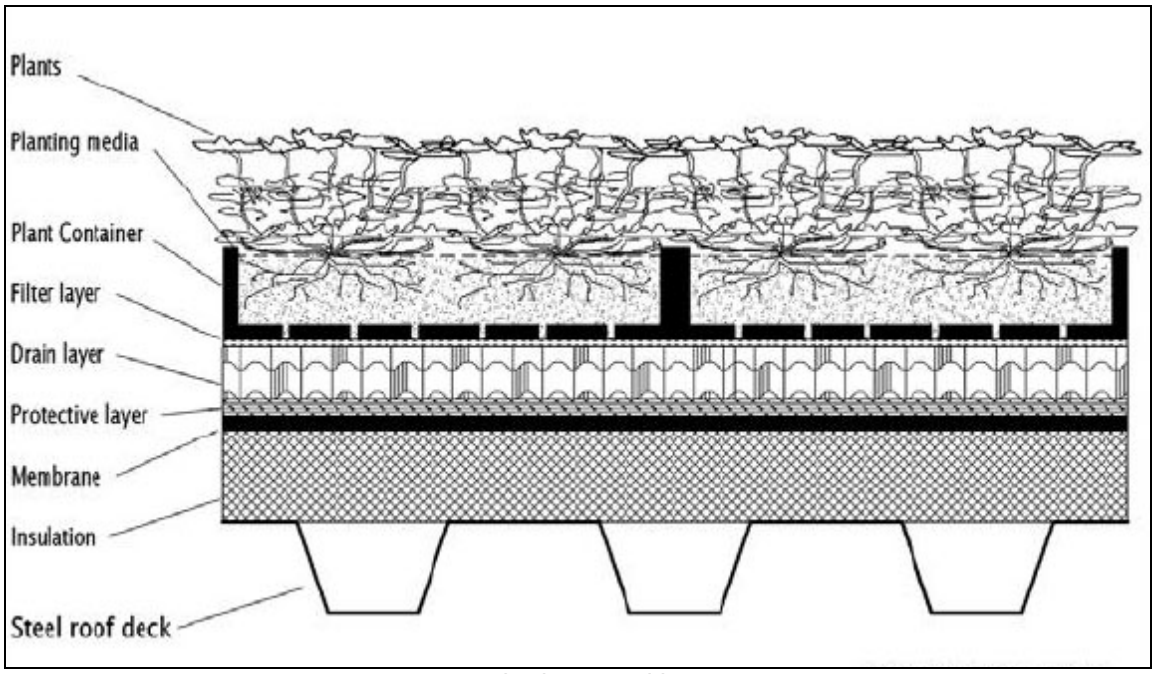
Figure 4.2.3 Other examples of green roofs

Source: City of Toronto (left); CWP (right)

Typical Details

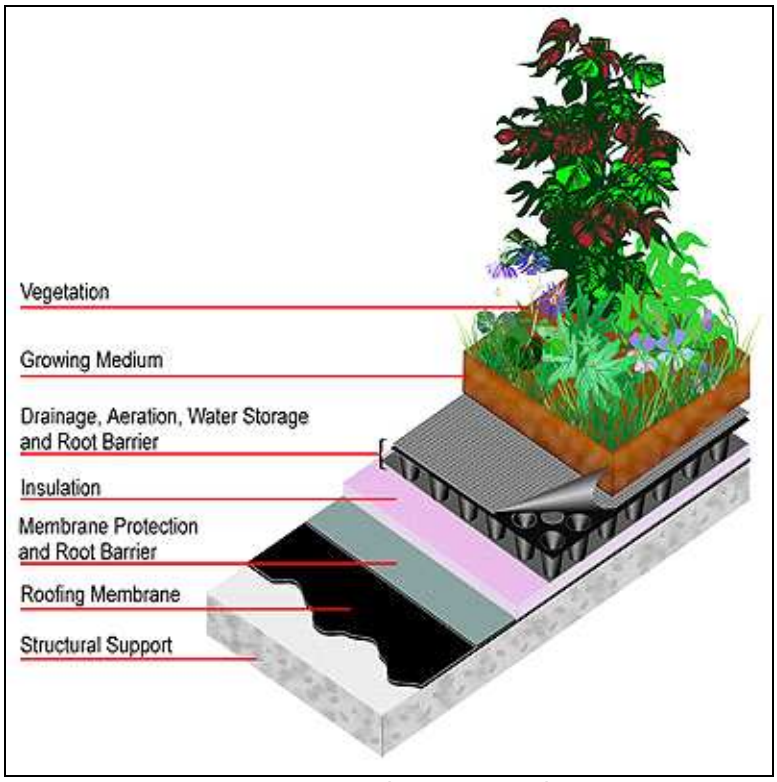
Schematic renderings of typical green roofs are provided in Figures 4.2.4 and 4.2.5.

Figure 4.2.4 Schematic of a green roof



Source: Shade Consulting, 2003

Figure 4.2.5 Green roof layers



Source: Great Lake Water Institute

Design Guidance

Only qualified professionals should design green roofs (*e.g.*, Green Roof Professional certification program, sponsored by Green Roofs For Healthy Cities; www.greenroofs.org).

Green roofs are composed of multiple layers that include:

- a roof structure capable of supporting the weight of a green roof system;
- a waterproofing membrane system designed to protect the building and roof structure;
- a drainage layer that consists of a porous medium capable of water storage for plant uptake;
- a filter layer to prevent fine particulate from the growing medium and roots from clogging the drainage layer;
- growing medium with appropriate characteristics to support selected green roof plants; and
- plants with appropriate tolerance for harsh roof conditions and shallow rooting depths.

Details on these layers are provided below.

Roof Structure
The load bearing capacity of the roof structure must be sufficient to support the soil and plants of the green roof assembly, as well as the live load associated with maintenance staff accessing the roof. Generally, a green roof assembly weighing more than 80 kilograms per square metre, when saturated, requires consultation with a structural engineer (Barr Engineering, 2003). Standards for dead and live design loads are available from ASTM International.

Green roofs may be installed on roofs with slopes up to 10%. On sloped roofs additional erosion control measures may be necessary to stabilize drainage layers.

As a fire resistance measure, non-vegetative materials, such as stone or pavers should be installed around all roof openings and at the base of all walls that contain openings (Barr Engineering, 2003). Materials used around roof openings should be non-leaching to prevent contamination of the green roof growing medium.

Waterproofing System
In a green roof system, the first layer above the roof surface is a waterproofing membrane. Two common waterproofing techniques used for the construction of green roofs are monolithic and thermoplastic sheet membranes. Another option is a liquid-applied inverted roofing membrane assembly system in which the insulation is placed over the waterproofing, which adheres to the roof structure. An additional protective layer is generally placed on top of the membrane followed by a physical or chemical root barrier. Once the waterproofing system has been installed it should be fully tested prior to construction of the drainage system. Electronic leak detection systems should also be installed at this time (The Folsom Group, 2004).

Drainage Layer
The drainage system includes a porous drainage layer and a geosynthetic filter mat to prevent fine growing medium particles from clogging the porous media. The drainage layer can be made up of gravels or recycled-polyethylene materials that are capable of water retention and efficient drainage. The depth of the drainage layer depends on the load bearing capacity of the roof structure and the stormwater retention requirements. The porosity of the drainage layer should be greater than or equal to 25% (PDEP, 2006).

Conveyance and Overflow
Once the porous media is saturated, all runoff (infiltrate or overland flow) should be directed to a traditional roof storm drain system. Landscaping style catch basins should be installed with the elevation raised to the desired ponding elevation. Alternately, roof drain flow restrictors can be used. Excess runoff can be directed through roof leaders to another stormwater BMP such as a rain barrel, soakaway, bioretention area, swale or simply drain to a pervious area (*i.e.*, downspout disconnection).

Growing Medium
The growing medium is usually a mixture of sand, gravel, crushed brick, compost, or organic matter combined with soil. The medium ranges between 40 and 150 millimetres

in depth and increases the roof load by 80 to 170 kilograms per square metre when fully saturated. The sensitivity of the receiving water to which the green roof ultimately drains should be taken into consideration when selecting the growing medium mix. Green roof growing media with less compost in the mix will have less leaching of nitrogen and phosphorus (Moran and Hunt, 2005). Low nutrient growing media also promotes the dominance of stress-tolerant native plants (TRCA, 2006). Fertilizer applied to the growing medium during production and the period during which vegetation is becoming established should be coated controlled release fertilizer to reduce the risk of damage to vegetation and leaching of nutrients into overflowing runoff. Application of fertilizer to the growing medium should not exceed a rate of 5 grams of nitrogen per square metre (Emilsson *et al*., 2007).

Landscaping

A qualified botanist or landscape architect should be consulted when choosing plant material. For extensive systems, plant material should be confined to hardier or indigenous varieties of grass and sedum. Some sedums, however are invasive. The use of native plants is encouraged (see Appendix B for guidance regarding plant species selection). Root size and depth should also be considered to ensure that the plant will stabilize the shallow depth of growing medium. The plant material should conform to the following:

- *Type of root preparation, sizing, grading and quality:* should comply with the Canadian Standards for Nursery Stock, 2006 Edition, published by the Canadian Nursery Trades Association.

- *Source of plant material:* should be grown in Zone 4 in accordance with Agriculture Canada's Plant Hardiness Zone Map.

- *Plant material:* should be free of disease, insects, defects or injuries and structurally sound with strong fibrous root systems. Should have been root pruned regularly, but not later than one growing season prior to arrival on site.

- *Bare root stock:* should be nursery grown, in dormant stage, not balled and burlapped or container grown.

- *Seed mixes:* should be Common No.1 Canada certified in accordance with Government of Canada Seeds Act and Regulation.

Modular Systems

Modular systems are essentially trays of vegetation in a growing medium that are prepared and grown off-site and placed on the roof for complete coverage. There are also pre-cultivated vegetation blankets that are grown in a flexible growing medium structure, rather than a rigid structure, allowing them to be rolled out onto the underlying green roof assembly. The advantage of these systems is that they can be removed for maintenance.

Other Design Resources
Several other resources that provide useful design guidance for green roofs are:

Canada Mortgage and Housing Corporation: Design Guidelines for Green Roofs..http://www.cmhc.ca/en/inpr/bude/himu/coedar/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=70146

2004 Portland Stormwater Management Manual. http://www.portlandonline.com/bes/index.cfm?c=dfbbh

Philadelphia Stormwater Management Guidance Manual. http://www.phillyriverinfo.org/Programs/SubprogramMain.aspx?Id=StormwaterManual

BMP Sizing
Green roofs reduce the effective impervious cover by providing a surface that hydrologically responds like a pervious area. Green roofs are typically sized based on the available roof area, as opposed to treatment volume requirements. However, flow restrictors can be added to the design to meet channel erosion control discharge criteria, which is determined by using the methodology in the relevant CVC and TRCA stormwater management criteria documents (CVC, 2010; TRCA, 2010).

Design Specifications
ASTM International released the following Green Roof standards in 2005:

- E2396-05 Standard Test Method for Saturated Water Permeability of Granular Drainage Media;
- E2397-05 Standard Determination of Dead Loads and Live Loads associated with Green Roof Systems;
- E2398-05 Standard test method for water capture and media retention of geocomposite drain layers for green roof systems;
- E2399-05 Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems; and
- E2400-06 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems.

Although the Ontario Building Code (2006) does not specifically address the construction of green roofs, requirements from the *Building Code Act* and Division B may apply to components of the construction. Further requirements from sections 2.4 and 2.11 of the 1997 *Ontario Fire Code* also require consideration.

Construction Considerations
An experienced professional green roof installer should install the green roof. The installer must work with the construction contractor to ensure that the waterproofing membrane installed is appropriate for use under a green roof assembly. Conventional green roof assemblies should be constructed in sections for easier inspection and

maintenance access to the membrane and roof drains. Green roofs can be purchased as complete systems from specialized suppliers who distribute all the assembly components, including the waterproofing membrane. Alternatively, a green roof designer can design a customized green roof and specify different suppliers for each component of the system.

4.2.3 Maintenance and Construction Costs

Maintenance
Green roof maintenance is typically greatest in the first two years as plants are becoming established. Vegetation should be monitored to ensure dense coverage becomes established. A warranty on the vegetation should be included in the construction contract.

Regular operation of a green roof includes:

- *Irrigation:* Watering should be based on actual soil moisture conditions as plants are designed to be drought tolerant. High soil moisture from unnecessary watering will reduce the runoff reduction benefits of the green roof.

- *Leak Detection:* Electronic leak detection is recommended. This system, also used with traditional roofs, must be installed prior to the green roof. Particular attention to leak detection should be paid in the first few months following installation (The Folsom Group, 2004).

Ongoing maintenance should occur at least twice per year (Magco, 2003) and should include:

- *Weeding:* Remove volunteer seedlings of trees and shrubs. Extensive green roofs are not designed for the weight of these plants, and the woody roots can damage the waterproofing.

- *Debris and Dead Vegetation Removal:* Debris and bird feces should be removed periodically. In particular, the overflow conveyance system should be kept clear (TRCA, 2006).

Installation and Operation Costs
The estimated cost for extensive green roofs is $65 to $230 CAD per square meter (TRCA, 2007a), not including the base roof, with modular systems in the lower end of the range. While green roofs are initially more expensive than traditional roofs, their lifecycle costs may be comparable to traditional roofs, when energy savings and extended roof longevity are factored in (TRCA, 2007a). Operation and maintenance costs are generally higher during the first two years of operation than in subsequent years as the vegetation becomes established. Literature estimates of annual maintenance costs during the first two years range from $2.70 to $44.00 per square metre (Peck and Kuhn, 2002; Stephens, *et al*., 2002; TRCA, 2007a). Design costs

typically run 5 to 10 percent of the total project cost and administration and review and approval costs are 2.5 to 5 percent of the total project cost (Peck and Kuhn, 2002).

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