THE CITY OF CALGARY

LOW IMPACT DEVELOPMENT GUIDELINES

MODULE 3 - GREEN ROOFS

Final Report | July 2014

WARDROP A TETRA TECH COMPANY

TETRA TECH

CARSON • McCULLOCH ASSOCIATES LTD.

Westhoff Engineering Resources, Inc.
Water Resources Management Consultants

IBI GROUP
Architects
Engineers

THE CITY OF CALGARY

The City of Calgary

LOW IMPACT DEVELOPMENT GUIDELINES
MODULE 3 - GREEN ROOFS

FINAL REPORT

JULY 2014

AUTHORS:

Scott Struck
Geosyntec
On behalf of Tetra Tech

Kerry Ross
Green T Design
Affiliate IBI Group
Architects, Engineers

Jonathan Sagi
ground3 inc. landscape architects
on behalf of Carson McCulloch
Associates Ltd.

TABLE OF CONTENTS

APPENDICES

TABLES AND FIGURES

LIST OF FIGURES

LIST OF TABLES

APPENDIX A

EXECUTIVE SUMMARY

Controlling stormwater runoff improves water quality and reduces contributions of pollutants and toxic chemicals into waterways. Given the vast surface area that urban rooftops represent, using green roofs as a part of a greater stormwater management strategy can add considerable opportunities for runoff mitigation and control to an urban landscape.

Once dismissed as impractical in the Calgary region due to climate considerations and added costs, green roofs are starting to gain wider acceptance in all of Alberta, including Calgary. Green roofs are recognized for many benefits – improved air quality, more energy efficient buildings as well as better stormwater management from building sites. Their contribution as a sustainable urban drainage strategy for stormwater management is well documented in Europe and other areas of North America. Green roofs, as an individual Low Impact Development (LID) strategy but also in combination with other LID practices, help reduce the stormwater runoff volume from buildings through capture and evapotranspiration and can temporarily store or slow roof runoff. They can also reduce and delay peak flow rates which lessen the burden on existing storm sewer infrastructure and can help to reduce the incidence of flooding.

This document provides guidance on the application of green roofs in the Calgary region. It includes information on the different green roof systems, planning, design, constraints, installation considerations, construction, maintenance, monitoring, and water quality and quantity performance of green roofs. In addition, it highlights several case studies featuring the information learned in each study. Perhaps most importantly, this guide provides a list and ranking of plant species that considers their suitability, availability, survivability, and use on green roofs in the greater Calgary region. Other maintenance and construction checklists are also included as additional products of the guide.

The intent is to provide users of this guide the necessary tools to inform and plan a green roof implementation for stormwater management. The resources contained within the document will assist users in achieving the benefits noted above to maintain and improve Calgary's water resources.

1.0 INTRODUCTION

The adoption of the modern green roof comes from Germany and Germanic speaking countries. This region of Europe is 30 years ahead of Calgary due to early policies supporting environmentally sustainable growth combined with financial incentives and programs to foster citizen awareness[1]. Green roofs have been embraced worldwide as an innovative way to introduce green infrastructure into urban areas and address the need for more sustainable building strategies. Green roofs are in keeping with the principles of "Smart Growth", and provide various environmental, economical, and social benefits. The objectives of this module are to:

- **Provide an overview and basic guidelines for the implementation of green roofs in Calgary with an emphasis on green roof media and vegetation;**
- **Provide guidance on how to quantify the resulting stormwater runoff quantity and quality;**
- **Provide strategies and checklists for green roof inspection and maintenance.**

1.1 GREEN ROOFS IN CALGARY AND REGION

In Calgary, the acceptance of green roofs is growing as awareness of the benefits associated with the technology spreads. The growth of experience and training amongst local design professionals and builders is increasing. However, many still believe that vegetated roofs are not viable in our region due in part to our distinct climate with colder temperatures combined with low levels of precipitation, a short growing season, strong winds and particularly the Chinook wind in the winter season.

While interest in green roof technology continues to grow in Alberta, major challenges to their implementation exist. Barriers include:

- **the harsh and variable climate;**
- **lack of a tested plant species list suitable to the climate and to a rooftop site (hardy to Zone 3a);**
- **smaller, less competitive market compared to Toronto, Vancouver, and Montreal;**
- **perceived higher maintenance costs and lack of understanding of the requirements;**
- **regulatory hurdles (municipal and provincial);**
- **higher capital costs and shipping distances for materials and supplies relative to other markets;**
- **lack of scientific research focused on the region; and**
- **potential Building Code compliance issues and more complex design criteria.**

1.2 SYSTEM DESCRIPTION

Also known as living roofs, landscapes-over-structures, vegetated roofs, or ecoroofs, the term green roof is a broad term to describe a contained vegetated space on top of a manmade structure at, below or above grade (Green Roofs for Healthy Cities (GRHC), 2010).

Green roofs are an extension of a new or existing roof and can be applied to a conventional or inverted (protected-membrane) assembly. They are typically constructed with a drainage system, filter cloth, a lightweight growing medium and plants on top of a high-quality waterproof membrane.

[1] Refer to: http://www.thesolutionsjournal.com/node/981 .

1.3 CATEGORIES

In North America, we have come to adopt the German classification and terms for green roofs recognizing two basic types: intensive and extensive. An intermediate type, the semi-intensive, is often distinguished as well. These terms describe the different depths and techniques but do not convey the use or purpose of different green roof constructions (Taylor, 2008). The intent of the green roof design is a key factor in determining the depth of the substrate, suitable vegetation and use of the roof (Connolly, 2011).

1.3.1 Intensive green roof

Intensive green roofs, also referred to as landscape-over-structure or roof gardens are typically found in subterranean or ground floor plazas as well as podium roofs. They are characterized by a greater depth of growing media (from 200 mm to 1 metre/8" to several feet deep) which results in a heavier total saturated weight. This increased depth provides the greatest flexibility in the selection of plant species including trees and shrubs. Intensive green roofs require more inputs in terms of supplemental irrigation and nutrients as well as maintenance. Intensive roofs are usually designed for pedestrian traffic, most commonly found on flat or terracing roofs and are the most costly to build and maintain.

1.3.2 Extensive green roof

An extensive green roof consists of thin layers of living vegetation installed on top of a typical flat or sloping roof. They are amongst the most economical roof greening systems to both build and maintain. Extensive roofs are often inaccessible because of the limited structural capacity of the roof. At 150mm or shallower they are very lightweight and may potentially be retrofit to existing structures without costly structural upgrades, subject to a proper engineering review. The palette of suitable plant species is restricted compared to intensive systems and traditional landscape practices are not always suitable.

1.1 American Hydrotech

1.2 R. Steiner/Roof Gardens

1.3 City of Portland

1.1 Roof garden on Vancouver Public Library is an example of an intensive green roof; 1.2 An extensive sedum roof in combination with areas for occupancy; 1.3 Example of a semi-intensive roof in Portland, Oregon;

1.3.3 Semi-intensive green roof

A semi-intensive green roof is thought of as a hybrid of the two green roof categories. A typical growing medium depth for a semi-intensive green roof is 150 to 200 mm (6 to 8 inches). This system is able to retain more stormwater than an extensive system and provides the potential to host a richer ecology. Though higher in maintenance requirements, this green roof system has the potential for a formal garden effect.

1.4 TYPES OF GREEN ROOF INSTALLATION

A green roof can be constructed in a variety of ways. They can be loose-laid or built-up systems installed layer by layer on the roof. Other options include modular systems that are partially built off-site in blocks or trays (typically 100 - 150 mm/4-6" in depth, hence extensive systems) and pre-grown sedum (or fescue) mats on sublayers of a root barrier, drainage fleece, and an engineered growing medium. With the last two methods components are combined into pre-fabricated modules that are placed on the roof for a more immediate application. These systems can be pre-cultivated or pre-grown before installation or planted on the roof. The modular and pre-cultivated mats are typically placed in an extensive system, although depending upon the roof structure, intensive, semi-intensive and extensive systems can be employed.

2.1 K.Ross

2.2 K.Ross

2.3 DCR Virginia

Images above illustrate the various steps in a loose-laid application: 2.1) installation of drainage mat and filter fabric; 2.2) sealing the joints in the rootbarrier; 2.3) placement of the growing medium; 2.4) planting of small nursery stock.

3.1 Liveroof

3.2 Xeroflor

3.3 GreenGrid

These images represent three different pre-cultivated green roof components: 3.1) modular trays with sedums; 3.2) sedum mats; 3.3) shallow modular containers.

2.0 GREEN ROOF PERFORMANCE

Green roofs can provide numerous functions benefiting stormwater quantity and quality. Stormwater retention and flow reduction are the primary water quantity benefits while reduced loadings of some nutrients can also occur, benefitting receiving water quality. One must recognize when using vegetated systems some leaching may occur at certain times of the year, but on an annual basis, green roof systems have been shown to reduce many water quality constituents of concern. In addition, based on observed life spans of green roofs, they can remain effective for more than 30 years.

2.1 WATER QUANTITY BENEFITS

As indicated above, there are many water balance benefits that green roofs can provide. Factors that affect stormwater retention in green roof systems include water holding capacity and depth of substrate, antecedent moisture conditions, rainfall intensity and/or precipitation depth, irrigation, and composition and extent of plant coverage (Getter et al. 2007; Mentens et al. 2006; Villarreal and Berndtsson 2005).

Relatively few field studies have been conducted in the Calgary region and there are many potential variables. Modelling tools can help fill in knowledge gaps to help in understanding water quality benefits provided by green roofs. Modelling studies for green roofs show that about half of annual precipitation runoff is retained on extensive green roofs (Berghage et al. 2007; US Environmental Protection Agency 2000).

To help with water quantity performance and design, the City of Calgary developed the Water Balance Spreadsheet for City of Calgary (WBSCC) model that can be used to estimate anticipated benefits of stormwater management practices. The WBSCC model can also be used as a green roof design tool similar to the Rational Method coefficients, SCS method curve numbers, and other models discussed in the City of Calgary Stormwater Management Manual.

The City of Calgary requested that this tool be used in determining the water quantity criteria and estimated benefits presented in this document. Representative input values were selected based on media characteristics and calibration with local monitoring data. A more complete discussion on the use, input parameters and results of the analyses of the WBSCC model are included in Appendix E.

2.1.1 Recommended criteria based on water quantity

Annual water retention depends less on the type of construction and media type but more on media depth (Fassman and Simcock, 2012). The demands of achieving water quantity benefits must be balanced with structural capabilities and budget requirements that design loads and roof superstructure require. Table 1 shows the recommended criteria for green roof design intended for stormwater benefits for the City of Calgary. These criteria provide general guidance for minimum (and upper range) criteria for green roof performance for the Calgary Region.

Table 1.
City of Calgary Recommended Green Roof Water Quantity Design Criteria

Parameter	Criteria		Methodology for Testing
	Low Value	High Value	
Media Depth	150 mm*	(No maximum)+	In situ measurement across entire application
Irrigation	No irrigation up to 4 mm of irrigation 3 times per week	11 mm of irrigation 3 times per week	Recommend metering of irrigation if applicable
Drainage Mat	Required for media less than 150 mm	Optional for media greater than 150 mm	Presence/Absence
Organic Matter (% dry weight)	3	8†	ASTM E2400 - 06
Field Capacity (%)	8	28	ASTM E2398-11
Wilting Point (%)	3	17	ASTM E2400 - 06
Porosity (%)	40	65	ASTM E2396-11
Hydraulic Conductivity (mm/hr)	200	500	ASTM E2396-11
Dry Bulk Density (g/cm³)	0.94	1.27	ASTM E2399-11
Particle Size Distribution (PSD) By Dry Weight	Sum of Particles Passing: <12.50 mm; 100% Passing 12.50 mm – 9.5 mm; 98% Passing 9.5 mm – 6.3 mm; 85% Passing 6.3 mm – 3.2 mm; 65% Passing 3.2 mm – 2.0 mm; 45% Passing 2.0 mm – 1.0 mm; 30% Passing 1.0 mm – 0.25 mm; 15% Passing 0.25 mm – 0.05 mm; 5% Passing <0.05 mm; 1% Passing		ASTM E2399

*** Media can be shallower for other purposes but not for water quantity control purposes.**
+ A structural analysis should be conducted to determine the maximum thickness of growing media that can be accommodated.
†High value of organic matter is limited based on the potential water quality concerns (leaching) associated with inclusion of higher values.

In general, and where possible, a green roof in the Calgary region should have a depth of at least 150 mm (6 inches) for the purpose of stormwater management to permit adequate flexibility in the type and variety of vegetation that can be incorporated, and to ensure greater survivability of plants. See Appendix C for the plant species selection and evaluation. While this minimum depth may be a little conservative, it assures the necessary benefits for meeting overall water quality and quantity objectives can be met, where shallower depths have less certainty in meeting these objectives.

Even though green roofs do not retain all runoff, one must recognize the benefit that they provide and understand that additional source control practices may be required on site to achieve more stringent water quantity and runoff objectives (including peak flow). This is notable for the Nose Creek, West Nose Creek, and Pine Creek watersheds for which runoff targets have already been determined.

2.2 WATER QUALITY BENEFITS

Green Roofs have shown significant benefits to water quality, primarily from annual load reduction. Studies of nutrient concentrations in runoff from green roofs have had mixed findings. The majority of studies conclude that green roofs can be a source of phosphorus in runoff (Berndtsson et al., 2006, 2009; Hathaway et al., 2008; Hutchinson et al., 2003; Köhler and Schmidt, 2003; Liptan and Strecker, 2003; MacMillan, 2004; Monterusso et al., 2004; Teemusk and Mander, 2007).

The percentage of compost in the soil media and the fertilizer used are two key components that have been cited as reasons for nutrient export, although annual runoff loading shows substantially decreases (Berndtsson et al., 2009; Emilsson et al., 2007; Hathaway et al., 2008; Teemusk and Mander, 2007). Copper (Cu) and zinc (Zn) are two metals most commonly analyzed in green roof runoff. However, because of volume reduction due to evapotranspiration, the potential increase in constituent concentrations are relatively minor when considering the benefits of green roofs on annual load reductions.

Pollutant load calculations based on modeling were used to estimate annual load reductions for nutrients and metals based on media depth. The values and model input are shown in Appendix E. While many other water quality constituents can be estimated using this method, those reported were for common constituents of concern in the City of Calgary and those for which local data were available (e.g., nutrients and metal species). Because of storm variability (e.g. intensity and duration) annual loading was the most appropriate manner for determining stormwater design benefits.

2.2.1 Recommended criteria based on water quality

Table 2 lists several key design recommendations to reduce leaching of water quality constituents of concern.

Table 2. City of Calgary Recommended Green Roof Water Quality Criteria

Parameter	Criteria	
	Low Value	High Value
Media Depth	150 mm	(No Maximum)
Irrigation	No irrigation up to 4 mm of irrigation 3 times per week	11 mm of irrigation 3 times per week
Organic Matter from Compost (% dry weight)*	3	8
Fertilizer†	Test soils first. If necessary, 5 grams per m^2 twice during the first year (spring and fall); once (spring) during the subsequent two years. Test media to determine if fertilizer is necessary after the first three years	Test soils first. If necessary, 10 grams per m^2 twice during the first year (spring and fall); once (spring) during the subsequent two years. Test media to determine if fertilizer is necessary after the first three years

*Non-manure, well-aged (>months) compost should be used that is free of objects larger than 20 mm.
†Depends on plant types used and quantity of organic matter.

Fertilizer application may be necessary to establish plants or to maintain plant health (a qualified plant specialist can assist with this determination). Laboratory testing can assist to determine nutrients in the media for the selected plant palette and the estimated quantities of fertilizer additions, if necessary. Use encapsulated slow release fertilizer no more than twice during the first year of establishment in the early spring and fall and then no more than once yearly for the next two years. No fertilizer should be applied following the first three years unless following laboratory testing of media, a plant specialist determines fertilizer additions are necessary for plant health. Application rates should be a minimal amount to maintain plant health.

If stormwater functions are to receive credit with installation of the green roof total phosphorus within the media may not exceed 10% (by volume) unless approved by a plant specialist. Again, laboratory testing is recommended to test for this threshold. Soluble N fertilizers are not recommended as it can leach into the runoff. Isobutydine diurea, a slow-release nitrogen fertilizer applied at approximately 5 grams per m^2 per application and Osmocote (N-P-K ratio of 15-9-12, respectively) at an application rate of approximately 10 grams per m^2 have been used with moderate success with more succulent plants, however, a plant specialist should be consulted to determine whether and how much fertilizer additions are necessary. Other slow release types of fertilizers may also be used as determined by a plant specialist.

Table 3 reports the predicted range of annual contaminant loadings that might occur from green roof effluent. These values were based on event mean concentrations and included load based reduction resulting from volume loss due to evapotranspiration with various media depths. These values will vary based on the design characteristics (e.g. media composition, media depth, fertilization, and irrigation) of the water quantity parameters discussed above.

Table 3.
Predicted Range of Effluent Loading Based on Media Depth for Water Quality Constituents.

Water Quality Constituent	Estimated Range of Annual Loading (low input value – high input value) kg/yr		
	With 75 mm of Media	With 150 mm of Media	With 300 mm of Media
Nitrate/Nitrite	4 – 17	2 – 7	0.5 – 2
Total Ammonia	7 – 18	3 – 8	0.3 – 1.5
Orthophosphate	15 – 175	8 – 70	1 – 9
Total Copper	0.100 – 0.165	0.045 – 0.075	0.007 – 0.125
Total Zinc	0.040 – 0.070	0.020 – 0.030	0.010 – 0.016
Total Mercury	0.018 – 0.028	0.008 – 0.012	0.0009 – 0.0013

As noted with water quantity, green roofs can retain a large number of rainfall events, depending on design. With deeper media, all roof runoff may be retained within the green roof media with no discharge. Similarly, this stormwater management practice may, at times, export some water quality constituents (typically dissolved constituents such as nitrate, phosphorus, and some metal species) which may require additional on-site source control practices to treat effluent such as bio-retention. However, one must recognize the annual loading benefit that green roofs provide as well as additional benefits beyond water quantity and quality.

3.0 OTHER BENEFITS

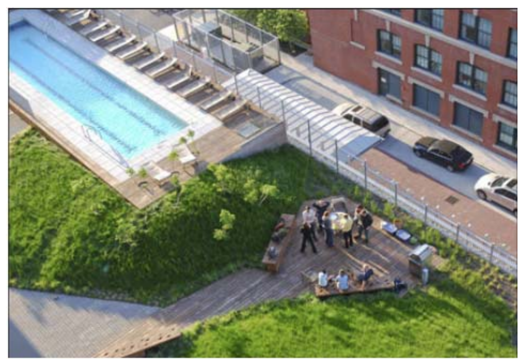
3.1 ECONOMIC, SOCIAL AND ENVIRONMENTAL BENEFITS

Green roofs offer a wide range of ecosystem services and social benefits. These benefits may be provided to the general public and/or private owner. The significance of the benefits associated with green roofs varies and is largely dependent upon the design intent, scale, climate, type of assembly, depth of growing medium and type of vegetation planted. Although green roofs are effective stormwater source control strategies, owners often base decisions on whether to include a green roof on other criteria and benefits.

3.1.1 Creating green or amenity space

The provision of green spaces, gardens for activity and amenity, and the protection of existing trees and vegetation give urban dwellers physical and visual connections to the natural environment. When a new building is built, lost green space could be compensated through the inclusion of a green roof. Currently in downtown Calgary, urban developments in the East Village and Beltline areas are seeing the inclusion of common rooftop gardens as amenity spaces for the building tenants.

5.1 FXFowle Architect



5.2 Landmark Studios

The provision of green space on new developments can increase property values and help drive sales of leased space.

3.1.2 Restoring biodiversity

Green roofs can help restore or replace habitat loss due to urban development and foster biodiversity in the Calgary region. Rooftop habitats can play several biodiversity roles including functioning as ‘stepping stone’ habitats that connect isolated habitat pockets with each other, or functioning as ‘island’ habitats, isolated ecosystems that are separate from other habitats. This can be beneficial to attract and support diverse urban plant, insect and bird communities, and in particular help increase survival of pollinators.

6.1 LiveRoof

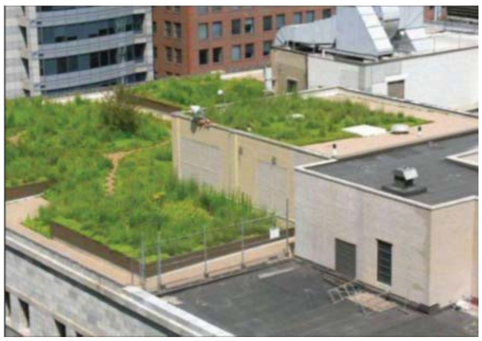
6.2 K.Ross

6.3 T.Liptan

Biodiversity found on Green Roofs includes bird eggs (6.1), dragonflies (6.2) and pileated woodpecker nests (6.3).

3.1.3 Improve energy efficiency (heating & cooling) and thermal comfort

Green roofs may provide moderate energy efficiency benefits through additional insulation, shading of the membrane, and evapotranspiration leading to a reduction in air-conditioning use. The energy savings are more pronounced during the summer and shoulder seasons (cooling) than in winter (heating). This efficiency benefits the health of a community by reducing particulate and greenhouse gas emissions through the reduced energy demands of a building (Architecture 2030). While Calgary is in a heating-dominant climate, recent research findings highlight energy savings in winter, particularly for poorly insulated existing buildings. Also, the thermal comfort of occupants on floors directly below the roof can be positively impacted by the addition of a green roof. There are other energy issues associated with excess heat gain from dark roofs, even in the Calgary area.



7.1 City of Chicago *7.2 City of Chicago* *7.3 National Research Council*

7.1 shows the green roof on the Chicago City Hall and the adjacent Illinois State Building. 7.2 illustrates the two roofs taken with an infrared camera showing the different surface temperatures of these roofs and surroundings. The light colour which corresponds with the exposed roof area indicates surface temperatures approaching 66°C [150°F], while the darker colour of the green roof area is closer to ambient temperature. 7.3, the Green Roof Research Centre at the National Research Council in Ottawa, demonstrated energy savings of 75% in summer and 26% in the winter (Liu/Bass), 2005)

3.1.4 Synergies with solar panels

Solar panels lose efficiency when overheated. For every degree Celsius above 25°C the panels lose 0.5% efficiency. While the Calgary region typically has only 20 days each year averaging 24° C and no days averaging above 25° C, rooftops are extreme environments and the temperature on the roof can exceed 50°C above the ambient temperature (Liu/Bass, 2005). Green roofs and solar panels are complementary technologies; solar panels shade the vegetation, helping keep moisture in the system while the cooler surface temperature of the green roof keeps the temperature under the solar panels constant and cool.

8.1 Architect T. Hotz *8.2 D.Sailor*

8.1 Illustrates the pairing of solar panels with a green roof on the Basel Congress Centre in Switzerland. 8.2 Ongoing research at Portland State University of Dr David Sailor and team examining the effects of solar panels and green roofs.

3.1.5 Extend the lifespan of waterproof membrane

Numerous studies illustrate that waterproof membranes under green roofs are likely to be more durable and long-lasting. Evidence from 40 year-old green roofs in Germany demonstrate that they extend the life of the waterproof membrane on these roofs compared to similar aged conventional non-vegetated roofs (Fraunhofer Institute, Germany). This is achieved because green roofs shade the membrane and protect it from heat and UV degradation as well as reduce mechanical damage and physical stress associated with expansion and contraction from extreme diurnal temperature changes. The life-cycle costs including the cost avoidance of roof replacement can therefore make green roofs a more attractive option to the long-term building owner (Porsche/Kohler, 2003).

9.1 S.Brenneisen

9.2 S.Brenneisen

9.1 & 9.2 The Moos Filtration Plant in Zurich, Switzerland built in 1914 demonstrates the effectiveness of the vegetated overburden in extending the service life of the waterproof membrane. While minor repairs have been made over the years, the waterproofing has yet to be replaced. Numerous rare plant species can be found on this roof.

3.1.6 Improved acoustical performance

Green roofs can improve the acoustical performance of a roof because of its high mass, low stiffness and dampening effect. (Connelly & Hodgson 2008). They can be useful in reducing noise pollution in urban areas, particularly in downtown, active industrial areas, as well as for sites along airport flight paths.

10.1 L.Velasquez

10.2 L.Velasquez

Green roofs on airport facilities have been found to reduce sound transmission through the roof by as much as 38%. These two green roofs are part of the Frankfurt Airport, Germany.

3.1.7 Improved air quality

Green roofs mitigate air pollution levels by lowering extreme summer temperatures, trapping particulates, and capturing potentially harmful gases such as CO, NO_2, O_3, PM_{10}, and SO_2. This increases air quality and reduces smog, contributors to respiratory diseases and stroke.

- **Depending on location, one square meter of grass roof can remove 0.2 kg of airborne particles from the air every year. (Peck & Kuhn 2003)**
- **1.5 square metres of uncut grass can produce enough oxygen to supply a human being with their yearly intake requirement of oxygen (Peck & Kuhn 2003; Currie 2005).**



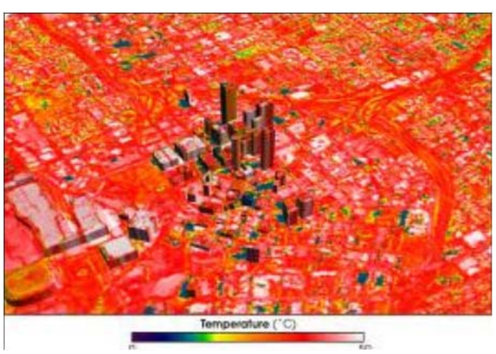
11.1 D. Bickell/Calgary Herald *11.2 Vancouver Sun* *11.3 Vestal Grove Blog*

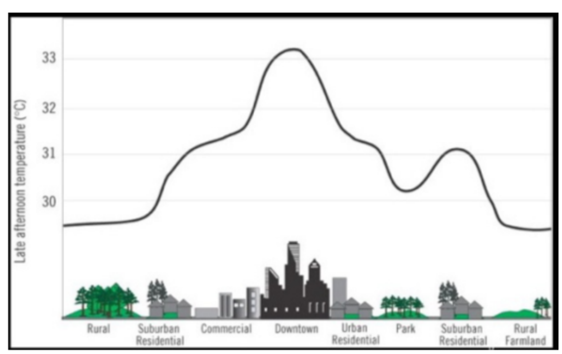
11.1 Image of Downtown Calgary on a poor -air quality day; 11.2 Grass and native vegetation on the Vancouver Convention Centre; 11.3 Cities that increase their amount of urban vegetative cover such as native prairie grasses can make a positive contribution to their air quality.

3.1.8 Reduced urban heat island effect

Reducing the heat-island effect results in more comfortable micro-climates near buildings and lessens a building's cooling load, thereby curbing reliance on fossil-fuel generated electricity and reducing associated particulate and greenhouse gas emissions (Currie & Bass 2005).

Green roofs, like other urban vegetation, help keep cities cool. Green roofs provide shade and remove heat from the air through evapotranspiration.



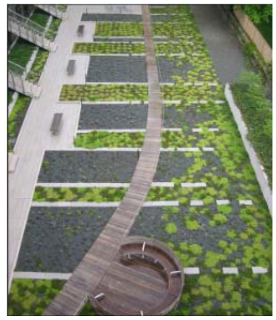


12.1 NASA *12.2 NASA*

12.1 This infrared satellite of the City of Atlanta illustrates the elevated temperatures (red areas) versus the cooler surfaces of urban forestry in green. The sketch in 12.2 demonstrates the significant difference between temperatures in the centre of urban areas versus outer lying regions. This phenomenon is known as the Urban Heat Island Effect.

3.1.9 Aesthetics/improved livability

As urban centres undergo urban renewal, increased densification and adopt the principles of "Smart Growth", green roofs offer new approaches to open space and urban amenities. They provide new architectural expressions, improved visual quality, and provide areas for gathering and comfort.


13.1 Walker Macy Landscape Architect *13.2 R. Burck Associates* *13.3 Robertson Condo Building*
Many green roofs can provide aesthetic improvement over conventional or non-greened roofs.

3.1.10 Incentives

In many jurisdictions, the addition of a green roof can qualify for various types of incentives such as density or floor-area-ratio density bonuses, tax credits, a fast-track permitting process and even grants for implementation. The City of Toronto offers $50/m^2 to qualified building owners to offset the cost of green roof construction. New York City provides tax credits equivalent to approximately $48/m^2. In the City of Calgary, green roofs have been an option for bonus density and increased FAR – check with Planning, Development & Assessment for details.

14.1 City of Portland, OR *14.2 New York City, NY* *14.3 City of Toronto, ON*
There are many municipal and state governments that offer a form of incentive for the inclusion of a green roof whether as part of new construction or as a retrofit. The City of Portland, Oregon (14.1), New York City (14.2) and the City of Toronto (14.3) have offered many rounds of incentives[2]. The images above represent the dedicated web portal for information and application to their green roof incentive programs.

3.1.11 Additional benefits

There are many other benefits that can be derived from green roofs such as increases to property values, increased health and wellbeing, potential increase to green jobs, contribution of green building rating (LEED, Sustainable Sites Initiative, Living Building Challenge) and numerous others. For more information on these other benefits, refer to Green Roofs for Healthy Cities, the industry association, www.greenroofs.com and other sources in Section 10 of this document.

[2] The various programs offered by municipalities actively encouraging green roofs often have a limited time frame. Some have implemented numerous incentive cycles to build interest and uptake in their communities.

4.0 PHYSICAL FEASIBILITY AND DESIGN APPLICATIONS

4.1 TYPICAL APPLICATIONS

Green roofs can be applied to a wide range of building types including commercial, institutional, industrial and residential (both single and multifamily). While preferably to applied to well supported and engineered structures of concrete and steel, wood framed buildings are also suitable. In general terms, the type of green roof utilized is driven by the design intent of the project, especially when examining retrofit scenarios versus new construction. Typical considerations include project goals and objectives, budget, and site constraints to note a few.

4.2 Key Components

Typically, a green roof assembly consists of six main components in addition to the typical structure, insulation and air vapour barriers. For pre-cultivated or modular systems, some may be combined. Typical components include:

- **Waterproofing;**
- **Drainage;**
- **Root barriers;**
- **Filtration;**
- **Engineered Growing Media;**
- **Vegetation.**

The typical components are outlined in detail below.

4.2.1 Waterproofing

Green roofs should be applied over a high-quality waterproofing system with a proven track record. The membrane can be applied on top of the structural deck in a conventional method, on top of insulation, a protected membrane, or inverted system. Types of suitable membranes include the following:

- **Modified bitumen such as SBS (Styrene-Butadiene-Styrene);**
- **Hot applied rubberized asphalt;**
- **Elastomeric membranes such as EPDM (ethylene propylene diene monomer);**
- **Thermoplastic membranes such as PVC (polyvinyl chloride) and TPO (thermoplastic polyolefin); and**
- **Built-up bitumen.**

Generally, there is no limitation on what waterproofing materials to use within a green roof assembly. However, increased membrane quality is prudent in a green roof design. The waterproofing system should be designed with redundancy, which extends to the base, cap and counter flashings forming part of the system. When green roof components are properly designed and installed, they can help to extend the life of the waterproofing system.

In Alberta, refer to the Alberta Roofing Contractors Association (ARCA) for recommendations.

4.2.2 Drainage

The type of drainage systems depends upon whether the roof deck is sloped or flat. Typical material and components that form part of the drainage system include:

- **Granular media;**
- **Roof drains/scuppers;**
- **Moisture retention mats;**
- **Porous mats of polystyrene; and**
- **Drainage pipes.**

All components of a green roof design must be reviewed to ensure that they do not impede drainage in any way or cause ponding on the roof, unless intentional. When a green roof design is combined with water storage on the same roof through the use of flow restrictors on drains, due care must be exercised and the combined water storage design must be brought to the attention of the structural engineer and reviewed to ensure that the roof loading does not exceed the capacity of the structure.

4.2.3 Rootbarrier

A root barrier typically comprised of high density polyethylene (HDPE), TPO, EPDM, or PVC sheets should be applied on top or beneath the drainage layer to protect the waterproofing from root penetration. The location for the root barrier depends upon the green roof system employed. If impervious concrete, PVC or TPO are used as the waterproofing layer, a separate root barrier is not required. However, since plant roots in semi-arid climates tend to be more aggressive, seeking water and nutrients, the addition of a root barrier provides added protection (Tolderlund, 2010).

4.2.4 Filtration

The purpose of the filtration layer is to prevent fines from the growing medium from entering the drainage system. Materials used for the filter layer are lightweight components and include:

- **Non-woven, non-biodegradable landscape fabric;**
- **Polypropylene matting; and**
- **Polyester fibre matting.**

4.2.5 Engineered growing media

The composition of the growing medium is of particular interest especially when a high water retention level is required. Properties that a suitable growing media should possess include (Friedrich 2006):

- **Good drainage and aeration;**
- **Water holding capacity (i.e. without getting too saturated or heavy);**
- **Nutrient holding capacity (i.e. cation exchange capacity - CEC);**
- **Permanence; (i.e. resist wind erosion and freeze-thaw)**
- **Lightweight but sturdy (i.e. cannot shrink or blow away);**
- **Low organic content (i.e. maximum 15%); and**
- **Stability (i.e. must anchor and support the plants).**

The required properties listed above encourage the use of specialized engineered soils as the only option, particularly if the project consists of an extensive green roof. Guidelines for soils mixes are presented in Table 4.

Table 4. Media Components Composition for Green Roofs

Intensive Green Roofs		Extensive Green Roofs	
Course lightweight Aggregate	35 – 75%	Course lightweight Aggregate	50 – 100%
Sand or fine aggregate	10 – 50%	Sand or fine aggregate	0 – 30%
Organic matter	5 – 15%	Organic matter	0 – 20%
Clay and Silt	0 – 2%	Clay and Silt	0%
Air content at maximum water capacity	15 – 45%	Air content at maximum water capacity	10 – 35%

4.2.6 Vegetation

Plant species selection objectives are dependent upon the design goals of the roof which may include function, performance, education or aesthetics. An integral component of this document is a plant matrix that lists suggested plant species for use in the Calgary Region. The matrix, explanation on how it was developed and the plant ranking sheets are included in Appendix C. In general terms, when developing a planting plan in the Calgary region, green roof designers should:

- **Select suitable native plants when possible**
- **Utilize plant communities with similar irrigation requirements**
- **Ensure the soil profile and texture is adequate for the selected vegetation**
- **Select plants with similar characteristics to simplify maintenance**
- **Select plants with low nutritional requirements**
- **Avoid plants that disperse seeds via winds**
- **Cluster plants and mimic natural organization**
- **Consider site criteria such as exposure, dominant wind direction and solar orientation**

When examining particular species suitability for green roof plantings, preference should be given to plants that exhibit the following characteristics:

- **Lateral rooting plants and plants which spread by rhizomes**
- **Self-seeding plants**
- **Species with horizontal growth habits**
- **Plants that are drought and wind tolerant**
- **At a minimum are hardy to Zone 3**
- **Are light weight at maturity (i.e. not woody plants)**

In all cases, invasive species (refer to Alberta Invasive Plant Council - http://www.invasiveplants.ab.ca) should be avoided to prevent potential harm to the natural environment.

4.3 OTHER COMPONENTS

4.3.1 Curbs and borders

Curbs and borders separate the green roof area from other roof components such as parapets, through-roof penetrations, drains, etc. They provide added protection from wind uplift and can act as a firebreak. Material used for curbs and borders include pre-cast concrete curbs, metal edging, planter boxes, recycled plastic timber, fibreglass and heavy timber.

The use of curbs and borders should not impede proper drainage. Material should be reviewed for compatibility with a wet environment and the use of soil amendments. They should also be durable and retain their form against the horizontal forces of the growing medium.

4.3.2 Protection board

The greatest risk to the waterproofing system is during the completion of construction. Once the membrane is installed, it is crucial to protect it during the installation of the green roof and other construction activities. The protection board must not break down in water and can be integral to the drainage system.

4.3.3 Irrigation

Although in many other climatic regions green roof systems are not necessarily irrigated, in the semi-arid region of Calgary irrigation should be installed. At a minimum, a simple automated irrigation system is recommended for all institutional, commercial or industrial green roof projects. While it is possible to design green roofs that do not require irrigation, they require close monitoring during periods of drought to determine whether plant survivability is threatened. Non-irrigated green roofs in Calgary should only be attempted by an experienced design team with a proven track record of implementing semi-arid green roofs.

Types of irrigation systems typically used on green roofs may include surface or subsurface drip, spray, or manual irrigation systems depending on the water source used and design specifics. The choice of irrigation system will depend on a variety of factors including building height, use of rainwater, parapet height, and other considerations. Where possible and particularly on new projects, collecting rainwater in cisterns, using other rainwater or runoff harvesting methods, and/or using building mechanical system drainage is recommended to prevent or limit the amount of potable water used, and minimize runoff generation.

Design considerations for irrigation systems includes: available water pressure and flow; isolation of the irrigation pipes from the membrane; plant species selection and the depth of the growing media; water holding capacity of the growing media; and whether any additional water retention measures will be used.

4.3.4 Maintenance paths

Where there may be frequent foot traffic on the roof for the inspection and maintenance of HVAC units or the green roof, a designated maintenance path should be employed to protect the membrane from use or damage. Various materials can be used, including precast concrete pavers, stone, wood decking and recycled rubber. Their application should not impede proper drainage and they should resist wind uplift.

4.3.5 Other design elements

Many other elements are used in conjunction with green roofs. Some of these include: lighting; planters; seating; guardrails and railings; shade structures, trellises; walkways, stepping stones; water features; outdoor furniture.

4.4 COMMON DESIGN CONSTRAINTS AND CONSIDERATIONS

Important considerations in the application of green roofs are the structural capacity, the integrity of the waterproofing systems, the vitality of the vegetation, and assessment of the microclimate of the site.

4.4.1 Structural capacity

The structural capacity to support a green roof depends upon the combined dead and live loads applied to the structure. The dead load represents anything that is permanently placed on the roof including the full weight of the green roof system including items such as pavers, water features, furnishing etc., as well as items hung below the structure (i.e., t-bar ceiling, mechanical ductwork, etc.). Live loads consist of changeable weight such as rain, snow, people or temporary components.

The weight of a green roof system includes all components from the membrane to the anticipated mature weight of the vegetation when fully saturated. Typical loads for green roof systems range from 0.42-1.05 kg/sq mm^2 [10-25 lb/sq ft] for an extensive system to 1.90-6.32 kg/sq mm^2 [45-150 lbs/sq ft] for an intensive system (refer to Green Roofs for Healthy Cities manuals).

4.4.2 Waterproofing

The perception exists that the addition of a green roof increases the probability for leaks in a roof. Despite this concern, it is increasingly understood that when properly designed and installed, green roofs are less likely to fail than conventional roofing systems as the waterproofing membrane is protected from mechanical damage and from heat and ultraviolet radiation which degrades the membrane.

4.4.3 Climate / microclimate

Calgary's average low temperature in the coldest month is -15.1° C and the average high temperature in the warmest month is 22.9° C. The average annual snowfall is 126.7 cm (49.9 in.) and rainfall is 320.6 mm (12.6 in.)[3]. Late spring blizzards are not unusual and only a few summer days surpass +30° C. (Reynolds, 2002). The region is characterized by very low levels of relative humidity and cool summer evenings. With only 115 frost-free days and low levels of precipitation there are critical items that should be addressed to ensure landscape viability such as appropriate plant selection, consideration to exposure and environment, soil structure and supplementary irrigation. Time of planting and protection from the elements is important in getting plants established on the green roof.

A comprehensive rooftop site analysis should be performed prior to the start of any green roof design. Important environmental considerations include solar orientation, direction and speed of the wind and areas of shading or reflection from the building proper or surrounding buildings.

---

[3] Refer to http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=2205&prov=&lang=e&dCode=1&dispBack=1&StationName=Calgary&SearchType=Contains&province=ALL&provBut=&month1=0&month2=12

4.4.4 Vegetation / substrate

With the exception of the intensive type of green roofs or rooftop gardens (refer to Section 1.4.1), most green roof growing media are within the range of 150 – 300 mm [6 – 12 in.] in depth. Slow-growing, shallow rooting perennial and succulent plants that can withstand the harsh conditions of a rooftop and planted in a minimum of 150 mm [6 in.] depth of substrate typically have the best chance to succeed. Green roof designers must match species type to the expected rooting depth available in the growing media, which should provide enough lateral growth to stabilize the growing media surface.

The planting plan may include accent plants to provide diversity and seasonal colour. Refer to Appendix C for information regarding plant species and their recommended plant media depths. There are concerns of export of nutrients from the media. Care should be taken to limit the potential export of phosphorus by testing media components and limiting the phosphorus input through media additives and fertilizers. Please see Section 2.2.1 for more water quality guidance related to substrate media and vegetation.

4.5 RELATED FACTORS

4.5.1 Retrofitting green roofs

If the membrane has reached the end of its lifespan, this is an opportune moment to add a green roof. When retrofitting a green roof, the structure must be assessed by a professional structural engineer to determine its structural capacity and limitations. The condition of the existing waterproofing must be reviewed by a qualified professional to determine the integrity of the waterproofing or whether repairs are required. Access, building services (water) and other conditions of the existing roof should be taken into consideration and reviewed by a competent design professional.

4.5.2 Local building codes

In Alberta, green roof projects are considered an extension of a conventional roof and must comply with the requirements of the building code for structural design, drainage and moisture protection and occupant safety (Peck & Kuhn 1999). The reference code in our jurisdiction is the Alberta Building Code 2006 (ABC 2006), a copy of which can be purchased at the Government of Alberta, Municipal Affairs website or technical book stores[4]. The ABC 2006 can also be referenced at any public library.

While the ABC 2006 code does not currently have provisions or reference standards for green roofs, of particular concern is an assembly's resistance to exterior fire exposure, wind uplift and structural support. In Calgary, a variance must be submitted when making a building permit application. Its purpose is to demonstrate that the green roof design has been reviewed and signed off by a registered professional in the Province of Alberta and that it complies with appropriate guidelines for the prevention of fire spread. It is recommended that applicants contact Development & Building Approvals at the City of Calgary for additional information.

If the roof is an occupied roof (that is, designed for individuals to congregate for amusement, educational or similar purposes) the design of the roof needs to provide proper access to people other than the maintenance staff. Additional regulations apply for occupancy, additional structural loading, exiting, lighting, guardrails and barrier-free access.

[4] Website information can be found at: http://www.municipalaffairs.gov.ab.ca/cp_building_codes_standards.cfm.

4.5.3 Safety on roofs

Safety on the rooftop is crucial at all stages of its development. During the installation of the green roof or for maintenance or inspection visits, a temporary means of protecting workers may be used such as fall arrest or fall restraint systems and temporary guardrails. Refer to ABC 2006 Part 8 and Occupational Health & Safety for specific information.

4.5.4 Construction costs

Construction costs depend upon numerous factors such as size of roof, depth of substrate, complexity of the design, type of green roof (extensive, intensive), level of roof above grade, site logistics, planting palette, type of vegetation, etc.

The reported costs of green roof projects in Alberta are higher compared to other regions in Canada (Toronto, Montreal, and Vancouver) where green roofs are more common. They are also more expensive than many other LID practices when solely looked at on an initial cost basis only. Given the numerous other benefits that green roofs can contribute, when life-cycle costs are taken into account, they make the investment more reasonable and are comparable to a conventional roof (Porsche & Kohler 2003).

Factors that influence cost include:

- **Type of green roof (i.e. intensive, semi-intensive, extensive, loose laid, modular)**
- **Size of green roof (i.e. larger scale projects often benefit from economy of scale)**
- **New versus retrofit projects (i.e. new construction is often less expensive than retrofits)**
- **Elevation above grade (i.e. is the project built at grade or several stories above necessitating some form of hoisting?)**
- **Roof accessibility (i.e. ladder, scaffolding, through building, roof hatch)**
- **Complexity of green roof design (i.e. is the roof a simple design or sophisticated ornamental design)**
- **Planting method and density of plantings (i.e. plugs, mature plants, cuttings, hydroseeding, amount of labour required)**
- **Market conditions (i.e. exceptionally active construction market and inexperience can lead to higher costs; a more mature market will lead to better pricing)**

When building a green roof, there are often various options to keep costs down. However, the design team should avoid value-engineering a green roof and review the design as a whole. One often cited reason for green roof failures is from a Value-Engineering exercise whereby the design or contracting team looks to save costs on a component by component basis rather than looking at the system as a whole or considering a phased approach to its construction.

4.5.5 Slope

To ensure proper drainage a minimum slope of 2% is recommended for the drainage planes of flat roofs (ARCA 2006). Slopes less than 2% can be found on many existing roofs but can result in inadequate drainage and ponding which can potentially damage the waterproofing and as well as plants.

While green roofs can be applied to steep slopes up to 40°, the design team must take appropriate actions to stabilize slopes greater than 10°, to resist shear and retain the growing medium on the roof. An erosion mat is recommended for all sloped roofs, particularly ones subject to higher wind speeds and facing the prevailing winds.

A variety of technical systems and methods have been developed to manage green roofs on slopes when they exceed 10° including erosion mats, cross battens, anti-slip cleats and “geogrid” and cable systems attached through to structure. These components will help tie the growing medium to the roof and hold the plants in place while a root system develops in the low-cohesion growing medium forming a greater resistance to shear forces. When the slope exceeds 30°, a higher level of structural control and construction approach will be required. It is prudent to develop the design solution with a structural engineer for this particular roof design.

Plants in sloped green roofs will have inconsistent conditions. The top of the slope will typically be drier while at the eaves or parapet edges, the growing medium can remain wet more frequently. Plant species selection and irrigation design should take this into consideration and a moisture retention mat should be incorporated. Different slopes and aspects will create dissimilar localized microclimates. Therefore the plant species palette for the different areas of the roof(s) should take this into consideration.

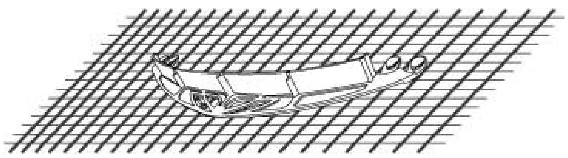


Figure 15.1: This system developed by Optigrun Green Roof Systems consists of an anti-slip cleat clipped to an anti-slip mesh, which is applied over the drainage layer. The plastic mesh is mechanically fastened at the top of the roof or roof ridge (Conservation Technology, Inc.)

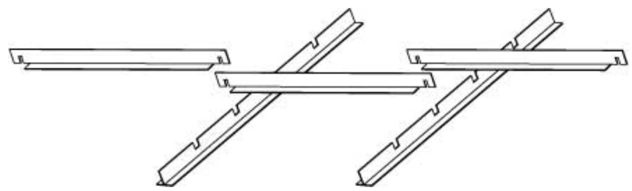


Figure 15.2: Another Optigrun system for slope stabilization entails anti-slip tees that interlock. They transfer the load of the green roof to a structural parapet or fascia. (Conservation Technology, Inc.)

Figure 16.1: shows the application of a geogrid underlayment on the sloped green roof at Lincoln Centre in New York City.

Figure 16.2: illustrates the subsequent steps in the Lincoln Centre green roof of applying the growing medium into the geogrid and layoing sod on top.

Case study 5 of the Van Dusen Botanical Garden found in Appendix A highlights another system of managing steep slopes on green roofs.

4.5.6 Storage of material and roof loading

In addition to ensuring that the new roof or retrofit can support the additional load of a green roof build up, storage of material and construction loading should be taken into consideration. In downtown areas where options for material storage at grade can be limited, rooftop storage is often a necessity. Rooftop storage provides a secure storage location, saves time and cost in retrieving matter from an offsite location (GSA) and limits the amount of mechanical hoisting and possible traffic disruption from repeated road closures.

When stored on the roof, green roof construction material particularly the growing medium and pallets of pavers or drainage aggregate should be distributed uniformly rather than stacked in one place causing point loading. When unsure of the structural capacity of the roof for construction loading, the builder should seek the advice of a structural engineer.

Materials should never be stored directly upon the waterproof membrane and contractor should protect the exposed membrane at all times. As with all construction material stored on building sites, builders must ensure that material is secured and tied down to resist wind uplift and the possibility of being blown off the roof, which can risk death or injury to people below.

4.5.7 Access

Site access and construction logistics, such as delivery and hoisting of materials, are important considerations for the construction of the green roof. How the roof will be accessed once completed is equally important whether it is through a roof hatch, an access stair and door, elevator or by a ladder. Guardrails, lighting, barrier-free access and occupant egress are required if the roof is used by building occupants, and should be designed by a registered professional.

4.5.8 Compaction of growing media

Growing media used in extensive/semi-intensive green roofs consist largely of inorganic material such as expanded slates and shale, lava, pumice, etc., (refer to section 4.2.5) which provides aeration as well as resistance to compaction. Typical growing medium is more resistant to compaction than regular loam because of its high aggregate/low organic content. However, excessive compaction can result from frequent foot traffic or storage of materials for repairs or use of the roof for different activities.

Pathways for roof traffic should be provided, particularly for regular maintenance activities such as access to rooftop units or window washing of building facade above. This will assist in prevention of plant damage and compaction of the growing medium. (GSA). If repairs are necessary in an area of the green roof, placing sheets of plywood over the adjacent vegetation may assist in spreading the load across the section of green roof. This can minimize any compaction of the growing media and offer some protection to the plant cover, particularly if it consists only of ground cover.

Should over-compaction occur resulting in a loss of vegetative cover, the growing media can be turned, raked, and replanted, taking care not to damage underlying layers, particularly the waterproofing

4.5.9 Best management practices for green roof design

Along with the emergence of North American standards, Best Management Practices (BMPs) are being developed to ensure building code compliance and to outline accepted construction practices. Typical BMPs include vegetation free setbacks from parapets, building facades, rooftop units, and roof penetrations. Refer also to Appendix B for some typical details. More specifically, BMPs include:

Wind and water erosion: some form of erosion protection should be considered for Calgary green roofs to prevent loss of growing medium and scouring, particularly if planting is delayed, the roof is sloping or in a highly exposed upper storey roof. Erosion mats or blankets, tackifiers or cover crops are some of the strategies used to prevent wind scouring or erosion. Seeding with a fast growing annual vegetated coverage or broadcasting sedum cutting can provide living coverage that helps with erosion control. Biodegradable or permanent erosion mats are available from a variety of sources. The anchor pins (metal or biodegradable plastic) must be placed into the growing medium carefully such that the underlying layers are not damaged, particularly the waterproof membrane.

Fire breaks: particularly used on large roof areas, a physical break in the vegetation coverage is recommended to diminish the potential spread of fire. While green roofs were employed in Germany as a means to protect highly flammable roofing systems from the risk of fire, there is concern that the presence of dry and dead vegetation on a rooftop could increase the risk of fire. Plant species selection, the use of an irrigation system and maintenance practices are related to this issue.

Vegetated-free zones at perimeters and breaks on larger roofs: at areas of the roof which are particularly vulnerable or prone to leaks, a vegetated-free zone is recommended both for greater ease of inspection and to ensure that plant roots do not burrow into the membrane. While there are different opinions on the required dimension of the setbacks, the areas where the setbacks are recommended include: perimeter walls and building facades, through-roof penetrations such as plumbing stacks, HVAC units, roof drains, etc.

4.5.10 Contract growing of plant material

As noted in Appendix C, Calgary is an emerging market for green roofs. As of the date of this manual, the supply market for species that are deemed suitable for green roof applications is immature. Therefore, to meet some of the species selections illustrated in the plant matrix, or to meet other criteria such as aesthetic considerations, site or regional considerations and micro-climate conditions, it may be required to contract with a nursery to grow certain plant species for a specific installation if required quantities or varieties are unavailable.

If the species selected is not contained in the plant matrix in Appendix C, it should be reviewed with a professional with noted experience in green roof construction. Consideration should be given to soil profiles and textures, irrigation requirements and the success / establishment of the selected species should be monitored closely. Modifications and adjustments may be required as high irrigation demands and low vegetation coverage and/or survival rates will adversely affect the storm water management function of the system.

5.0 REGIONAL AND SPECIAL CASE DESIGN ADAPTATIONS

5.1 COLD CLIMATE AND WINTER PERFORMANCE

Several design adaptations may be needed to ensure the successful overwintering of green roofs in the Calgary area. The most important is to match plant species and adequate depth of growing media to plant hardiness zone. A minimum depth of 150 mm [6 in.] is recommended for green roofs on the prairies and the Chinook region as a result of early applications that did not successfully overwinter.

Bark mulch is commonly used to help planted areas retain moisture, resist weed pressure and buffer against cold temperature. This type of mulch is not appropriate on a green roof as it is too lightweight to stay in place. Further to this, it is not recommended as over the long term, it tends to breakdown quickly, can block drains, and alter the pH of the engineered growing medium (Snodgrass). Other forms of mulch may be suitable but their addition will need to be factored into the overall weight of the system.

5.2 LOW LEVELS OF PRECIPITATION

With only 412.6 mm (16.2 in.) of annual precipitation of which 320.6 mm (12.6 in.) is rainfall during the growing season, irrigation and moisture retention components should be considered for green roofs in the Calgary region. While many drought tolerant plant species are well suited to the thin profile of a green roof, it is worth repeating that rooftops are extreme environments and green roofs are artificial man-made constructions. Sensible use of supplemental irrigation, see Sections 2.1.1 and 2.1.2 and Appendix E, will be required to ensure the following:

- **that the roof performs its stormwater function as well as other benefits;**
- **there is consistent vegetated cover;**
- **that the green roof continues to meet the owner's design intent.**

5.3 CHINOOK WIND

One of the strongest climatic features is the Chinook winds that settle in over the Calgary region several times a year. This weather inversion brings warmer temperatures and strong drying winds, often melting the insulating snow cover. Over extended periods of several days, the Chinook conditions can result in bringing plants out of dormancy.

At elevated heights of rooftops especially on the skyscrapers and tall buildings, this wind phenomenon results in even higher wind speeds. This increases the speed at which moisture is lost from the planting media itself and evergreen varietal plants. While a minimum 150 mm growing media depth is recommended, greater growing media depths and the use of supplemental water retention will provide some additional protection against desiccation. Perforated screens or winds breaks blocking or dispersing winds may prove more effective in ensuring adequate spring moisture levels, thereby providing a more favourable site condition.

6.0 CONSTRUCTION

Green roofs should only be installed by experienced contractors knowledgeable about building construction, waterproofing and greenroofing. While there are many landscape contractors with experience in building landscapes over structures at grade, working at elevated heights on a building presents additional challenges and requirements. Similarly, roofing contractors require either in-house landscape expertise or subcontractors with experience with the living components of a green roof.

Proper coordination of construction sequencing, hoisting and storage of materials on the roof is of critical importance to ensure that the roof is built correctly according to the drawings and specifications. Determining how material will be placed on to the roof (refer to section 4.5.6 Storage) and how construction workers will access the work area should also be taken into consideration (refer to Section 4.5.7 Access). An inexperienced team should consider including a specialist in green roof design and construction, such as a Green Roof Professional (GRP) or enrolling in focused courses in green roof construction.

6.1 CONSTRUCTION SEQUENCE

There are many ways to construct or assemble a green roof. Many of the steps depend upon the type of green roof, method of assembly, design complexity, s well as whether the project is a new roof or a retrofit scenario. Typical construction considerations of an inaccessible extensive or semi-intensive include the following:

- **Construct roof deck to appropriate slope and specifications;**
- **Install waterproofing including flashings, counterflashing, etc. as per manufacturer's specifications;**
- **It is recommended that a flood test or other method of membrane integrity test be conducted prior to adding any overburden. This will be a requirement of ARCA as part of their warrantee program, which is currently in development;**
- **While protecting the membrane from damage, add the green roof system components (i.e., root barrier, drainage layer, filter fabric) and other related items such as drain collars, curbing or containment;**
- **Install irrigation according to layout illustrated in construction drawings and specifications;**
- **The engineered growing medium should be blended prior to arriving at the site and a test sample should be taken to ensure that the blend meets the required design specifications. It should be moistened and compacted every several inches to achieve the desire compaction rate;**
- **Prior to planting, the growing medium should be saturated. Planting should follow the planting plan prepared with the construction documents. Plants suitable for a rooftop environment should be selected as per Appendix C or as per manufacturer if selecting a system;**
- **A green roof is thought to be established when it reaches 80% coverage (FLL). For a loose-laid or in-situ green roof, it may take 24-36 months depending upon the method of propagation for the roof to be fully established in the Calgary region.**

6.2 CONSTRUCTION INSPECTION

In addition to the consultant reviews of the installation, inspection during the construction process is necessary to ensure that the green roof is built according to the construction documents (drawings and specifications). It is required that the construction inspection checklist be signed off by a qualified third-party at the critical stages noted on the inspection form to confirm that the contractor has properly interpreted the construction documents. For the purpose of this document, a qualified individual is a licensed Landscape Architect, Architect, Engineer or Green Roof Professional (individual or company) who has demonstrated experience with the design, construction and installation requirements of a green roof.

The system build-out should occur in sections for easier inspection as well as maintenance access during the process. It is the responsibility of the contractor to coordinate inspections with the third-party inspectors as required in completing the Construction and Inspection Checklist.

Key items and stages to inspect include, but are not limited to:

- **Placement of the waterproof membrane;**
- **Placement of drainage layer and system;**
- **Placement of curbs and containment;**
- **Installation of irrigation system;**
- **Placement of growing media to ensure conformance to construction plans;**
- **Plants to ensure they are healthy, installed correctly and placed according the planting plan;**
- **Substantial completion for use and occupancy approvals.**

It is preferable that the contract for the green roof installer extends into the warranty and establishment period. Should a separate contract for maintenance be issued, a necessary overlap should occur where maintenance contractors receive operations and training by the contractor responsible for the original installation.

The construction inspection checklist is included in Appendix D.

7.0 MAINTENANCE

7.1 MAINTENANCE INSPECTIONS AND ONGOING OPERATIONS

The design life of a green roof can be maintained or even extended with proper inspection and maintenance throughout the roof life. While many of the green roof components have explicit design lifetime warranties from manufacturers, some components such as media, substrate, and plants are dependent upon many climatic, installation, design, and maintenance factors. Green Roof warranties are often tied to maintenance requirements, which, if not executed, can render the warranty null and void. When design lifetimes have been reached, replacement may be necessary to continue adequate performance of the green roof. Please check with manufacturers to determine applicable specifications.

Inspection is also necessary to evaluate and understand the condition of green roof components. Inspection and maintenance checklists detailing the type and frequency of maintenance should follow manufacturer's specifications. Tolerances of green roof components should not vary more than 10% (higher or lower) of those given in Chapter 2 for meeting water quantity and quality objectives. Media depths should be inspected across the width and length of the green roof.

A maintenance log and plan shall be established prior to the completion of the project, and the review of the log is a critical path item in the construction inspection checklist. A sample log is included in Appendix D. Anticipated maintenance budgets should be discussed early in the design process to ensure that the design intent aligns with maintenance expectations and abilities. The amount of maintenance and specific tasks will depend upon the type of green roof, installation method, complexity of the design, etc. Warranties are often tied to maintenance requirements, which, if not executed, can render the warranty null and void.

Typical maintenance practices include watering, weeding, fertilizing and clean up. Tasks relating specifically to ensuring protection of the membrane include inspection of joints, borders, drains, roof penetrations, etc. The inspection of the membrane may be required up to several times a year.

Less common and less frequent inspection of items for water quality purposes include inspection of the particle size distribution of the media substrate to determine whether breakdown of media structure has occurred. Breakdown of media can significantly impact the stormwater performance of a green roof. Smaller particle sizes can inhibit hydraulic conductivity and media permeability affecting the rate at which the roof can dewater. To maintain adequate performance the range of particle sizes should not vary more than 5% compared to the values given in Chapter 2.

Care of the plants will be most critical during the establishment period which can be as long as 24-36 months. If the green roof system is pre-cultivated, the green roof is expected to be fully established within the first growing season.

Beyond the establishment period, the following long-term maintenance tasks may apply:

Spring clean-up (early May depending upon the spring):

- **Remove debris and dead plant material, and dispose of material;**
- **Add replacement plants as required;**
- **Inspect and clean drains;**
- **Initialize irrigation system.**

Summer growing season:

- **Confirm irrigation system functioning and watering meeting requirements;**
- **Inspect plant health (i.e. check for deficiencies, pests);**
- **Weed vegetated areas and dispose of weeds;**
- **Inspect and clean drains;**
- **Remove debris.**

Fall clean up (mid-late September):

- **Remove biomass and debris, and dispose of material;**
- **Fertilize (if required);**
- **Blow out and winterization of irrigation system.**

Winter:

- **Inspect roof as per supplier's recommendations;**
- **Minimal site inspections should be made between November through March for review of drainage, debris, etc.**

7.2 GREEN ROOF MAINTENANCE LOG

As a part of the ongoing evaluation of a green roof that serves as a component in the stormwater management system of a site, a yearly maintenance log (sample included in Appendix D) will be required to be kept on-site for review by Water Resources staff, when requested. The purpose of the log is to ensure that certain tasks are being performed on an ongoing basis and that the components of the green roof are being monitored and evaluated for their continued function in the system.

The log can follow the template included or can be drafted by the maintenance group or building manager looking after the components. In all cases, the review and approval of the log to be utilized is a requirement during the construction inspection phase.

The sample included in the module recognizes that there are some tasks that are to be completed on an annual basis and other tasks that are seasonal. Plant coverage and health is a primary concern and irrigation and fertilization rates should be monitored closely (and adjusted as identified by a qualified green roof professional; see monitoring recommendations in Appendix F) during the maintenance and establishment phase to ensure adequate levels to support a healthy plant community.

8.0 REFERENCE STANDARDS AND GUIDELINES FOR GREEN ROOFS

The purpose of standards is to provide a common basis of design and construction and to help avoid failures, as failures could impede further growth to the North-American green roof market and to discuss their relevance for the North-American green roof market.

Unlike in Germany, where green roofs are already highly standardized, most projects in North America are custom-made solutions. The individual evaluation of research results and technical information of manufacturers and material suppliers is very difficult, especially without the availability of commonly accepted definitions, requirements and testing methods. While American Standard Testing Methods (ASTM) regulations in this field are emerging, existing standards developed in Europe continue to be a useful source of information.

8.1 FORSCHUNGSGESELLSCHAFT LANDSCHAFTSENTWICKLUNG LANSCHAFTSBAU (FFL)

Forschungsgesellschaft Landschaftsentwicklung Lanschaftsbau or simply FLL is the German Landscape Research, Development and Construction Society. This organization has been responsible for the development of the most comprehensive prescriptive guidelines published on green roofs covering the planning, installation and maintenance of green roofs. Most green roof standards and guidelines developed in North America are based upon the FLL Standards.

8.2 AMERICAN SOCIETY FOR TESTING METHODS (ASTM)

ASTM continues to build a set of performance standards necessary to the designing, specifying and installation of green roofs. To date, these standards include:

- **ASTM E2397-11 Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems;**
- **ASTM E2396-11 - Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Vegetative (Green) Roof Systems;**
- **ASTM E2398-11 15-Feb-2011 - Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetative (Green) Roof Systems;**
- **ASTM E2399-11 01-Apr-2011 - Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems;**
- **ASTM E2400-06 15-Jan-2006 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems;**
- **ASTM WK28504 – New Guide for Selection of Waterproofing Membranes for Green Roofs (under development).**

8.3 AMERICAN NATIONAL STANDARDS INSTITUTE/SINGLE-PLY ROOFING INSTITUTE (ANSI/SPRI WITH GRHC)

New fire and wind design standards for green roofs were developed by ANSI and SPRI in collaboration with Green Roofs for Healthy Cities. These standards reinforce the importance of maintenance and explicitly state the building owner's responsibility for upkeep of vegetation and adequate water supply. Maintenance information in this guidance document draws on this source.

VF-1 External Fire Design Standard for Vegetation Roofs
This design standard provides a method for designing external fire resistance for vegetative roofing systems. It is intended to provide a minimum design and installation reference for those individuals who design, specify, and install vegetative roofing systems. It shall be used in conjunction with the installation specifications and requirements of the manufacturer of the specific products used in the vegetative roofing system.

RP-14 Wind Design Standard for Vegetative Roofing Systems
This standard provides a method of designing wind uplift resistance of vegetative roofing systems. It is intended to provide a minimum design and installation reference for those individuals who design, specify, and install vegetative roofing systems. It shall be used in conjunction with, or enhanced by, the installation specifications and requirements of the manufacturer of the specific products used in the Vegetative Roofing System.

8.4 FM GLOBAL – PROPERTY LOSS PREVENTION DATA SHEET 1-35 – GREEN ROOF SYSTEMS

Although not a standard setting organization, FM Global is a large commercial and industrial property insurance risk management organization that issues engineering guidelines to reduce the risks associated with property loss due to fire, weather or equipment loss. They are a large player in the commercial market and within many municipalities in the US and Canada. They incorporate loss prevention data sheets into a set of guidelines.

8.5 GREEN ROOFS MANUALS AND GUIDELINES

Maintenance issues have emerged as one of the most important factors to the long-term success of a green roof. Two recent guidelines have been created to help provide an overview of regular maintenance tasks for both the establishment stage and over the life of the green roof. These guidelines are: "Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West" by Colorado Green Roofs, and the "Advanced Green Roof Maintenance" half-day course offered by Green Roofs for Healthy Cities.

For more information on guidelines, refer to the Resources in Section 10 – Resources below.

9.0 ACKNOWLEDGEMENTS

In addition to our peer reviewers, Professor Daniel Roehr and Kevin Kong from the University of British Columbia, we would like to thank the following individuals who generously shared information and images, reviewed the document and provided feedback, offered suggestions, etc.:

Carole Dobson and Marie-Anne Boivin, Soprema
Dawna Sagi, ground3 Inc. landscape architects
Ron Schwenger, Architek Green Building Solutions
Trevor Sziva, Alberta Roofing Contractors Association

10.0 RESOURCES

10.1 MUNICIPALITIES

- City of Toronto
  http://www.toronto.ca/greenroofs/index.htm
- City of Portland - Ecoroof blog
  http://www.portlandonline.com/bes/index.cfm?c=50716
- City of Chicago -
  http://www.cityofchicago.org/city/en/depts/doe/supp_info/green_roof_grantsprograms.html

10.2 GREEN ROOF ASSOCIATIONS/PORTALS

- Green Roofs for Healthy Cities
  www.greenroofs.org
- Greenroofs.com
  www.greenroofs.com

10.3 INTERNATIONAL

- International Green Roof Association (IGRA)
  http://www.igra-world.com/index.php
- Scandanavian Green Roof Association/Augustenborg's Botanical Roof Garden
  http://www.greenroof.se
- Livingroofs.org
  www.livingroofs.org
- United Kingdom
  http://www.greenroofguide.co.uk/what-are-green-roofs

10.4 ACADEMIC/RESEARCH CENTRES

- British Columbia Institute of Technology (BCIT) Centre for Architectural Ecology
  http://commons.bcit.ca/greenroof
- Michigan State University - Green Roof Research Program
  www.hrt.msu.edu/greenroof
- Penn State - Centre for Green Roof Research
  http://horticulture.psu.edu/cms/greenroofcenter
- Columbia University/Con Edison
  http://earthsky.org/water/green-roofs-offer-solution-for-nyc-stormwater-woes
- Colorado State University
  http://greenroof.agsci.colostate.edu
- GRIT Lab – University of Toronto
  http://grit.daniels.utoronto.ca
- University of British Columbia – Green Skins Lab
  http://www.greenskinslab.sala.ubc.ca/cover.htm

10.5 STANDARDS/GUIDELINES

- Forschungsgesellschaft Landschaftsentwicklung Lanschaftsbau FLL
  A downloadable version of the FLL Guideline is available in English. See the "Online" section of the following website).
  www.fll.de
- American Standards & Testing Methods (ASTM)
  www.astm.org
- CMHC Design Guidelines
  http://www.cmhc.ca/en/inpr/bude/himu/coedar/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=70146
- Whole Building Design Guide
  http://www.wbdg.org/resources/greenroofs.php?r=env_roofing

11.0 CONTACTS

Listed below are a number of contacts of companies providing green roof components and systems in the Alberta market. This list is not exhaustive and is meant to be added to as the market grows. This contact list is provided for information only and does not constitute a recommendation.

Soprema (full green roof system, including membrane) Product: Sopranature Contact: Carole Dobson/Shawn Frayn Soprema Technical Representative Phone: : 403-561-1323/403-248-8837 E-mail: cadobson@soprema.ca/ sfrayn@soprema.ca www.soprema.ca	**Sarnafil Ltd.** Product: SarnaVert CA-Mississauga, Ont. Phone: 905 271 7009 E-mail: stan.graveline@sarnafilus.com www.sarnafil.ca
Zinco Canada (green roof system) Extensive and Intensive systems Ron P. Schwenger ~ Principal Phone: 604-714-0028 E-mail: ron@architek.comgreenroof@zinco.ca www.zinco.ca	**Garland Canada Inc.** Product: Greensheild Toronto, Ontario Phone: 416-747-7995 Toll Free: 800-387-5991
Hydrotech Canada (have a membrane to filter cloth system as well as three main soil blends) Contact: John Riley Phone: 604-593-5601 Fax: 604-593-7424 Cell: 778-867-6125 E-mail: john@icdi.ca www.icdi.ca	**Tremco** (can provide waterproofing, drainage system, moisture retention mat…+ works with LandSourceOrganix to supply the engineered soil) Contact: Derek Semeniuk Phone: (800) 668-9879 E-mail: dsemeniuk@tremcoinc.com www.tremcoroofing.com
Siplast Product: Teranap Green Roof System North Vancouver, BC Contact: Bob Thurston Phone: 604-929-7687 www.siplast.com	**Firestone Roofing/Pilot Group** Contact: Larry Shoesmith Phone: 403-251-5593 E-mail: larry@pilotgroup.ca
LiveRoof (precultivated modular tray) **Eagle Lake Turf Farms Ltd.** Strahmore, AB Nathan Gill Phone: 403-295-2377 E-mail: sustainable@eaglelakelandscape.com www.eaglelakelandscape.com	**XeroFlor Canada** (green roof layers – sedum mats and meadow systems- membrane not included) Contact: Sasha Aguilera Phone: 416-637-5772 Ext 5002 Cell: 647-466-5595 E-mail: sasha@xeroflorcanada.ca www.xeroflorcanada.ca
Elevated Landscape Technologies ELT (green roof layers – sedum mats and meadow systems- membrane not included) Products: EZ Grow; ELT Living Walls Branford, Ontario Phone: 1-866-306-7773 www.eltgreenroofs.com	

12.0 REFERENCES

Printed Publications:

Alberta Roofing Contractors Association ARCA. 2006. *Manual on Green Roofing Practice and Accepted Roofing Systems*

Alberta Tree Movers & Nurseries. *Wholesale Catalogue 2001.* High River, AB.

Banting, Doug, James Li, and Paul Missios. 2005. *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto*. Toronto, ON: Earth and Environmental Technologies (OCE-ETech).

Berghage, Robert, Ann Wolf, and Charlie Miller. 2008. *Testing Green Roof Media for Nutrient Content. Proceedings 6th Annual Greening Rooftops for Sustainable Communities Conference, Awards & Trade Show*. Baltimore, MD. The Cardinal Group, Toronto,

Berghage, R.D., Beattie, D., Jarrett, A.R., Thuring, C., Razaei, F., O'Conner, T.P., 2009. *Green roofs for stormwater runoff control.* EPA 600-R-09-026. National Risk Management Research Laboratory Office of Research and Development U.S. Environmental Protection Agency, Cincinnati, OH.

Berndtsson, J.C., Emilsson, T., Bengtsson, L., 2006. *The influence of vegetated roofs on runoff water quality*. Sci. Total Environ. 355, 48–63.

Berndtsson, J.C., Bengtsson, L., Jinno, K., 2009. *Runoff water quality from intensive and extensive vegetated roofs.* Ecol. Eng. 35, 369–380.

Bishop, W. (2009). *Trees & Shrubs for the Prairies*. Landscape Alberta Nursery Trades Association. Edmonton: Sundog Printing.

Cantor, Steven L., 2008. *Green Roofs in Sustainable Landscape Design*. New York. WW Norton.

City of Portland. 2010. *Portland Ecoroof Guide.*

City of Waterloo; *Feasibility of Green Roofs and City Wide Implementation Plan;* Final Report, December 2004.

Connelly, Maureen, Karen Liu, and John Schaub. 2006. *BCIT Green Roof Research Program, Phase 1 Summary of Data Analysis, Observation Period, Jan. 1, 2005 to Dec. 31, 2005. Report to Canada Mortgage and Housing Corporation.* Ottawa, ON: Canada Mortgage and Housing Corporation.

Connelly, M. and M. Hodgson. 2008. *Sound transmission loss of green roofs.* In: Proceedings 6th Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show. Baltimore, MD. Green Roofs for Healthy Cities, Toronto.

Cormack, R.G.H. (1977). *Wildflowers of Alberta*. Edmonton: Hurtig Publishers

Cooper-Marcus, C. and M.Barnes. 1999; Healing Gardens: *Therapeutic Benefits and Design Recommendations.*

Currie, B. and B. Bass. 2007. *Estimates of Air Pollution Mitigation with Green Plants and Green Roofing using UFORE Model.* Urban Ecosystems Volume 11, Number 4, 409-422, DOI: 10.1007/s11252-008-0054-

Dane, J.H. and G.C. Toppe, eds., 2002. Methods of Soil Analysis Part 4 Physical Methods, Soil Science Society of America, Inc. Madison, Wisconsin, USA.

DeNardo, J.C., Jarrett, A.R., Manbeck, H.B., Beattie, D.J., Berghage, R.D., 2005. *Stormwater mitigation and surface temperature reductions by green roofs.* Trans. ASAE 48, 1491–1496.

Deutsch, Barbara, Heather Whitlow, (Casey Trees) and Michael Sullivan, Anouk Savineau, Brian Busiek (LimnoTech). 2007. *The Green Build-out Model: Quantifying the Stormwater Management Benefits of Trees and Green Roofs in Washington, DC.*

Dunnett, Nigel and Noel Kingsbury. 2008. *Planting Green Roofs and Living Walls.* Portland, OR: Timber Press.

Eagle Lake Nurseries Ltd. *2011 Wholesale Catalogue.* Strathmore, AB.

Emilsson, T., Berndtsson, J.C., Mattsson, J.E., Rolf, K., 2007. *Effect of using conventional and controlled release fertilizer on nutrient runoff from various vegetated roof systems.* Ecol. Eng. 29, 260–271.

Fassman, Elizabeth, Robyn Simcock, and Emily Voyde. 2010. *Extensive Green Roofs for Stormwater Mitigation (uncopyedited draft).* Auckland, NZ: Auckland Regional Council Environmental Research.

Getter, K.L., Rowe, D.B., 2006. *The role of extensive green roofs in sustainable development.* HortScience 41, 1276–1285.

Glass, Charles C., Peter A. Johnson. 2008. *Monitoring of a New Green Roof for Water Quality and Quantity. Proceedings 6th Annual Greening Rooftops for Sustainable Communities Conference, Awards & Trade Show, Baltimore, MD.* Toronto, ON: The Cardinal Group.

Greater London Authority. 2008. *Living Roofs and Walls; Technical Report: Supporting London Plan Policy.*

Green Roofs for Healthy Cities. 2010. Green Roof Training Course Manuals; Green Roof Design 101,

Green Roof Design and Installation 201, Green Roof Waterproofing and Drainage 301, Green Roof Plants and Growing Media 401, Advanced Green Roof Maintenance; Toronto, ON.

Gregoire, B.G., and J.C. Clausen, 2011. *Effect of a modular extensive green roof on stormwater runoff and water quality Ecol.* Eng. 37, 963-969.

Hathaway, A.M., Hunt, W.F., Jennings, G.D., 2008. *A field study of green roof hydrologic and water quality performance.* Trans. ASABE 51, 37–44.

Hutchinson, D., Abrams, P., Retzlaff, R., Liptan, T., 2003. *Stormwater monitoring two ecoroofs in Portland, Oregon.* Paper presented at the First Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show, Chicago, IL.

Köhler, M., Schmidt, M., 2003. *Study of Extensive Green Roofs in Berlin: Part III Retention of contaminants (Saskia Cacanindin, Trans.).* Technical University of Berlin, Berlin, Germany.

Leatherbarrow, L. & Reynolds, L. (2002). *Perfect Plant Partners: Beautiful Plant Combinations for Prairie Gardens.* Calgary: Fifth House Ltd.

Liptan, T., Strecker, E., 2003. *EcoRoofs (Greenroofs) – a more sustainable infrastructure. In: Proc. of the National Conference on Urban Stormwater: Enhancing Programs at the Local Level , Chicago, IL, February 17–20.*

Looman, J. (1992). *Prairie Grasses: Identified and Described by Vegetative Character.* Agriculture Canada. Ottawa: Canada Communication Group

Long, B., S. Clark, R. Berghage, and K. Baker. 2006. *Water Environment Foundation; Green Roof Media Selection for the Minimization of Pollutant Loadings in Roof Runoff.*

Long, B., S. Clark, R. Berghage, and K. Baker. 2008. *Green Roofs — A BMP for Urban Stormwater Quality*? World Environmental and Water Resources Congress, 2008.

Lui, K. and B. Bass, *Performance of Green Roof Systems*; NRCC 4725; May 2005; .Proceedings from Cool Roofing Symposium, Atlanta, Georgia

Lui, K. and Minor, J. 2005. *Performance Evaluation of an Extensive Green Roof.* National Research Council of Canada, City of Toronto, ON.

MacMillan, G. 2004; *"Stormwater Performance of a Green Roof in Toronto," Toronto Region Conservation Authority. Proceedings 2nd Annual Greening Rooftops for Sustainable Communities Conference, Awards & Trade Show, Portland, OR.* Toronto, ON: The Cardinal Group.

MacMillan, G., 2004. Y*ork University rooftop garden stormwater quantity and quality performance monitoring report.* In: Proc. of the Second North American Green Roof Conference: Greening Rooftops for Sustainable Communities , Portland, OR, June 2–4.

Monterusso, M.A., Rowe, D.B., Rugh, C.L., Russell, D.K., 2004. *Runoff water quantity and quality from green roof systems.* Acta Hortic. 639, 369–376.

Moran, A., B. Hunt, and G. Jennings. 2004. *A North Carolina Field Study to Evaluate Green Roof Runoff Quantity, Runoff Quality, and Plant Growth.* Raleigh, NC: North Carolina State University.

Moran, A., B. Hunt, et al. 2005. *"Hydrologic and water quality performance from green roofs in Goldsboro and Raleigh, North Carolina." Proc. of 3rd North American Green Roof Conference: Greening rooftops for sustainable communities.* Washington, DC. 4–6.

Peck, S. W. and C. Callaghan. 1999. *Greenbacks from Green Roofs: Forging a New Industry in Canada.* CMHC/SCHL.

Parkland Nursery & Landscape Services Ltd. *Fall 2008 / Spring 2009 Wholesale Catalogue.* Red Deer, AB.

Peck, S. W. and M.Kuhn. 2003. *Design Guidelines for Green Roofs CMHC/SCHL.*

Porsche,U. and M. Kohler. 2003. L*ife Cycle Costs of Green Roofs – A Comparison of Germany, USA and Brazil;* World Climate and Energy Event, 2003.

Roehr, Daniel and Yuewei Kong. 2010. "*Retro-Greening" Suburban Calgary: Application of the Green Factor to a Typical Calgary Residential Site.* Landscape Journal 29:2-10. ISSN 0277-2426

Saxton, K. E. and W. J. Rawls, 2006. *Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions*, Soil Science Society of America Journal. 70:1569-1578

Snodgrass, E C. and L.L. Snodgrass. 2006. *Green Roof Plants.* Portland, OR: Timber Press.

Snodgrass, E.C and Linda McIntyre. 2010. *Green Roof Manual: A Professional Guide to Design, Installation, and Maintenance.* Portland, OR: Timber Press.

Teemusk, A., Mander, Ü., 2007. *Rainwater runoff quantity and quality performance from a greenroof: the effects of short term events.* Ecol. Eng. 30, 271–277.

Toop, E.W. & Williams, S. (1991). *Perennials for the Prairies.* Edmonton: University of Alberta
Ulrich, Roger (1992-09). *"How Design Impacts Wellness".* Healthcare Forum Journal.

Van Seters, T., L. Rocha, and G. MacMillan. 2002. *Evaluation of the Runoff Quantity and Quality Performance of an Extensive Green Roof in Toronto, Ontario.* Toronto, ON: Toronto and Region Conservation Authority.

VanWoert, N. D., D. B. Rowe, et al.. 2005. *Green Roof Stormwater Retention: Effects of Roof Surface, Slope, and Media Depth.* J Environ Qual 34(3): 1036-1044.

Villarreal and Bengtsson, L. 2005. *Response of a sedum green roof to individual rain events*. Ecological Engineer, Volume 25, Issue 1.

Weiler, Susan K., and Katrin Scholz-Barth. 2009. *Green Roof Systems.* John Miley & Sons, Inc. ISBN 978-0-471-67495-5.

Online documents

Architecture 2030; www.architecture2030.org/theproblem/problem_energy

ALCLA Native Plant Restoration Inc. (2010). *Native Wildflower Plants.* Retrieved November 15, 2010, from http://www.alclanativeplants.com

Build Direct Blog; http://blog.builddirect.com/greenbuilding/green-jobs-green-roofs-and-roof-gardens ; August 5th, 2011

Eagle Nurseries Ltd. (2009). *2009 Suggested Greenroof Plant Selection.* Retrieved November 15, 2010, from http://www.eaglelakenurseries.com .

Government Services Administration; GSA Green Roof Benefits and Challenges; 2011; http://www.gsa.gov/portal/mediaId/158783/fileName/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.action

Whole Building Design Guide, Extensive green roofs; June 2010; http://www.wbdg.org/resources/greenroofs.php

Environment Canada; http://www.climate.weatheroffice.gc.ca/climate_normals/results_e.html?stnID=2205&lang=e&dCode=1&StationName=CALGARY&SearchType=Contains&province=ALL&provBut=&month1=0&month2=12

Leslie Reynolds, Facing the Chinook; 2002, www.Icangarden.com

Tolerlund, Leila; Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West; University of Colorado Denver
http://www.epa.gov/region8/greenroof/pdf/GreenRoofsSemiAridAridWest.pdf

APPENDIX A.

REGIONAL GREEN ROOF CASE STUDIES AND LESSONS LEARNED

Case Study 1:
Alberta Ecoroof Initiative Research & Demonstration Project, University of Calgary

A1.1 K.Ross *A1.2 R.Thornton* *A1.3 K.Ross*

A1.1 illustrates the layers in the construction process. The drainage mat, filter fabric and wooden curbs for containment of the growing medium are shown. A1.2 Shows the established vegetation on the ecoroof. A1.3 View of the green roof from the building interior

Client: Calgary Innovates (formerly Calgary Technologies Inc.)

This local case study project illustrates the design and composition of a loose laid system (Soprema). Small installations of modular systems (Xeroflor, LiveRoof) were subsequently added to provide a demonstration of the difference systems. While the blend of grass species added outcompeted many of the flowering native forbs, the project was also useful for plant species trials.

A short-term study of stormwater monitoring platform was made by Westhoff Engineering Resources to evaluate the runoff reduction and water quality attributes of two green roof plots relative to a reference green roof.

Location:	3553 31 St. NW, Calgary, AB
Building Type:	Commercial
Roof Area:	Green roof area = 250 m^2 [2700 sq ft]
Cost of Green Roof:	N/A
Construction Type:	Retrofit
Green Roof Type:	Extensive and Semi-intensive
Date completed:	Phase 1 2005; Phase 2 2006

Project Description:
The Alberta Ecoroof Initiative (AEI) is a long term demonstration project to increase public awareness with respect to green roof technology.

The AEI is located at the Alastair Ross Technology Centre in northwest Calgary. The project entails 250m^2 [2700 sq ft] of ecoroof on top of an existing roof of the Alastair Ross Technology Centre located in the University of Calgary Research Park. The area of the demonstration project located is over a portion of the facility which links two office wings and is public accessible for viewing during office hours.

The raised platforms for stormwater research were constructed adjacent to the ecoroof . Additional pre-cultivated green roof systems were applied for demonstration purposes. Research into thermal performance and additional plant species trials are underway in 2014.

Overall Project Objectives:

- Evaluate plant species and substrate depth and type
- Determine storm water retention and runoff quality
- Provide education & outreach
- Evaluate thermal performance and energy efficiency

Design Team:

Green roof design:	Green T Design/Studio T Design
Construction drawings:	CPV Group/Stantec
Structural Engineers:	RJC Consulting Engineers
Construction:	Volunteer crew led by Flynn Canada w/ support from Soprema.
Stormwater monitoring:	Westhoff Engineering Resources

Benefits:

- Aesthetics
- Energy Efficiency
- Biodiversity
- Stormwater Management
- Visible expression of sustainability

The green roof project contributed to BOMA Go-Green Award & Building's TOBY (The Office Building of the Year 2007)

Green roof characteristics:

Solar exposure:	75%
Slope:	4%
Drainage:	2 drains/side & drains internally to storm system
Waterproofing	PVC mechanically fastened membrane (installed in 2000)
Green roof:	Sopranature by Soprema; 4 assemblies on each side
Depth of growing medium:	113mm (4.5"), 150mm (6") & 200mm (8")
Type of growing medium:	Sopraflor I & Sopraflor X

Vegetation:
Primarily native plants were selected. While many of the selected plant species successfully overwintered, over time grasses outcompeted many of perennials.

Initial plant density:	10 plant /m^2
Plant species introduced:	
Flowering Forbs:	Solidago decumbens, Ratibida columnaris, Gailardia aristata, Erigeron glabellus, Sisyrinchillum, Penstemon confertus, Polemonium pulcherrimum, Fragaria virginana, Geranium richardsonii, Antennaria pavifolia, Rubeckia hirta, Sedum Acre, Sedum Sparium
Shrubs/evergreens:	Arctostaphylos uva-ursi
Grasses:	Bouteloua gracilis, Festuca scabrella, Bromus ciliates, Stipa viridul
Irrigation:	Roof is manually irrigated

Maintenance regime:	For the first two years while the roof was being established, weekly to bi-weekly inspections for watering and weeding was required from mid-June through to mid or late August depending upon the temperature and amount of precipitation. The vegetation is left over winter and mowed once a year with a weed-wacker. Tree seedlings and volunteer species found on the Alberta Government's invasive species list are removed. Other volunteers such as native campanula or fire weed are left for their contribution to biodiversity and colour.
Maintenance access:	The roofs are accessed through a doorway from the second floor
Frequency of weeding:	Initially weekly, during establishment. Currently weeding is bi-weekly or monthly with concentrated effort during June and July.
Fertilizer application:	Slow-release fertilizer was applied in third year only
Pesticide/herbicide use:	None

Monitoring Results from the Raised Platform Study:

Water Quality:
To predict the performance of the two engineered media, runoff samples from the two 4' x 8' sample plots were analyzed for orthophosphate, nitrogen, nitrate, biochemical oxygen demand (BOD), fecal coliforms and total suspended solids (TSS). A total of four runoff samples were collected after four different rain events occurring in August and September of 2007. A control roof using conventional roof technology (SBS waterproof membrane installed on a wood frame structure) was also sampled.

Analytical results show concentrations of orthophosphate, ammonia nitrogen, total ammonia, nitrate, and total suspended solids were higher in runoff sampled from growing media Sopraflor "L" than water sampled from growing media Sopraflor "X". The likely explanation for the difference is that plant media "L" had higher organic matter content (50-60%) compared to Sopraflor "X" (5-10%). Even with higher concentrations after installation, column studies have shown that a reduction in pollutant concentrations over time can be expected, with concentration reaching a point of diminishing export over several years (2-4 years).

Other water quality results showed total ammonia, orthophosphate, and nitrate levels from both green roof media exceeded the water quality objectives (WQO) for the Bow River. The WQOs for total ammonia, total phosphorous (of which orthophosphate is a part), and nitrate are 0.04 to 0.2 mg/L, 0.012-0.075 mg/L, and 0.13 to 0.267 mg/L, respectively. Total suspended solids data (TSS) from the green roofs are not expected to exceed recommended guidelines. Canadian Council of Ministers of the Environment TSS guidelines state a maximum increase of 5 mg/L from background levels for any long-term exposure (e.g. inputs lasting between 24h and 30d) and 25 mg/L from background levels for short-term exposure (e.g. 24 hour period).

It should be noted that pollutant concentrations from the control roof were consistently lower than both green roofs in this study, although the green roofs provided runoff volume mitigation (~68-75% over the period tested) resulting in reduced annual loads from the green roofs.

Water Quantity:
As mentioned above, good runoff volume mitigation was a product of both green roofs in the study. Retention capacity was lower in months were rainfall was high, such as May and June (28-55%). Total retention capacity was greater for Sopraflor “L” compared to Sopraflor “X” (66% and 59%, as, respectively). The retention capacities of the green roofs during July, August, and September were much higher (81-99%) likely due to less rainfall and increased evapotranspiration with the higher summer temperatures. The water retention Capacity performance of the green roofs were dependent upon irrigation frequency, rainfall volume, rainfall intensity, humidity, evapotranspiration, and the length of the interval between rainfall events, making these parameters important in green roof water quantity performance.

Challenges/Lessons Learned:

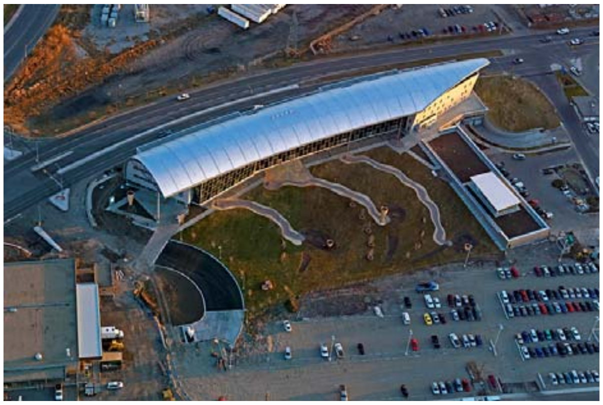
The plugs were planted in July, 2006 during a heat wave. To keep the growing medium moist and prevent the plants from wilting, daily watering was required for a period of two weeks. Care was taken to ensure that plugs were firmly pushed in the growing medium while a root system integrated them into the surrounding growing medium.

The low density planting regime of (200mm o.c./8" o.c.) of native plant plugs, provide coverage very slowly. Use of cuttings and/or seeds could have accelerated vegetated coverage. Over time, grasses have largely out competed low growing flowering forbs, particularly in plots with higher organic content.

Now in its ninth year, the maintenance activities are significantly less and consist of routine inspections, occasional weeding, infill planting and manual watering in extended periods of drought.

For more information on the Alberta Ecoroof Initiative, see www.greentdesign.com

Case Study 2:
The Water Centre Office Building, City of Calgary




A2.1 City of Calgary *A2.2 K. Ross*
A2.1 Manchester Water Centre as viewed from above. A2.2 Current view of vegetation established on the green roofs

Client: The City of Calgary

This local case study project illustrates the design and composition of a loose laid system (Soprema) on a new institutional project.

Location: Manchester Industrial Area, Calgary, Alberta
Building Type: Institutional
Roof Area: 892 m^2 [9600 sq ft]
Cost of Green Roof: Waterproofing & Green Roof: $3.35/$m^2$ [$36/sq ft]
Construction Type: New construction
Green Roof Type: Intensive
Date Completed: August 2007

Project Description:
The Water Centre is a new sustainable 17,000 m^2 [183,000 sq ft] building for The City of Calgary. This facility was strategically designed and constructed to be environmentally friendly and energy efficient. The project achieved LEED Gold by using less energy, less water, and was constructed with a high level of recycled material content. The Water Centre site was remediated from a pre-existing brownfield condition to meet the most stringent reclamation guidelines in Canada. An intensive green roof covers the one storey high field wing at the East end of the site.

Building Features:
- Green roof
- Rainwater collection and reuse
- Naturally daylight building
- Low energy HVAC and electrical systems
- Exemplary construction waste diversion

Overall Achievements:
- 91% construction waste diverted from the landfill by sorting and recycling
- 72% reduction in wastewater
- 59% reduction in water use
- 52% savings in annual energy consumption

Design Team:

Architects:	Manasc Isaak Architects/Sturgess Architects
Landscape Architect:	Carlyle & Associates
Structural Engineers:	RJC Consulting Engineers
Mechanical & Electrical	Keen Engineering (now Stantec)
Civil Engineering	Urban Systems Ltd
Costing	Spiegel Skillen
Acoustical	ACI Acoustical Consultants

Construction Team:

Construction Managers:	Dominion Construction
Roofing Contractor:	Skyline Roofing
Landscape Contractor:	Alpha-Better

Benefits:

- Stormwater mitigation
- Energy Efficiency
- Aesthetics
- Biodiversity

Green roof characteristics:

Solar exposure:	90%
Slope:	2%
Waterproofing:	Soprema's Colvent System
Green roof:	Sopranature by Soprema
Depth of growing medium:	12" (300mm)
Type of growing medium:	Sopraflor I
Irrigation:	Subsurface irrigation

Vegetation:

Plant species:	Allium/Chives – 150mm pots at 300mm spacing Campanula rotundifolia "Olympia" Sedum spurium "Dragons Blood"

Challenges/Lessons Learned:

Initial establishment: plant species that did not overwinter successfully in first year (Campanula rotundifolia Olympia"); there was insufficient maintenance to maintain graphic landscape pattern which resulted in grasses overtaking other species and plant succession. While there is good vegetative coverage, the current landscape does not resemble the original design intent.

The green roof is currently undergoing review for leaks in a few areas. An action plan is being developed to address the issue. More information regarding its construction and upkeep will be available pending the completion of this work.

Case study submitted courtesy of the Alberta Ecoroof Initiative as part of the Alberta Prairie Green Roof Tour (2008)

Case Study 3:
Centre Culture et Environment, Frederick Back, Quebec City


A3.1 Soprema


A3.2 Soprema


A3.3 Soprema

A3.1 View of wildflower meadow on green roof. A3.2 Close up of wildflower species. A3.3 Maintenance of vines and garden on the Vivre en Ville project

Client: Vivre en Ville

This case study project illustrates the design and composition of a loose laid system (Soprema) in the cold climate region of Quebec City. It provides an overview of a built project established over seven years ago with a diverse plant species palette. It also describes the costs both to build and maintain the green roof and characterizes the maintenance tasks.

Project location: Quebec City
Roof Area: 730 m^2 [7867 sq ft]
Cost of Green Roof: $.75/m^2 [$8.00/sq ft] (green roof material costs)
Date Completed: 2005
Green Roof Category: Extensive
Green Roof Type: Institutional
Construction type: Retrofit

Project Description:
An extensive green roof was installed on two roofs of different levels of an existing building and a vegetable garden was installed on the roof of a new building section. The two main roof areas are extensive, not accessible but they can be seen from inside the building and outside from the terraces. They were planted on their edge with perennials and hand sowed on the surface with a mix of natives, perennials and grass seeds. Sub-irrigation was used only during the first year for plants establishment. The principal characteristic is that the green roof system weights only 17 PSF, which was the maximum allowed, thanks to a very light growing medium used in a thickness of 125 mm [5"].

Design Team:
Landscape Architect: Vivre en Ville
Horticulturist: MAGJC Inc
Growing Medium Consultant: Les Composts du Québec
Architect: Brière, Gilbert + Ass architects
Irrigation Design: MAGJC Inc.

Construction Team:
Roofing Consultant: Toitures Quatre Saisons Inc.

Green Roof Characteristics:

Slope:	2%
Type of Membrane:	Double-ply modified bitumen membranes of Soprema.
Drainage layer:	Polypropylene core laminated with a geotextile. (Sopradrain 10 G of Soprema)
Type of Growing Media:	Light growing medium which contains 74% Recycled content, 30%mineral aggregates and 50% organic matter (Sopraflor LL of Soprema)
Growing Media Depth:	125 mm [5"]
Type of irrigation:	Sub-irrigation by capillary mat with includes a drip irrigation (Aquamat Jardin of Soprema)

Vegetation:

Plant list and planting: The vegetable garden area includes tomatoes, beans, carrots, peas and many herbs.

Two existing roofs were planted on the perimeter with perennials in containers, including the following species: Sedum, Thymus, Solidago, Hemerolallis, Saxifraga, Fragaria, Potentilla and Allium.

The two roofs were sown with a mix of native plants, grasses and perennials provided by Indigo Horticulture under the commercial name: Mélange Indigo Couleur at a rate of 40 kg/ha. The species included in the mix are: Agastache foeniculum, Coreopsis lanceolata, Dalea purpurea, Desmodium canadense, Ecninacea purpurea, Elymus Canadensis, Helenium automnale, Heliopsis helianthoides, Liatris spicata,Lolium perenne, Monarda fistulosa, Panicum virgatum, Rudbeckia hirta, Angropogon scoparius, Sorghastrum nutans, Aster leavis, Aster novae-angliae

Initial plant density (spacing):	14/ m^2
Re-plantings:	none
Planting method:	100 mm pots

Maintenance:

Frequency of irrigation:	once/week in first year; none in subsequent years
Current Maintenance Company:	none
Access for maintenance and watering:	stairway
Frequency of weeding the first year:	none
Frequency of weeding the second year:	4 times
Fertilizer applications:	none
Any pesticide/herbicide:	none

Maintenance recommendations were included in the architect's specifications.

Maintenance cost: $1.08/m² [10¢/sq ft]

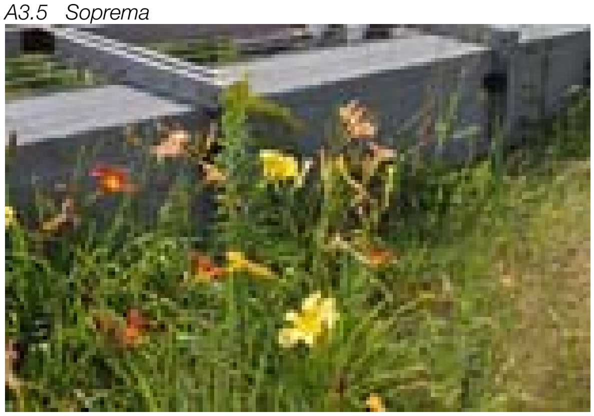
Challenges/Lessons Learned:

The roof was sown in late November during very high winds. The erosion control product installed on top of the growing medium (Soil Stabilizer) ensured that the very light growing medium remained in place throughout the winter despite very windy conditions. The green roof has been maintained very rarely since its establishment almost ten years ago and currently there are few weeds. Initially, the green roof should have been irrigated with an overhead sprinkler system during 4 to 6 weeks establishment period at the beginning of the spring, however this was not done. This caused a delay in the establishment of the plants of about one year and some species did not germinate. No other seed sowing was conducted afterwards. Therefore, some species in the original seed mix are not present on the roof. The resulting meadow landscape continues to thrive after nine years with a natural aesthetic appearance and minimum maintenance. Some of the native plants that were added in a section of the lower roof as a research work are now perfectly blended to the meadow.

A3.4 Soprema

A3.5 Soprema

A3.6 Soprema



A3.7 Soprema

A3.4 A pneumatic pump and hose were used to convey growing medium of a green roof. A3.5 Growing medium placed on roof. A3.6 View of wildflower meadow. A3.7 Close up of flowering species

Case study submitted courtesy of: Soprema

Case Study 4:
Faculty of Agriculture Pavilion, Laval University, Quebec City



A4.1 M.-A. Boivin *A4.2 M.-A. Boivin* *A4.3 M.-A. Boivin*

A4.1 Early establishment of green roof trials at the University Laval. A4.2 Close up of plant trials, University Laval. A4.3 Mature vegetation on University Laval roof

Client: Laval University

This case study project describes the first Canadian test roof for extensive green roof systems. It was built 18 years ago and is still in operation. The particular purpose of the research was to explore overwintering of a diverse selection of plant species for the Zone 4b region. It provides an overview of the system design, costs both to build and maintain the green roof and characterizes the maintenance tasks.

Location: Quebec City
Roof Area: 255 m^2 [2755 sq ft]
Cost of green roof: $107.60/ m^2 [$10.00/sq ft]
Completion date: November 1994
Green roof category: Extensive
Green roof type: Institutional
Construction type: Retro-fit

Project Description:
A study was carried out at The Horticultural Research Center of Laval University to determine the effect of rooftop microclimate on the acclimatization of 85 herbaceous perennials chosen for their local hardiness on the ground on a 25 years basis and their drought resistance. Two green roofs were installed on the roofs of two levels on a 30-year-old building for a total area of 255 m^2 [2755 sq ft]. Both roofs were divided in experimental parcels on 1 m^2 in which 125 perennials species were planted or sowed in three different depths of growing medium: 50, 100 and 150 mm [2", 4" & 6"]. The upper roof was sowed in some larger sections with wild flower meadow mixes, perennials and shrubs. After 3 years, the growing medium of the upper roof was equalized at 15 mm [6"] because most of the plants were dead in the shallower parcels. A minimum maintenance was done during the four first years, including watering, weeding and fertilizing. Then no maintenance was done at all for 12 years.

Design Team:
Architect: Coté Chabot Morel Architectes

Construction team: Not available

Green roof characteristics:

Slope:	2%
System components:	
Type of Membrane:	Modified bitumen of Soprema
Drainage layer:	Expanded polystyrene panels of 25 mm thick; Sopradrina PSE of Soprema
Type of Growing Media:	2 different types of growing medium with a red lava rock basis and two different % of organic matter: 5-10 and 30-40.
Growing Media Depth:	50, 100 and 150mm
Type of irrigation:	Manual
Initial plant density:	9 plants/m^2 [1@10" o.c.]
Re-plantings:	9 plants/m^2 [1@10" o.c.]
Planting method:	100 mm containers

Vegetation:
Plant list and planting:

Perennials: Allium shoenoprasum, Ajuga reptans, Anemona pulsatilla, Anthemis rudolphiana, Armeria maritime, Arenaria verna aurea, Aster alpinus, Aubrieta deltoidea, Campanula persicifolia, Centaurea cyanus, Cerastium tomentosum, Coreopsis lanceolata, Chrysanthemum x rubellum, Dianthus carthusianorium, Dianthus deltoides 'Fire Light', Draba aizoides, Escholzia californica, Erica carnea, Festuca ovina, Festuca ovina glauca, Geranium endressii, Geranium macrorrhizum 'Bevans Variety', Geranium sanguineum, Gypsophila repens, Helictrotrichon sempervirens, Iris germanica, Iris intermedia, Iris pumila, Lamium maculatum, Lavandula vera, Leontopodium alpinum, Petrorhagia saxifraga, Phlox subulata, Salvia officinalis, Saponaria ocymoïdes, Sedum álbum, Sedum ellacombianum, Sedum ewersii, Sedum floriferum 'Weihenstephaner Gold', Sedum x hybridum, Sedum lydium, Sedum reflexum, Sedum sexangulare, Sedum spurium 'Tricolor', Sedum spurium 'Red Carpet', Sedum stoloniferum, Sempervivum marmoreum, Sempervivum tectorum, Thymus serpyllum, Thymus vulgaris, Veronica incana, Viola cornuta

Ferns: Dennstaedia punctiloba, Dryopteris marginalis, Onoclea sensibilis, Polypodium virginianum,Polystichum acrostichoides, Pteridium aquilinum

Shrubs: Juniperus sabina 'Blue Danube', Physocarpus opulifolius 'Nanus', Picea abies 'Repens', Picea abies, 'Ohlendorfii', Rhododendron x 'Ramapo', Spiraea callosa 'Alba'

Grass mixes and monucultures: Buchloe dactyloides, Dactylis glomerata variegate, Alymus canadenses, Festuca arundinacea, Festuca ovina glauca, Festuca ovina var duriuscula, Festuca rubra L.var rubra, Festuca rubra var commutate, Poa pratensis

Maintenance:

Frequency of irrigation- first year:	once a week when needed
Frequency of irrigation- second year:	every two weeks
Current Maintenance Company:	University researchers
Type of access for maintenance:	stairs
Frequency of weeding the first year:	every two weeks
Frequency of weeding - second year:	every two weeks
Fertilizer applications:	once each three years
Any pesticide/herbicide:	no
Maintenance Manual:	From the manufacturer's specifications.
Maintenance Cost:	$2.69/ m^2 [$0.25/sq ft]

Challenges/Lessons learned:

These roofs were maintained at a minimum for several years and are now not maintained at all. It is interesting to see that after some years, when the roof is properly covered with the species in the right thickness of growing medium, there are no external weeds coming and no tree seedlings. It appears that the green roof has reached an ecological equilibrium where the vegetation does not significantly move or change. In the past 10 years the roof has only been accessed to take pictures and make observations.

Case study submitted courtesy of: Soprema

Case Study 5:
VanDusen Gardens Visitors Centre, Vancouver

A5.1 Architek

A5.2 Architek

A5.1 View of undulating green roof. A5.2 View of front entry to the VanDusen Gardens pavilion.

Client: Vancouver Board of Parks and Recreation

This case study project describes a technically challenging green roof design that was developed as part of the Living Building Challenge framework. It uses a custom blend of growing medium placed in what is called a Georaster soil retention system for the steeply sloped areas. Three different growing media blends were used for the different slope and microclimatic areas of the roof.

Location: Vandusen Botanical Gardens, Vancouver, BC
Building Type: Cultural Institution
Roof Area: 2043 m^2 [22,000 sq ft]
Construction Type: New Construction
Green Roof Type: extensive - sloped
Cost of green roof: Range from $183-312/$m^2$ [$17 - $29/sq ft]
Completion date: October 2011

Project Description:
A LEED Platinum building, the VanDusen Gardens Visitors Centre was designed to meet Net-Zero water and energy and the Living Building Challenge building. It features undulating roofs that help form the shape of a native orchid. Complex and radically sloped areas of the green roof were engineered with shear barrier for anti-slip and erosion control.

Design Team:
Landscape Architect: Cornelia Oberlander with Sharp & Diamond
Horticulturist: Bryce Gauthier + Internal - Vandusen
Growing Medium: Sumas Gro Media, Architek, Zinco Canada
Architect: Busby Perkins + Will
Roofing Consultant: Architek SBP Inc. + Metropolitan Roofing
Technical Consulting: Architek SBP Inc., Zinco Canada
Structural Engineering: Fast & Epp, Vancouver
MEP Engineering: Zinco Canada

Construction Team:
General Contractor: Ledcor Construction
Landscape Contractor: Houston Landscapes

Green Roof Characteristics:

Slope: Various

Green roof assemblies: Different green roof build-ups by Zinco: a) Floradrain FD 40 – Landbridge area. b) Floraset FS 75 – Sloped Petal areas. c) Georaster system – Oculus area.

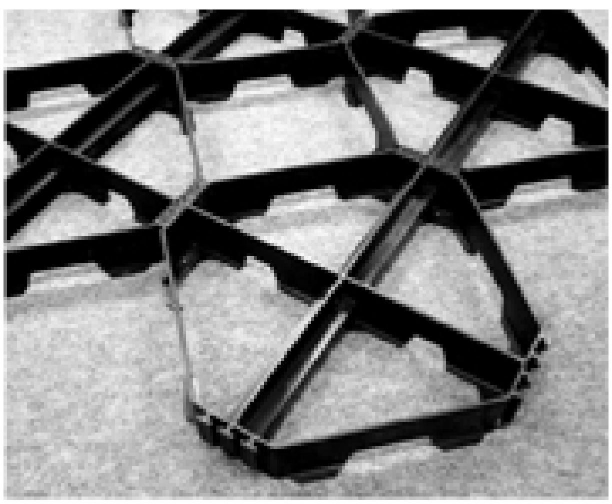
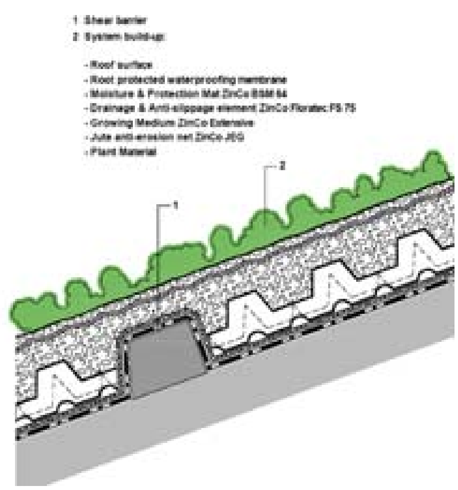
Growing Medium: The growing medium from Sumas Grow media was specified by Sharp & Diamond to FLL standards @ 150mm.

Planted materials: Hydro-seeded grasses with perennial meadow flowers embedded throughout in plug and bulb form.



A5.3 Architek *A5.4 Architek* *A5.5 Architek*

A5.3 Installation of geogrid slope retention system on steepest slope on building. A5.4 Installation of growing medium on same part of the slope. A5.5 Vegetation getting established on slope

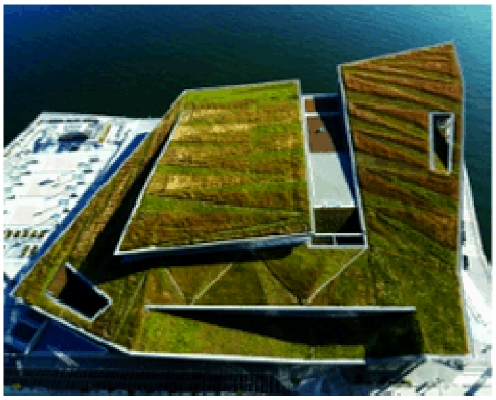



A5.6 Architek *A5.7 Architek*

A5.6 Close up of georaster slope retention device. A5.7 Schematic detail illustrating how the georaster device connects to structure

Case study submitted courtesy of: Architek SBP Inc.

Case Study 6:
Vancouver Convention Centre, Vancouver



A6.1 PWL Landscape Architects *A6.2 PWL Landscape Architects*
A6.1 Aerial view of 2.64 hectare roof on the Vancouver Convention Centre VCC. A6.2 Distant view of green roof on the Vancouver Convention Centre

Client:	Vancouver Convention Centre Expansion Project
Location:	Vancouver, BC
Building Type:	Cultural/Institution
Roof Area:	2.64 hectares {283,140 sq ft) sloping roof; it constitutes the largest green roof in Canada
Cost of green roof:	Not available
Construction type:	New construction, expansion to existing building
Green Roof Category:	Extensive
Installation date:	April 2009

Project Description:
Designing for Maintenance: One of the primary objectives for the Vancouver Convention Centre (VCC) green roof was to design a living system with low maintenance requirements. The scale and complexity of the project – a 2.64 hectare [283,140 sq ft] sloping roof utilizing over 400,000 plugs, 80,000 bulbs, and 128 kilograms of seed – required that the design team work very closely with the both the client and the maintenance contractors to ensure that a budget for maintenance was part of the tender for the project.

In fact, the installation and maintenance contractors were involved in the project since the planning and testing stages, ensuring a seamless transition from construction through to long-term care and maintenance. Complete transparency and continuous feedback between PWL Partnership Landscape Architects and Holland Landscapers have proven key to the success of the project.

Given the softer climate of Vancouver, a four-season approach to maintenance was planned. The landscape architects created a maintenance specification, which has evolved over time, with recommendations from the maintenance team. For example, the initial specifications called for the removal of any plant species not included in the original planting design. However, it became apparent that some volunteer species were nearly impossible to remove from the roof; therefore maintenance contractors identified and removed woody species and volunteers that were part of the government of British Columbia's noxious species list.

One unique feature of the project is the conveyance runnel system which zigzags along the sloping roof and slowly directs excess stormwater to roof drains. The runnels consist of 30-centimeter-wide aluminum-edged, rock-filled channels perforated on the uphill side and solid on the downhill side. Roof drains located in the runnels are easy to see and inspect, however, the designers did not anticipate that plants would persistently colonize the runnels and need to be removed. In the second year, the removal of plants from drainage runnels by hand-pulling was introduced, but this strategy proved to be too time consuming. In the third year, plants were removed from the drainage runnels using a line trimmer.

Annual mowing of the roof was originally scheduled for September/October. When grasses reached a meter in height in October 2009, Holland Landscapers "hired a sickle mower, a custom-made, self-propelling, one-man industrial scything machine" [1]. They used brush-cutters, essentially industrial weed-whackers, for the edges and the slopes. The first attempt took three passes, the hardest part being the steep slopes which can run between 13 and 53 degrees. The entire job took three workers ten days of hard work.

Holland Landscapers refined this process in subsequent years. Instead of the industrial scything machine, they now use a bog mower set up at 6" off the ground, which can accomplish the trim in one pass. The mower can only pass within 3 meters of the edge of the roof, so line trimmers are used by landscapers with personal fall arrest systems to trim the rest. This process requires a crew of up to six landscapers. With no chemical fertilizers, herbicides or pesticides used, the majority of the clippings are left on the roof to be composted back into the growing media as a natural fertilizer.

Additionally, beekeepers tending to hives on the roof noticed that native aster was blooming well into the late summer and fall. They recommended retaining the aster for the benefit of the bees, so mowing is now delayed until November.

Growing media testing was performed in both the first and second year. PWL's specification for the media allowed for a 15% change in organic content by volume. Testing indicated that the organic content had changed by 10-12% in some areas of the roof – within the target range. Growing media testing was not performed in the third year.

The maintenance budget includes an allowance for regular inspections. Now that the vegetation is established, Holland Landscapers visit a minimum of twice per month to determine in supplementary irrigation is needed.

Access and Safety:
All members of the maintenance team must be certified in fall protection, and must sign in with building security before ascending to the roof. Access to the roof for green roof maintenance personnel is provided by a freight elevator to the upper floor and a loading access door. Since the loading access door is at a different height than the actual roof, the aforementioned bog mower needs to be lifted up about four feet by the maintenance team to reach the roof.

The location and spacing of anchor points for fall protection systems has presented some challenges for maintenance personnel. Although these were designed and installed along the perimeter of the building in accordance with building code, some maintenance tasks require frequent disconnecting and reconnecting to different tie-off points. An alternate solution would have been to install an aircraft line along the perimeter of the building where connections for fall arrest systems are free to slide along as workers move.

[1] "The Grass is Greener on the Upper Side". Ian Brown. The Globe and Mail. Wednesday, February 24, 2010. (http://www.pwlpartnership.com/#/our-news/2010/grass-greener-upper-side).

Benefits:

- Biodiversity
- Stormwater Management
- Energy Efficiency (roof cooling)
- Urban Agriculture (beekeeping)
- LEED Platinum

DesignTeam:

Landscape Architects:	PWL Partnership Landscape Architects Inc.
Mechanical Engineer:	Stantec Inc.
Architects:	DA/MCM +LMN
Structural Engineer:	Glotman Simpson Consulting Engineers
Horticultural Consultant:	Rana Creek Habitat Restoration

Construction Team:

Landscape Contractors:	Holland Landscapers Ltd.
Electrical Engineers:	Schenke Bawol Engineering Ltd.
Propagation Contractors:	NATS Nursery Ltd.
Roofing Contractors:	Flynn Canada Ltd.
Contractors:	PCL Constructors Westcoast Inc.
Steep Sloped Components:	American Hydrotech, Inc.

Green Roof Characteristics:

Solar exposure:	90%
Slope:	Varies, up to 53°
Waterproofing:	Tremco's Permaquick® reinforced hot-applied rubberized asphalt buildup roofing system with root barrier cap sheet
Insulation:	XPS rigid insulation over the waterproofing in an inverted assembly
Leak detection:	Electronic Field Vector Mapping by International Leak Detection (ILD)
Drainage:	Drainage mat with custom drainage runnels criss-crossing the roof
Growing medium:	150mm custom blend of growing medium complete with lava as light weight aggregate, sand and organic content (waste products from the timber industry, food and yard waste) at 40.25 lbs/sq ft
Retention grid:	Retention webbing by Hydrotech on steep slopes, anchored to structure
Irrigation:	Drip-irrigation using treated VCC blackwater from onsite facility as main water source; de-salinated ocean water as secondary source. Irrigation system activated by moisture sensors in roof.

Vegetation:

400,000 initial plants of 25 different species native to the Pacific Northwest

Plugs: Common Thrift (Armeria maritime); Douglas Aster (Aster subspicatus); Slimstem Reed Grass (Calamagrostis stricta); Dense Sedge (Carex densa); Chamiso Sedge (Carex pachystachya); Pacific Meadow Sedge (Carex pansa); Berkeley Sedge (Carex tumulicola); Beach Strawberry (Fragaria chiloensis); 'Pacifica' Silverrweed (Potentilla anserine); Broad Leafed Stonecrop (Sedum spathulifolium)

Seed: Bent Grass (Agrostis pallens); Pearly Everlast (Anaphalis margaritacea); California Poppy (Eschscholzia maritime); Idaho Fescue (Festuca idahoensis); 'Quatro' Quatro Sheeps Fescue (Festuca ovina vulgaris); Creeping Red Fescue (Festuca rubra); June Grass (Koeleria macranthe); Calfornia Blue-eyed Grass (Sisyrinchium bellum)

Bulbs: Hooker's Onion (Allium acuminatum); Nodding Onion (Allium cernuum); Harvest Brodiaea (Brodiaea coronaria); Fools Onion (Brodiaea hyancinthina); Common Camas (Camassia quamash)

A6.3 PWL Landscape Architects

A6.4 PWL Landscape Architects

A6.5 VanCity Buzz

A6.6 VanCity Buzz

A6.3 Close up of vegetation getting established on the roof. A6.4 Mature vegetation on the VCC green roof. A6.5 Annual mowing of VCC green roof. A6.6 Maintenance work on VCC green roof

Challenges/Lessons Learned:

Various construction work was ongoing (e.g. sheet metal and glazing professionals; security camera, weather station, and duct installers) which required that contractors walk on the green roof. This resulted in compaction in some areas of the roof and slumping of slopes. The green roof installer had to scarify the soil, fluff it up, re-distribute and replant where necessary. Where the soil was compacted, growth of the vegetation was set back.

Irrigation needed to be interrupted periodically during interior construction. Careful planning and communication between contractors was critical to ensuring that the green roof received adequate irrigation during these periods.

Case study provided courtesy of PWL Landscape Architects

Case Study 7:
Pavillon Charles de Koninck, Quebec City



A7.1 Soprema *A7.2 Soprema* *A7.3 Soprema*
A7.1 View of multiple green roofs on Pavillon de Konick. A7.2 Overhead view of one of the roofs. A7.3 Close up of vegetation

Client: Laval University

This case study project describes a eight year old non-irrigated extensive green roof in Quebec City. It provides an overview of the system design, costs both to build and maintain the green roof and characterizes the maintenance tasks.

Location: Québec City
Roof Area: 600 m^2 [6456 sq ft]
Building Type: Institutional
Cost of green roof: \$86/m^2 [\$8.00 /sq ft] (green roof material cost - excluding reinforcement and watertproofing)
Construction Type: New construction
Green Roof Category: Extensive
Completion date: 2006

Design Team:
Landscape Architect: Horticulture Services, Laval University
Horticulturist: Horticulture Services, Laval University
Growing Medium Consultant: Soprema
Architect: Lemay Michaud Architecture Design
Irrigation Design: Hydralis Inc.
Roofing Consultant: Toitures Jules Chabot

Construction Team: Not available

Project Description:
An extensive green roof was installed on four roofs of a new building located in the courtyard of an existing building and on two terraces on the underground level. The great variety of textures and colors of the grasses and perennials can be admired from the upper levels of the surrounding building. The six green roofs are extensive and non-irrigated. They were planted with native and ornamental grasses and perennials in 100 mm containers at a density of 5 to 14 plants/m^2. A water retention capillary mat supplies in water the four elevated roofs with the possibility to provide water during drought periods, thanks to integrated drip irrigation. The irrigation system was used only during the first summer for plants establishment and was not used during the three last years.

Plant list and planting:
Perennials: Astilbe rosea, Athyrium filix-femina, Echinacea purpurea, Echinacea purpurea 'Alba', Heuchera 'Black Beauty', Hemerocallis fulva, Hemerocallis 'Stella di oro', Liatris spicata, Lythrum salicaria, Rudbeckia fulgida

Grasses: Calamagostis acutifolia 'Karl Foster', Elymus arenarius, Panicum virgatum

Initial plant density (spacing):	14/m^2
Re-plantings:	none
Planting method	100 mm pots

System components:

Slope:	2%
Type of Membrane:	Double-ply modified bitumen membranes of Soprema
Drainage layer:	Polypropylene core laminated with a geotextile.
Type of Growing Media:	Sopraflor I of Soprema; Light growing medium which contains 74% Recycled content, 30% mineral aggregates and 50% organic matter, made with crushed brick, blond peat, perlite, sand and vegetable compost.
Growing Media Depth:	150 mm
Type of irrigation:	Aquamat Jardin of Soprema; a sub-irrigation drip irrigation integrated in a capillary mat

Maintenance:

Frequency of irrigation-first year:	once a week
Frequency of irrigation-second year:	none
Access for maintenance & watering:	interior ladder
Current Maintenance Company:	none
Type of access for maintenance:	interior ladder
Frequency of weeding-first year:	4 times
Frequency of weeding-second year:	4 times
Fertilizer applications:	none
Any pesticide/herbicide:	none

Storage for maintenance tools and products: yes, storage is provided in the University Maintenance building. A maintenance manual was prepared and is held with the people of horticulture in charge of the landscaping of university. The maintenance manual was prepared and included in the architect's specifications.

Maintenance Costs: $1.08/m^2 [$0.10 sq ft]

Challenges/Lessons learned:

The elegant roof garden with multiple roofs was designed to be subsurface irrigated in the long term. All selected species of plants were chosen for their drought resistance as well as well as their hardiness for this 4b zone that receives an abundance of snow. The green roof areas were supposed to receive a moderate maintenance program, including preprogrammed irrigation system linked to a moisture sensor and a weeding twice a month. However, after the first year the maintenance personnel observed that all the green roofs could thrive without the need for supplemental irrigation.

It was also determined that only one inspection and quick weeding four times a year was sufficient. The 150mm (6 inches) of growing medium on a water retention capillary mat retains sufficient levels of water for the green roof in this climatic region. The high-density planting and the fact that the green roofs are enclosed in the courtyard of a higher building may have had an effect on the very low weeding requirement. Finally the six green roofs that were first designed to be more semi-intensive turned out to be sustainable on the long term with a minimum maintenance as real extensive green roofs.

A7.4 Soprema

A7.5 Soprema

A7.4 View of green roofs from building interior. A7.5 Exterior view of green roofs from the ground level.

Case study submitted courtesy of: Soprema

Specific Challenges/Lessons Learned

When designed and constructed correctly, green roofs should be less prone to some types of roof failure because many of the components are protected from potential sources of damage such as mechanical damage, UV degradation, etc. However, as the waterproofing is buried beneath the overburden, repairs of a green roof can be more difficult and costly. Failure of a green roof damages the reputation of green roofs as important LID and green building strategy but also create further barriers to their implementation.

Typical reasons for green roof failures were evaluated in Germany and documented by W. Ernst in 2002. The reasons for the failures were found to fall into the following broad categories (as summarized by Green Roof Services LLC):

- **Defective construction 45%**
- **Improper design 34%**
- **Material failure 14%**
- **Inappropriate use of materials 7%**

While the Calgary market is still young and it is often difficult to share information about lessons learned and failures, it is crucial to investigate, remediate and communicate problems to limit damage and help prevent problems on future projects.

While by no means exhaustive, the following images illustrate a few examples of problems encountered on projects locally and in North America. As this meant to be a living document other examples can be added over time.

Poor Plant Establishment

Poor or dead vegetation can result from the wrong plant species selection for a given depth/type of growing medium, lack of understanding of the building's microclimate and aspect or performance on slopes. It is often more difficult to establish vegetation within the higher wind zones on a roof at edges or around parapets, as per Figure A8.1.


A8.1 Green Roof Service


A8.2 K.Ross


A8.3 K.Ross

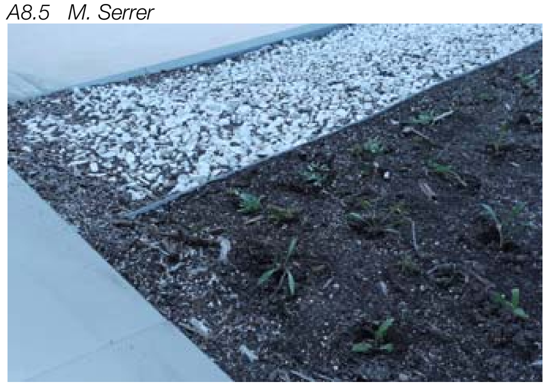
A8.1 Poor vegetation coverage at roof perimeter. A8.2 Patchy coverage an a pre-cultivated sedum mat system. A8.3 One homogeneous pre-cultivated sedum mat system used on a complex roof shape with different slopes and aspects.

Wind Erosion

Wind erosion can wreak havoc on the establishment of the vegetated cover as well as over the long-term life of the green roof. Image A8.4 was taken immediately after weeding. The open areas should be seeded or infill-planted to reduce the amount of exposed growing media which can lead to wind scour and loss of growing media over time. New weed seeds can also more easily germinate in these areas.
Figure A8.5 in the upper right, illustrates one of the roofs at the Pine Creek Waste Treatment Center in southeast Calgary. This particular roof is west facing and had good vegetated cover when visited in 2008. However, it was built without vegetated-free zones at the perimeter and over time, the wind has worked to open up areas starting at the edges and corners. This resulted in significant wind damage and the roof was scoured right down to the rootbarrier and drainage mat.

The bottom right image, A8.6, illustrates another local roof located in a suburban area at the fourth floor level, also facing the prevailing winds. While a tackifier was used during the planting phase as an erosion strategy, a significant amount of growing medium has migrated into the decorative aggregate and in many places, the roots of the small plug plants had become exposed. Remedial work has corrected this and the mature planting now provides sufficient resistance to the wind.

A8.5 M. Serrer



A8.4 Green Roof Service *A8.6 K.Ross*

A8.4 Open growing medium exposed after weeding. A8.5 Wind damaged green roof on Pine Creek Waste Treatment Centre A8.6 Wind erosion on local green roof

Ponding on Rooftops

While some ponding of water on rooftops can be tolerated for up to 48 hours (NRCA), it may be the result of poor design with no slope, a sagging structure, no or inadequate number of drains, drains that are blocked or are located at high points on the roof. Figures A8.7 and A8.8 illustrate roofs with significant ponding. Ponding on a green roof is incompatible with the drought tolerant plant species typically used on extensive and semi-intensive green roofs. Vegetation should not occur in areas that are expected to pond.

A8.7 www.heidler.com

A8.8 Monroe Courrier

A8.7 Ponding of water on a roof. A8.8 Ponding of water on an uneven roof

Poor Drainage

Figure A8.9 illustrates how drains, even when properly isolated by a vegetated-free zone, must be inspected and kept clear of plants and debris for proper functioning. Image A8.10 illustrates a drain that has not been inspected for some time. Figure A8.10 shows that left unchecked, plants on a green roof can migrate to the drain box and potentially block it. Figure A8.12 at the bottom right shows a green roof that was planted with drought tolerant sedums into which abundant runoff from the roof above is delivered by the downspout and drains into the vegetated area. The overly wet environment is not compatible with the sedum coverage.

A8.9 www.maintenanceforgreenroofs.com *A8.10 www.speedyrouters.com*
A8.9 Blocked drain on a green roof A8.10 Clogged roof drain

A8.11Green Roof Service *A8.12 Enviromat/www.wildlifeservices.co.uk*
A8.11 Sedums encroaching in drain A8.12 Downspout drains into drought tolerant green roof system

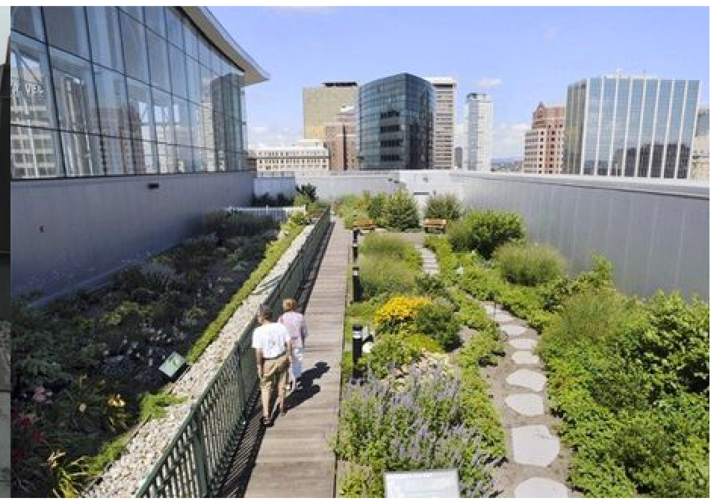
Little or No Maintenance

Lack of maintenance can lead to volunteer species overtaking the planted areas. Figure A8.13 illustrates how dense grasses can create a suffocating blanket of biomass over the sedums robbing them of sunlight and nutrients. Figure A8.14 illustrates a roof that was overtaken by an invasive weed species (Lamb's Quarters) that may have been brought in with the growing medium and may have resulted from significant overwatering from an overhead irrigation system and a gap in the regular maintenance regime. Adhering to a regular maintenance schedule, adjusting the frequency as needed is the best way to stay on top of weeding and ensuring the health of the roof.

A8.13 Green Roof Services *A8.14 K.Ross*
A8.13 Unmaintained green roof A8.14 Extremeweed coverage by invasive species

Micro Climates

Individual micro climates on and around buildings should be taken into account during the design phase and plant species selection. The different areas on a roof can provide significant variation in the amount of exposure to and intensity of sunlight and wind, affecting moisture both received and retained. Figure 8.15 illustrates a roof in downtown Calgary. An area of the roof was consistently clear of snow through out the winter due to solar reflection from the adjacent building and wind. This area of the roof was drier which led to slower vegetated growth in the spring. Figure A8.16 illustrates the 6300 sq ft green roof on the Connecticut Science Centre, in Hartford. Given the multiple micro climates of the rooftop, the design response was to provide different vegetated areas: a shade garden, an alpine garden and a children's sensory garden. The vegetated cover was tailored to the unique microclimates of the rooftop.



A8.15 K.Ross *A8.16 Greenroofs.com*

A8.15 Different microclimates on green roof. A8.16 Different planted areas for different microclimates on the roof

Appendix A - List of Figures

APPENDIX B.

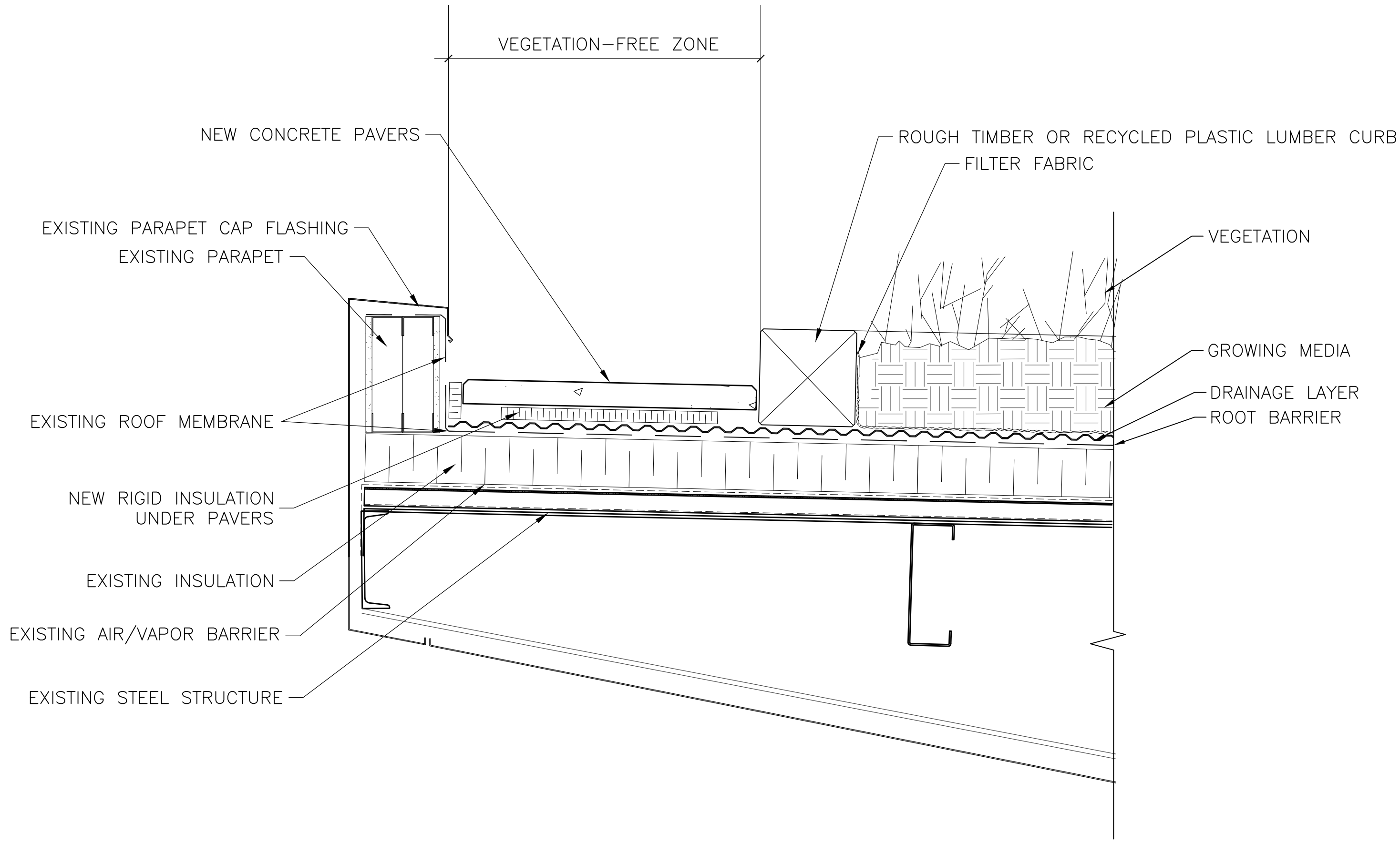
CONSTRUCTION DETAILS

When preparing construction details for your green roof project, consideration should be made for all conditions of the roof where the green roof is intended. These details should not be over generalized, rely solely upon manufacturer-supplied details or employ typical stock details.

Different green roof system components may be constructed differently, for example the location of a root barrier layer is sometimes placed above the drainage layer where in others, it is located directly above the waterproofing layer. Some components may not be required with particular waterproofing assemblies. Where the structure can support the load of a green roof, they can be constructed over concrete, steel and even wood structures. Particular attention should be paid to edging and perimeters, drains and scuppers, plumbing stacks, expansion joints.

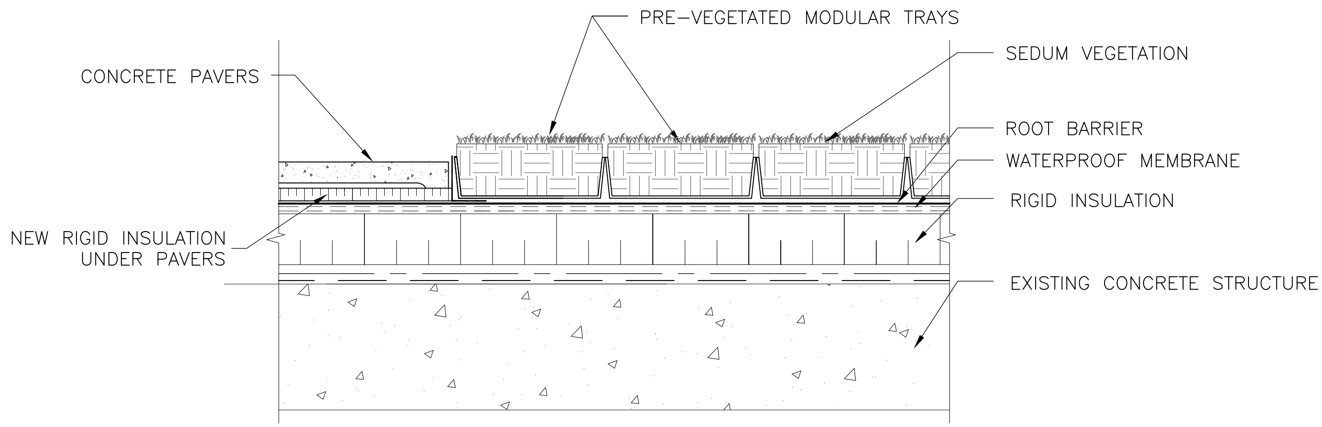
The following examples illustrate a number of green roof systems and details from various projects in Alberta. The focus in this document is on mainly extensive and semi-intensive systems which are likely types of systems to be employed for stormwater management purposes. Illustrated are the following: loose-laid, planted green roofs; pre-vegetated modular trays; pre-vegetated mats on concrete, steel and wood-framed structures; on flat (2% slopes) and low slopes (10%). They are presented not-to-scale and are intended as illustration only.

APPENDIX B - LIST OF FIGURES



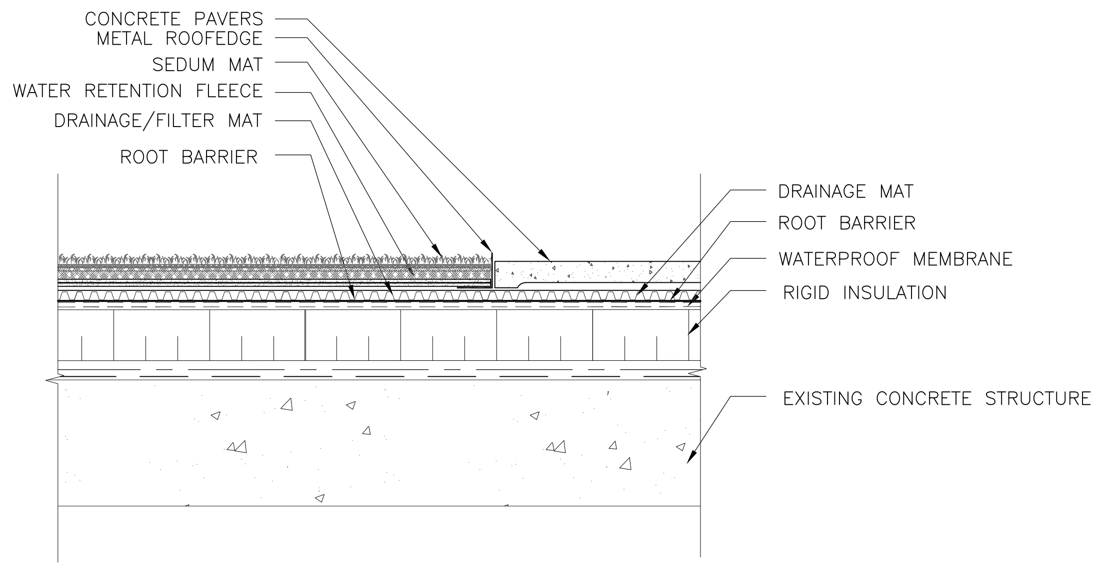
EXTENSIVE LOOSE–LAID GREEN ROOF ON EXISTING STEEL STRUCTURE

Figure B1.1



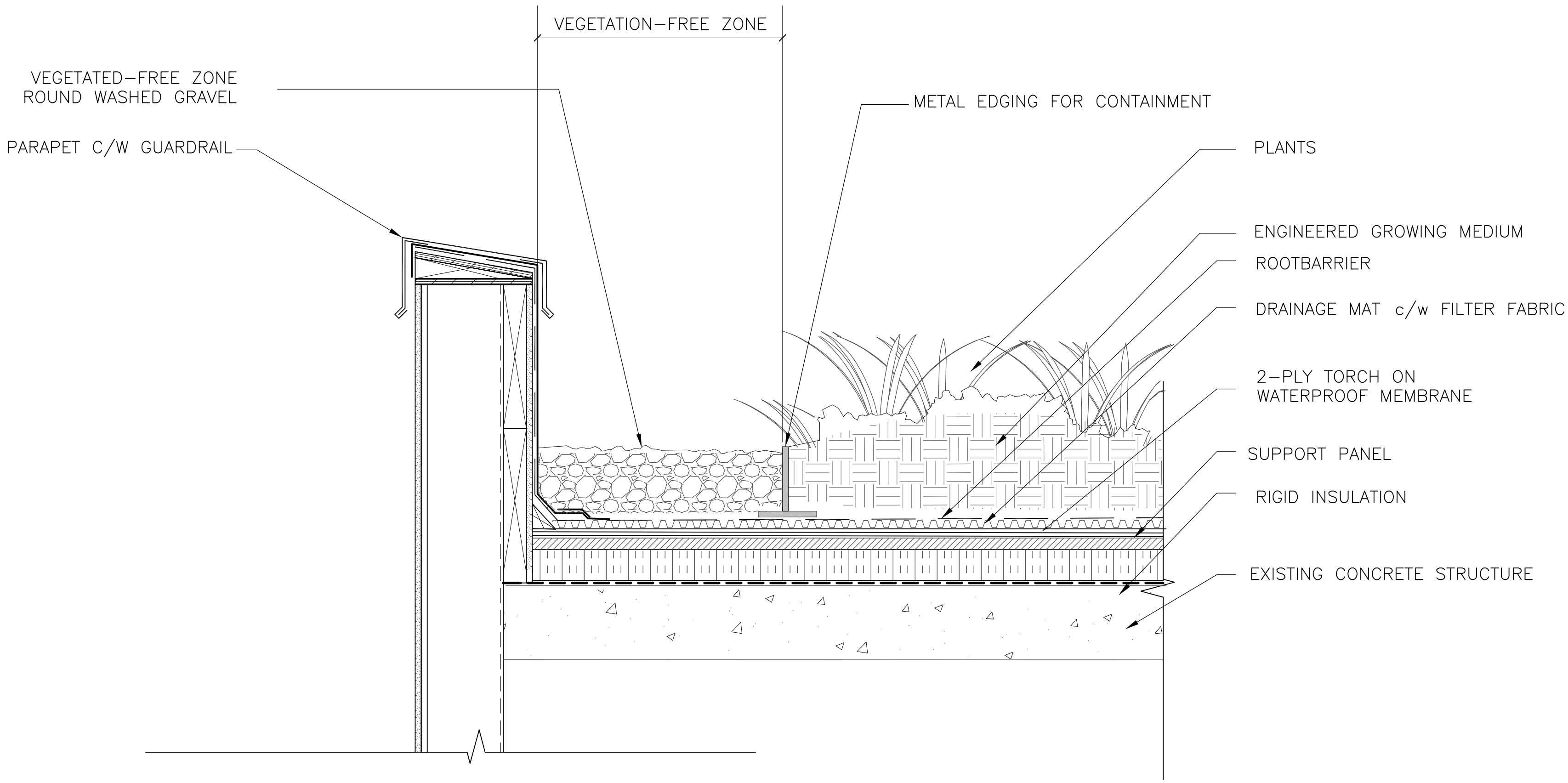
PRE–VEGETATED MODULAR TRAYS ON EXISTING CONCRETE STRUCTURE

Figure B1.2



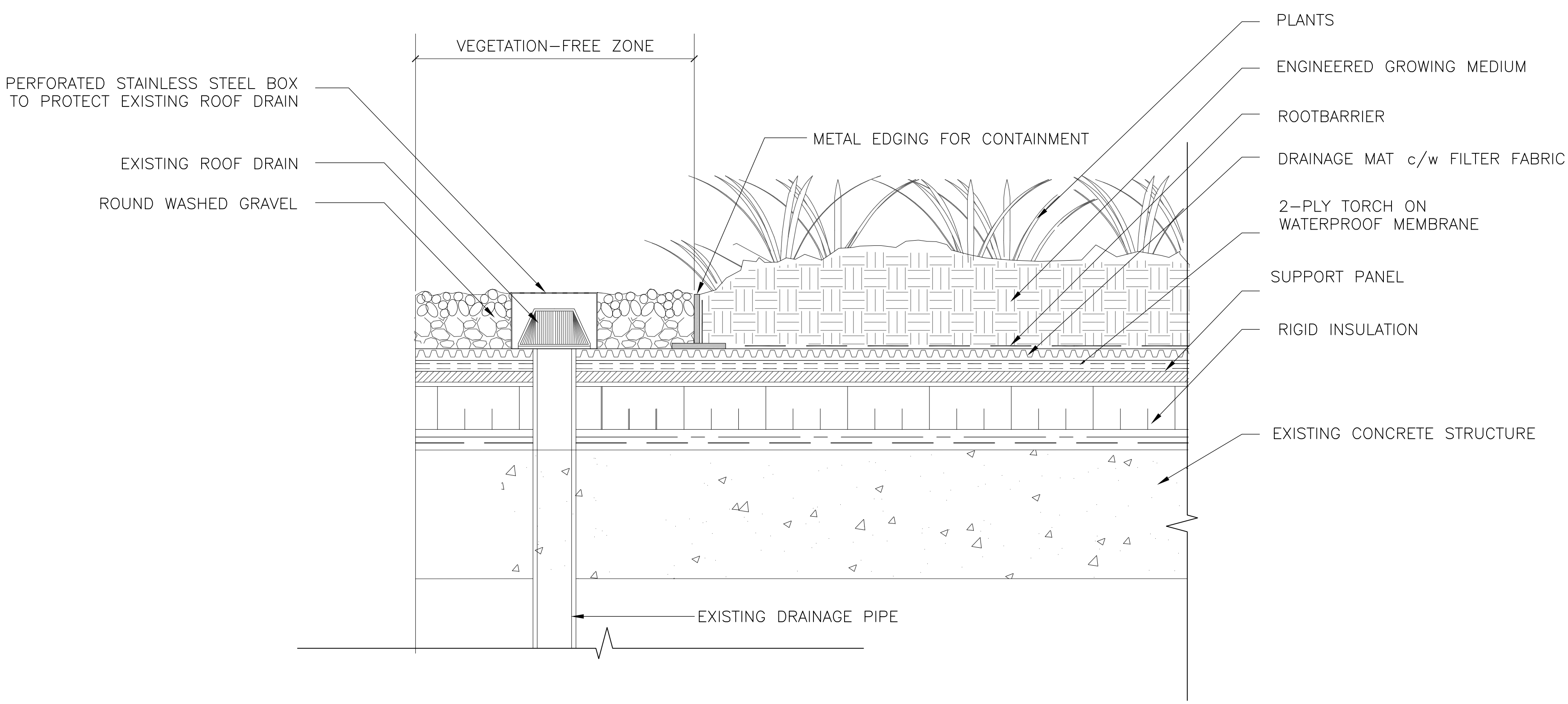
PRE–VEGETATED SEDUM MAT ON EXISTING CONCRETE STRUCTURE

Figure B1.3



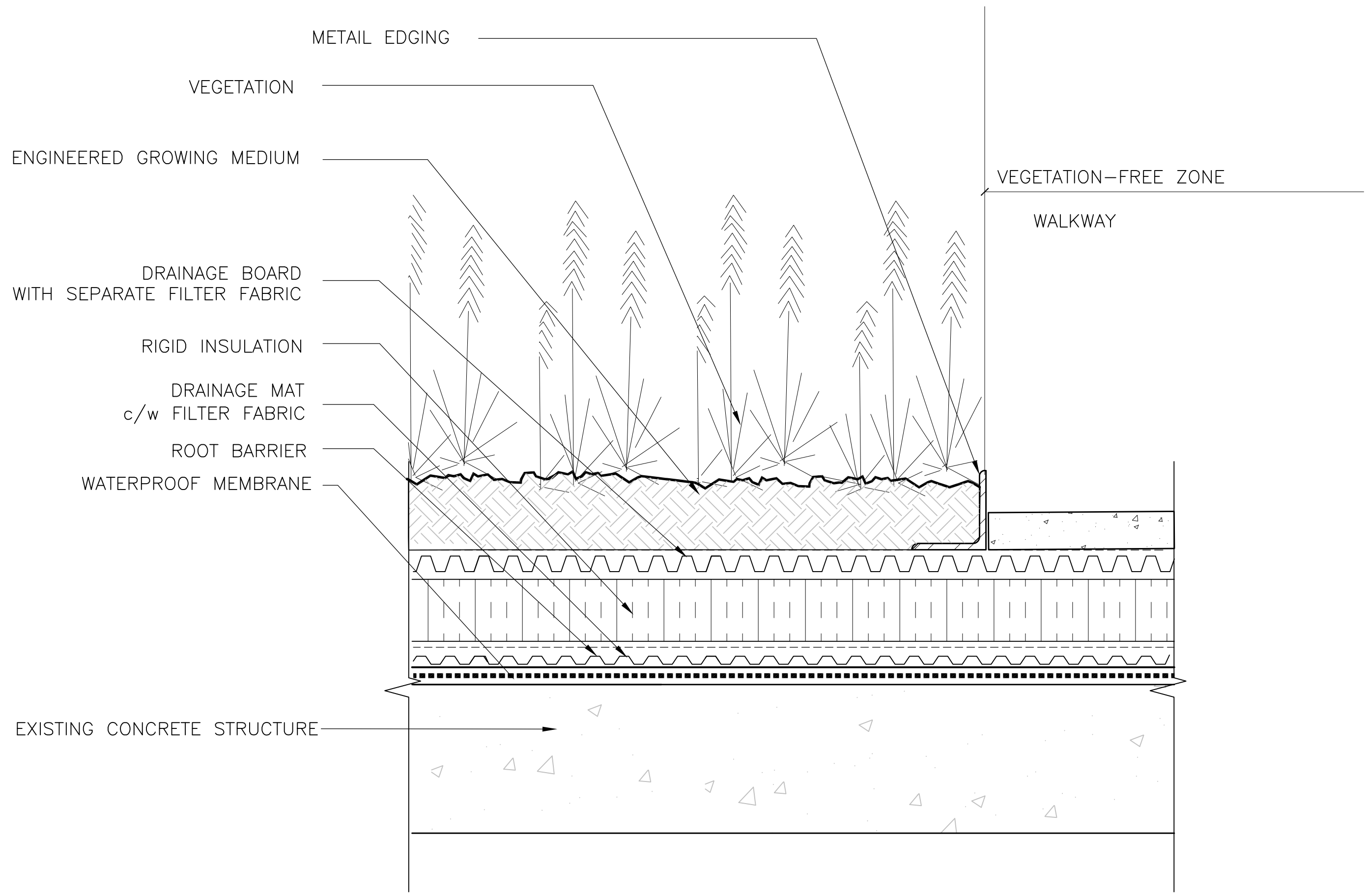
EXTENSIVE LOOSE–LAID GREEN ROOF ON EXISTING CONCRETE STRUCTURE @ PARAPET EDGE

Figure B1.4



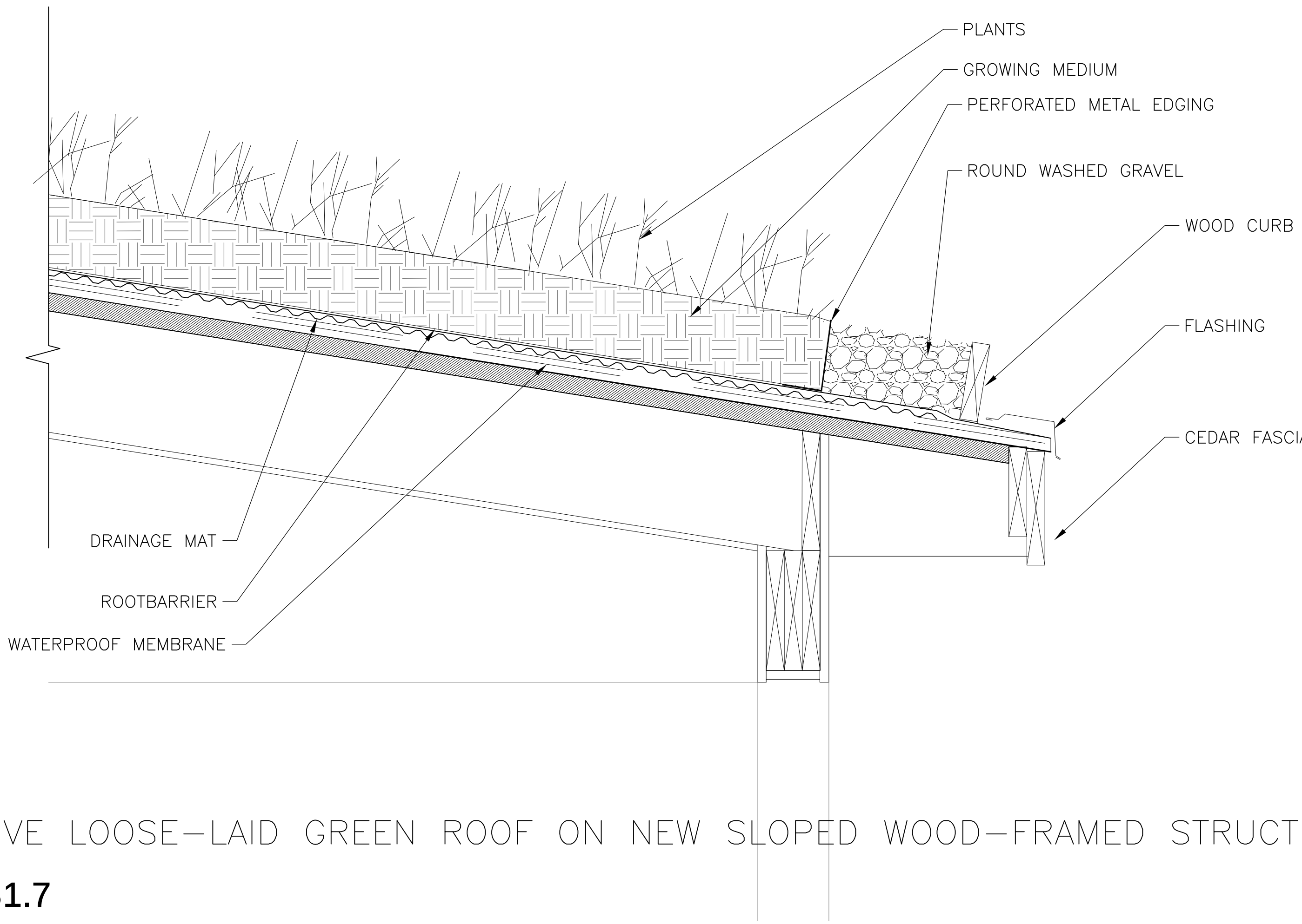
EXTENSIVE LOOSE—LAID GREEN ROOF ON EXISTING CONCRETE STRUCTURE @ DRAIN

Figure B1.5



EXTENSIVE LOOSE—LAID GREEN ROOF ON EXISTING CONCRETE STRUCTURE

Figure B1.6



EXTENSIVE LOOSE–LAID GREEN ROOF ON NEW SLOPED WOOD–FRAMED STRUCTURE

Figure B1.7

APPENDIX C.

PLANT SPECIES EVALUATION

While research is currently underway testing and evaluating certain plants species and varieties, to date no comprehensive list exists documenting suitable plants for green roof applications in the Calgary area.

To begin formulating an applicable list for this module, the project team began by aggregating current plant information including manufacturer listed suggestions and products, what is produced by local nurseries, native plant lists and plants used on existing green roofs in the region. Where commonalities were found in species and varieties, and desirable characteristics noted, these plants were selected for evaluation in a matrix.

Evaluation Matrix

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

			Plant		Criteria							
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	Plant notes
Thin												
100mm (4")	L	P	*Aegopodium podararia 'Variegatum'*	Snow on the Mountain /Goutweed		1	1				2	Spreading; invasive species
100mm (4")	L	P	*Allium cernuum*	Nodding Onion	1	1	1	1	1		5	Herb; bulb
100mm (4")	L	P	*Allium shoenoprasum*	Chives	1	1	1	1	1	1	6	Herb; bulb
100mm (4")	L	P	*Allium tuberosum*	Garlic Chives	1	1		1	1		4	Herb; bulb
100mm (4")	L	P	*Antennaria dioica 'Rosea'*	Pussy-Toes	1	1	1		1	1	5	Ground cover, spreading
100mm (4")	H	P	*Arenaria montana*	Mountain Sandwort	1	1					2	Shallow roots vulnerable to drought
100mm (4")	L	P	*Armeria maritima*	Sea Pink	1	1	1		1	1	5	Compact, grows in low clumps, grass-like
100mm (4")	M	P	*Campanula cohlearifolia*	Creeping/Dwarf Bellflower		1	1				2	Spreading underground shoots
100mm (4")	M	P	*Camplanula rotundafolia*	Harebell Bellflower	1	1	1	1		1	5	Forms a low mound of fine, grass-like leaves, spreads by rhizomes
100mm (4")	L	P	*Castilleja lutescens*	Yellow Paintbrush		1		1	1		3	Semi-parasitic / parasitic roots
100mm (4")	M	P	*Cerastium tomentosum*	Snow-in-Summer	1	1	1				3	Forms low, fast-spreading mat
100mm (4")	L	P	*Dianthus alpinus*	Alpine Pink	1				1		2	True alpine species of Pinks, forming low cushion
100mm (4")	M	P	*Dryas octopetala*	White Dryad	1	1	1	1			4	Prostrate, trailing perennial sub-shrub, forming large colonies
100mm (4")	M	G	*Festuca ovina var. glauca*	Blue Fescue /Sheep's Fescue	1	1	1				3	Radiating clump growth habit
100mm (4")	L	P	*Fragaria virginiana*	Wild Strawberry	1		1	1		1	4	Grows from short scaly rhizomes, with several slender trailing runners (stolons)
100mm (4")	L	P	*Geranium macrorrhizum 'Bevans'*	Bevans Scented Cranesbill		1			1		2	Fast spreading ground cover
100mm (4")	L	P	*Geum triflorum*	Prairie Smoke		1	1	1	1	1	5	Each plant has 3 drooping flowers, woolly seed heads, spreads by rhizomes
100mm (4")	L	P	*Gypsophila repens*	Creeping Baby's Breath	1	1	1		1		4	Forms low mat of leaves, heavy self-seeder
100mm (4")	L	G	*Koeleria cristata/K. macrantha*	Prairie June Grass		1		1	1	1	4	Tall, erect grass with no rhizomes
100mm (4")	M	P	*Phlox subulata*	Moss Phlox	1	1	1				3	Ground cover, prostrate mat growth
100mm (4")	M	P	*Saponaria ocymoides*	Rock Soapwort	1	1	1				3	Vigorous low creeping plant; invasive, drought tolerant once established
100mm (4")	H	P	*Saxifraga arendsii*	Rockfoil		1	1				2	Dislikes drought and hot humid summer
100mm (4")	L	P	*Sedum album*	White Stonecrop	1		1		1		3	Very drought-tolerant sedum, winter interest
100mm (4")	L	P	*Sedum ewersii*	Blue Stonecrop	1	1	1		1		4	Forms low, non-spreading mound of rounded leaves
100mm (4")	L	P	*Sedum floriferum 'Weihenstephaner Gold'*	Weinhenstephaner Gold Stonecrop	1		1		1		3	Quickly forms a dense mat with long summer blooming period
100mm (4")	L	P	*Sedum hispanicum var. Minus*	Spanish Stonecrop	1		1		1		3	Drought-tolerant once established, delicate foliage, winter interest
100mm (4")	L	P	*Sedum kamchaticum*	Russian Stonecrop	1	1	1		1	1	5	Clump forming
100mm (4")	L	P	*Sedum kam. 'Variegatum'*	Variegated Russian Stonecrop	1	1	1		1	1	5	Compact with variegated foliage, spreading with rooting stems up to 30 cm long
100mm (4")	L	P	*Sedum robustum 'Rosy Glow'*	Rosy Glow Stonecrop	1	1	1		1		4	Clump forming
100mm (4")	L	P	*Sedum rupestre 'Angelina'*	Angelina Stonecrop	1		1		1		3	Quick spreading groundcover with needle-like foliage
100mm (4")	L	P	*Sedum rupestre 'Blue Spruce'*	Blue Spruce Stonecrop	1		1		1		3	Quick spreading groundcover with needle-like foliage
100mm (4")	L	P	*Sedum sieboldii*	Sieboldii Stonecrop		1	1		1		3	Low mounding, foliage with seasonal interest
100mm (4")	L	P	*Sedum spectabile 'Stardust'*	White Stardust Stonecrop		1	1		1		3	Light green foliage
100mm (4")	L	P	*Sedum spurium*	Two-row Stonecrop	1	1	1		1	1	5	Creeping
100mm (4")	L	P	*Sedum spurium 'Dragon Blood'*	Dragon's Blood Stonecrop	1	1	1		1		4	Creeping to form a thick patch
100mm (4")	L	P	*Sedum spurium 'Fuldaglut'*	Fuldaglut' ('Fulda Glow') Stonecrop	1		1		1		3	Drought and shade tolerant; an improved Dragon's blood
100mm (4")	L	P	*Sedum spurium 'Tricolor'*	Tricolor Stonecrop	1	1	1		1	1	5	Low carpet of small leaves
100mm (4")	L	P	*Sedum spurium 'Voodoo'*	Voodoo Stonecrop	1		1		1		3	Drought-tolerant, long-lived

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk Plant Type: grasses (G), perennials (P), shrubs (S)

Evaluation Matrix

			Plant		Criteria							Criteria notes
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	Manufacturer List: Plants have been included that appear in current manufacturer literature Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius Published or Documented: Plant appears in publications cataloguing plants suitable to our region Native: Plant is documented or catalogued as native Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings
100mm (4")	L	P	*Sedum stenopetalum*	Common/Wormleaf Stonecrop			1	1	1		3	Clump forming lance-shaped, linear, or three-lobed leaves
100mm (4")	L	P	*Sempervirum tectorum*	Purple Hens and Chicks	1	1	1		1	1	5	Forms a basal rosette of succulent sessile leaves, very frost resistant
100mm (4")	L	P	*Thymus praecox*	Mother-of-Thyme		1	1				2	Flat-growing evergreen ground cover
100mm (4")	M	P	*Thymus serphyllum*	Creeping Thyme	1	1	1				3	Prostrate sub-shrub, 2 cm tall
100mm (4")	H	P	*Veronica repens*	Creeping Speedwell		1	1				2	Evergreen, dense carpeting plant
Medium												Plant notes
200mm (8")	L	P	*Achillea milefolium*	Common Yarrow	1	1	1	1	1	1	6	Herbaceous, spreads by rhizomes
200mm (8")	L	P	*Agastache foeniculum*	Giant Hyssop		1	1	1			3	Bushy upright clump, grows well with numerous prairie meadow plants
200mm (8")	H	G	*Agropyron smithii*	Western Wheat Grass		1	1	1			3	Erect, sod-forming, with long slender rhizomes
200mm (8")	H	G	*Agropyron subsecundum*	Awned Wheat Grass		1	1	1			3	Erect, tufted, with fibrous roots
200mm (8")	H	P	*Alchemilla mollis*	Lady's Mantle	1	1	1				3	Self-seeds prolifically, requires moist soil; not drought tolerant
150mm (6")	L	P	*Alyssum montanum*	Mountain Gold Allysum		1	1		1		3	Evergreen ground cover
150mm (6")	M	P	*Anemone multifida*	Cut-leved Anemone		1	1	1			3	Forms low mounds or tufts of leaves, clump growth
150mm (6")	M	P	*Anemone patens/Pulsatilla patens*	Prairie Crocus/Pasque Flower			1	1			2	Long-lived perennial with a thick woody taproot, self-seeding
150mm (6")	L	P	*Antennaria aprica*	Low Everlasting/Pussy Toes			1	1			2	Forms thin to dense patches of mat-forming leaves and short erect flower stems; deep extensive roots
150mm (6")	L	P	*Antennaria parvifolia*	Small-leaved Pussy Toes			1	1			2	Stoloniferous, mat-forming; deep and delicate root system
150mm (6")	M	P	*Arabis caucasica*	White Rockress		1	1				2	Dwarf and prostrate, mat-forming, fine multiple absorbing roots
150mm (6")	M	P	*Arctostophylos uva-ursi*	Kinnikinnick/Bearberry	1	1	1	1		1	5	Procumbent plant with very few roots
150mm (6")	L	S	*Artemisia cana*	Sagebrush		1	1	1	1	1	5	Taproot with lateral roots
200mm (8")	L	S	*Artemisia frigida*	Pasture Sagewort		1	1	1	1		4	Tap root system and numerous surface roots
200mm (8")	L	P	*Artemisia ludoviciana*	Prairie Sagewort		1	1	1	1	1	5	Spreads by rhizomes
200mm (8")	H	P	*Aruncus diocus*	Goat's Beard		1	1				2	Tall perennial, self-seeds freely, spreads from underground runners; prefers moist soil
150mm (6")	M	P	*Aster alpinus*	Alpine Aster		1	1	1			3	Spreads by rhizomes
150mm (6")	M	P	*Aster ericoides/A. pansus*	Trusted White Prairie Aster		1	1	1			3	Extensive root system of rhizomes and stolons
150mm (6")	M	P	*Aster laevis*	Smooth Aster	1	1	1	1			4	Short rhizome root system
150mm (6")	H	P	*Astilbe japonica*	Japanese Astilbe	1	1					2	Shallow root system
150mm (6")	H	P	*Astilbe arendsii*	False Spirea	1	1	1				3	Shallow roots, needs moisture
150mm (6")	M	P	*Astragalus canadensis*	Canada Milk Vetch		1		1			2	Taproot and rhizomes
150mm (6")	M	P	*Aquilegia flavescens*	Yellow Columbine		1	1	1			3	Deep roots
200mm (8")	L	G	*Bouteloua gracilis*	Blue Gramma		1	1	1	1	1	5	Shallow-rooted, densely-tufted, with fibrous roots, occasionally with very short scaly rhizomes
200mm (8")	L	G	*Bromus anomalus*	Nodding Brome		1		1	1		3	Tall erect bunchgrass without rhizomes
200mm (8")	L	G	*Bromus ciliatus*	Fringed Brome		1	1	1	1		4	Tall with fibrous roots
200mm (8")	H	G	*Calamagrostis stricta*	Northern Reed Grass			1				1	Thrives in wet soil
150mm (6")	M	P	*Campanula carpatica*	Carpathian Harebell	1	1	1				3	Spreads by rhizomes
200mm (8")	L	P	*Castilleja miniata*	Red Indian Paintbrush		1	1	1	1		4	Semi-parasitic on the roots of grasses and forbs
200mm (8")	L	P	*Centaurea montana*	Mountain Cornflower	1	1	1		1	1	5	Forms bushy clumps of leaves, may self-seed, spreading
150mm (6")	L	P	*Chrysopsis villosa/ Heterotheca villosa*	Hairy Golden Aster		1	1	1	1		4	Deep roots, low spreading, fast to aggressive
150mm (6")	M	P	*Cleome serrulata*	Bee Plant/Clammyweed		1		1			2	Annual, grows on sandy soil

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk Plant Type: grasses (G), perennials (P), shrubs (S)

Evaluation Matrix

Criteria notes:

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

			Plant		Criteria							Criteria notes
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	
150mm (6")	L	P	*Delphinium bicolor*	Low Larkspur			1	1	1		3	Thickly branching root system
200mm (8")	L	P	*Delphinium glaucum*	Tall Larkspur		1	1	1	1		4	Fibrous, multi-branched ascending rhizomes
150mm (6")	M	G	*Deschampsia ceaspitosa*	Tufted Hair Grass		1	1	1		1	4	Erect, densely-tufted, with fibrous, deep extensive roots
150mm (6")	M	P	*Dianthus deltoides*	Maiden Pinks	1	1	1	1			4	Drought tolerant once established, mat forming foliage
150mm (6")	M	P	*Dodecatheon pulchellum*	Shooting Star		1	1	1			3	Very short erect rootstock
150mm (6")	H	P	*Dryas drummondii*	Mountain Avens		1	1	1			3	Forms symbiotic relationships with fungi
200mm (8")	M	P	*Echinacea purpurea*	Purple Coneflower	1	1	1	1	1	1	6	Grows from a short caudex with fibrous roots
200mm (8")	M	G	*Elymus canadensis*	Canada Wild Rye		1	1	1			3	Tall, erect perennial grass with short rhizomes
200mm (8")	M	G	*Elymus cinereus (E. piperi)*	Giant Wild Rye		1	1	1			3	Very tall, tufted perennial grass with short, thick knotted rhizomes
200mm (8")	L	P	*Epilobium angustifolium*	Fireweed		1	1	1	1		4	Fibrous root system
150mm (6")	M	P	*Erigeron caespitosus*	Tufted Fleabane		1	1	1			3	Short, tufted growth habit
150mm (6")	M	P	*Erigeron glabellus*	Smooth Fleabane		1	1	1			3	Sub-simple caudices and fibrous-rooted
200mm (8")	L	G	*Festuca idahoensis*	Bluebunch Fescue		1	1	1	1		4	Erect, densely-tufted perennial grass with fibrous roots
200mm (8")	L	G	*Festuca scabrella/F.hallii*	Rough Fescue		1		1	1		3	Spreads by short rhizomes
200mm (8")	L	P	*Gailardia aristala*	Gailardia/Indian Blanket		1	1	1	1	1	5	Hairs on leaves resist wind desication, may spread by seed
200mm (8")	M	P	*Galium boreale*	Northern Bedstraw		1	1	1			3	Creeping roots, self-seeding
200mm (8")	H	P	*Geranium sanguineum*	Cranesbill/Geranium	1	1	1			1	4	Forms a bushy mound, quick to fill in
200mm (8")	H	P	*Geranium richardsonii*	Wild White Geranium		1	1	1			3	Deep fibrous root system; rhizomes on older plants
200mm (8")	H	P	*Geranium viscosissimum*	Sticky Purple Geranium		1	1	1			3	Hairy plant with sticky surface
150mm (6")	L	P	*Gutierrezia diversifolia*	Broomweed		1		1	1		3	Dense bushy sub-shrub, multi-branched
150mm (6")	L	P	*Haplopappus spinulosus*	Spiny Iron Plant		1	1	1	1		4	Slender perennial with weekly bristled leaves
200mm (8")	M	P	*Hedysarum alpinum*	Alpine Hedysarum/Sweetvetch		1		1			2	Erect plant with many stems from the crown, long thick root
200mm (8")	M	P	*Hedysarum boreale*	Northern Hedysarum		1		1			2	Silky hairs
200mm (8")	L	P	*Helianthus subrhomboideus*	Rhombic Leaved Sunflower		1	1	1	1		4	Spreading quickly by rhizomes
150mm (6")	M	G	*Helictotrichon sempervirens*	Blue Oat Grass	1	1	1				3	Clump forming
200mm (8")	L	P	*Hemerocallis x 'Eenie Weenie'*	Eenie Weenie Daylily	1	1			1		3	Short groundcover; true dwarf
200mm (8")	L	P	*Hemerocallis x 'Stella D'oro'*	Stella D'oro Daylily		1	1		1	1	4	Watering required to establish deep, extensive root system
150mm (6")	M	P	*Heuchera sanguinea*	Coral Bells	1	1	1				3	Shallow root system
150mm (6")	L	P	*Heuchera richardsonii*	Richardson Alumroot		1	1	1	1		4	Clump-forming, shallow roots developing woody bases
200mm (8")	H	G	*Hierochloe odorata*	Sweetgrass		1	1	1			3	Erect, sweet-smelling, sod-forming perennial grass with extensive rhizomes
150mm (6")	L	P	*Iberis sempervirens*	Evergreen Candytuft	1	1	1		1		4	Sub-shrub; requires good snow cover, mounded foliage
200mm (8")	H	P	*Iliama rivularis*	Wild Mountain Hollyhock		1	1	1			3	Stout, leafy perennial, spreads by rhizomes
150mm (6")	L	P	*Inula ensifolia*	Swordleaf Inula	1		1		1		3	Clump forming, spreads by rhizomes
150mm (6")	H	P	*Iris missouriensis*	Rocky Mountain Iris		1		1			2	Widely spreading from thick rhizomes
200mm (8")	M	P	*Iris pallida 'Albo varieagata'*	Sweet Silver Variegated Iris		1	1				2	Well drained soil, full-sun and rich humus soil
200mm (8")	M	P	*Iris pallida 'Aureo varieagata'*	Sweet Golden Variegated Iris		1	1				2	Tall growing, spreading
150mm (6")	L	P	*Iris pumila*	Dwarf Bearded Iris	1	1	1		1		4	Spreads by rhizomes, fleshy stem, borderline invasive
150mm (6")	H	P	*Iris versicolor*	Blue Flag Iris		1		1			2	Forms large clumps from thick, creeping rhizomes
200mm (8")	L	P	*Liatris punctata*	Blazing Star/Dotted Gayfeather		1	1	1	1		4	Deep woody rootstock

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk   Plant Type: grasses (G), perennials (P), shrubs (S)

Evaluation Matrix

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

			Plant		Criteria							Criteria notes
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	
200mm (8")	M	P	*Liatris spicata*	Purple Gayfeather	1	1	1		1	1	5	Growing from corms
200mm (8")	L	P	*Lilium philadelphicum*	Western Wood Lily		1	1	1	1		4	Herb; bulb
150mm (6")	L	P	*Linum perenne 'Saphyr'*	Blue Perennial Flax	1	1	1		1		4	Compact, clump forming bushy mound of small leaves
150mm (6")	L	P	*Linum lewisii/ L. perenne*	Wild Flax		1	1	1	1		4	Erect, weak-stemmed perennial with deep taproot
150mm (6")	L	P	*Lupinus argenteus*	Wild Lupine/Silvery Lupine		1	1	1	1		4	Nitrogen fixer
200mm (8")	H	P	*Monarda fistulosa*	Wild Bergamot/Native Bee-Balm		1	1	1		1	4	Deep, strongly branched roots and shallow rhizomes
150mm (6")	M	P	*Oenothera biennis*	Common Evening Primrose		1	1	1			3	Erect, stout-stemmed plant
150mm (6")	L	P	*Oenothera caespitosa*	Tufted Evening Primrose/Rock Rose		1	1	1	1		4	Rosette of lobed, toothed leaves; grows in clay soil
150mm (6")	L	P	*Oxytropis sericea*	Early Yellow Oxytropis/Locoweed		1	1	1	1		4	Clump forming
150mm (6")	L	P	*Oxytropis splendens*	Showy Oxytropis/Locoweed		1	1	1	1		4	Grows from heavy taproot and woody root crown
150mm (6")	M	P	*Papaver alpinum*	Alpine Poppy	1	1	1				3	Short-lived, prolific seeder
150mm (6")	M	P	*Papaver nudicaule 'Wonderland Mix'*	Wonderland Iceland Poppy		1	1				2	Short-lived, prolific seeder
200mm (8")	M	P	*Penstemon confertus*	Yellow Penstemon/Beardtongue		1	1	1		1	4	Fall interest
200mm (8")	M	P	*Penstemon fruticosus*	Shrubby Penstemon/Beardtongue		1	1	1			3	Sub-shrub; low-maintenance, spreading
200mm (8")	L	P	*Penstemon nitidus*	Smooth Blue Beardtongue		1	1	1	1	1	5	Single to clump growth
200mm (8")	L	P	*Petalostemon purpureum*	Purple Prairie Clover		1	1	1	1		4	Nitrogen fixer
150mm (6")	L	P	*Phacelia sericea*	Scorpion Weed/Alpine Phacelia		1	1	1	1		4	Tap-rooted, branched woody base
150mm (6")	M	G	*Phalaris arundinacea 'Picta'*	Variegated Ribbon Grass			1	1			2	Spreads by rhizomes; invasive
150mm (6")	M	G	*Poa alpina*	Alpine Bluegrass		1		1			2	Scattered, dense clumps
150mm (6")	M	G	*Poa palustris*	Fowl Bluegrass		1	1	1			3	Tall, loosely-tufted, fibrous roots
150mm (6")	L	P	*Polemonium pulcherrimum*	Jacob's Ladder		1	1	1	1	1	5	Herb; clump of erect stems
150mm (6")	H	P	*Potentilla anserina*	Silverweed Cinquefoil		1	1		1		3	Prostrate, creeping
150mm (6")	L	P	*Potentilla concinna*	Prairie/Early Cinquefoil		1	1		1		3	Sub-shrub, sub-alpine
150mm (6")	L	P	*Potentilla nepalensis 'Miss Willmott'*	Miss Willmott Potentilla		1	1		1		3	Clump forming
200mm (8")	M	P	*Ratibida columnifera*	Prairie Coneflower	1	1	1	1			4	Taproot, may spread by seed
150mm (6")	M	P	*Rudbeckia fulgida*	Orange Coneflower	1	1	1	1			4	Bushy upright clump from fibrous and fleshy roots
150mm (6")	L	P	*Rudbeckia hirta*	Wild Black Eyed Susan	1	1		1	1		4	Self-seeding
150mm (6")	L	P	*Sedum spectabile 'Autumn Joy'*	Autumn Joy Stonecrop	1	1	1		1		4	Drought tolerant, fast growing
200mm (8")	M	G	*Schizachryium scoparium*	Little Bluestem		1		1		1	3	Clump forming
200mm (8")	L	P	*Sisyrinchium montanum*	Blue-Eyed Grass		1	1	1	1		4	Short rhizomes and fibrous roots
150mm (6")	M	P	*Solidago canadensis*	Canada Goldenrod		1	1	1			3	Fibrous root system producing creeping rhizomes; forms colonies
150mm (6")	M	P	*Solidago decumbens*	Mountain Goldenrod		1	1	1		1	4	Dwarf Golden Rod
150mm (6")	L	P	*Solidago rigida/Oligoneuron rigidum*	Stiff Goldenrod		1	1	1			3	Grows from a vertical caudex, non-spreading
200mm (8")	L	G	*Stipa comata*	Needle & Thread Speargrass		1	1	1	1		4	Erect, densely-tufted with fibrous roots
200mm (8")	L	G	*Stipa curtiseta*	Western Porcupine Grass		1	1	1	1		4	Densely tufted, tall bunchgrass with long, flat or in-rolled leaves
200mm (8")	L	G	*Stipa viridula*	Green Needle Grass		1	1	1	1		4	Tufted
200mm (8")	L	P	*Thermopsis rhombifolia*	Golden Bean		1	1	1	1		4	Clump form, colonizing
150mm (6")	M	P	*Veronica allionii*	Alpine Speedwell		1					1	Compact, carpet forming
150mm (6")	H	P	*Veronica incana*	Wooly Speedwell	1	1	1				3	Clump forming

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk Plant Type: grasses (G), perennials (P), shrubs (S)

Evaluation Matrix

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

Plant					Criteria							
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	Plant notes
150mm (6")	H	P	*Viola adunca*	Wild Blue Violet		1	1	1			3	Hairy, compact plant growing from a small rhizome system
150mm (6")	H	P	*Viola canadensis*	Western Canada Violet		1	1	1			3	Spreads by rhizomes, may be aggressive
150mm (6")	M	P	*Viola cornuta*	Violet	1	1					2	Short-lived; forms low, bushy mound of leaves
150mm (6")	H	P	*Zizia aptera*	Heart-Leaved Alexander		1		1			2	Fall interest
Thick												Plant notes
300mm (12")	L	S	*Juniperus communis*	Common Juniper		1	1	1			3	Woody, prefers acidic soils
300mm (12")	L	S	*Juniperus horizontalis*	Creeping Juniper	1	1			1	1	4	Deep, extensive root system
300mm (12")	L	S	*Potentilla fruticosa*	Shrubby Cinquefoil	1	1	1	1	1		5	Fibrous roots; width of crown spread
300mm (12")	L	S	*Rosa acicularis*	Prickly Rose		1	1		1		3	May spread by roots
300mm (12")	L	S	*Rosa arkansana*	Prairie Wild Rose	1	1	1		1		4	Low growing; prickly stems
300mm (12")	L	S	*Rosa woodsii*	Common Wild Rose		1	1	1	1		4	May spread by roots
300mm (12")	L	S	*Symphoricarpos albus*	Snowberry		1		1	1		3	Thicket forming by way of rhizomes or underground stems
300mm (12")	L	S	*Symphoricarpos albus 'Magic Berry'*	Magic Berry Coralberry		1		1	1		3	Spreading compact habit
300mm (12")	L	S	*Symphoricarpos occidentalis*	Buckbrush/Coralberry		1		1	1		3	Extensive root system; bank stabilizer
300mm (12")	L	S	*Spiraea betulifolia*	Birch-Leaved Spiraea		1		1	1		3	Spreads from extensive root system
300mm (12")	H	S	*Spiraea japonica*	Japanese Spiraea	1	1					2	Deep extensive root system
300mm (12")	M	S	*Spiraea x vanhouttei*	Bridal Wreath Spiraea	1	1					2	Well developed root system

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk Plant Type: grasses (G), perennials (P), shrubs (S)

Ranking Group 1-2

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

			Plant		Criteria							
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	Plant notes
Thin												Plant notes
100mm (4")	L	P	*Aegopodium podararia 'Variegatum'*	Snow on the Mountain /Goutweed		1	1				2	Spreading; invasive species
100mm (4")	H	P	*Arenaria montana*	Mountain Sandwort	1	1					2	Shallow roots vulnerable to drought
100mm (4")	M	P	*Campanula cohlearifolia*	Creeping/Dwarf Bellflower		1	1				2	Spreading underground shoots
100mm (4")	L	P	*Dianthus alpinus*	Alpine Pink	1				1		2	True alpine species of Pinks, forming low cushion
100mm (4")	L	P	*Geranium macrorrhizum 'Bevans'*	Bevans Scented Cranesbill		1			1		2	Fast spreading ground cover
100mm (4")	H	P	*Saxifraga arendsii*	Rockfoil		1	1				2	Dislikes drought and hot humid summer
100mm (4")	L	P	*Thymus praecox*	Mother-of-Thyme		1	1				2	Flat-growing evergreen ground cover
100mm (4")	H	P	*Veronica repens*	Creeping Speedwell		1	1				2	Evergreen, dense carpeting plant
Medium												Plant notes
150mm (6")	M	P	*Anemone patens/Pulsatilla patens*	Prairie Crocus/Pasque Flower			1	1			2	Long-lived perennial with a thick woody taproot, self-seeding
150mm (6")	L	P	*Antennaria aprica*	Low Everlasting/Pussy Toes			1	1			2	Forms thin to dense patches of mat-forming leaves and short erect flower stems; deep extensive roots
150mm (6")	L	P	*Antennaria parvifolia*	Small-leaved Pussy Toes			1	1			2	Stoloniferous, mat-forming; deep and delicate root system
150mm (6")	M	P	*Arabis caucasica*	White Rockress		1	1				2	Dwarf and prostrate, mat-forming, fine multiple absorbing roots
200mm (8")	H	P	*Aruncus diocus*	Goat's Beard		1	1				2	Tall perennial, self-seeds freely, spreads from underground runners; prefers moist soil
150mm (6")	H	P	*Astilbe japonica*	Japanese Astilbe	1	1					2	Shallow root system
150mm (6")	M	P	*Astragalus canadensis*	Canada Milk Vetch		1		1			2	Taproot and rhizomes
200mm (8")	H	G	*Calamagrostis stricta*	Northern Reed Grass			1				1	Thrives in wet soil
150mm (6")	M	P	*Cleome serrulata*	Bee Plant/Clammyweed		1		1			2	Annual, grows on sandy soil
200mm (8")	M	P	*Hedysarum alpinum*	Alpine Hedysarum/Sweetvetch		1		1			2	Erect plant with many stems from the crown, long thick root
200mm (8")	M	P	*Hedysarum boreale*	Northern Hedysarum		1		1			2	Silky hairs
150mm (6")	H	P	*Iris missouriensis*	Rocky Mountain Iris		1		1			2	Widely spreading from thick rhizomes
200mm (8")	M	P	*Iris pallida 'Albo varieagata'*	Sweet Silver Variegated Iris		1	1				2	Well drained soil, full-sun and rich humus soil
200mm (8")	M	P	*Iris pallida 'Aureo varieagata'*	Sweet Golden Variegated Iris		1	1				2	Tall growing, spreading
150mm (6")	H	P	*Iris versicolor*	Blue Flag Iris		1		1			2	Forms large clumps from thick, creeping rhizomes
150mm (6")	M	P	*Papaver nudicaule 'Wonderland Mix'*	Wonderland Iceland Poppy		1	1				2	Short-lived, prolific seeder
150mm (6")	M	G	*Phalaris arundinacea 'Picta'*	Variegated Ribbon grass			1	1			2	Spreads by rhizomes; invasive
150mm (6")	M	G	*Poa alpina*	Alpine Bluegrass		1		1			2	Scattered, dense clumps
150mm (6")	M	P	*Veronica allionii*	Alpine Speedwell		1					1	Compact, carpet forming
150mm (6")	M	P	*Viola cornuta*	Violet	1	1					2	Short-lived; forms low, bushy mound of leaves
150mm (6")	H	P	*Zizia aptera*	Heart-Leaved Alexander		1		1			2	Fall interest
Thick												Plant notes
300mm (12")	H	S	*Spiraea japonica*	Japanese Spiraea	1	1					2	Deep extensive root system
300mm (12")	M	S	*Spiraea x vanhouttei*	Bridal Wreath Spiraea	1	1					2	Well developed root system

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk Plant Type: grasses (G), perennials (P), shrubs (S)

Ranking Group 3-4

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

			Plant		Criteria							
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	Plant notes
Thin												Plant notes
100mm (4")	L	P	*Allium tuberosum*	Garlic Chives	1	1		1	1		4	Herb; bulb
100mm (4")	L	P	*Castilleja lutescens*	Yellow Paintbrush		1		1	1		3	Semi-parasitic / parasitic roots
100mm (4")	M	P	*Cerastium tomentosum*	Snow-in-Summer	1	1	1				3	Forms low, fast-spreading mat
100mm (4")	M	P	*Dryas octopetala*	White Dryad	1	1	1	1			4	Prostrate, trailing perennial sub-shrub, forming large colonies
100mm (4")	M	G	*Festuca ovina var. glauca*	Blue Fescue /Sheep's Fescue	1	1	1				3	Radiating clump growth habit
100mm (4")	L	P	*Fragaria virginiana*	Wild Strawberry	1		1	1		1	4	Grows from short scaly rhizomes, with several slender trailing runners (stolons)
100mm (4")	L	P	*Gypsophila repens*	Creeping Baby's Breath	1	1	1		1		4	Forms low mat of leaves, heavy self-seeder
100mm (4")	L	G	*Koeleria cristata/K. macrantha*	Prairie June Grass		1		1	1	1	4	Tall, erect grass with no rhizomes
100mm (4")	M	P	*Phlox subulata*	Moss Phlox	1	1	1				3	Ground cover, prostrate mat growth
100mm (4")	M	P	*Saponaria ocymoides*	Rock Soapwort	1	1	1				3	Vigorous low creeping plant; invasive, drought tolerant once established
100mm (4")	L	P	*Sedum album*	White Stonecrop	1		1		1		3	Very drought-tolerant sedum, winter interest
100mm (4")	L	P	*Sedum ewersii*	Blue Stonecrop	1	1	1		1		4	Forms low, non-spreading mound of rounded leaves
100mm (4")	L	P	*Sedum floriferum 'Weihenstephaner Gold'*	Weinhenstephaner Gold Stonecrop	1		1		1		3	Quickly forms a dense mat with long summer blooming period
100mm (4")	L	P	*Sedum hispanicum var. Minus*	Spanish Stonecrop	1		1		1		3	Drought-tolerant once established, delicate foliage, winter interest
100mm (4")	L	P	*Sedum robustum 'Rosy Glow'*	Rosy Glow Stonecrop	1	1	1		1		4	Clump forming
100mm (4")	L	P	*Sedum rupestre 'Angelina'*	Angelina Stonecrop	1		1		1		3	Quick spreading groundcover with needle-like foliage
100mm (4")	L	P	*Sedum rupestre 'Blue Spruce'*	Blue Spruce Stonecrop	1		1		1		3	Quick spreading groundcover with needle-like foliage
100mm (4")	L	P	*Sedum sieboldii*	Sieboldii Stonecrop		1	1		1		3	Low mounding, foliage with seasonal interest
100mm (4")	L	P	*Sedum spectabile 'Stardust'*	White Stardust Stonecrop		1	1		1		3	Light green foliage
100mm (4")	L	P	*Sedum spurium 'Dragon Blood'*	Dragon's Blood Stonecrop	1	1	1		1		4	Creeping to form a thick patch
100mm (4")	L	P	*Sedum spurium 'Fuldaglut'*	Fuldaglut' ('Fulda Glow') Stonecrop	1		1		1		3	Drought and shade tolerant; an improved Dragon's blood
100mm (4")	L	P	*Sedum spurium 'Voodoo'*	Voodoo Stonecrop	1		1		1		3	Drought-tolerant, long-lived
100mm (4")	L	P	*Sedum stenopetalum*	Common/Wormleaf Stonecrop			1	1	1		3	Clump forming lance-shaped, linear, or three-lobed leaves
100mm (4")	M	P	*Thymus serphyllum*	Creeping Thyme	1	1	1				3	Prostrate sub-shrub, 2 cm tall
Medium												Plant notes
200mm (8")	L	P	*Agastache foeniculum*	Giant Hyssop		1	1	1			3	Bushy upright clump, grows well with numerous prairie meadow plants
200mm (8")	H	G	*Agropyron smithii*	Western Wheat Grass		1	1	1			3	Erect, sod-forming, with long slender rhizomes
200mm (8")	H	G	*Agropyron subsecundum*	Awned Wheat Grass		1	1	1			3	Erect, tufted, with fibrous roots
200mm (8")	H	P	*Alchemilla mollis*	Lady's Mantle	1	1	1				3	Self-seeds prolifically, requires moist soil; not drought tolerant
150mm (6")	L	P	*Alyssum montanum*	Mountain Gold Allysum		1	1		1		3	Evergreen ground cover
150mm (6")	M	P	*Anemone multifida*	Cut-leved Anemone		1	1	1			3	Forms low mounds or tufts of leaves, clump growth
200mm (8")	L	S	*Artemisia frigida*	Pasture Sagewort		1	1	1	1		4	Tap root system and numerous surface roots
150mm (6")	M	P	*Aster alpinus*	Alpine Aster		1	1	1			3	Spreads by rhizomes
150mm (6")	M	P	*Aster ericoides/A. pansus*	Trusted White Prairie Aster		1	1	1			3	Extensive root system of rhizomes and stolons
150mm (6")	M	P	*Aster laevis*	Smooth Aster	1	1	1	1			4	Short rhizome root system
150mm (6")	H	P	*Astilbe arendsii*	False Spirea	1	1	1				3	Shallow roots, needs moisture
150mm (6")	M	P	*Aquilegia flavescens*	Yellow Columbine		1	1	1			3	Deep roots

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk   Plant Type: grasses (G), perennials (P), shrubs (S)

Ranking Group 3-4

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

			Plant		Criteria							Criteria notes
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	
200mm (8")	L	G	*Bromus anomalus*	Nodding Brome		1		1	1		3	Tall erect bunchgrass without rhizomes
200mm (8")	L	G	*Bromus ciliatus*	Fringed Brome		1	1	1	1		4	Tall with fibrous roots
150mm (6")	M	P	*Campanula carpatica*	Carpathian Harebell	1	1	1				3	Spreads by rhizomes
200mm (8")	L	P	*Castilleja miniata*	Red Indian Paintbrush		1	1	1	1		4	Semi-parasitic on the roots of grasses and forbs
150mm (6")	L	P	*Chrysopsis villosa/ Heterotheca villosa*	Hairy Golden Aster		1	1	1	1		4	Deep roots, low spreading, fast to aggressive
150mm (6")	L	P	*Delphinium bicolor*	Low Larkspur			1	1	1		3	Thickly branching root system
200mm (8")	L	P	*Delphinium glaucum*	Tall Larkspur		1	1	1	1		4	Fibrous, multi-branched ascending rhizomes
150mm (6")	M	G	*Deschampsia ceaspitosa*	Tufted Hair Grass		1	1	1		1	4	Erect, densely-tufted, with fibrous, deep extensive roots
150mm (6")	M	P	*Dianthus deltoides*	Maiden Pinks	1	1	1	1			4	Drought tolerant once established, mat forming foliage
150mm (6")	M	P	*Dodecatheon pulchellum*	Shooting Star		1	1	1			3	Very short erect rootstock
150mm (6")	H	P	*Dryas drummondii*	Mountain Avens		1	1	1			3	Forms symbiotic relationships with fungi
200mm (8")	M	G	*Elymus canadensis*	Canada Wild Rye		1	1	1			3	Tall, erect perennial grass with short rhizomes
200mm (8")	M	G	*Elymus cinereus (E. piperi)*	Giant Wild Rye		1	1	1			3	Very tall, tufted perennial grass with short, thick knotted rhizomes
200mm (8")	L	P	*Epilobium angustifolium*	Fireweed		1	1	1	1		4	Fibrous root system
150mm (6")	M	P	*Erigeron caespitosus*	Tufted Fleabane		1	1	1			3	Short, tufted growth habit
150mm (6")	M	P	*Erigeron glabellus*	Smooth Fleabane		1	1	1			3	Sub-simple caudices and fibrous-rooted
200mm (8")	L	G	*Festuca idahoensis*	Bluebunch Fescue		1	1	1	1		4	Erect, densely-tufted perennial grass with fibrous roots
200mm (8")	L	G	*Festuca scabrella/F.hallii*	Rough Fescue		1		1	1		3	Spreads by short rhizomes
200mm (8")	M	P	*Galium boreale*	Northern Bedstraw		1	1	1			3	Creeping roots, self-seeding
200mm (8")	H	P	*Geranium sanguineum*	Cranesbill/Geranium	1	1	1			1	4	Forms a bushy mound, quick to fill in
200mm (8")	H	P	*Geranium richardsonii*	Wild White Geranium		1	1	1			3	Deep fibrous root system; rhizomes on older plants
200mm (8")	H	P	*Geranium viscosissimum*	Sticky Purple Geranium		1	1	1			3	Hairy plant with sticky surface
150mm (6")	L	P	*Gutierrezia diversifolia*	Broomweed		1		1	1		3	Dense bushy sub-shrub, multi-branched
150mm (6")	L	P	*Haplopappus spinulosus*	Spiny Iron Plant		1	1	1	1		4	Slender perennial with weekly bristled leaves
200mm (8")	L	P	*Helianthus subrhomboideus*	Rhombic Leaved Sunflower		1	1	1	1		4	Spreading quickly by rhizomes
150mm (6")	M	G	*Helictotrichon sempervirens*	Blue Oat Grass	1	1	1				3	Clump forming
200mm (8")	L	P	*Hemerocallis x 'Eenie Weenie'*	Eenie Weenie Daylily	1	1			1		3	Short groundcover; true dwarf
200mm (8")	L	P	*Hemerocallis x 'Stella D'oro'*	Stella D'oro Daylily		1	1		1	1	4	Watering required to establish deep, extensive root system
150mm (6")	M	P	*Heuchera sanguinea*	Coral Bells	1	1	1				3	Shallow root system
150mm (6")	L	P	*Heuchera richardsonii*	Richardson Alumroot		1	1	1	1		4	Clump-forming, shallow roots developing woody bases
200mm (8")	H	G	*Hierochloe odorata*	Sweetgrass		1	1	1			3	Erect, sweet-smelling, sod-forming perennial grass with extensive rhizomes
150mm (6")	L	P	*Iberis sempervirens*	Evergreen Candytuft	1	1	1		1		4	Sub-shrub; requires good snow cover, mounded foliage
200mm (8")	H	P	*Iliama rivularis*	Wild Mountain Hollyhock		1	1	1			3	Stout, leafy perennial, spreads by rhizomes
150mm (6")	L	P	*Inula ensifolia*	Swordleaf Inula	1		1		1		3	Clump forming, spreads by rhizomes
150mm (6")	L	P	*Iris pumila*	Dwarf Bearded Iris	1	1	1		1		4	Spreads by rhizomes, fleshy stem, borderline invasive
200mm (8")	L	P	*Liatris punctata*	Blazing Star/Dotted Gayfeather		1	1	1	1		4	Deep woody rootstock
200mm (8")	L	P	*Lilium philadelphicum*	Western Wood Lily		1	1	1	1		4	Herb; bulb
150mm (6")	L	P	*Linum perenne 'Saphyr'*	Blue Perennial Flax	1	1	1		1		4	Compact, clump forming bushy mound of small leaves
150mm (6")	L	P	*Linum lewisii/ L. perenne*	Wild Flax		1	1	1	1		4	Erect, weak-stemmed perennial with deep taproot

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk Plant Type: grasses (G), perennials (P), shrubs (S)

Ranking Group 3-4

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

			Plant		Criteria							Criteria notes
Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking	
150mm (6")	L	P	*Lupinus argenteus*	Wild Lupine/Silvery Lupine		1	1	1	1		4	Nitrogen fixer
200mm (8")	H	P	*Monarda fistulosa*	Wild Bergamot/Native Bee-Balm		1	1	1		1	4	Deep, strongly branched roots and shallow rhizomes
150mm (6")	M	P	*Oenothera biennis*	Common Evening Primrose		1	1	1			3	Erect, stout-stemmed plant
150mm (6")	L	P	*Oenothera caespitosa*	Tufted Evening Primrose/Rock Rose		1	1	1	1		4	Rosette of lobed, toothed leaves; grows in clay soil
150mm (6")	L	P	*Oxytropis sericea*	Early Yellow Oxytropis/Locoweed		1	1	1	1		4	Clump forming
150mm (6")	L	P	*Oxytropis splendens*	Showy Oxytropis/Locoweed		1	1	1	1		4	Grows from heavy taproot and woody root crown
150mm (6")	M	P	*Papaver alpinum*	Alpine Poppy	1	1	1				3	Short-lived, prolific seeder
200mm (8")	M	P	*Penstemon confertus*	Yellow Penstemon/Beardtongue		1	1	1		1	4	Fall interest
200mm (8")	M	P	*Penstemon fruticosus*	Shrubby Penstemon/Beardtongue		1	1	1			3	Sub-shrub; low-maintenance, spreading
200mm (8")	L	P	*Petalostemon purpureum*	Purple Prairie Clover		1	1	1	1		4	Nitrogen fixer
150mm (6")	L	P	*Phacelia sericea*	Scorpion Weed/Alpine Phacelia		1	1	1	1		4	Tap-rooted, branched woody base
150mm (6")	M	G	*Poa palustris*	Fowl Bluegrass		1	1	1			3	Tall, loosely-tufted, fibrous roots
150mm (6")	H	P	*Potentilla anserina*	Silverweed Ciquefoil		1	1		1		3	Prostrate, creeping
150mm (6")	L	P	*Potentilla concinna*	Prairie/Early Cinquefoil		1	1		1		3	Sub-shrub, sub-alpine
150mm (6")	L	P	*Potentilla nepalensis 'Miss Willmott'*	Nepal Potentilla 'Miss Willmott'		1	1		1		3	Clump forming
200mm (8")	M	P	*Ratibida columnifera*	Prairie Coneflower	1	1	1	1			4	Taproot, may spread by seed
150mm (6")	M	P	*Rudbeckia fulgida*	Orange Coneflower	1	1	1	1			4	Bushy upright clump from fibrous and fleshy roots
150mm (6")	L	P	*Rudbeckia hirta*	Wild Black-Eyed Susan	1	1		1	1		4	Self-seeding
150mm (6")	L	P	*Sedum spectabile 'Autumn Joy'*	Autumn Joy Stonecrop	1	1	1		1		4	Drought tolerant, fast growing
200mm (8")	M	G	*Schizachryium scoparium*	Little Bluestem		1		1		1	3	Clump forming
200mm (8")	L	P	*Sisyrinchium montanum*	Blue-Eyed Grass		1	1	1	1		4	Short rhizomes and fibrous roots
150mm (6")	M	P	*Solidago canadensis*	Canada Goldenrod		1	1	1			3	Fibrous root system producing creeping rhizomes; forms colonies
150mm (6")	M	P	*Solidago decumbens*	Mountain Goldenrod		1	1	1		1	4	Dwarf Golden Rod
150mm (6")	L	P	*Solidago rigida/Oligoneuron rigidum*	Stiff Goldenrod		1	1	1			3	Grows from a vertical caudex, non-spreading
200mm (8")	L	G	*Stipa comata*	Needle & Thread Speargrass		1	1	1	1		4	Erect, densely-tufted with fibrous roots
200mm (8")	L	G	*Stipa curtiseta*	Western Porcupine Grass		1	1	1	1		4	Densely tufted, tall bunchgrass with long, flat or in-rolled leaves
200mm (8")	L	G	*Stipa viridula*	Green Needle Grass		1	1	1	1		4	Tufted
200mm (8")	L	P	*Thermopsis rhombifolia*	Golden Bean		1	1	1	1		4	Clump form, colonizing
150mm (6")	H	P	*Veronica incana*	Wooly Speedwell	1	1	1				3	Clump forming
150mm (6")	H	P	*Viola adunca*	Wild Blue Violet		1	1	1			3	Hairy, compact plant growing from a small rhizome system
150mm (6")	H	P	*Viola canadensis*	Western Canada Violet		1	1	1			3	Spreads by rhizomes, may be aggressive
Thick												Plant notes
300mm (12")	L	S	*Juniperus communis*	Common Juniper		1	1	1			3	Woody, prefers acidic soils
300mm (12")	L	S	*Juniperus horizontalis*	Creeping Juniper	1	1			1	1	4	Deep, extensive root system
300mm (12")	L	S	*Rosa acicularis*	Prickly Rose		1	1		1		3	May spread by roots
300mm (12")	L	S	*Rosa arkansana*	Prairie Wild Rose	1	1	1		1		4	Low growing; prickly stems
300mm (12")	L	S	*Rosa woodsii*	Common Wild Rose		1	1	1	1		4	May spread by roots
300mm (12")	L	S	*Symphoricarpos albus*	Snowberry		1		1	1		3	Thicket forming by way of rhizomes or underground stems

<u>Water Need</u>: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk <u>Plant Type</u>: grasses (G), perennials (P), shrubs (S)

Ranking Group 3-4

Profile Depth (minimum)	Water Need	Plant Type	Botanical Name	Common Name	Manufacturer List	Local Nursery Availability	Published or Documented	Native	Suitable Characteristics	Tested	Ranking		Criteria notes
300mm (12")	L	S	*Symphoricarpos albus 'Magic Berry'*	Magic Berry Coralberry		1		1	1		3		Spreading compact habit
300mm (12")	L	S	*Symphoricarpos occidentalis*	Buckbrush/Coralberry		1		1	1		3		Extensive root system; bank stabilizer
300mm (12")	L	S	*Spiraea betulifolia*	Birch-Leaved Spiraea		1		1	1		3		Spreads from extensive root system

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk   Plant Type: grasses (G), perennials (P), shrubs (S)

Ranking Group 5-6

Criteria notes

Manufacturer List: Plants have been included that appear in current manufacturer literature
Local Nursery Availability: Plants currently available and catalogued from local nurseries - 100 km radius
Published or Documented: Plant appears in publications cataloguing plants suitable to our region
Native: Plant is documented or catalogued as native
Suitable Characteristics: i.e.: drought tolerant, hardy, withstands exposed locations, spreading, self seeding
Tested: Has been utilized in previous green roof installations in Calgary, includes test and commercial plantings

Profile Depth (minimum)	Water Need	Plant Type	Plant: Botanical Name	Plant: Common Name	Criteria: Manufacturer List	Criteria: Local Nursery Availability	Criteria: Published or Documented	Criteria: Native	Criteria: Suitable Characteristics	Criteria: Tested	Ranking	Plant notes
Thin												Plant notes
100mm (4")	L	P	*Allium cernuum*	Nodding Onion	1	1	1	1	1		5	Herb; bulb
100mm (4")	L	P	*Allium shoenoprasum*	Chives	1	1	1	1	1	1	6	Herb; bulb
100mm (4")	L	P	*Antennaria dioica 'Rosea'*	Pussy-Toes	1	1	1		1	1	5	Ground cover, spreading
100mm (4")	L	P	*Armeria maritima*	Sea Pink	1	1	1		1	1	5	Compact, grows in low clumps, grass-like
100mm (4")	M	P	*Camplanula rotundafolia*	Harebell Bellflower	1	1	1	1		1	5	Forms a low mound of fine, grass-like leaves, spreads by rhizomes
100mm (4")	L	P	*Geum triflorum*	Prairie Smoke		1	1	1	1	1	5	Each plant has 3 drooping flowers, woolly seed heads, spreads by rhizomes
100mm (4")	L	P	*Sedum kamchaticum*	Russian Stonecrop	1	1	1		1	1	5	Clump forming
100mm (4")	L	P	*Sedum kam. 'Variegatum'*	Variegated Russian Stonecrop	1	1	1		1	1	5	Compact with variegated foliage, spreading with rooting stems up to 30 cm long
100mm (4")	L	P	*Sedum spurium*	Two-row Stonecrop	1	1	1		1	1	5	Creeping
100mm (4")	L	P	*Sedum spurium 'Tricolor'*	Tricolor Stonecrop	1	1	1		1	1	5	Low carpet of small leaves
100mm (4")	L	P	*Sempervirum tectorum*	Purple Hens and Chicks	1	1	1		1	1	5	Forms a basal rosette of succulent sessile leaves, very frost resistant
Medium												Plant notes
200mm (8")	L	P	*Achillea milefolium*	Common Yarrow	1	1	1	1	1	1	6	Herbaceous, spreads by rhizomes
150mm (6")	M	P	*Arctostophylos uva-ursi*	Kinnikinnick/Bearberry	1	1	1	1		1	5	Procumbent plant with very few roots
150mm (6")	L	S	*Artemisia cana*	Sagebrush		1	1	1	1	1	5	Taproot with lateral roots
200mm (8")	L	P	*Artemisia ludoviciana*	Prairie Sagewort		1	1	1	1	1	5	Spreads by rhizomes
200mm (8")	L	G	*Bouteloua gracilis*	Blue Gramma		1	1	1	1	1	5	Shallow-rooted, densely-tufted, with fibrous roots, occasionally with very short scaly rhizomes
200mm (8")	L	P	*Centaurea montana*	Mountain Cornflower	1	1	1		1	1	5	Forms bushy clumps of leaves, may self-seed, spreading
200mm (8")	M	P	*Echinacea purpurea*	Purple Coneflower	1	1	1	1	1	1	6	Grows from a short caudex with fibrous roots
200mm (8")	L	P	*Gailardia aristala*	Gailardia/Indian Blanket		1	1	1	1	1	5	Hairs on leaves resist wind desication, may spread by seed
200mm (8")	M	P	*Liatris spicata*	Purple Gayfeather	1	1	1		1	1	5	Growing from corms
200mm (8")	L	P	*Penstemon nitidus*	Smooth Blue Beardtongue		1	1	1	1	1	5	Single to clump growth
150mm (6")	L	P	*Polemonium pulcherrimum*	Jacob's Ladder		1	1	1	1	1	5	Herb; clump of erect stems
Thick												Plant notes
300mm (12")	L	S	*Potentilla fruticosa*	Shrubby Cinquefoil	1	1	1	1	1		5	Fibrous roots; width of crown spread

Water Need: low (L) - 4mm 3x/wk, medium (M) - 8mm 3x/wk, high (H) - 11mm 3x/wk   Plant Type: grasses (G), perennials (P), shrubs (S)

1

APPENDIX D.

CHECKLISTS

Design Submission Checklist – The proposed green roof must be reviewed prior to construction in order to ensure the system has been designed in such a way as to meet the requirements and performance expectations set forth by the City of Calgary, Water Resources. Drawings and specifications are to be reviewed in tandem with the Design Submission Checklist.

The Checklist is to be completed by a Qualified Third Party and contain the signatures of the owner and/or owner's representative, the designer and the reviewer. Hard copy drawings and specifications must be maintained on site along with the Checklist for the duration of construction.

Construction Completion Inspection Checklist - Inspection at the completion of the construction process is necessary to ensure that the green roof has been constructed according to the plans and specifications as provided through the Design Submission Checklist. If changes to the original approved design have occurred, they are to be summarized on this Checklist or attached to it. Any and all changes must be verified prior to acceptance of the roof as to have not impacted the performance and viability of the approved design.

The Checklist is to be completed by a Qualified Third Party and contain the signatures of the contractor, the designer and the reviewer. This Checklist will also note the final inspection and completion date and the anticipated end of the maintenance and warranty phase.

Maintenance Log/Checklist - As a part of the ongoing evaluation of a green roof that serves as a component in the storm water management system of a site, a yearly maintenance log will be required to be submitted to The City of Calgary – Water Resources. The purpose of the log is to ensure that certain tasks are being performed on an ongoing basis and that components of the green roof are being monitored and evaluated for their continued function.

Maintenance and Warranty Inspection Checklists – Years 1, 2 and 3 – For green roofs installed under this module, the warranty and maintenance period is 3 years from the date of the Construction Completion Inspection Checklist final inspection date. The green roof system must be inspected yearly and in conjunction with the review of maintenance logs, on the anniversary of construction completion. Yearly inspection checklists ensure the green roof is functioning as intended and serve to capture any revisions, modifications, and/or repairs performed during the course of the warranty.

The Year Three Inspection shall act as a final review for the warranty process in order to ensure the green roof is performing as intended and is expected to continue to do so. All Checklists are to be completed by a Qualified Third Party and contain the signatures of the contractor, the designer and the reviewer. Compliance is for the life of the installation and periodic inspections may be requested by the City of Calgary, Water Resources to review ongoing performance of the roof.

Qualified Third Party – is defined as an industry professional (or company) with demonstrated experience with green roof construction and/or specifications that may specialize in architecture, engineering, landscape architecture, construction or the supply and specification of green roof products.

The qualified third party must be a separate entity from the designer and contractor for the green roof under inspection. It is however acceptable for the qualified third party to be a representative of a manufacturer or supplier of green roofing products when propriety materials such as media and plants are being utilized. In all cases, products must meet the guidelines, recommendations and requirements of this module.

For additional clarification on qualified third parties, please contact the City of Calgary, Water Resources.

GREEN ROOF DESIGN SUBMISSION CHECKLIST

NOTE: The undersigned agree and certify that all requirements on this checklist have been reviewed and properly identified as part of this submission. The undersigned understand that this checklist will be used as a tool for review of green roofs by Water Services and confirm that a review of the green roof has been undertaken by a qualified third party. Refer to the City of Calgary document "Source Control Practices Handbook: Low Impact Development Guidelines: Module 3 - Green Roofs: Appendix D" for definition of qualified third party.

	Project location: Address: Unit #:			
	Design information - provide on plans or summary sheet included with submission	YES	NO	N/A
Design information	Location of building(s) with green roof system			
	Surface area of roof:			
	Percent coverage of roof area by growing media:			
	Type and thickness of growing media:			
	If multiple media / thickness used, distinguish between media and thickness, identify coverage and areas:			
	Additional comments:			
Design requirements	Supporting hydrologic computations of the operation of the green roof system, including peak runoff rates and annual runoff volumes are provided.			
	Expected annual runoff amount: ______________________			
	Description of failure mechanism and consequences of failure with respect to level of surface is provided.			
	The system satisfies applicable City of Calgary and province of Alberta building codes, and has been signed off by the required professionals. Submitted drawings are to be stamped and sealed.			
	The growing media have low N- and P- indices to minimize leachate from the media			
	Nitrogen indices: _______________ Phosphorus indices:________________			
	The vegetation has been selected / specified by a qualified individual(s) or entity with green roof specialization and reflects plant types as illustrated in the Source Control Practices, LID module 3 Green Roof manual. List and detail deviations if any on a separate sheet to be included with this form.			
	An Operations and Maintenance (O&M) Manual and Maintenance Log are being proved to the owner of the property for which the green roof is proposed. Maintenance Log to be submitted for review as part of the Construction Inspection Checklist. Refer to Source Control Practices, LID module 3 Green Roof manual.			
	The Erosion and Sediment Control Plan makes provisions to ensure that the growing media will not be mobilized by wind or water forces at any stage during the construction process.			
Plans	List relevant drawing sheets and specification numbers here. Attach hard copy drawings and specifications to this checklist and maintain on site.			

Signatures	In signing below, I/we confirm that the green roof design has been undertaken in accordance to the guidelines and recommendations contained in the City of Calgary document "Source Control Practices Handbook: Low Impact Development Guidelines: Module 3 - Green Roofs" and any applicable Provincial building codes and City regulations and development requirements.		
	Owner / Developer (Name, Address, Phone, Email)	Designer (Name, Address, Phone, Email)	Third Party Review (Name, Address, Phone, Email)
	Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):

GREEN ROOF CONSTRUCTION COMPLETION INSPECTION CHECKLIST

NOTE: Construction completion inspection and this form to be performed and filled out by a qualified third party. Refer to City of Calgary document "Source Control Practices Handbook: Low Impact Development Guidelines: Module 3 - Green Roofs: Appendix D" for definition of qualified third party. The requirements and procedures outlined in this inspection checklist are to be completed in addition to any construction code and building approval requirements. Conforming to the requirements in this checklist in no way supersedes or signifies compliance with building and development regulations for the City of Calgary and the province of Alberta.

Project location: Address: Unit #:

	INSPECTION DATE: mm/dd/yy	YES	NO	N/A
Design and construction	Green roof size and layout is according to approved plans and specifications			
	Vegetation free buffer at penetrations, parapets and curbs installed as required			
	Waterproofing and flashings installed according to manufacturer's specifications			
	Leak test performed			
	Soil sample, texture classification, nutrient analysis and specification submitted for review			
	Slopes greater than 10% incorporate stabilization measures			
	If public access, appropriate safety measures incorporated			
	The submitted samples and materials are as indicated on the approved plans			
	Irrigation drawings, water requirement calculations and specifications submitted for review			
Materials	Drainage components installed as per approved drawings			
	Root barriers installed as per approved plans			
	Water retention mats installed as per approved plans			
	Media depth as indicated on approved plans			
	Soil utilized matches submitted and recorded sample and texture			
	Tackifier samples and specifications submitted if utilized			
	Mulch samples and specifications submitted for review if utilized			
Planting and Irrigation	Irrigation installed as per approved plans - leak test performed prior to covering			
	Plant types, quantity, sizes and species as per design submission - note deviations if any and provide rationale			
	Planting layout as per approved plans - note deviations if any and provide rationale			
	Planting as per construction details - verify depth and mulch cover			
	Irrigation system tested and is operational - note adjustments if required			
	Submit fertilization plan in accordance to Specification Section 32 99 00 or contract requirements.			
	Submit as-built drawings for records - include plant layout, irrigation and all features/components			
	Yearly maintenance log submitted for review			

Signatures

In signing below, I/we confirm that the green roof construction has been undertaken in accordance to the contract documents and specifications and with the policies and procedures set forth in the City of Calgary document noted above.

Contractor (Name, Address, Phone, Email)	Designer (Name, Address, Phone, Email)	Third Party Review (Name, Address, Phone, Email)
Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):

Notes

note corrective actions (if any) required from intial construction completion inspection:

Date of final inspection and construction completion Begin 3 year warranty and maintenance phase:	mm/dd/yy	**Anticpated end of maintenance and warranty phase:**	mm/dd/yy

GREEN ROOF CONSTRUCTION MAINTENANCE LOG

maintenance log for the for the year of _________

Site Name:	Contractor:
Address:	Contractor Contact:
Owner:	Site Contact:

mm/dd	Weeding	Fertilization	Planting	Irrigation Operation	Irrigation Adjustment	Garbage Removal	Drain Inspections	Repairs	Other	**Notes:** List changes and/or deviations (if any) from the original design and provide rationale as to why required. Provide documentation that changes do not detrimentally impact anticipated performance of the installation.	Initial
01/											
01/											
02/											
02/											
03/											
03/											
04/											
04/											
05/											
05/											
06/											
06/											
07/											
07/											
08/											
08/											
09/											
09/											
10/											
10/											
11/											
11/											
12/											
12/											

Legend: C = complete M = monitor for future corrective action R = requires repair

Irrigation Settings	Cycle	Rate	Notes:
Date:			
Date:			
Date:			

Additional Comments: (include date and initials)

GREEN ROOF MAINTENANCE AND WARRANTY INSPECTION - YEAR 1

NOTE: Maintenance and Warranty inspection - Year 1 and this form to be performed and filled out by a qualified third party. Refer to City of Calgary document "Source Control Practices Handbook: Low Impact Development Guidelines: Module 3 - Green Roofs: Appendix D" for definition of qualified third party. The requirements and procedures outlined in this inspection checklist are to be reviewed in conjunction with maintenance logs. The purpose of this form is to ensure the green roof is functioning as intended and to capture revisions/modifications/repairs as required. Conforming to the requirements in this checklist in no way supersedes or signifies compliance with building and development regulations for the City of Calgary and the province of Alberta.

Project location: Address: Unit #:

	INSPECTION DATE: mm/dd/yy	Y	N	n/a	Notes:
Design Elements	Vegetation free buffer at penetrations, parapets and curbs				
	Waterproofing and flashings in good repair, indicate testing method				
	Monitoring and absence of roof leaks				
	Media depth as per approved plans (note changes)				
	Soil test to determine fertilizer application				
	If public access, appropriate safety measures in good repair				
	Plant performance, note replacements or changes to design				
	Min cover after 1 growing season 60%, spacing <500 mm				
	Completed yearly maintenance log submitted for review				

Irrigation

Irrigation cycle

Irrigation delivery schedule

Fertilizer

Spec requirements

Soil Testing Lab Name and Address

Results and recommendations

Rate and application date

Signatures

In signing below, I/we confirm that the green roof inspection has been undertaken in accordance with the policies and procedures set forth in the City of Calgary document noted above.

Contractor (Name, Address, Phone, Email)	Designer (Name, Address, Phone, Email)	Third Party Review (Name, Address, Phone, Email)
Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):

Notes

Summarize corrective actions required / performed in accordance with project specifications:

GREEN ROOF MAINTENANCE AND WARRANTY INSPECTION - YEAR 2

NOTE: Maintenance and Warranty inspection - Year 2 and this form to be performed and filled out by a qualified third party. Refer to City of Calgary document "Source Control Practices Handbook: Low Impact Development Guidelines: Module 3 - Green Roofs: Appendix D" for definition of qualified third party. The requirements and procedures outlined in this inspection checklist are to be reviewed in conjunction with maintenance logs. The purpose of this form is to ensure the green roof is functioning as intended and to capture revisions/modifications/repairs as required. Conforming to the requirements in this checklist in no way supersedes or signifies compliance with building and development regulations for the City of Calgary and the province of Alberta.

Project location: Address: Unit #:

	INSPECTION DATE: mm/dd/yy	Y	N	n/a	Notes:
Design Elements	Vegetation free buffer at penetrations, parapets and curbs				
	Waterproofing and flashings in good repair, indicate testing method				
	Monitoring and absence of roof leaks				
	Media depth as per approved plans (note changes)				
	Soil test to determine fertilizer application				
	If public access, appropriate safety measures in good repair				
	Plant performance, note replacements or changes to design				
	Min cover after 2 growing seasons 80%, spacing <300 mm				
	Completed yearly maintenance log submitted for review				

Irrigation

Irrigation cycle

Irrigation delivery schedule

Fertilizer

Spec requirements

Soil Testing Lab Name and Address

Results and recommendations

Rate and application date

Signatures

In signing below, I/we confirm that the green roof inspection has been undertaken in accordance with the policies and procedures set forth in the City of Calgary document noted above.

Contractor (Name, Address, Phone, Email)	Designer (Name, Address, Phone, Email)	Third Party Review (Name, Address, Phone, Email)
Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):

Notes

Summarize corrective actions required / performed in accordance with project specifications:

GREEN ROOF MAINTENANCE AND WARRANTY INSPECTION - YEAR 3 - FINAL INSPECTION

NOTE: Maintenance and Warranty inspection - Year 3 - Final Inspection and this form to be performed and filled out by a qualified third party. Refer to City of Calgary document "Source Control Practices Handbook: Low Impact Development Guidelines: Module 3 - Green Roofs: Appendix D" for definition of qualified third party. The requirements and procedures outlined in this inspection checklist are to be reviewed in conjunction with maintenance logs. The purpose of this form is to ensure the green roof is functioning as intended and to capture revisions/modifications/repairs as required. Conforming to the requirements in this checklist in no way supersedes or signifies compliance with building and development regulations for the City of Calgary and the province of Alberta.

	Project location: Address:				Unit #:
	INSPECTION: mm/dd/yy	Y	N	n/a	Notes:
Design Elements	Vegetation free buffer at penetrations, parapets and curbs				
	Waterproofing and flashings in good repair, indicate testing method				
	Monitoring and absence of roof leaks				
	Media depth as per approved plans (note changes)				
	Soil test to determine fertilizer application				
	If public access, appropriate safety measures in good repair				
	Plant performance, note replacements or changes to design				
	Min cover after 3 growing seasons 90%, spacing <25 mm				
	Completed yearly maintenance log submitted for review				
Irrigation	Irrigation cycle				
	Irrigation delivery schedule				
Fertilizer	Spec requirements				
	Soil Testing Lab Name and Address				
	Results and recommendations				
	Rate and application date				

Signatures	In signing below, I/we confirm that the green roof inspection has been undertaken in accordance with the policies and procedures set forth in the City of Calgary document noted above.		
	Contractor (Name, Address, Phone, Email)	Designer (Name, Address, Phone, Email)	Third Party Review (Name, Address, Phone, Email)
	Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):	Signature and Date (mm/dd/yy):
Notes	Summarize corrective actions required / performed in accordance with project specifications:		
	Date of final inspection and conclusion of warranty and maintenance phase:	mm/dd/yy	

APPENDIX E.

PERFORMANCE OF GREEN ROOF SYSTEMS

Water Quantity Benefits

Stormwater retention in green roof systems depends on the water holding capacity and depth of substrate, antecedent moisture conditions, rainfall intensity and/or precipitation depth, irrigation, and composition and extent of plant coverage (Getter et al. 2007; Mentens et al. 2006; Villarreal and Berndtsson 2005).

Field monitoring data for green roofs in various regions including Calgary have recorded significant benefit from green roofs on runoff volume control, showing volume reduction is an undeniable benefit not always afforded by "on the ground" LID devices. Studies cite annual precipitation retention of 50-75 % for periods of data collection greater than a few months (Hutchinson et al. 2003; Mentens et al. 2006; Moran et al. 2005; Villarreal and Bengtsson 2005; Westhoff Engineering Resources, Inc., 2008). Shorter duration studies (< 6 months) have reported slightly less retention compared to precipitation (DeNardo et al. 2005; Liu 2003; Moran et al. 2005).

The ranges in retention observed is thought to be partly due to time of year studied, sampling methods, climate, and the method used to calculate retention. Gregoire and Clausen (2011) concluded that there are many factors that affect the amount of precipitation retained by a green roof but one that is in control of the designer is a higher water holding capacity of growing media.

Modelling is a tool that can be used to predict rainfall retention benefits. Past modeling studies have predicted between 45-55 percent of annual precipitation runoff retention for extensive green roofs (Berghage et al. 2007; US Environmental Protection Agency 2000). The City of Calgary has released a water balance spreadsheet model that can be used to estimate benefits annual precipitation retention benefits. The intended purpose of the model was to simulate the precipitation-runoff processes for urban catchment areas within the City of Calgary. The model can also be used to evaluate the performance of source control practices and stormwater management facilities.

There are many representative methods to specify green roof parameters based on drainage area and expected performance. While the Water Balance Spreadsheet for the City of Calgary (WBSCC) model was not designed to have the capability to represent all features of green roof components, a reasonable representation can be done to match relevant input parameters.

The most difficult aspect in using the spreadsheet model for representing engineered green roof media characteristics is in representing the engineered media of green roofs through standard modelling of soil characteristics such as percent sand, silt, and clay, porosity, field capacity, wilting point, saturated hydraulic conductivity, and an evapotranspiration modification factor. Similar issues can be found with other approaches found in the City of Calgary Stormwater and Design Manual.

Some design techniques such as the Rational Method and Soil Conservation Service method (SCS) require runoff coefficients and curve numbers which should reflect general green roof specifications including media depths and should be regionally or locally calibrated. Runoff coefficients typically range from 0.5 to 0.85 for green roofs, with those with 150 mm or more of media depth having values closer to 0.5. Shallower green roof media (e.g., 75-100 mm), which may be appropriate for retrofit of green roofs or to achieve other objectives, have runoff coefficients of 0.74-0.85.

Curve number values should typically be between 63 and 90. Estimates for adjusted curve numbers as a function of media depth suggest values of 88, 82, 73, and 68 for media depths of 100 mm, 150 mm, 225 mm, and 300 mm, respectively, although variability is expected between wet and dry seasons. Other calculations such as Horton's equation require parameters such as a decay coefficient and drying time which have not been well documented for green roofs. See the City of Calgary Stormwater Management Manual for the use of other runoff estimation methods.

Within the WBSCC model (and similar input to other models), the determination of media water content and runoff for green roof media is similar to how it is represented for other pervious surfaces within the tool. For seepage, the procedure is slightly different to account for the lack of subsoil. The effective water content of the media mass is calculated as depth of media times the water content at any given time. The field capacity of media limits the seepage while the water content varies between the wilting point, field capacity, and the porosity of the media under normal conditions. If ponding is allowed, which is typically not the case for green roofs other than through subsurface retention mats, additional water retention beyond porosity can be represented.

The model was run with the input values listed in Table E-1. Also shown in the table is the comparable range of values from the FLL. Changes to input variables can result in predictions of water balance performance providing a better understanding of how design variations can potentially affect green roof performance.

Table E-1.
City of Calgary Water Balance Spreadsheet Model Input Values and FLL Range Categories.

Parameter	WBSCC		FLL Values				
	Input value low	Input value high	Very low	Low	Medium	High	Very high
Organic Matter (% dry weight)	3	8†	< 0.5	0.5 to 2	2 to 4	4 to 10	>10
Percent Fraction of Silt and Clay	1	10	<0.5	0.5 to 1	1 to 5	5 to 10	>10
Field Capacity (%)	8	28	< 12	12 to 23	23 to 35	35 to 46	>46
Hydraulic Conductivity (mm/hr)	200	250	< 25	25 to 125	125 to 250	250 to 500	>500
Dry Bulk Density (g/cm3)	0.94	1.27	< 0.80	0.80 to 0.96	0.96 to 1.12	1.12 to 1.28	>1.28

†High value of organic matter is limited based on the potential for leaching.

The most significant design parameter that is an important design variable for green roofs is media depth. This variable then was used as the dependent variable to determine the outcome when other variables change. Several other variables thought to be critical for performance and plant survivability include irrigation, inclusion of drainage mats, and the amount of organic matter in media. Modeling using the WBSCC model was done to evaluate these variables.

Following many model runs to determine the most sensitive parameters several assertions can be made. The first is that changes in irrigation amounts can significantly affect annual precipitation retention (Figure E-1). Irrigation regimes of no irrigation, low irrigation of 264 mm/year (application of 4 mm, 3 times/week for 22 weeks), and high irrigation of 726 mm/year (application of 11 mm, 3 times/week for 22 weeks) were used in the model.

These irrigation regimes are typical of existing irrigation schedules based on native vegetation and landscape plant requirements in the Calgary region. As can be seen, the range of annual precipitation retained on the green roof varies from 10% to nearly 100% depending on media depth. Differences low and high irrigation regimes make on annual precipitation retained is significant.

Green roofs with shallower (< 100 mm) media depths can retain about 67% of the annual rainfall for 12mm of irrigation per week (low irrigation regime) but perform much poorer for higher irrigation regimes (33 mm of irrigation per week), achieving about 12% annual precipitation retained. However for deeper (300 mm) media depths, the annual precipitation retained is much greater than the shallow media with low irrigation achieving nearly 97% while high irrigation results in about 62% of precipitation retained overall.

It is recommended then that media thickness and irrigation regimes be considered for each green roof application and the overall objectives. From a water balance perspective, media depth should not be less than 100-150 mm. If this shallower media depth is selected, irrigation regimes should be lower, reflecting the low irrigation regime modeled to achieve water quality and quantity benefits. Likewise, the plant palette selected for the shallower roof media and low irrigation regime should be selected based on these constraints.

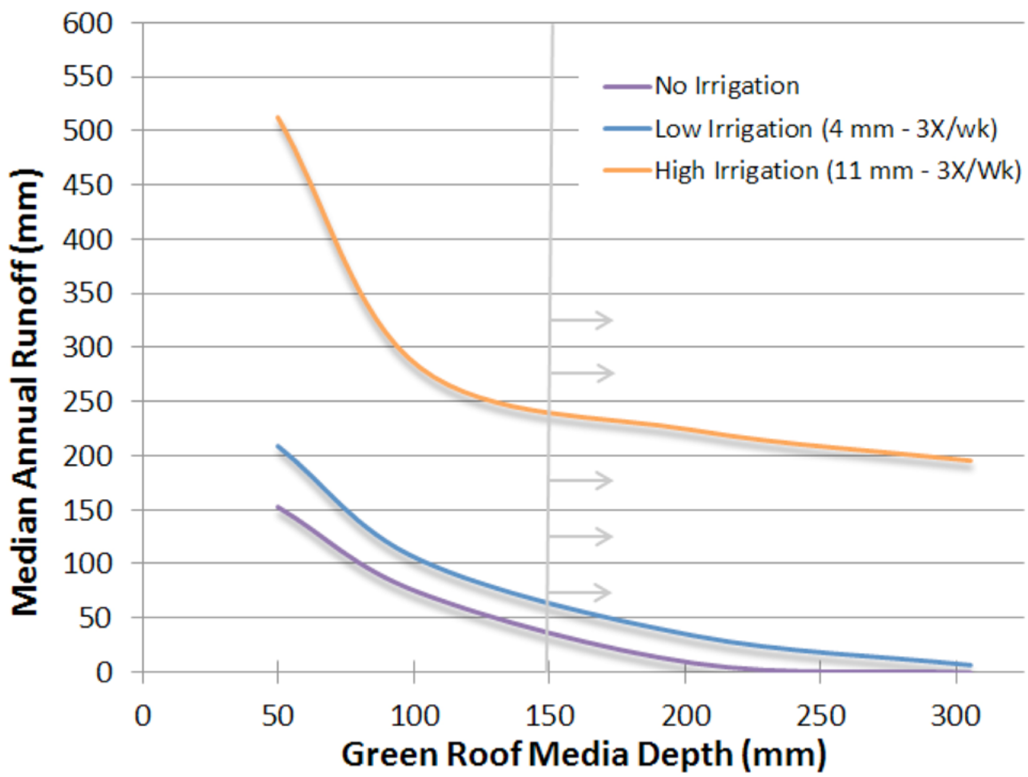


Figure E-1.
Annual runoff based on irrigation.

If higher irrigation rates are needed for plant survivability or other needs, additional on-site storage or re-use would be required.

While much less significant, model runs for retention mat volume were also analyzed having individual effects of up to 20 percent at shallower media depths but little to no affect at media depths greater than about 200-250 mm (Figure E-2).

The parameters in Table 3 that most influenced the rate of runoff from green roofs was the percent of organic matter, which in the WBSCC changes the porosity, field capacity, wilting point, and the saturated hydraulic conductivity. Figure E-3 demonstrates the benefit in reduction of runoff with using a high value (8%) organic matter compared to a lower value (2%) (shown with irrigation).

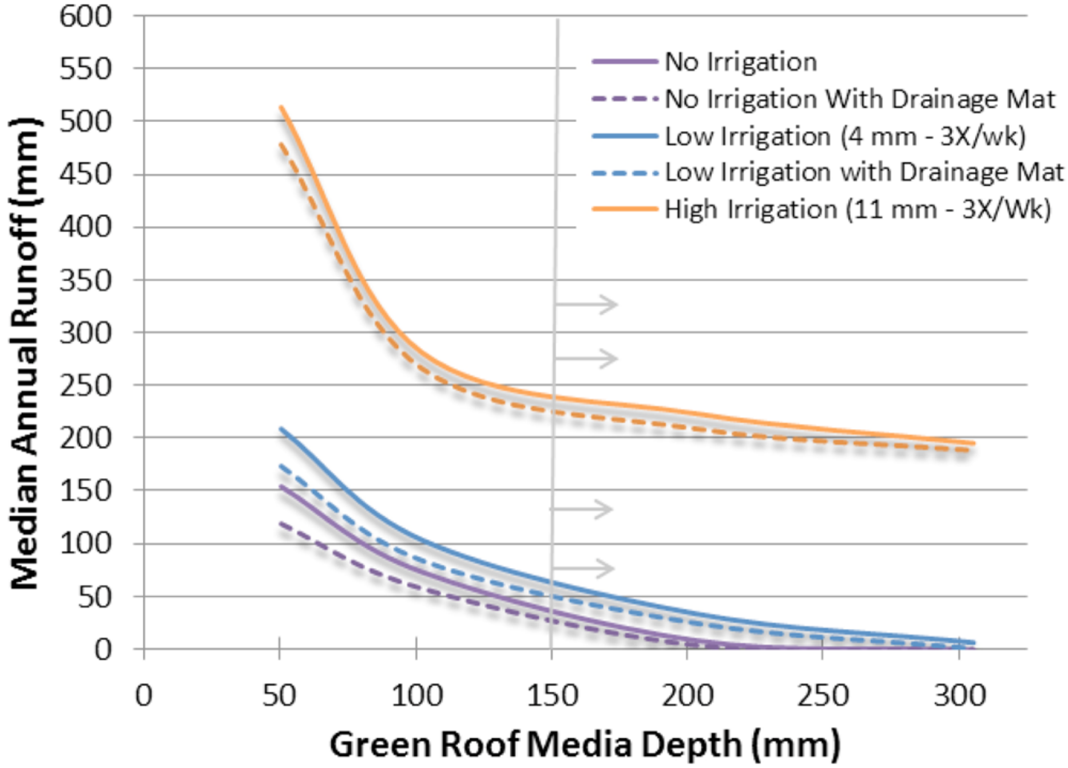


Figure E-2.
Annual runoff based on inclusion of drainage mats and irrigation.

Overall, the percent of organic matter content in the media had similar result to drainage mats with about a 20% difference at shallower media depths when 8% of organic matter is used. These results along with the FLL guidelines suggest that the percent organic matter should be specified to between 2 and 10 percent to meet plant needs and improve water holding capacity, with 8% recommended. This value is thought to maximize runoff retention but limit potential export of nutrients.

Media depth had a significant impact on water retention with depths below 100 mm much lower than depths above 150mm. This would suggest that media depth and anticipated irrigation demand might be the dominant determinants for annual water retention performance. Similarly, these two variables are key factors in selecting the plant palate most suitable for green roofs. Drainage mats and organic matter content are also variables that can affect overall performance. Figure E-4 shows the modeled scenario resulting in the least runoff. This scenario had 8% organic matter and a 5 L/m2 drainage mat.

With this modeled "best case" scenario allowing about 16 mm, 27 mm, and 210 mm of predicted runoff per year for no irrigation, low irrigation, and high irrigation green roofs, respectively. Even though these modeling scenarios for the green roofs do not retain all runoff, one must recognize the benefit that they provide and understand that additional source control practices may be required to achieve water quantity and runoff objectives. This is notable for the Nose Creek, West Nose Creek, and Pine Creek watersheds which already have determined runoff targets.

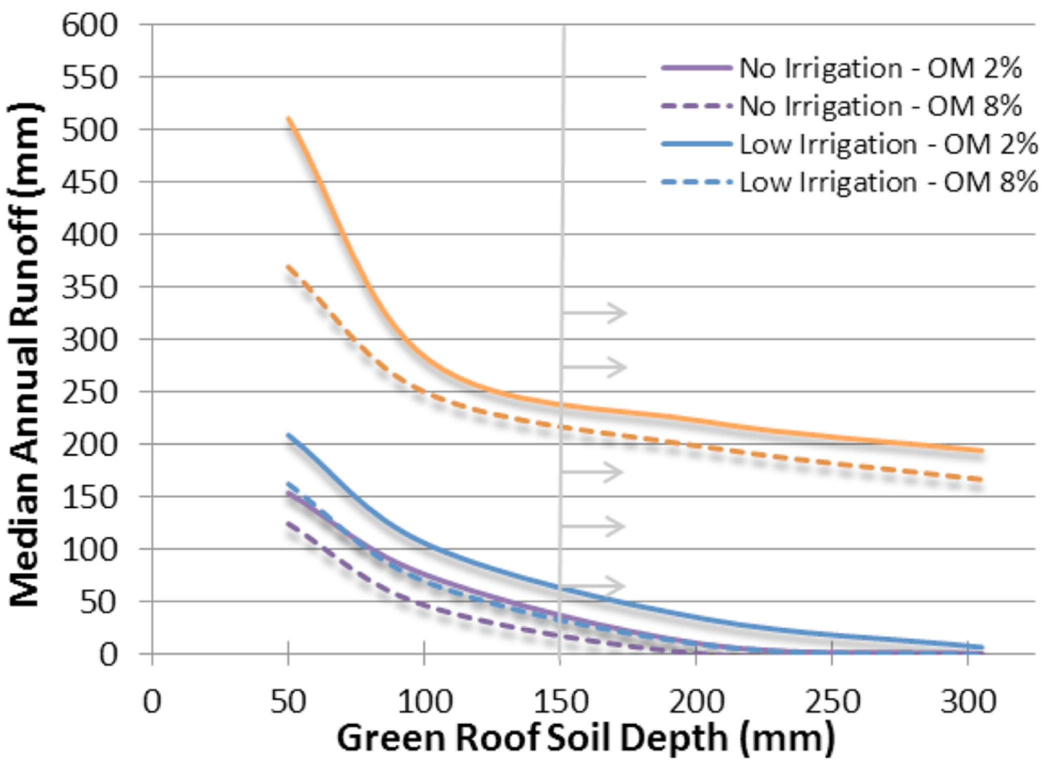


Figure E-3.
Annual runoff based on organic matter, irrigation regime, and media depth.

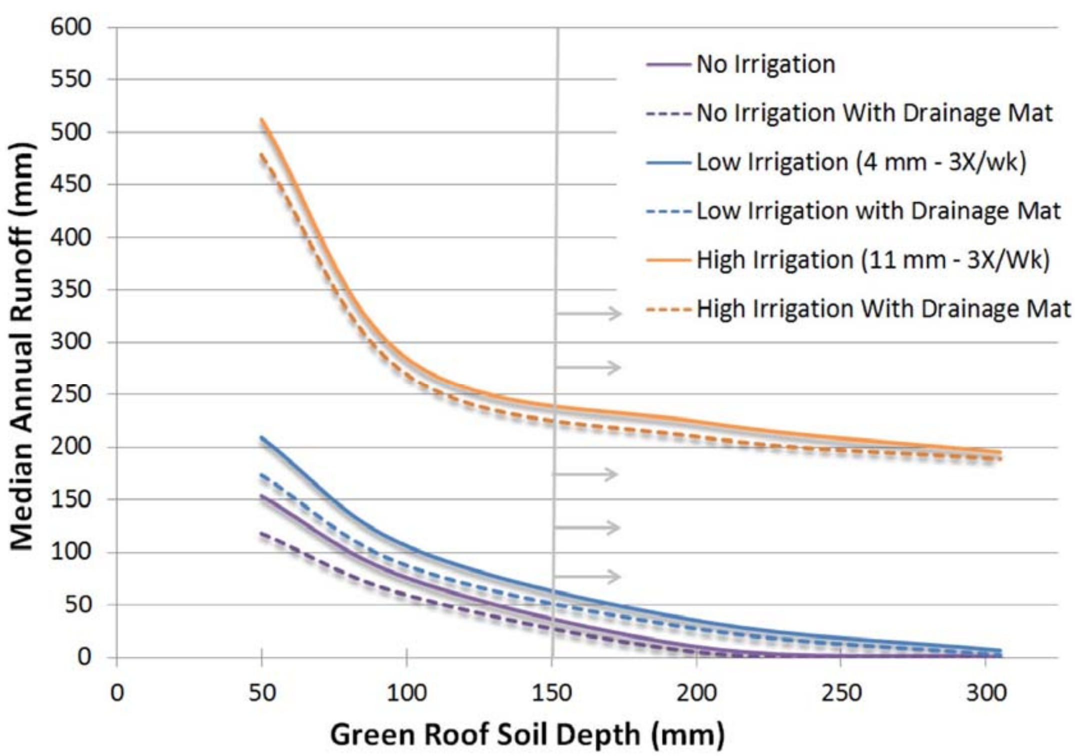


Figure E-4.
Annual runoff based on irrigation regime and 5L/m² drainage mat.

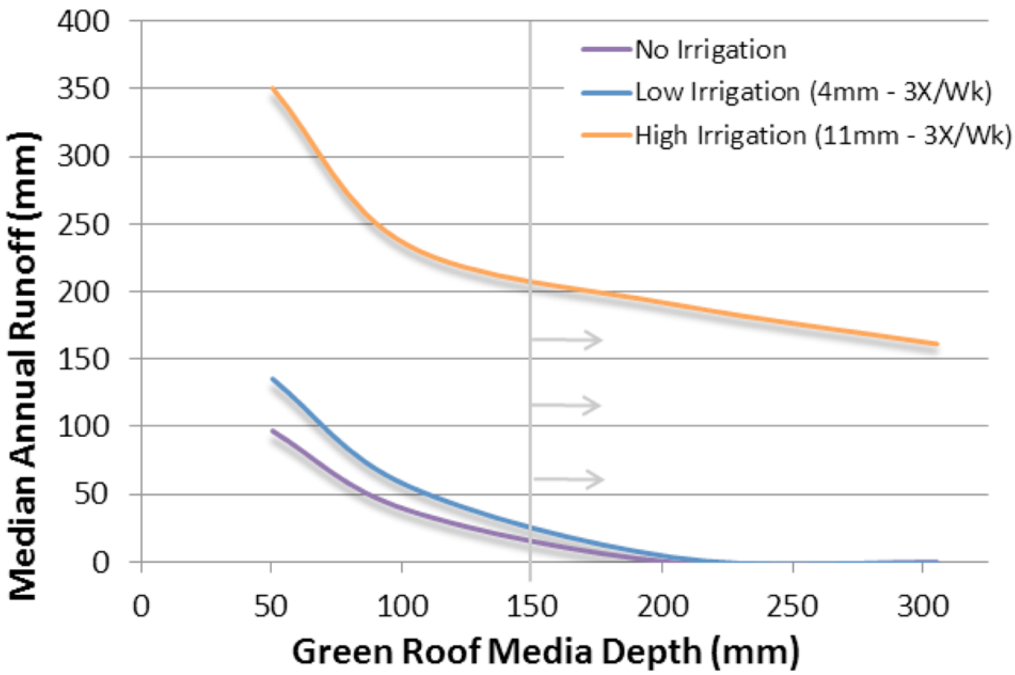


Figure E-5.
Annual runoff based on 8% organic matter and 5L/m² drainage mat.

Peak flow reductions are another water quantity benefit with studies often showing between a 50% and 87% peak flow reduction depending on the region and type of rain event. Berghage et al. (2007) cites several German studies that report about 50 percent peak flow reductions while Hutchinson et al. (2003) report an 80 percent peak flow reduction for individual storm events from a Portland, Oregon (USA) green roof over a 15-month period.

Moran et al. (2005) saw an average of 87 and 57 percent reductions compared to peak rainfall for two different sites in North Carolina (USA). Peak flow was not modeled for the guidance as the model operates on a daily time step. Other methods such as the rational method, graphical peak discharge method, National Resources Conservation Service (NRCS) tabular method (e.g., TR-55), and unit hydrograph method can be used to predict peak flow.

Water Quantity Testing and Assurance

An understanding of the media characteristics is necessary to assure water quantity benefits of the green roof installation. Laboratory testing can be used to determine the values of individual components and subsequent substrate blends. Many of these tests are detailed through a combination of FLL (2002) testing protocols and common Canadian agronomic methods.

Critical values include (but are not limited to): dry-bulk density, hydraulic conductivity (similar to saturated permeability which describes the media properties), and plant available water (estimated by the difference between field capacity and the permanent wilting point [Fassman and Simcock, 2012]).

However, plant available water can also be determined in the laboratory using agronomic methods (e.g. tension test over range 10-1500 kPa [0.1-15 bar] as described by Gradwell and Birrell (1979). The media is often considered to be at permanent wilting point when the water potential in the soil is at or below -1.5 MPa.

Estimates of these values can also be obtained by relating the green roof media to the texture of the soils (see Saxton and Rawls, 2006). Laboratory testing however is recommended on media initially to better understand the properties compared to the tool used for determining benefits (Dane and Topp, 2002). In situ testing while more difficult is also feasible. However, double or single-ring infiltration methods as testing for infiltration or hydraulic conductivity (saturated permeability) are not appropriate to test green roof systems.

Moisture content below the permanent wilting point (also known as ‘hygroscopic water’) generally cannot be accessed by the plants for transpiration, is a relatively small volume, and is unlikely to be “lost” to the atmosphere except under more extreme temperatures.

Water Quality Benefits

Green Roofs can provide benefits to water quality, especially when considering the potential for annual load reductions. While several studies have shown an increase in nutrient concentrations in runoff from green roofs others have shown that this may be a temporary result as media are conditioned. Excess phosphorus concentrations in runoff from green roofs has been shown in a number of studies (Berndtsson et al., 2006, 2009; Hathaway et al., 2008; Hutchinson et al., 2003; Köhler and Schmidt, 2003; Liptan and Strecker, 2003; MacMillan, 2004; Monterusso et al., 2004; Teemusk and Mander, 2007).

Quantities of compost in the soil media as well as the amount of fertilizer applied to the systemare cited reasons for this outcome (Berndtsson et al., 2009; Emilsson et al., 2007; Hathaway et al., 2008; Teemusk and Mander, 2007). An increase in the concentration of total suspended solids total dissolved solids, and chemical oxygen demand (COD) as well as Copper (Cu), lead (Pb) and arsenic (As) has also been observed in the effluent from green roofs (Glass et al., 2007) These can exceed allowable limits in some locations. However, Gregoire and Clausen (2011) found that average retention rates of about 32% for total nitrogen (N), 34% for total Kejldahl N, 23% for nitrate-nitrite N, and 11% for ammonia compared to control roof retention. Both total phosphorus and orthophosphate were exported by the study roofs but showed less export than the control roofs.

Total metal concentrations of lead, zinc, and mercury from green roof effluent had percent loading reductions of 100, 66, and 61 percent, respectively. Dissolved forms of the metals also had loading removals of 100, 71, and 32 percent for of lead, zinc, and mercury, respectively. While green roofs have been shown to be a sink for NH3–N, Pb and Zn, with minor retention of TN and TKN, volume reduction will reduce total loading for most water quality constituents.

Figures E-6 through to E-10 show potential reductions of loading based primarily on volume reduction but also low and high concentration values from selected local and international studies with green roof outflow concentration data studies.

The range of values for effluent water quality load should be between the low and high values (or error bars). The selected values did not exclude background concentrations (and loading) that may be included in the rainfall. Volume reduction values were calculated using primarily sand media and with no irrigation. This would be expected to provide a conservative loading estimate as irrigation would likely result in dilution of effluent concentrations.

While many other water quality constituents can be predicted using this method, those reported were for common constituents of concern and those for which local data was available. Annual values can be prorated to a storm event based on actual rainfall data and the runoff from the green roof beyond the designed retention volume.

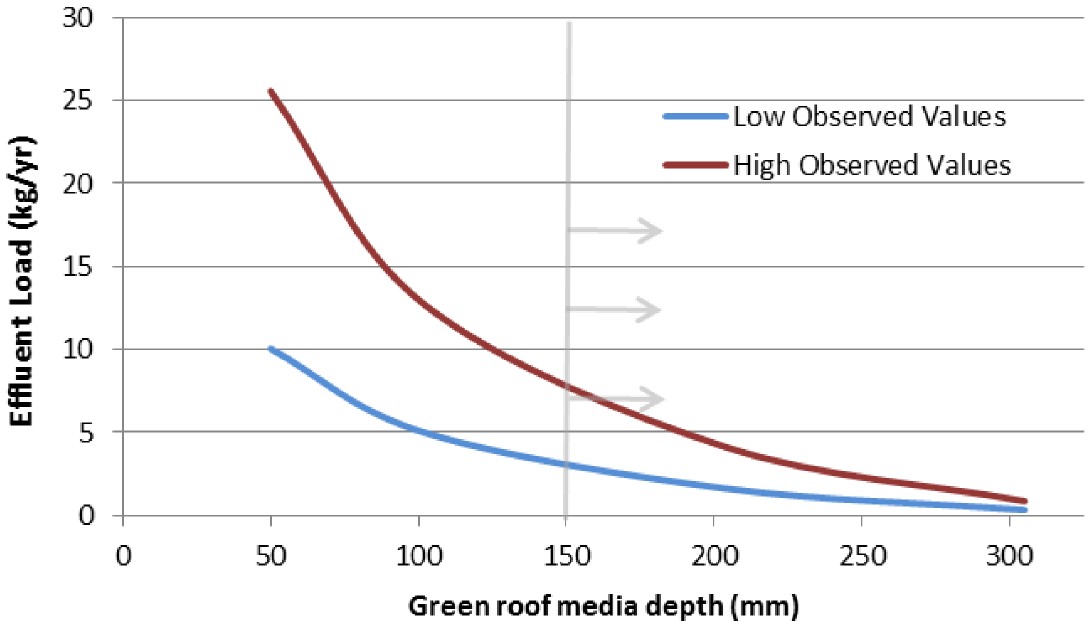


Figure E-6.
Observed annual load of total ammonia.

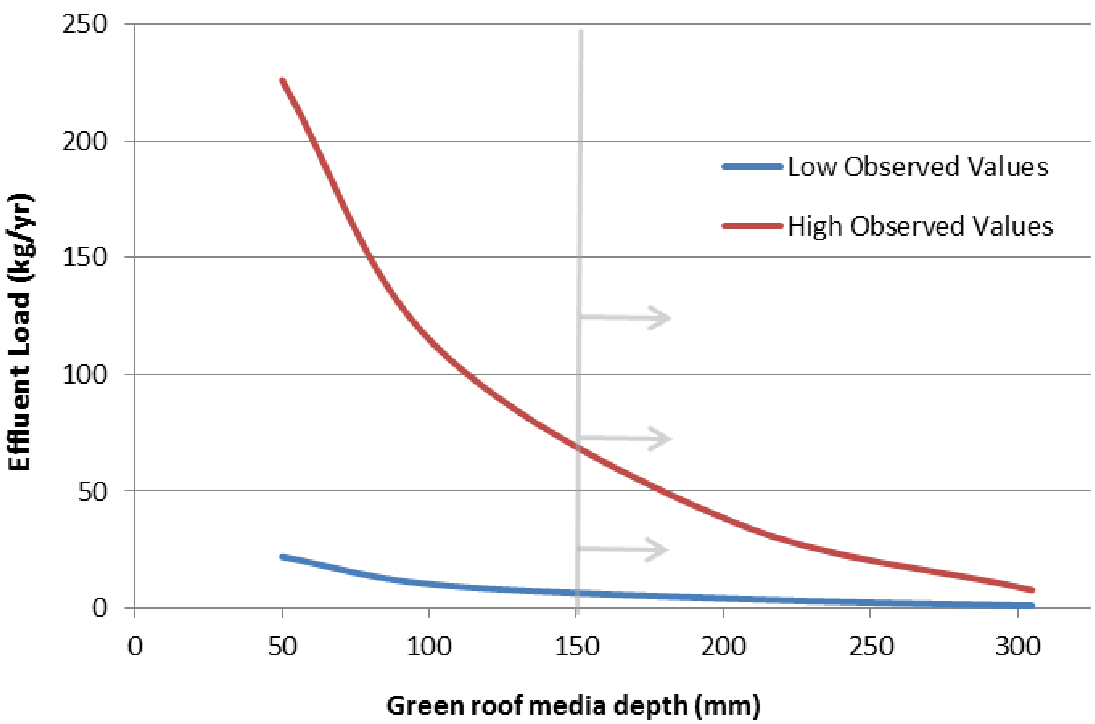


Figure E-7.
Observed annual load of orthophosphate.

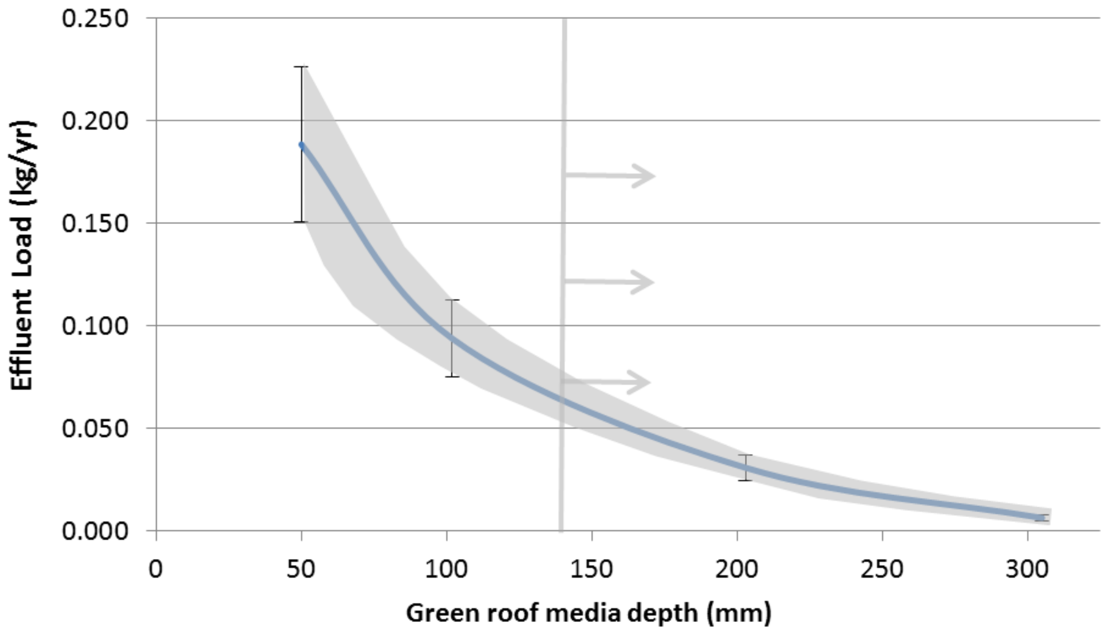


Figure E-8.
Observed annual load of total copper (error bars represent a 20% uncertainty).

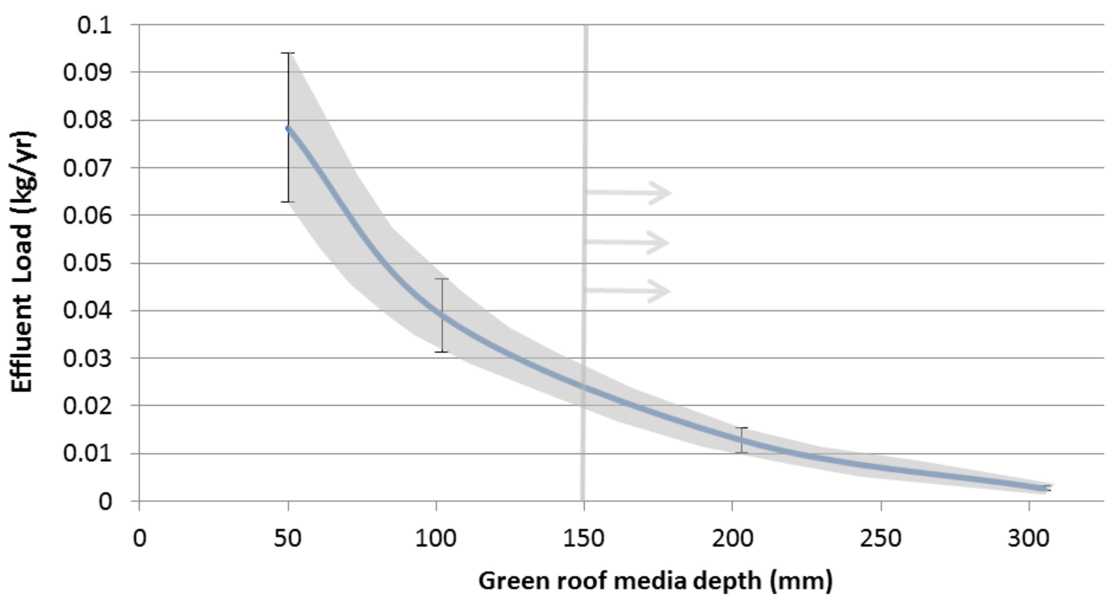


Figure E-9.
Observed annual load of total zinc (error bars represent a 20% uncertainty).

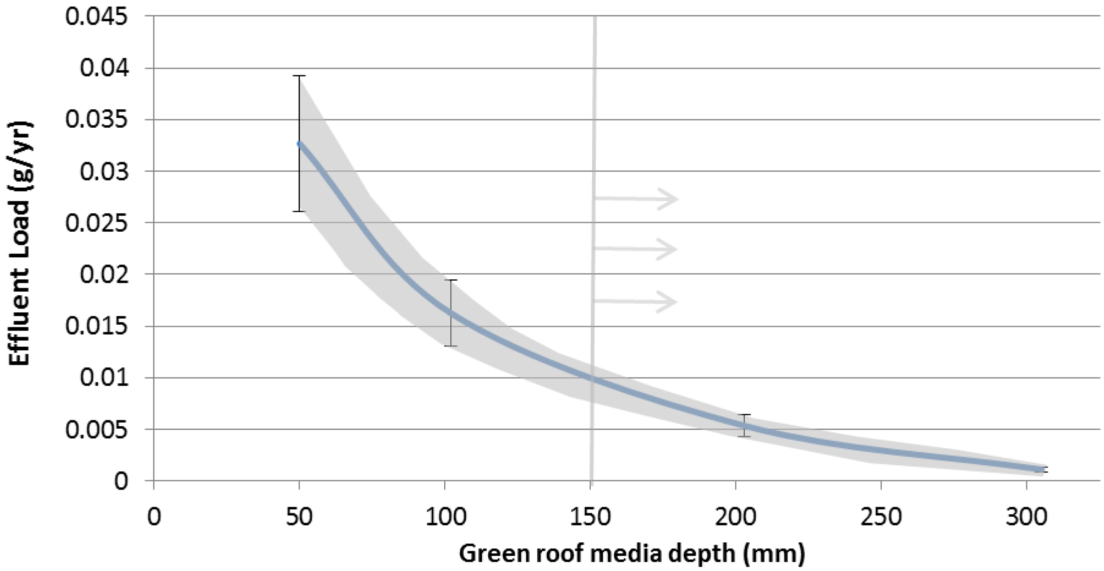


Figure E-10.
Observed annual load of total mercury (error bars represent a 20% uncertainty).

The range of values for effluent water quality load should be between the low and high values (or error bars). The selected values did not exclude background concentrations (and loading) that may be included in the rainfall. Volume reduction values were calculated using primarily sand media and with no irrigation. This would be expected to provide a conservative loading estimate as irrigation would likely result in dilution of effluent concentrations. While many other water quality constituents can be predicted using this method, those reported were for common constituents of concern and those for which local data was available. Annual values can be prorated to a storm event based on actual rainfall data and the runoff from the green roof beyond the designed retention volume.

APPENDIX F.

GREEN ROOF MONITORING

Monitoring Considerations and Approaches

There are two primary needs for green roof monitoring: one is to determine green roof performance; the other is for monitoring maintenance. The latter is addressed in Section 6 and with a checklist in Appendix D. Developing a green roof monitoring program that produces useful results indicating the performance of the system (the water quality and water quantity benefits of a green roof) that meet the project objective can take significant thought before any samples are collected. One method when considering how to organize a green roof performance monitoring program is to divide it into four phases:

- Planning
- Design
- Implementation
- Evaluation

1. The Planning Phase - is a critical first step in developing an efficient green roof performance monitoring program. In the planning phase, program goals are defined, background information is collected and resources are identified. Using this information, specific project objectives can be formulated. These objectives form the framework within which the remainder of the performance monitoring program is designed, implemented and evaluated. Well defined goals and objectives are the most fundamental step in the development of a monitoring plan.

2. The Design Phase - translates the objectives into an action plan. Issues that need to be defined include monitoring approach, parameter selection, hydrologic data collection protocols, water quality data (including chemical, physical, and biological parameters) collection protocols, identification/selection of equipment and materials, and quality assurance/quality control (QA/QC) initiatives. The product of the design phase should be a quality assurance project plan (QAPP) that lays out these details, providing a pathway for meeting the monitoring program objectives. This phase is the foundation of the project and should be given considerable attention. A poorly-designed monitoring program could produce misleading data and erroneous conclusions, resulting in great deal of wasted time and money.

In designing a monitoring program the characteristics specific to green roof design must be considered. These characteristics affect the ability to measure effluent flow rates and particular pollutants of concern, as well as the ease of monitoring.

Typical performance monitoring includes parameters such as rainfall, effluent from green roof, and water quality sampling of effluent often as a composite or event mean sample. Potential monitoring issues with green roofs can include difficulty in isolating outflow points (including drainage mats). Maintenance regime should also be documented. It is best to use a comparative roof to compare monitoring values with compared to rain concentrations as typical asphalt or shingle roofs can also contribute particulates and other chemical constituents.

Table F-1 presents important parameters that should be considered when monitoring green roofs as well as the watershed significance for monitoring that parameter. This list can be tailored to the individual water body to which the green roof discharges.

Table F-1. Potential Monitoring Parameters

Parameter	What to Monitor	Watershed Significance
Flow regime	• Outflow (flow rate and volume) from Green Roof • Irrigation to Green Roof • Precipitation	• Water flow rates affect pollutant wash-off and transport • Flow variations affect channel stability and fish habitat • Maintaining pre- and post-development water balance
Nitrates	• Nitrate concentration (event mean concentration) of outflow	• Sources can include breakdown of organic matter and fertilizer leaching • Groundwater, point and non-point sources • Nutrient affecting algae growth, potentially toxic to fish and a drinking water issue in groundwater
Total phosphorus	• Phosporus concentration (event mean concentration) of outflow	• Sources can include breakdown of organic matter and fertilizer leaching • Nutrient affecting algae growth • Can be a point and non-point sources
Metals (Ni, Cu, Al, Zn, Fe)	• Metals concentrations (event mean concentration) of outflow	• Relates to specific source depending on metal – background mineral, urban runoff or point source.

The number of possible parameters that may be measured in a green roof monitoring program can be extensive. It is often impractical to measure all the parameters. Therefore select constituents should be determined based on their how the information will satisfy the monitoring objectives. The most important parameters would likely be water balance and nutrients. The design phase of a green roof monitoring program should include the selection of appropriate parameters and the location where outflow can easily and reliably be measured.

The questions in Table F-2 address a list of key considerations that may be useful during the parameter selection process.

Table F-2. Key questions for monitoring programs.

Question	Key Considerations
What parameters are required to meet the monitoring program objectives and goals?	If the monitoring program objectives are well defined, this may be the only question that needs asking. The objectives and goals will depend in part on the given type of monitoring program. Parameters which are appropriate to meet the objectives and goals of a baseline monitoring program to establish green roof design may be different from those of an effective monitoring program. Further, green roofs may be implemented for many reasons, which could include regulatory compliance or protection of sensitive ecosystems, etc. These reasons typically define the monitoring objectives and goals and, in turn, the list of appropriate parameters. For example, if a green roof is constructed to aid in the compliance with water quality criteria or standards for phosphorus must be measured.

Question	Key Considerations
Do any regulatory or legal requirements apply to the green roof or its receiving waters?	Those parameters specified in any regulatory requirements or court-ordered legal requirements must be included in the green roof monitoring program. Applicable surface water quality standards of the receiving water should be reviewed before the final parameter selection. For example, if the water quality criteria specify levels for total metals and the monitoring plan only calls for soluble metals or vice versa; the data may not be able to answer key questions concerning the effectiveness of the green roof.
What are the beneficial uses and impairments (if any) of the receiving water?	Beneficial uses or impairments of receiving waters are often the underlying reason for green roof implementation. Monitoring programs can be used as verification that the Green roof is fulfilling its intended purpose. It has been recognized that in many instances the water quality problem will directly indicate what variables should be monitored. For instance, if the Green roof discharges near a public beach, pathogens or bacterial indicator monitoring will be important. Or, if the Green roof discharges to a stream that supports a healthy game fish population, then in-stream biological indicators may be useful.
Are there any parameters that are particularly useful for evaluating the type of green roof being monitored?	Some parameters will be more important than others, depending on the type of Green roof being monitored (e.g., extensive, semi-intensive, intensive).

3. The Implementation Phase - involves three main actions: equipment installation and testing, sample handling and processing, and preliminary review of results. The preliminary review of results compares collected data against the quality assurance and quality control (QA/QC) initiatives verifying that data and other checks are within reasonably expected ranges. All results that fail the QA/QC measures should be flagged and eliminated if necessary.

Figure 2. Example of monitoring equipment for a Green Roof.

4. The Evaluation Phase - once a good set of quality assured data has been produced, the evaluation phase begins. The evaluation phase has one main objective: data analysis. Sample processing typically produces pollutant data in the form of concentrations. Pollutant loads can be calculated through the mathematical combination of concentration data with the associated flow data. Loads are useful information when evaluating long-term impacts.

Green roof pollutant removal efficiency can be calculated using any number of methods, including percent removal, summation of loads, regression of loads, reduction in mean concentration, irreducible concentration, achievable efficiency, removal relative to water quality limits, various multi-variate and non-linear models, effluent probability method and linear regression of input versus output concentrations. The most common method to evaluate the pollutant removal efficiency of a green roof is percent of rainfall retained and load reduction from a comparative control roof or concentrations in collected rain.