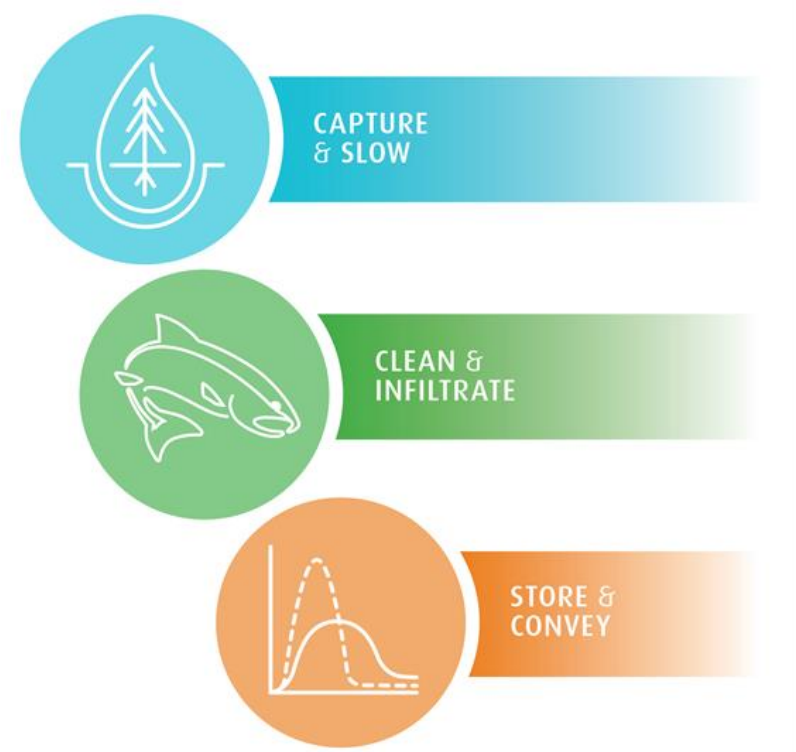

APPENDIX H – EXTENSIVE GREEN ROOFS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Green Roof Systems[1]

Description

A green roof is a conventional roof with a waterproof membrane and layers of drainage and growing medium that support living vegetation.

Green roofs with a relatively shallow growing medium thickness (less than 300 mm) are generally called 'extensive green roofs'. They may be designed for stormwater management, insulation and climate amelioration functions, and usually have no public access. Vegetation is selected for its ability to withstand harsh conditions and its ability to maintain itself over the long term.

Figure 1 Extensive green roof, CRD Headquarters, Fisgard St., Victoria

'Intensive green roofs' are usually designed with public access and use in mind, and have deeper growing medium depths (greater than 300 mm) to support larger plants and trees. Intensive green roofs also have stormwater benefits, but are heavier and more expensive to develop and maintain.

This section is focused on the stormwater aspects of extensive green roofs.

Applications

- Suitable for many rooftop situations – industrial and warehousing, commercial buildings, municipal office complexes, hospitals, schools, institutional/administrative buildings and offices, residential developments and garages.
- Suitable for flat roofs and, with specialized design, roofs of up to 20º slope. Roofs may be inverted or traditional flat roofing systems, but shingle and tile roofs are not suitable for greening.

[1] **Adapted with permission from Metro Vancouver.**
Original document: Metro Vancouver's Stormwater Source Control Design Guidelines 2012, primary author Kerr Wood Leidal Associates Ltd. with Lanarc Consultants Ltd and Goya Ngan, http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf
Adaptations authored by: Opus International Consultants (Canada) Limited
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd

- Green roofs provide multiple benefits, including:
  - Reduction in stormwater peak flows; smaller winter event peak flows were attenuated 30% in monitoring of the Vancouver Public Library roof.
  - Reduction in rainfall volume leaving the roof due to evaporation and evapo-transpiration. A typical extensive green roof of about 75 mm in growing medium can be designed to reduce annual runoff by more than 50%.
  - The seasonal rainfall patterns on the west coast mean that green roofs have less effect in the wet winter season, retaining 13-18% of rainfall, versus 86-94% in the summer in Metro Vancouver. However, no single GSI facility alone is effective to manage the entire range of rainfall events, rather a combination of GSI facilities are normally implemented to manage the stormwater.
  - The purpose of the green roof is to capture frequent rain with low intensity only. Once the soil is saturated, the runoff will flow through the outlets to the stormwater system.
  - Mitigation of the urban heat island effect, which is raising the temperatures of cities and increasing energy use as well as increasing the effects of air pollution.
  - Air filtration, removing fine particulates from the air.
  - Reduction in heat gain and the need for air conditioning in the summer – peak sensible cooling needs can be reduced by about 25%.
  - Reduced heat loss in the winter; heat loss in Toronto was reduced 10-30%. Research at BCIT found heat transfer through the roof was reduced 80% in summer and 40% in winter.

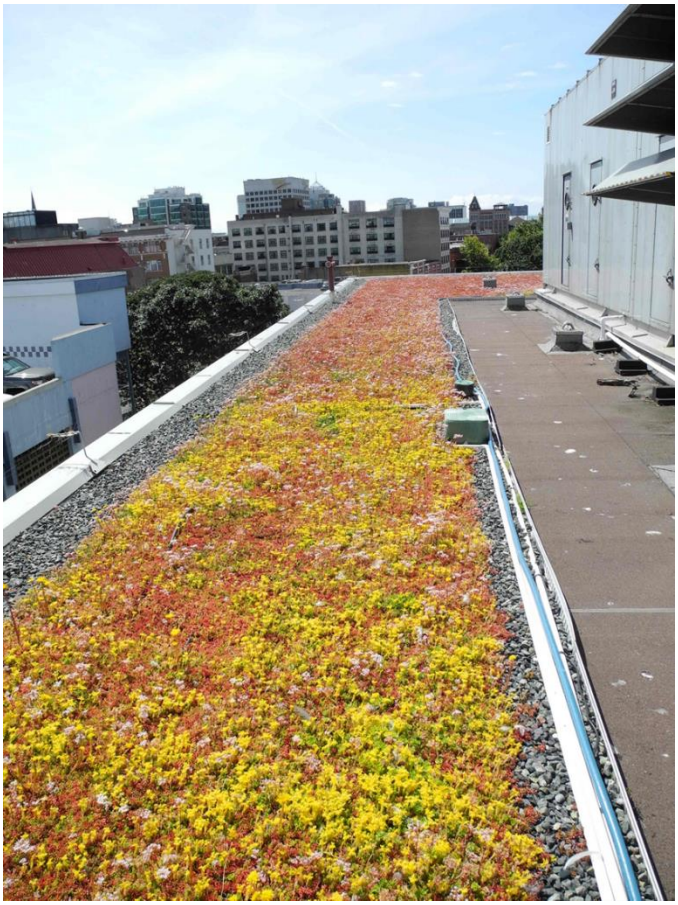

Figure 2 Extensive green roof, CRD Headquarters, Fisgard St., Victoria

Figure 3 Intensive green roof, CRD Headquarters, Fisgard St., Victoria

- There is no set equation to calculate this heat loss reduction with a green roof. Potential reductions are determined based on performance monitoring on some projects.
- Roof membrane protection and life extension. European studies have revealed that green roof installation can double the life span of a conventional roof, by helping to protect the membrane from extreme temperature fluctuations, ultraviolet radiation, and mechanical damage.
- Sound insulation – tests at BCIT found that typical extensive green roof can reduce sound by 2 to 13 dB.
- Increasing biodiversity in urban areas by providing habitat for birds, insects, native plants, and rare or endangered species.
- Aesthetic value and increased urban green space.

Figure 4 Extensive green roof under construction, CRD Headquarters, Fisgard St., Victoria

Limitations

- Green roofs must be designed with an awareness of the loading of the roof on the underlying structure. However, use of lightweight growing medium has created solutions where saturated growing medium can be installed without structural upgrading beyond the standard requirements, especially in concrete buildings or new construction.
- National standard for green roofs are covered under the Canadian Landscape Standard.
- Green roofs, as extensions of the roofing system, must comply with the BC Building Code.

Professional Consultants

- Selection of professional consultants depends on the function of the green roof, the size of the project, the location of the project, and the green roof experience of the primary consultant and/or project instigator. A structural engineer may be required to determine the existing, or required, loading capacity of the roof. An architect may be required to co-ordinate the project as well as the design and detailing of the building and roof, including material specifications. A landscape architect may be required for the layout of the planting areas and the selection of the plants. A mechanical engineer may be required to calculate the heating and cooling implications of the green roof, and to discuss integration with existing and proposed rooftop mechanical equipment and drainage needs.

Extensive Green Roof Types

Extensive green roofs can be 1 of following designs:

- Multiple layer construction – consists of either: i) a 3-layer system including separate drainage course, filter layer and growing medium or; ii) a 2-layer system where the growing medium is sized to not require a filter between it and the underlying drainage layer. Extensive Green Roof may be installed over either a conventional or an inverted roof system.
- Single layer construction – consists of a growing medium which includes the filter and drainage functions.

Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Start the design of the green roof at the same time as the design of the building or retrofit project, so that the structural load of the green roof can be balanced with the structural design of the building. From the outset, involve all design disciplines – structural, mechanical and electrical engineers, architects and landscape architects – and include roofing design professionals in a collaborative and optimization effort.
4. Provide construction and maintenance access to extensive green roofs. Access through a 'man door' is preferable to access through a small roof hatch. Provide areas of storage for maintenance equipment. Review the Workers' Compensation Board of British Columbia Standards' requirements for safety of maintenance workers. Provide a hose bib for manual watering during establishment if no automatic irrigation system is planned.
5. Roofs with less than 2% slope require special drainage construction so that no part of the growing medium is continuously saturated. As the slope increases, so does the rate of rainfall leaving the roof. This can be compensated for by using a medium with high water storage capacity. Roofs with over 20° angle surfaces require special precautions against sliding and shearing. If inverted roof systems are used with exterior insulation, good drainage needs to be provided to prevent continuous saturation of the insulation, and subsequent damage. With inverted roofs, the green roof components must allow moisture to move upwards from the insulation and to eventually evaporate.
6. Provide plant free zones to facilitate access for inspections and maintenance and prevent plants from spreading moisture onto exposed structural components. They can also function as a measure against fire and wind-uplift. They should be at least 50 cm wide and located along the perimeter, all adjacent facades and covered expansion joints, and around each roof penetration.
7. Fire breaks of non-combustible material, such as gravel or concrete pavers, 50 cm wide, should be located every 40 m in all directions, and at all roof perimeter and roof penetrations. Other fire control options include use of sedums or other succulent plants that have a high water content, or a sprinkler irrigation system connected to the fire alarm.

8. There are several choices of waterproof membranes. Thermoplastic membranes, such as polyvinyl chloride or thermal polyolefin using hot air fusion methods are commonly used for green roof applications. Elastomeric membranes like ethylene-propylene rubber materials have high tensile strength and are well-suited to large roof surfaces with fewer roof penetrations. Modified bitumen sheets are usually applied in 2 layers and are commonly available. Liquid-applied membranes are generally applied in 2 liquid layers with reinforcement in between. The quality is variable. A factor in choosing a waterproofing system is resistance to root penetration (for more information see below).

9. Provide protection against root penetration of the waterproof membrane by either adding a root barrier or using a membrane that is itself resistant to root penetration (more cost efficient). Resistance to root penetration is not being tested in Canada at time of writing[2]. Thermoplastic and elastomeric membranes in suitable thicknesses are usually resistant to root penetration. Roofing membranes, existing or new, which contain bitumen or other organic materials are susceptible to root penetration and micro-organic activity. These types of roofing membranes need to be separated from the growing medium by a continuous root barrier unless they contain an adequate root repelling chemical or copper foil.

10. Chemically incompatible materials such as bitumen and polyvinyl chloride require a separation layer.

11. When the roofing membrane installation is complete, but prior to installing layers above the waterproof membrane, it should be tested by flooding and thorough inspection. Any leaks should be repaired prior to installing materials above the membrane.

12. Install a protection layer to protect the waterproof membrane/root barrier from physical damage caused by construction activities, sharp drainage materials such as lava rock or broken expanded clay, and subsequent levels of stress placed on the roof.

13. The drainage layer may be drain rock, but is often a lightweight composite such as lava, expanded clay pellets, expanded slate or crushed brick. If weight is a concern, rigid plastic materials that allow rapid lateral drainage may be used. The drainage layer may also function to store water and make it available to the vegetation during dry periods. The top of the drainage layer is normally separated from the growing medium by non-woven filter cloth.

14. Light weight growing medium is often a combination of pumice, lava rock, expanded clay or other lightweight absorbent filler, with a small amount of organic matter. Recommended between 6% and 8% organic matter. When properly sized, a mineral-based growing medium is able to retain stormwater as effectively as soil high in organic matter without the disadvantage of compacting and breaking down over time.

15. In calculating structural loads, always design for the saturated weight of each material.

16. Light weight growing medium can be subject to wind erosion when dry. If planting is delayed through a dry weather season, provide a wind erosion control blanket over the growing medium.

[2] Check with the manufacturer to determine if the membrane is resistant to root penetration according to the German FLL Root Penetration Test, 2002.

17. Plant choices for extensive green roofs are limited to plants that can withstand the extremes of temperature, wind, and moisture condition on a roof. Typically, extensive green roofs use a variety of non-invasive mosses, sedums, sempervivums, alliums, other bulbs and herbs, and grasses (see Supplemental 1: Planting Templates & Plant Lists for suggestions).
18. Avoid specifying or allowing volunteer plant materials with aggressive root systems (e.g., bamboo, couch grass, tree seedlings). Supply and install growing medium that is free of weeds.
19. Design planting to respect microclimate and sun/aspect conditions. Collaborate with mechanical engineers on placement of exhaust vents, and design plantings accordingly.
20. Avoid swaths of 1 species. The chances of creating a self-maintaining plant community are increased when a wide mix of species is used.

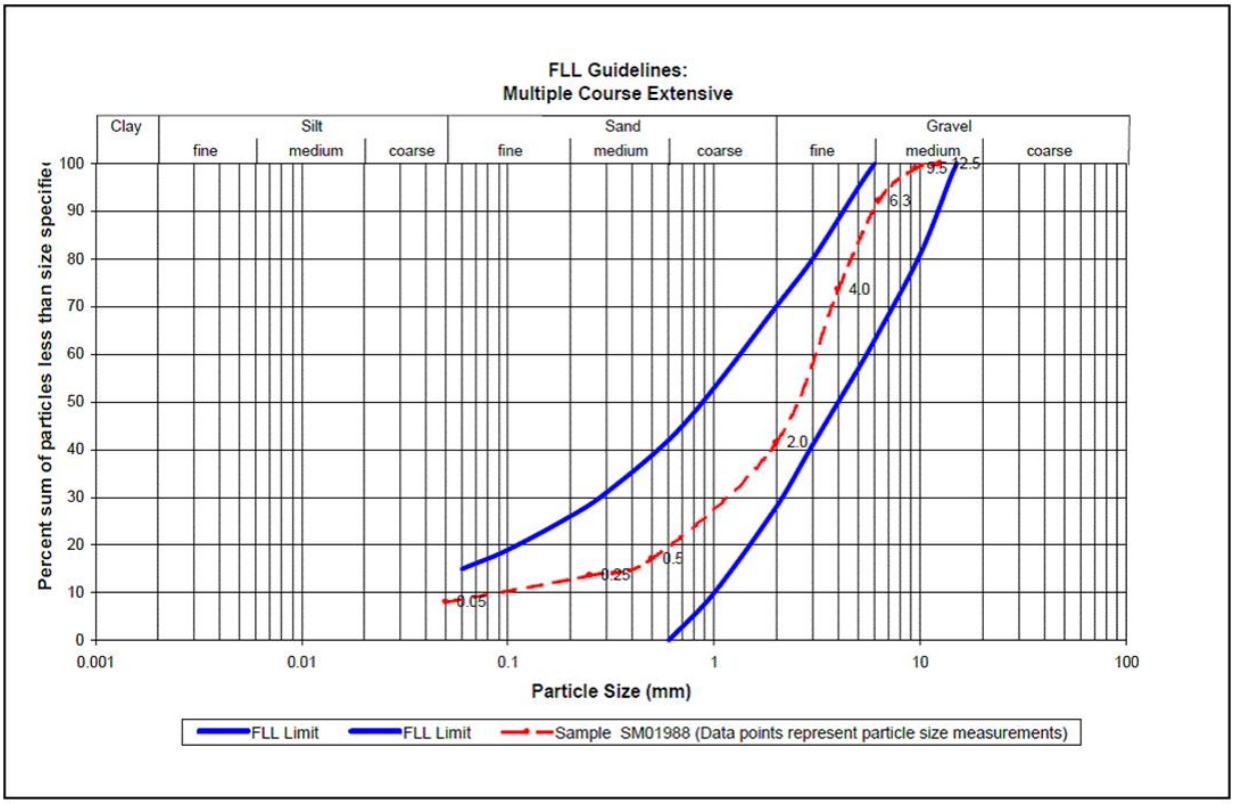

Figure 5 Particle (grain) size distribution range for substrates used in multiple layer extensive green roofs (FLL, 2008, Guidelines for the Planning, Execution and Upkeep of Green-Roof Sites). Image Credit: Agricultural Analytical Services Laboratory, Pennsylvania State University

21. Planting methods include seeding, hydroseeding, spreading of sedum sprigs, planting of plugs or container plants, and installing pre-cultivated vegetation mats.
22. If automatic irrigation is required, low volume and rainwater reuse systems are preferred.

23. Provide intensive maintenance for the first 2 years after the plant installation – including watering in dry periods, removal of weeds, light fertilization with slow release complete fertilizers, and replacement of dead plants. It is recommended that the maintenance contract for the first 3-5 years be awarded to the same company that installed the green roof and that the service be included in the original bid price. Once established, a typical extensive green should require only 1 or 2 annual visits for weeding of undesired plants, clearing of plant-free zones and inspecting of drains and the membrane. Installers should have experience with green roof systems. It may be preferable to have 1 company handle the entire project from roofing to planting to avoid scheduling conflicts and damage claims (Peck & Kuhn, 2001). If it is not possible, make a clear separation between the responsibilities of the roofing contractor and those of the green roof contractor.
24. Although green roof membranes will last longer than others, leaks can still occur at flashings or through faulty workmanship. Some companies are recommending an electronic leak detection system to pinpoint the exact location of water leaks, for easier repair.
25. Consider the environmental impact of each green roof material. How much energy was required to extract, manufacture and deliver the material? Is there a suitable material derived from local recycled products? What effect does the material have on water quality? How often must it be replaced? How will it be disposed of? Is it recyclable?
26. Several local companies provide complete green roof service, and offer a range of long-term guarantees on the entire assembly. This type of comprehensive installation may be more expensive than comparable 'off the shelf' products not specifically designed for green roof use. The decision on risk management is with the owner.

Guideline Specifications

- ASTM E2777 – 14 Standard Guide for Vegetative (Green) Roof Systems.
- ASTM E2400 / E2400M – 06(2015)e1 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems.
- BC Standard for Extensive Green Roofs 'Growing Medium Type 1P: Extensive Green Roof-Inaccessible', or growing medium as approved by green roof system manufacturer.
- Green roofs must be designed with an awareness of the loading of the roof on the underlying structure. However, use of lightweight growing medium has created solutions where saturated growing medium can be installed without structural upgrading beyond the standard requirements, especially in concrete buildings or new construction.
- National standard for green roofs are covered under the Canadian Landscape Standard.
- Green roofs, as extensions of the roofing system, must comply with the BC Building Code.

Sizing Green Roofs

Sizing for a green roof alone is fairly straightforward and simplified sizing approaches have been developed that do not require water balance modelling or continuous simulation.

1. In general, a green roof is sized to capture a portion of the rain that falls on it through retention of water in the soil and on the vegetation, and evaporation and evapotranspiration.
2. Sizing presented here is for evaporation/evapotranspiration of rainwater for "capture" and prevention of site runoff.
3. Sizing process here assumes that the entire roof area will be covered by a green roof and sizing determines the depth of soil required.

Sizing for Depth Capture Criteria: R mm in 24 hrs

See Appendix A, Table 1 to determine R mm of rain in 24 hrs for area-specific GSI facility rainfall capture targets – confirm with respective municipality.

1. Determine the soil depth required:

$$D_S = \frac{R}{0.2}$$

Where:
DS = Depth (thickness) of Green Roof soil (mm)
R = Rainfall capture depth (mm)
0.2 = Water holding capacity of the soil calculated as field capacity minus wilting point (unitless)

2. Check whether the calculated soil depth is within the standard depth range of 150 to 600 mm. If the calculated depth exceeds 600 mm, the overflow from the green roof could be directed to an infiltration rock trench or other facility and the combined facilities should be evaluated using water balance calculations.

Green Roof Design Example for Capture of R mm/24-hour Criteria

Scenario Description

A green roof is proposed to capture a portion of the runoff from a building roof (see illustration below).

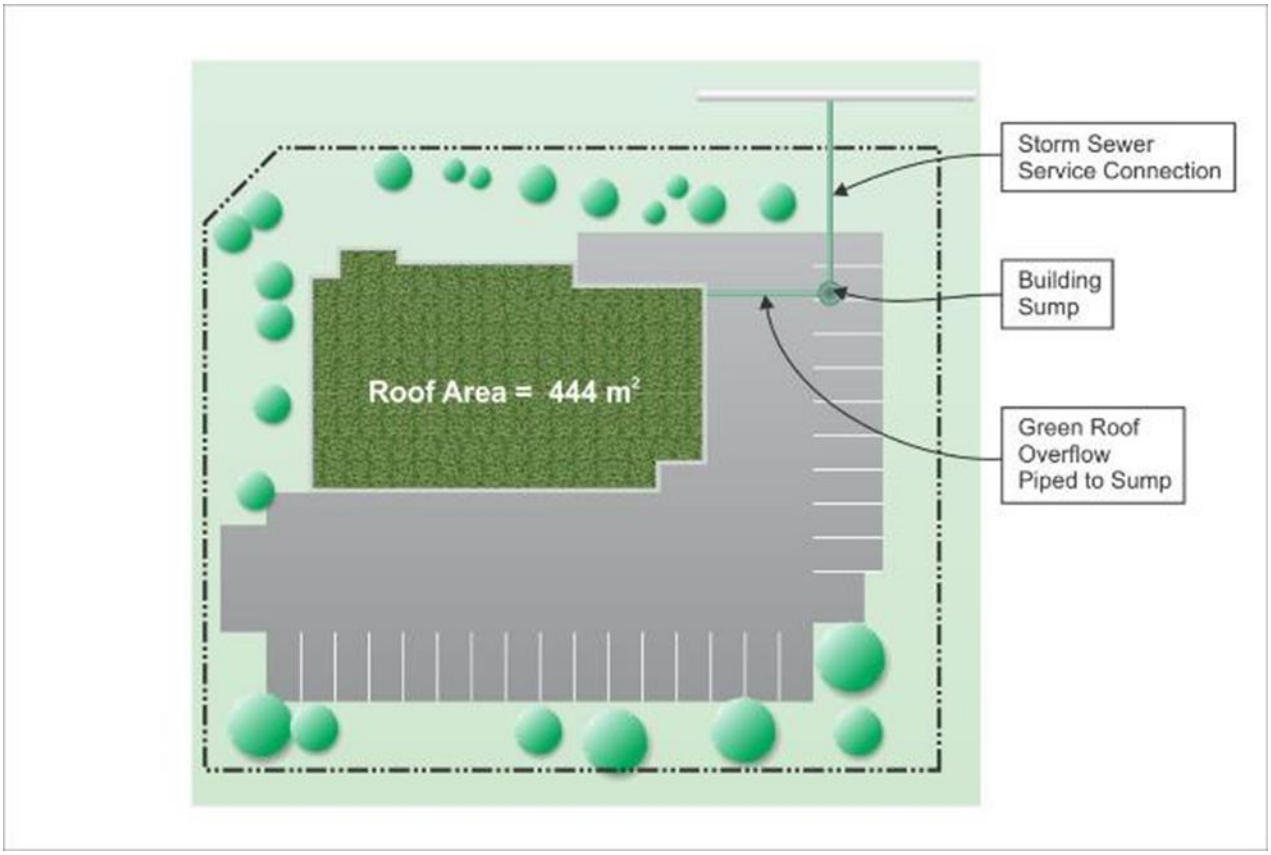

Figure 6 Example – Roof area covered with green roof

The following parameters are known:

- Roof area = 444 m²
- 2-year 24-hour rain depth = 53 mm
- Capture target is 72% of 2-year 24-hour rain amount = 38 mm

Determine the required green roof topsoil thickness.

Sizing

Determine the soil depth required:

$D_S = \frac{R}{0.2} = \frac{38mm}{0.2}$ =190 mm of topsoil depth is required to meet the rainfall capture target.

Note: the above calculation assumes a "typical" green roof construction; there is significant room for improvement in performance with modifications to the underdrain or drainage layer to improve capture.

Hydraulic Components

- **Underdrain**: To prevent the green roof topsoil from becoming saturated and negatively impacting the plant roots, an underdrain layer is standard practice for green roofs. The underdrain layer also reduces the likelihood of roof membrane leakage by relieving water pressure on the membrane.
- **Overflow**: During extreme rainfall, the topsoil infiltration capacity may be overwhelmed resulting in ponding of water on the soil surface and runoff. This excess water is collected by an overflow designed to limit the water level on the roof.
- **Discharge**: The green roof topsoil underdrain and the overflow are connected to roof water leaders or downspouts to convey excess water to the municipal storm sewer.

GSI Driver Effectiveness – Runoff Reduction and Pollutant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Green roofs are designed so that water drains vertically through the media and then horizontally along a waterproof layer towards the outlet. The CRD has monitored the performance of the green roof on their downtown offices with the following results:

- 36% retention of annual rainfall
- 24-minute average delay of peak runoff during wet season and 2-hour average delay during dry season
- 90% reduction in peak runoff flow

Some pollutant removal occurs by the filtering of the stormwater in the growing medium. Green roofs are also efficient of reducing stormwater runoff. Estimates of GSI driver effectiveness are shown in Table 1.

Table 1 Runoff Reduction and Pollution Removal Summary Table

Green Roof GSI Facilities	
GSI Driver	***Estimated Effectiveness or typical % Removal**
Capture & Slow – Volume Runoff Reduction	40-60
Store & Convey – Rate Control Delay Peak	90
Clean & Infiltrate – Water Quality Treatment	Highly variable with design. Below are typical results. Research has observed good retention and at times production and export of nutrients.
Total Suspended Solids (TSS)	60 to >95
Phosphorus	Most green roofs see an increased export of nutrients

Note: * Performance of individual facilities will vary depending on site-specific contexts and facility design.

Sources:
https://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs
http://www.creditvalleyca.ca/wp-content/uploads/2012/02/lid-swm-guide-chapter4-4.2-green-roofs.pdf

Maintenance

Proper maintenance and operation of the green roof are essential to ensure the performance and benefits continue over the life of the installation. Each green roof installation will have specific design, operation, and maintenance guidelines provided by the manufacturer and installer.

Routine Maintenance

The following maintenance guidelines are for extensive roof systems and provide a general set of standards for long-term roof garden performance:

- All green roof components (structural, waterproofing, drainage layers, soil substrate, vegetation, and drains) should be inspected biannually for proper operation throughout the life of the facility.
- Drain inlets should be inspected to ensure unrestricted rainwater flow from the drainage layer to the roof drain system.
- An operation and maintenance plan and inspection schedule should be provided to the property owner.
- Written guidance or training for operation and maintenance should be provided to the property owner.
- A maintenance log should be kept by the property owner.

ACTIVITY	OBJECTIVE	SCHEDULE
Clear inlet pipes	Maintain free drainage	Twice annually
Inspect drain pipe for cracks, settling and alignment	Maintain free drainage	Twice annually
Inspect fire ventilation points	Fire and safety	Twice annually
Remove invasive and nuisance plants	Promote selected plant growth and maintain aesthetics	Twice annually (schedule inspections prior to seed dispersal)
Remove and replace dead material	Maintain aesthetics and reduce weed growth	Annually
Irrigation	Maintain healthy vegetation	Consult manufacturer's guidelines
Check for ponding water	Ensure proper infiltration and drainage	Monthly

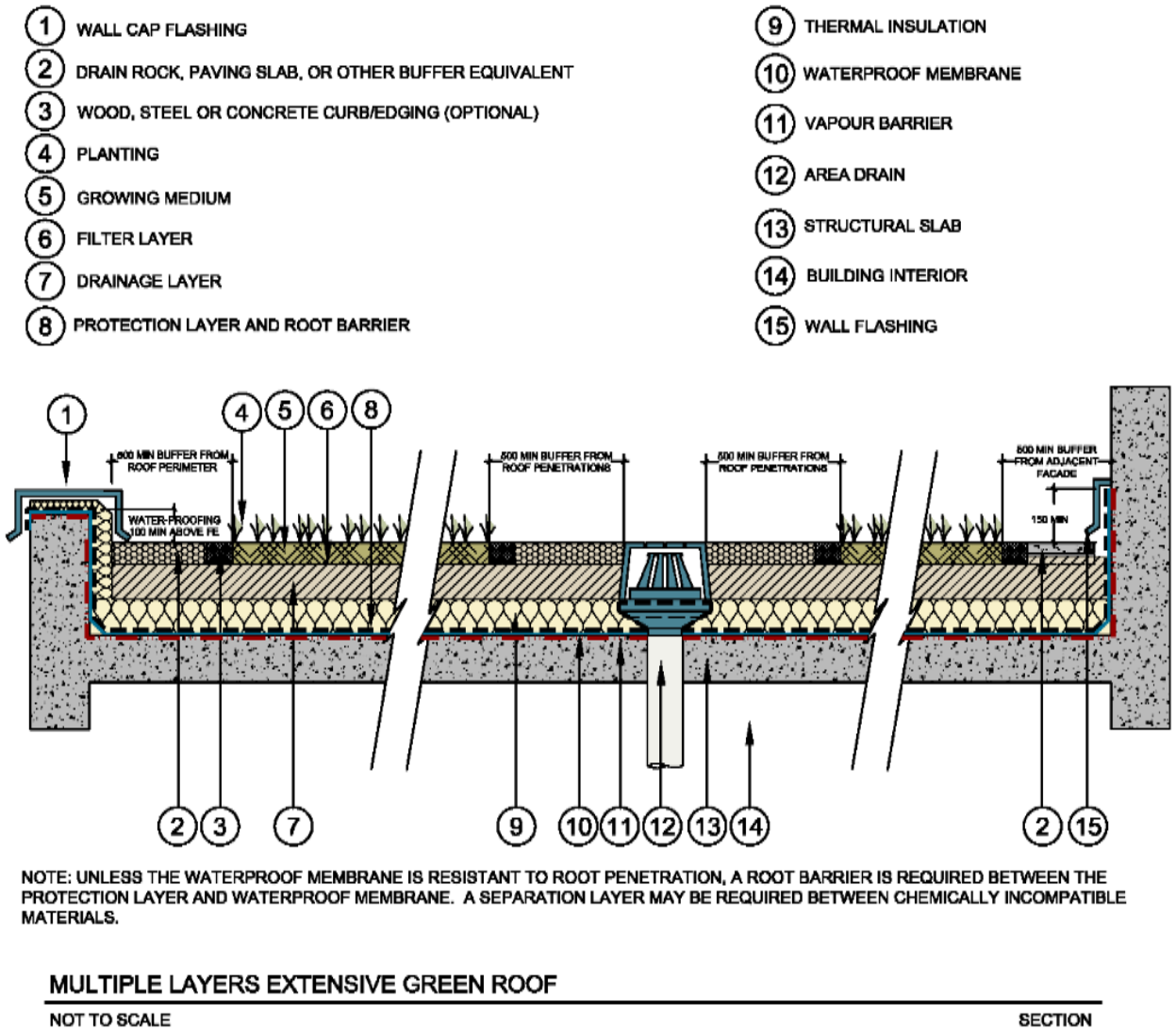

Figure 7 Multiple Layers Extensive Green Roof (Not to scale, Section)

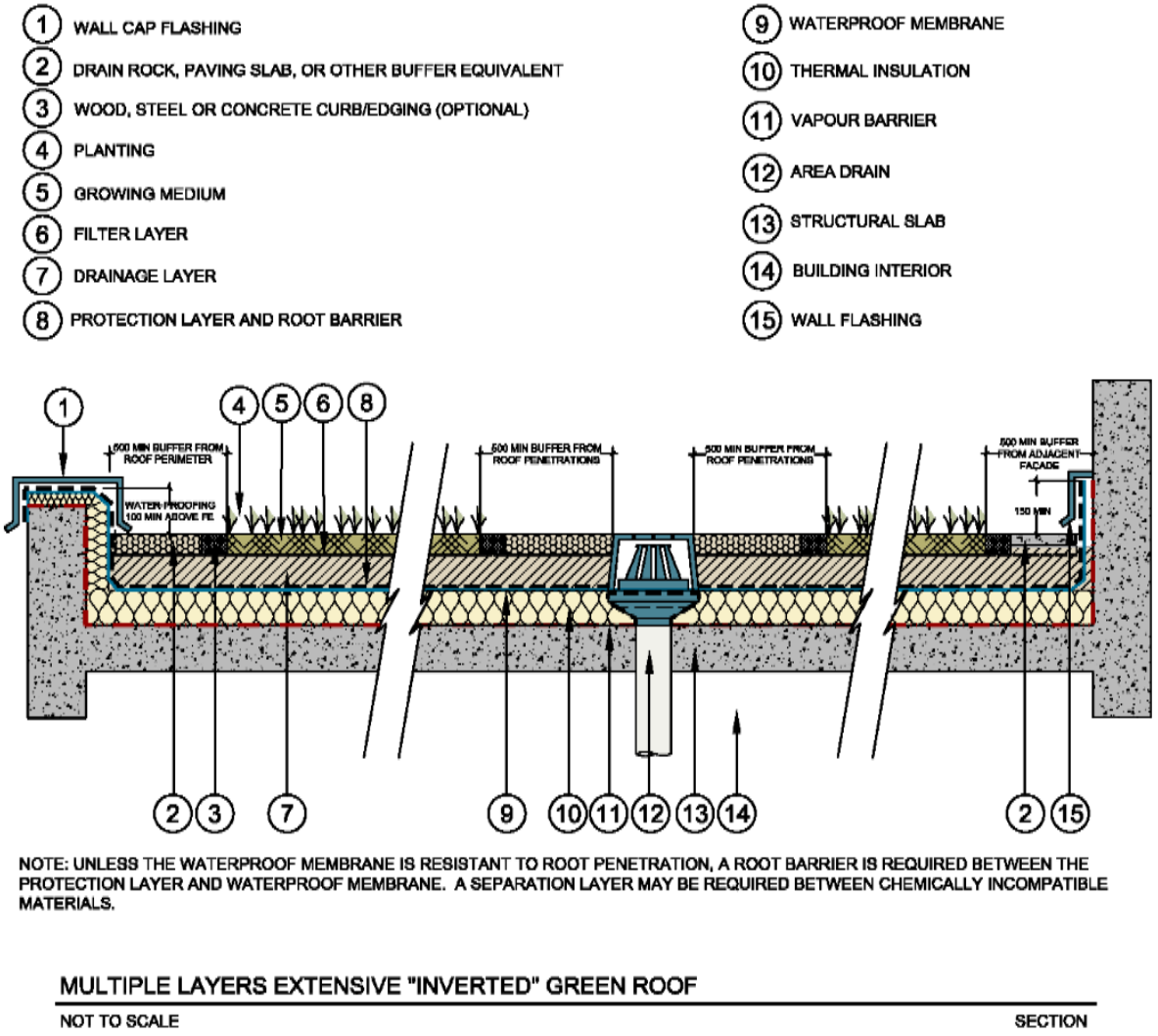

Figure 8 Multiple Layer Extensive Green "Inverted" Roof (Not to scale, Section)

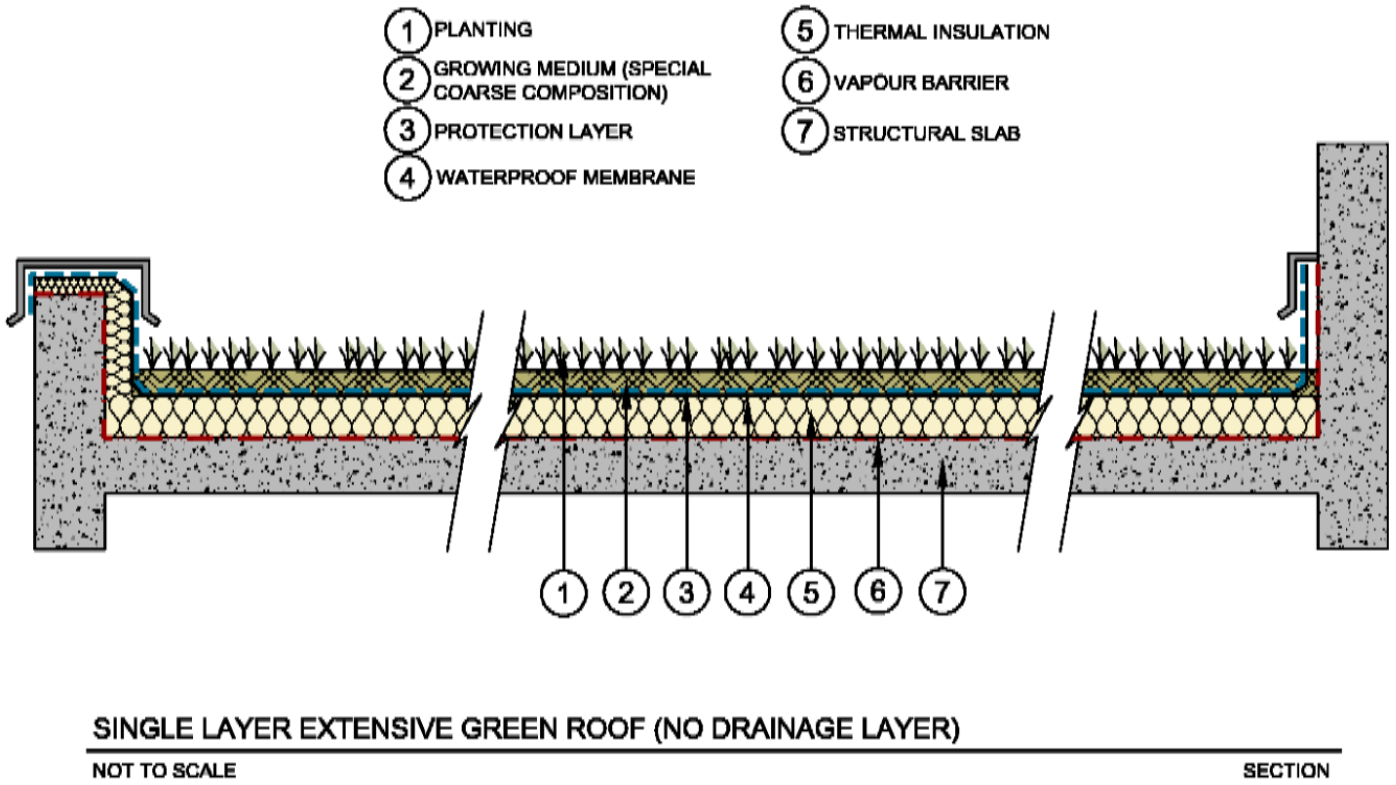

Figure 9 Single Layer Extensive Green Roof (No Drainage Layer) (Not to scale, Section)