5.4.9 Green Roofs

Description: A green roof consists of vegetated cover used to mimic the hydrologic performance of surface vegetation rather than the surface of an impervious roof. They are effective in reducing the volume of runoff from a roof as well as the rate at which runoff leaves a rooftop. Green roofs help to minimize thermal impacts to downstream receiving waters. They may be designed to accommodate functions ranging from solely rainfall management to more complex systems that integrate rainfall management with livable/usable space.

Figure 1: Greenroof on top of Hallsdale Powell Utility District, TN (Source: SMART Center).

Site Constraints:

- Load capacity of roof
- Roof pitch
- Roof access

Key Design Criteria:

- Load capacity of roof
- Inclusion/exclusion of various layers
- Media composition
- Plant selection

Maintenance:

- Watering, fertilizing, and weeding especially in the first 2 years while plants are becoming established

Advantages:

- Provides volume reduction
- Extends life of a conventional roof by up to 20 years
- Provides increased insulation and energy savings
- Wildlife habitat potential
- Provides sound insulation
- Reduces urban heat island effect
- Utilizes otherwise impervious surface for runoff management
- Protects roof structure from weathering

Disadvantages:

- More maintenance than conventional roof
- May require irrigation
- Potential for roof leaks
- Not suited for groundwater recharge purposes

Design Checklist:

- ❑ Identify management goal(s)
- ❑ Review site constraints
- ❑ Review design criteria
- ❑ Protect site resources
- ❑ Size channel for site conditions
- ❑ Submit plans for review

1. Design

Green roofs are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Green roofs capture and temporarily store stormwater runoff in the growing media before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates from the surface or transpires through plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

A green roof is a layer of vegetated media installed on top of a conventional flat or slightly sloped roof that consists of waterproofing material, root permeable filter fabric, growing media, and specially selected plants. There are two different types of green roof systems: intensive green roofs and extensive green roofs:

- Intensive systems have a deeper growing media layer that ranges from 6 inches to 4 feet thick, which is planted with a wider variety of plants including trees and shrubs.
- Extensive systems typically have much shallower growing media (under 6 inches), which is planted with carefully selected drought tolerant vegetation, usually sedums. Extensive green roofs are much lighter and less expensive than intensive green roofs and are recommended for use on most development and redevelopment sites.

Designers may wish to pursue other design objectives for vegetated roofs, such as energy efficiency, green building or LEED points, architectural considerations, visual amenities, and landscaping features, which are often maximized with intensive green roof systems. However, these design objectives are beyond the scope of this specification. This specification is intended for situations where the primary design objective of the green roof is stormwater management and addresses only extensive roof systems.

1.1 Suggested Applications

Green roofs are ideal for use on commercial, institutional, municipal and multi-family residential buildings. They are particularly well suited for use on ultra-urban development and redevelopment sites where space for infiltrative practices can be limited. Green roofs can be applied to most roof surfaces, although concrete roof decks are preferred. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for green rooftops due to pollutant leaching through the media (Clark *et al,* 2008).

1.2 Site Constraints

- Green roofs typically need to support 15-30 psf more than a conventional roof
- Optimal roof slope = 1-2 % and max roof slope = 25% with baffles
- Roof access door area >= 16 sf with minimum dimension of 2 ft

Structural Capacity of the roof: Designers must not only consider the stormwater storage capacity of the green roof, but also its structural capacity to support the weight of the additional water. A conventional rooftop typically must be designed to support an additional 15 to 30 pounds per square foot for an extensive green roof. As a result, a structural engineer, architect, or other qualified professional should be involved with all green roof designs to ensure that the building has enough structural capacity to support a green roof.

Roof Slope: Treatment volume is maximized on relatively flat roofs (a slope of 1 to 2%). However, some slope is needed to promote positive drainage and prevent ponding and/or prolonged saturation of the growing media. Green roofs can be installed on rooftops with slopes up to 25% if baffles, grids, or strips are used to prevent slippage of the media. The effective treatment volume, however, diminishes on rooftops with steep slopes (Van Woert et al, 2005).

Roof Access: Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 2 feet. Designers should also consider how they will get construction materials up to the

roof (e.g., by elevator or crane), and how construction materials will be maneuvered and stockpiled in the limited space.

Building Codes: The green roof design should comply with local building codes with respect to roof drains and emergency overflow devices. If the green roof is designed to be accessible to the public, the access must not only be convenient for installation and maintenance purposes, but also must adhere to local building codes and other regulations for access and safety.

Construction Cost: When viewed strictly as stormwater treatment systems, green roofs can cost $12 to $25 per square foot (Moran et al, 2004, Schueler et al 2007). These cost analyses, however, do not include life cycle cost savings relating to increased energy efficiency, higher rents due to green building scores and increased roof longevity. These benefits over the life cycle of a green roof may make it a more attractive investment compared to traditional roof prices.

Risks of Leaky Roofs: Although well designed and installed green roofs have fewer problems with roof leaks than traditional roofs, there is a perception among property managers, insurers, and product fabricators that this emerging technology could have a greater risk of problems. For an excellent discussion on how to properly manage risk in green roof installations, see Chapter 9 in Weiler and Scholz-Barth (2009).

1.3 Design Criteria

Green roofs typically consist of layers which are designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Green roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after initial establishment. Tray systems are also available with removable dividers allowing the media to meld together creating a seamless appearance but with less difficulty in construction.

Green roofs are typically designed to manage the rainfall that falls onto the vegetated area. They also may be sized to manage runoff from other roof areas where vegetation may not be established (e.g., areas of steeply pitched roofs, air conditioning units). Green roofs that receive drainage from more steeply sloped roof areas should include an area for velocity dissipation (i.e., cobbles) prior to runoff flowing onto the vegetated area.

Regardless of the complexity of the system, green roofs may be designed and constructed to meet stormwater management requirements. Green roof plant species generally have shallow root systems, good regenerative qualities, and resistance to direct solar radiation, drought, frost, and wind. In addition to stormwater benefits, green roofs provide benefits in terms of increased longevity of the roofing system (by protecting the roof from temperature extremes) and insulation benefits that may reduce heating or air-conditioning energy costs. Green roofs always include one or more drainage layers, separation fabrics (which may include root barriers), and a waterproofing system. Designs and specifics vary with different manufacturers and designers.

Overall Sizing: Green roof areas should be sized to capture a portion of the treatment volume. The required size of a green roof will depend on several factors, including the porosity and hydraulic conductivity of the growing media and the underlying drainage materials. Site designers and planners should consult with green roof manufacturers and material suppliers for specific sizing guidelines. As a general sizing rule, the following equation can be used to determine the water quality treatment storage volume retained by a green roof:

$$V = (A * D * n)/12$$

where

V = storage volume (cu. ft.)
A = roof area (sq. ft.)
D = media depth (in.)
n = media porosity (usually 0.3, but consult manufacturer specifications)

Structural Capacity of the Roof: Green roofs can be limited by the additional weight of the fully saturated growing medium and plants, in terms of the physical capacity of the roof to bear structural loads. The designer should consult with a licensed structural engineer or architect to ensure that the building will be able to support the additional live and dead structural load and determine the maximum depth of the green roof system and any needed structural reinforcement. In most cases, fully-saturated extensive green roofs have a maximum load of about 30 psf, which is fairly similar to traditional new rooftops (12 to 15 lbs./sq. ft.) that have a waterproofing layer anchored with stone ballast. For an excellent discussion of green roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E2397, Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems.

Functional Elements: A green roof is composed of up to eight different systems, or layers, listed below from bottom to top, that are combined together to protect the roof and maintain a vigorous cover. Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system as a whole must be assessed to meet design requirements. Some manufacturers offer proprietary green roofing systems, whereas in other cases, the designer or architect must assemble their own system, in which case they are advised to consult Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006) and Dunnett and Kingsbury (2004).

1. **Deck Layer:** The roof deck is the foundation of a green roof. It may be composed of concrete, wood, metal, plastic, gypsum, or a composite material. The type of deck material determines the strength, load bearing capacity, longevity and potential need for insulation in the green roof system. In general, concrete decks are preferred for green roofs, although other materials can be used as long as the appropriate system components are matched to them.
2. **Waterproofing Layer:** All green roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including built up roofs, modified bitumen, single-ply, and liquid-applied methods (see Weiler and Scholz-Barth, 2009 and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the green roof system.

   Depending on the waterproofing materials selected, a supplemental root-fast layer may be required to protect the primary waterproofing membrane from plant roots. Insulation, if included in the roof covering system, may be installed either above or below the primary waterproofing membrane. Most green roof cover systems can be adapted to either roofing configuration.
3. **Insulation Layer (optional):** Many green rooftops contain an insulation layer, usually located above, but sometimes below, the waxcess water from the vegetation root zone. The drainage layer should consist of synthetic or inorganic materials (e.g. gravel, recycled polyethylene, etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors and roof leader. The required depth of the drainage layer is governed by both the required stormwater storage capacity and the structural capacity of the rooftop. ASTM E2396 and E2398 can be used to evaluate alternative material specifications.

   The drainage layer below the growth media should be designed to convey the 10-year storm without inundating the growing media. The drainage layer should convey flow to an outlet or overflow system such as a traditional rooftop drainage system with inlets set slightly above the elevation of the green roof surface. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging.

   Internal building drainage, including provisions to cover and protect deck drains or scuppers, must anticipate the need to manage large rainfall events without inundating the cover. All green roofs must provide a safe way for water to exit the system when large storms generate more stormwater runoff than the media can hold. The inclusion of a positive overflow route ensures that flooding risks, which can cause overloading of the structural capacity of the building and related property damage, are minimized. The positive overflow route is most often via the downspouts and roof gutters normally provided in the building design. Underdrains may be designed as perforated pipes connected to roof gutters or manufactured products that promote positive drainage.

6. **Root-Permeable Filter Fabric:** A semi-permeable polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it.
7. **Growing Media:** The next layer is the growing media, which is typically 4 to 6 inches deep. The depth and composition of the media is described in Materials Specification Section below. The recommended growing media for extensive green roofs is composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria or other similar materials. The remaining media should contain no more than 15% organic matter, normally well-aged compost. The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media should have a maximum water retention capacity of around 30%. It is advisable to mix the media in a batch facility prior to delivery to the roof. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).
8. **Plant Cover:** The top layer typically consists of slow-growing, shallow-rooted, perennial, succulent plants that can withstand harsh conditions at the roof surface. An experienced design professional should be consulted to select the plant species best suited to a given installation. Guidance on selecting the appropriate vegetated roof plants for hardiness zones in Tennessee can be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually Sedum species) and accent plants can be used to enhance the visual amenity value of a green roof.

   A planting plan must be prepared for a green roof by a landscape architect, botanist or other professional experienced with vegetated roofs, and it must be reviewed and approved by the local stormwater program. Plant selection for vegetated rooftops is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most vegetated roof installations is a hardy, low-growing succulent, such as Sedum, Delosperma, Talinum, Semperivum, or Hieracium that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006).

Other vegetation considerations:

- The species and layout of the planting plan should reflect the building location, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and shading by surrounding buildings. In addition, plants should be selected that are fire resistant and able to withstand heat, cold, and high winds.
- Designers should also match species to the expected rooting depth of the growing media, which can provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on green roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most green roof plant species will not be native to the Southeast (which is in contrast to native plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of green roof plant nurseries in the region, designers should order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract grown.
- The planting window extends from the spring to early fall, although it is important to allow plants to root thoroughly before the first killing frost. Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary green roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- When appropriate species are selected, most green roofs will not require supplemental irrigation, except as required during the first year that the green roof is being established or during periods of drought. Green roof covers intended to achieve water quality benefits should not be fertilized.
- The green roof design should include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.

- The goal for green roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining and requires minimal mowing, trimming, or weeding.
- May include a wind erosion stabilization system.

USING THE TNRRAT: Upon specifying a design storm, a drainage area, and any media depths, the TNRRAT will output the volume of water captured by the green roof and any volume of water leaving the green roof and potentially needing further treatment.

Material Specifications: Standards specifications for green roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The American Society for Testing and Materials (ASTM) has recently issued several overarching green roof standards, which are described and referenced in Table 1. Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" green roof systems or modules.

Table 1: Extensive Vegetated Roof Material Specifications.

Material	Specification
Roof	Structural Capacity should conform to ASTM E2397-05, *Practice for Determination of Live Loads and Dead Loads Associated with Green (Vegetated) Roof Systems.* In addition, use standard test methods ASTM #2398-05 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems,* and ASTM E2399-05 for *Maximum Media Density for Dead Load Analysis.*
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Roof Barrier (Optional)	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	1 to 2 inch layer of clean, washed granular material, such as ASTM D 448 size No. 8 stone. Roof drains and emergency overflow should be designed in accordance with local Codes.
Filter Fabric	Needled, non-woven, polypropylene geotextile. Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent.
Growth Media	85% lightweight inorganic materials and 15% organic matter (e.g. well-aged compost). Media should have a maximum water retention capacity of around 30%. Media should provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM #2396-05.
Plant Materials	Low plants such as sedum, herbaceous plants, and perennial grasses that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems.*

1.4 Typical Details

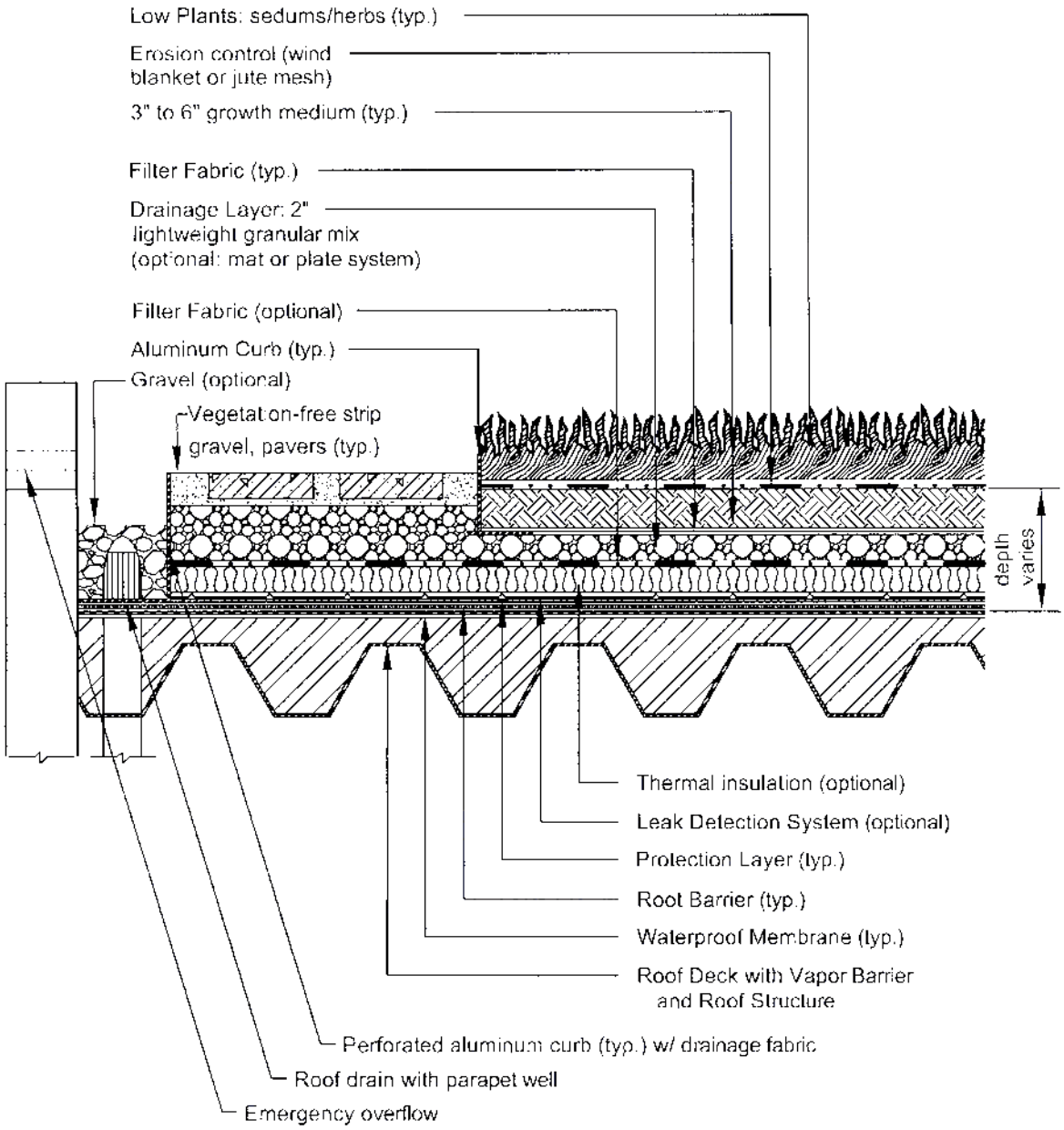

Figure 2: Typical Section – Extensive Vegetated Roof (Source: Northern VA Regional Commission).

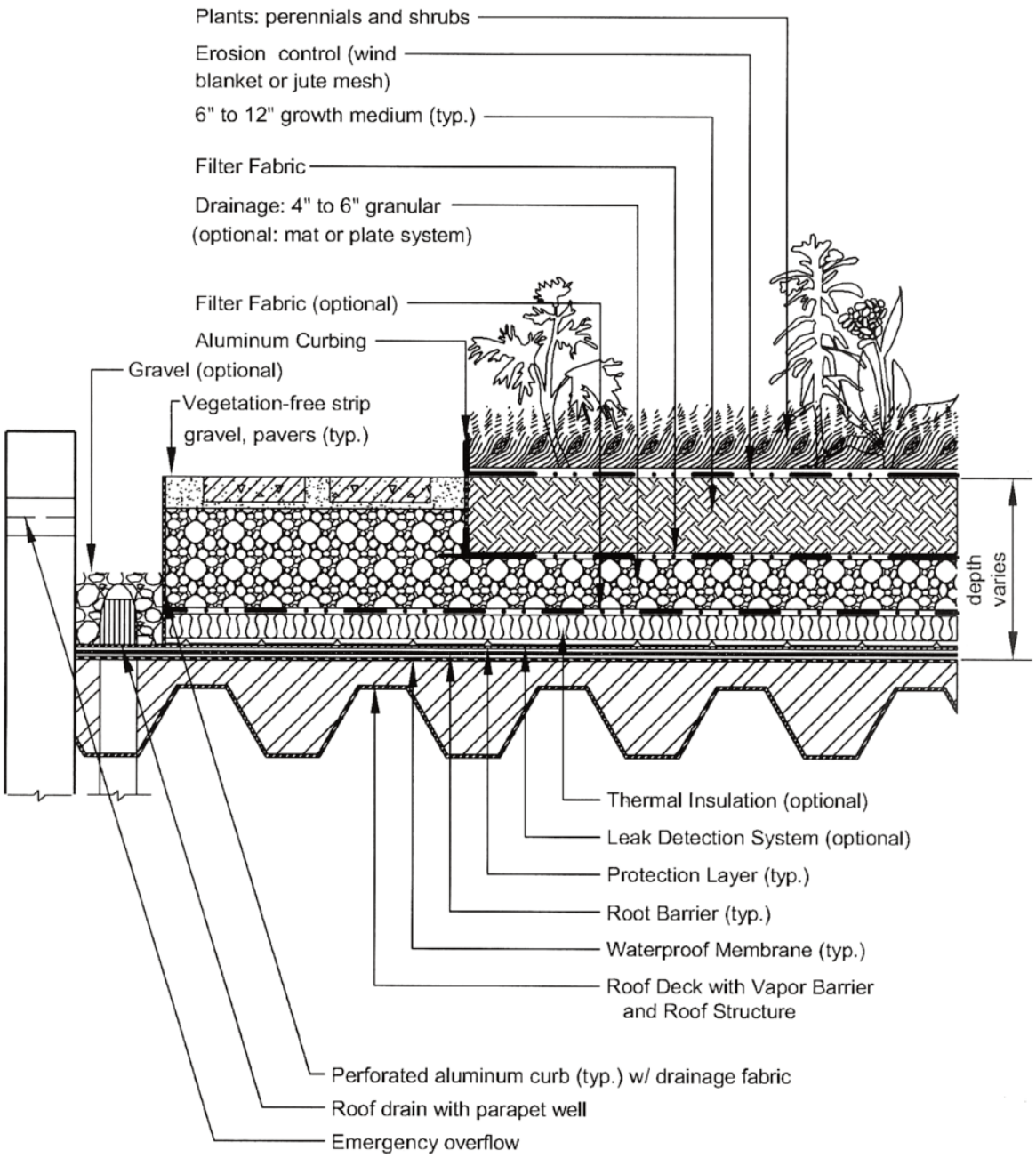

Figure 3: Typical Section – Intensive Vegetated Roof (Source: Northern VA Regional Commission).

Figure 4: Vegetated roof cross-section (Source: NCSU-BAE).

2. Construction

2.1 Pre-Construction

Implement temporary erosion controls, including control measures for dust suppression, during construction until vegetation has been suitably established.

2.2 Construction

An experienced installer should be retained to construct the green roof system. The green roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains.

Given the diversity of extensive green roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method, according to manufacturer's specifications.
- Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours.
- Add additional system components (e.g., optional insulation, optional root barrier, drainage layer, and interior drainage system, and filter fabric), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric. The growing media should be covered until planting to prevent weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction.
- The growing media should be moistened prior to planting and then planted with the ground cover and other plant materials, per the planting plan, or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- It generally takes 12 to 18 months to fully establish the green roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth. Watering is needed during the first summer. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth, 2009, for a photo guide of common rooftop weeds).
- Most construction contracts should contain a Care and Replacement Warranty that specifies a 75% minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75% for flat roofs and 90% for pitched roofs.

2.3 Construction Inspection

Inspections are needed to ensure that the green roof is built in accordance with the design plan and manufacturer's specificiations. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

Careful construction supervision is needed during several steps of green roof installation, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight;
- During placement of the drainage layer and drainage system;
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth;
- Upon installation of plants, to ensure they conform to the planting plan;
- Before issuing use and occupancy approvals.

After the green roof has been constructed, the developer must have an as-built certification of the green roof conducted by a registered professional engineer. The as-built certification verifies that the SCM was installed as designed and approved. The following components are vital components of a properly working green roof and should be addressed in the as-built certification:

1. Protection of vulnerable areas (abutting vertical walls, roof vent pipes, outlets, air conditioning units and perimeter areas) from leakage;
2. Profile view of facility including typical cross-sections with dimensions;
3. Growing medium specification including dry and saturated weight;
4. Filter fabric specification;
5. Drainage layer specification;
6. Waterproof membrane specification, including root barriers;
7. Stormwater piping associated with the site, including pipe materials, sizes, slopes, invert elevations at bends and connections; and
8. Planting and irrigation plan.

3. Maintenance

Examples of the requirements for the Maintenance Document are in Appendix F. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to the local stormwater program.

A green roof should be inspected twice a year during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns (see Table 2). In addition, the green roof should be hand-weeded to remove invasive or volunteer plants, and plants/media should be added to repair bare areas (refer to ASTM E2400). Many practitioners also recommend an annual application of slow release fertilizer in the first few years after the green roof is installed. If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., Electrical Field Vector Mapping) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of the waterproof membrane. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the green roof plant communities.

Table 2: Typical Maintenance Activities Associated with Green Roofs.

Activity	Schedule
Water to promote plant growth and survival.	As needed
Inspect the vegetated roof and replace any dead or dying vegetation.	Following Construction
Inspect the waterproof membrane for leaking or cracks.	Semi-annually
Annual fertilization.	As needed
Weeding to remove invasive plants.	As needed
Inspect roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris.	Semi-annually
Inspect the green roof for dead, dying or invasive vegetation. Plant replacement vegetation as needed.	As needed

Green roofs designed to integrate human occupancy of roof space should have a maintenance program that includes frequent inspection and removal of accumulated trash and debris.

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