VIRGINIA ~~DCR~~ DEQ STORMWATER DESIGN SPECIFICATION No. 5

VEGETATED ROOF

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SECTION 1: DESCRIPTION

Vegetated roofs (also known as *green roofs, living roofs* or *ecoroofs*) are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Vegetated 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 or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads otherwise generated by rooftops.

Vegetated roofs typically contain a layered system of roofing. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. There are two different types of vegetated roof systems:

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

Vegetated roofs in general are designed to have minimal maintenance requirements. Plant species are selected so that the vegetated roof will require minimal irrigation or fertilization *after* vegetation is initially established. It is best to utilize a roof system that is pre-vegetated prior to installation, as having established plants reduces maintenance costs and weed and erosion risk, and ensures good plant health.

> ***NOTE:*** *This specification is intended for situations where the primary design objective of the vegetated roof is stormwater management and, unless specified otherwise, addresses extensive roof systems.*

Designers may wish to pursue other design objectives for vegetated roofs, such as energy efficiency, green building or Leadership in Energy and Environmental Design (LEED) points, architectural considerations, visual amenities and landscaping features, which are often maximized with intensive vegetated roof systems. However, this design specification is focused solely on meeting the specific performance criteria of the Virginia Stormwater Management Program (VSMP) regulations; while the implementation of a vegetated roof as outlined by this specification may very well achieve some of the LEED design objectives (other than stormwater) as listed in **Section 2,** the designer should consult the appropriate guidance to verify compliance.

SECTION 2: PERFORMANCE

The overall stormwater functions of vegetated roofs are summarized in **Table 5.1**.

Table 5.1: Summary of Stormwater Functions Provided by Vegetated Roofs [1]

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	60%
Total Phosphorus (TP) EMC Reduction[2] by BMP Treatment Process	0	0
Total Phosphorus (TP) Mass Load Removal	45%	60%
Total Nitrogen (TN) EMC Reduction[2] by BMP Treatment Process	0	0
Total Nitrogen (TN) Mass Load Removal	45%	60%
Channel Protection & Flood Mitigation [3]	Use the following Curve Numbers (CN) for Design Storm events: 1-year storm = 64; 2-year storm = 66; 10-year storm = 72; and the 100 year storm = 75	

[1] Sources: CWP and CSN (2008) and CWP (2007).
[2] Moran et al (2004) and Clark et al (2008) indicate no nutrient reduction or even negative nutrient reduction (due to leaching from the media) in early stages of vegetated roof development.
[3] See Miller (2008), NVRC (2007) and MDE (2008)

Leadership in Energy and Environmental Design (LEED®). The LEED® point credit system designed by the U.S. Green Building Council (USGBC) and implemented by the Green Building Certification Institute (GBCI) awards points related to site design and stormwater management. Several categories of points are potentially available for new development and redevelopment projects. **Chapter 6** of the 2013 *Virginia Stormwater Management Handbook* (2nd Edition) provides a more thorough discussion of the site planning process and design considerations as related to Environmental Site Design and potential LEED credits. However, ~~VDCR~~ the Virginia Department of Environmental Quality (DEQ) is not affiliated with the USGBC or GBCI and any information on applicable points provided here is based only on basic compatibility. **Designers should research and verify scoring criteria and applicability of points as related to the specific project being considered through USGBC LEED resources.**

Table 5.2. Potential LEED® Credits for Vegetated Roof[1]

Credit Category	Credit No.	Credit Description
Sustainable Sites	SS5.1	Site Development: Protect or Restore Habitat
Sustainable Sites	SS5.2	Site Development: Maximize Open Space[2]
Sustainable Sites	SS6.1	Stormwater Design: Quantity Control
Sustainable Sites	SS6.2	Stormwater Design: Quality Control
Sustainable Sites	SS7.1	Heat Island Effect: Non-Roof[3]
Sustainable Sites	SS7.2	Heat Island Effect: Roof
Energy & Atmosphere	EAPre1	Fundamental Commissioning of the Building Energy Systems[4]
Energy & Atmosphere	EA1	Optimize Energy Performance

[1] Actual site design and/or BMP configuration may not qualify for the credits listed. Alternatively, the project may actually qualify for credits not listed here. Designers should consult with a qualified individual (LEED AP) to verify credit applicability.
[2] For projects located in urban areas that earn SS Credit 2, vegetated roof can contribute to compliance with SS Credit 5.2.
[3] If used to cover parking.
[4] Required Pre-Requisite for EA1.

SECTION 3: DESIGN TABLE

The major design goal for Vegetated roofs is to maximize nutrient removal and runoff volume reduction. To this end, designers may choose the baseline design (Level 1) or choose an enhanced (Level 2) design that maximizes nutrient and runoff reduction. In general, most intensive vegetated roof designs will automatically qualify as being Level 2. **Table 5.3** lists the design criteria for Level 1 and 2 designs.

Table 5.3. Vegetated Roof Design Guidance

Level 1 Design (RR:45; TP:0; TN:0)	Level 2 Design (RR: 60; TP:0; TN:0)
Tv = 1.0 (Rv)[1] (A)/12	Tv = 1.1 (Rv) [1] (A)/12
Depth of media up to 4 inches	Media depth 4 to 8 inches
Drainage System	2-inch stone drainage layer
No more than 20% organic matter in media	No more than 10% organic matter in media
All Designs: Must be in conformance to ASTM (2005) International Green (Vegetated) Roof Stds.	
[1]Rv represents the runoff coefficient for a conventional roof, which will usually be 0.95. The runoff reduction rate applied to the vegetated roof is for "capturing" the Treatment Volume (Tv) compared to what a conventional roof would produce as runoff.	

SECTION 4: TYPICAL DETAILS

Figure 5.1. Photos of Vegetated Roof Cross-Sections (source: B. Hunt, NCSU)

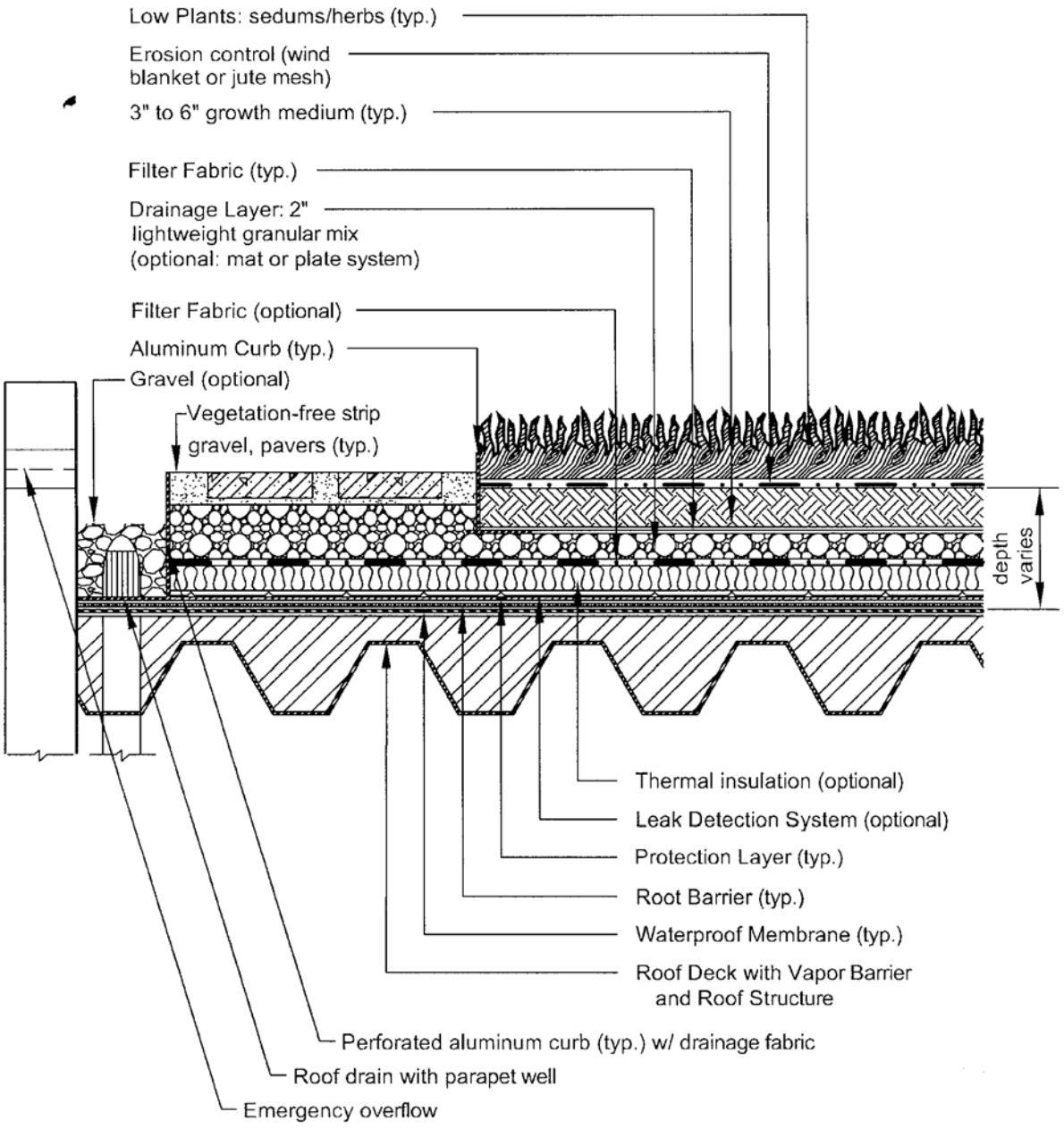

Figure 5.2. Typical Section – Extensive Vegetated Roof
(Source: Northern VA Regional Commission)

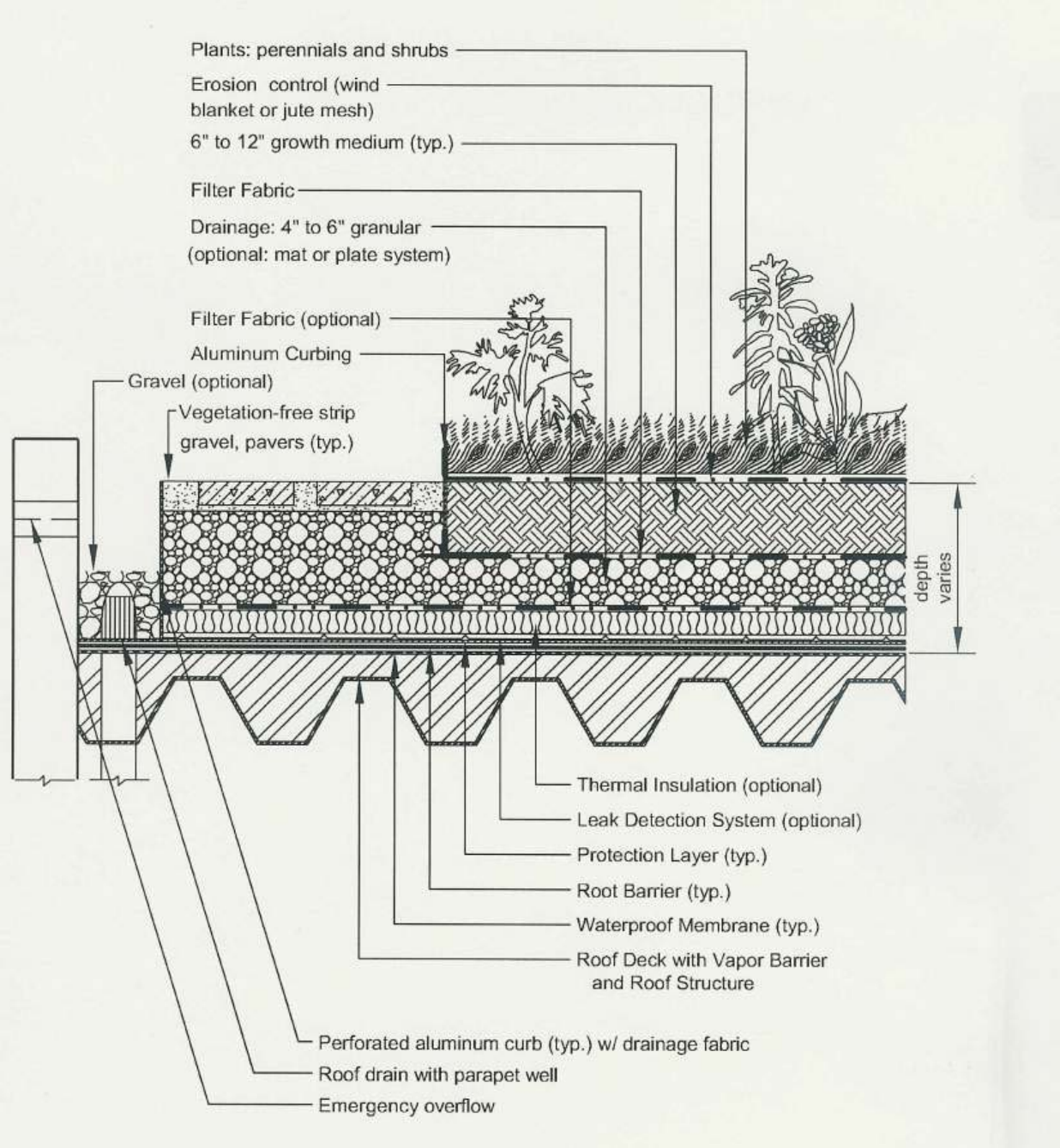

Figure 5.3. Typical Section – Intensive Vegetated Roof
(Source: Northern VA Regional Commission)

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

5.1. Typical applications

Vegetated 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. Vegetated roofs can be used on a variety of rooftops, including the following:

- Non-residential buildings (e.g. commercial, industrial, institutional and transportation uses)
- Multi-family residential buildings (e.g. condominiums or apartments)
- Mixed-use buildings

Local regulations may also permit the use of vegetated roofs on single family residential roofs; however the designer should verify any requirements or limitations that may be in the local zoning or building codes.

5.2. Common Site Constraints

Structural Capacity of the Roof. When designing a vegetated roof, designers must not only consider the stormwater storage capacity of the vegetated 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 (psf) for an extensive vegetated roof. As a result, a structural engineer, architect or other qualified professional should be involved with all vegetated roof designs to ensure that the building has enough structural capacity to support a vegetated roof.

Roof Pitch. Treatment volume (*Tv*) is maximized on relatively flat roofs (a pitch of 1 to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Vegetated roofs can be installed on rooftops with slopes up to 25%, however, a qualified designer should be consulted regarding any vegetated roof proposed for a 2/12 pitch or greater. Further, the drainage system must be carefully designed in conjunction with any baffles, grids, or strips that may be used to prevent slippage of the media on a sloped roof,. The effective *Tv* of the roof system diminishes on rooftops with steep pitches (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 through a penthouse 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 24 inches (NVRC, 2007). 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 stockpiled in the confined space.

Roof Type. Vegetated roofs can be applied to most roof surfaces, although concrete roof decks are preferred. Certain roof materials, such as fiberglass shingles, exposed treated wood and uncoated galvanized metal, may not be appropriate for vegetated rooftops due to pollutant leaching through the media (Clark et al, 2008).

Setbacks. The design of vegetated roofs shall be in accordance with **ANSI/SPRI VF-1 External Fire Design Standard** for minimum criteria for fire breaks and setback dimensions for all roof penetrations, such as mechanical sheds, penthouses, ducts, pipes, skylights, etc., as well as rooftop electrical, HVAC, and other mechanical systems.

Retrofitting Vegetated Roofs: Retrofitting of existing rooftops would appear to be an attractive option for redevelopment. However, there are key feasibility factors to consider when evaluating a retrofit, including but not limited to the following:

- The structural capacity of the existing rooftop area. This includes a balance between the structural weight tolerances and the required resistance to wind uplift. The designer should refer to **ANSI/SPRI RP-14 Wind Design Standard for Vegetated Roofing Systems**;
- The age and accessibility of the existing roof; and
- The capability of the building's owners to maintain it.

Options for vegetated roof retrofits are described in Profile Sheet RR-3 of Schueler et al (2007).

Local Building Codes. Building codes often differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits. In addition, the vegetated roof design should comply with the Virginia Uniform Statewide Building Code (VUSBC) with respect to roof drains and emergency overflow devices.

Construction Cost. When viewed strictly as stormwater treatment systems, vegetated roofs can cost between $12 and $25 per square foot, ranking them among the most costly stormwater practices available (Moran et al, 2005, Schueler et al 2007). These cost analyses, however, do not include life cycle cost savings relating to increased energy efficiency, higher rents associated with LEED building certification, and increased roof longevity due in part to the insulating feature of the planting media (see Risks of Roof Leaks below). These benefits over the life cycle of a vegetated roof may make it a more attractive investment. In addition, some communities may offer subsidies or financial incentives for installing vegetated roofs.

Risks of Roof Leaks. Well designed and installed vegetated roofs should have less problems with roof leaks than traditional roofs due to the protective layer provided by the vegetated roof: UV light blockage, less temperature induced expansion and contraction of waterproofing material seams, and projectile blockage. For a discussion on how to properly manage risk in vegetated roof installations, see Chapter 9 in Weiler and Scholz-Barth (2009).

SECTION 6: DESIGN CRITERIA

6.1. Overall Sizing

The required size or depth of a vegetated 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 vegetated 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 vegetated roof:

$$Vegetated\ Roof\ Volume = (RA * D * \eta)/12$$

Where:

RA Storage Volume = Roof area storage volume provided in the media (cu. ft.)
RA = vegetated roof area (sq. ft.)
D = media depth (in.)
η = media porosity (usually 0.25, but consult manufacturer specifications)

The resulting RA Storage volume can then be compared to the required *Tv* for the entire rooftop area (including all non-vegetated areas) to determine if it meets or exceeds the required *Tv* for Level 1 or Level 2 design, as shown in **Table 5.2** above. Vegetated roofs are not typically designed to capture runoff from other areas of the roof and are considered Level 1 or Level 2 based on the *Tv* storage volume for the rainfall depth landing on the portion of roof being designed.

Guidance for selecting the appropriate post development CN for the vegetated roof for four different design storms is also provided in **Table 5.3**; in general, lower curve numbers are associated with more frequent design storms. In most cases, the maximum design storm is the 10-year event.

6.2. Structural Capacity of the Roof

Vegetated roofs can be limited by the additional weight of the fully saturated soil 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 vegetated roof system and any needed structural reinforcement.

In most cases, fully-saturated extensive vegetated roofs have loads of about 15 to 30 lbs./sq. ft., which is fairly similar to traditional new rooftops (12 to 15 lbs./sq. ft.) that have a waterproofing layer anchored with stone ballast. For discussion of vegetated roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E-2397, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems*.

6.3. Functional Elements of a Vegetated Roof System

A vegetated roof is composed of up to eight different systems or layers, 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 vegetated 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 layer is the foundation of a vegetated 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 and water proofing in the vegetated roof system.

2. ***Waterproofing Layer.*** All vegetated 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 vegetated roof system. The design of the waterproofing layer should also consider methods of leak detection.

3. ***Insulation Layer.*** Many vegetated rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems.

4. ***Root Barrier.*** The next layer of a vegetated roof system is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals or other chemicals that could leach into stormwater runoff should be avoided. Similarly, fibrous systems should be avoided since roots tend to adhere and tangle in the fibers allowing possible penetration of the waterproofing layer.

5. ***Drainage Layer and Drainage System.*** A drainage layer is placed between the root barrier and the growing media to convey excess 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 moisture while also 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. Extended retention of water in this layer should be avoided due to potential root rot. 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.

6. ***Root-Permeable Filter Fabric.*** A semi-permeable polypropylene filter fabric is normally placed between the drainage layer and the growing media of a conventional system – not a try or hybrid system, to prevent the media from migrating into the drainage layer and clogging it. Proper installation of the fabric is crucial to avoid pooling of water in the drainage layer and leading to root rot.

7. ***Growing Media.*** The next layer in an extensive vegetated roof is the growing media, which is typically 2.5 to 8 inches deep. The depth and composition of the media is described in Section 6.5.

8. ***Plant Cover.*** The top layer of a vegetated roof consists of non-native, shallow-rooted, perennial, succulent plants that can withstand harsh conditions at the roof surface. Guidance on selecting the appropriate vegetated roof plants for hardiness zones in the Chesapeake Bay watershed can be found in Snodgrass and Snodgrass (2006). A mix of drought tolerant *Sedum* species and accent plants can be used to enhance the visual amenity value of a vegetated roof.

6.4. Pretreatment

Pretreatment is not needed for vegetated roofs.

6.5. Filter Media Composition

The recommended growing media for extensive vegetated 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 20% organic matter, normally well-aged compost (see Stormwater Design Specification No. 4). The percentage of organic matter should be limited, since it can clog the permeable filter fabric, and lead to increased weed growth while also leaching nutrients into the runoff from the roof. 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).

The composition of growing media for intensive vegetated roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the vegetated roof planting plan, the growing media must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees.

6.6. Conveyance and Overflow

The drainage layer below the growth media should be designed to convey the 10-year storm without backing water up to into 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 vegetated 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.

6.7. Vegetation and Surface Cover

A planting plan must be prepared for a vegetated roof by a landscape architect, botanist or other professional experienced with vegetated roofs, and it must be reviewed and approved by the local development review authority.

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). Much of the Chesapeake Bay watershed lies within USDA Plant Hardiness Zone 7, although some northern areas of the watershed fall in the colder Hardiness Zone 6, and some areas in the extreme southeastern portion of the watershed fall in the slightly warmer Hardiness Zone 8 (AHS, 2003).

A list of some common vegetated roof plant species that work well in the Chesapeake Bay watershed can be found in **Table 5.4** below. Designers may also want to directly contact the short list of mid-Atlantic nurseries for vegetated roof plant recommendations and availability. Designers

should encourage the use of at least five species of plants to accommodate seasonal and environmental variation or shifts.

- Plant choices can be much more diverse for deeper intensive vegetated roof systems. Herbs, forbs, grasses, shrubs and even trees can be used, but designers should understand they have higher watering, weeding and landscape maintenance requirements.
- The species and layout of the planting plan should reflect the location of building, 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.

Table 5.4. Ground Covers for Vegetated Roofs in Chesapeake Bay Watershed

Plant Hardiness Zone 7	Plant Hardiness Zone 6
Delosperma 'Tiffendell Magenta'	*Delosperma cooperi*
Hieracium lanatum	*Delosperma ecklonis var.latifolia*
Sedum lineare 'Variegatum'	*Hieracium villosum*
Sedum makinoi	*Orostachys boehmeri*
Sedum tetractinum	*Sedum hispanicum*
Sedum stoloniferum	*Sedum pluricaule var. ezawe*
	Sedum urvillei
Note: Landscape architects should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for definitive list of vegetated roof plants, including accent plants.	
Vegetated Roof Plant Vendors in Mid-Atlantic States	
Riverbend Nursery 1295 Mt. Elbert Road NW Riner, VA 24149 800-638-3362 www.riverbendnursery.com	Emery Knolls Farm 3410 Ady Road Street. Maryland 21154 410-452-5880 www.greenroofplants.com
Carolina Stonecrops, Inc. 159 Bay Shore Drive Nebo, NC 28761 828-659-2851 www.greenroofplants4u.com	North Creek Nurseries, Inc. 388 North Creek Road Landenburg, PA 19350 877-326-7584 www.northcreeknurseries.com
Roofscapes, Inc. 7114 McCallum Street Philadelphia, PA 19119 215-247-8784 www.roofmeadow.com	

- Designers should also match species to optimize the expected rooting depth of the growing media, which can also 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 vegetated roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most vegetated roof plant species will *not* be native to the Chesapeake Bay watershed (which is contrast to *native* plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of vegetated roof plant nurseries in the region, designers should order plants or pre-grown trays at least 6 (and up to 12) months prior to the expected planting

or installation date. It is also advisable to have plant materials contract-grown (see **Table 5.4** above for a current list of mid-Atlantic vegetated roof plant nurseries).

- When appropriate species are selected, and depending on installation date, most vegetated roofs in the Bay watershed will not require supplemental irrigation, except for possible temporary irrigation during the hot, dry summer months as the vegetated roof is established. More frequent irrigation will likely be required to achieve establishment of a plug planted system. 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 vegetated roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for vegetated roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation (minimal mowing, trimming and weeding) that is self-sustaining. .
- The vegetated roof design should include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the vegetated areas of the roof for weeding and making spot repairs. Installation of walkways should be coordinated with the drainage design.

6.8. Material Specifications

Standards specifications for North American vegetated 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 vegetated roof standards, which are described and referenced in **Table 5.5** below.

Designers and reviewers should also fully understand manufacturer specifications for each system component listed in **Section 6.3**, particularly if they choose to install proprietary “complete” vegetated roof systems or modules.

Table 5.5. Extensive Vegetated Roof Material Specifications

Material	Specification
Roof	Structural Capacity should conform to ASTM E-2397-05, *Practice for Determination of Live Loads and Dead Loads Associated with Green (Vegetated) Roof Systems*. In addition, use standard test methods ASTM E2398-05 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems*, and ASTME 2399-05 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.
Root Barrier	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 VUSBC.
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	80% lightweight inorganic materials and 20% 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 E2396-05.
Plant Materials	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*.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Vegetated roofs are an ideal stormwater control measure for karst terrain, although it is advisable to direct downspout discharges at least 15 feet away from the building foundation to minimize the risk of sinkhole formation.

7.2. Coastal Plain

Vegetated roofs are an acceptable runoff reduction practice for the coastal plain, but they have a limited water quality function, since rooftops are not a major loading source for nutrients or bacteria. Designers should also choose plant materials that can tolerate drought and salt spray.

7.3. Cold Climate and Winter Performance

Several design adaptations may be needed for vegetated roofs. The most important is to match the plant species to the appropriate plant hardiness zone. In parts of the Bay watershed with colder climates, vegetated roofs should be designed so the growing media is not subject to freeze-thaw, and provide greater structural capacity to account for winter snow loads.

7.3. Acid Rain

Much of the Bay watershed experiences acid rain, with rainfall pH ranging from 3.9 to 5.1. Research has shown that vegetated roof growing media can neutralize acid rain (Berhage et al, 2007), but it is not clear whether acid rain will impair plant growth or leach minerals from the growing media.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

Given the diversity of extensive vegetated 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 or electronic test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric) or modules, 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 surface. Allow for some settlement by adding additional medium depth. 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 and the media saturated such that water is running from all the vegetated sections of the roof immediately after installation and routinely during establishment.
- It generally takes 12 to 18 months to fully establish the vegetated roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth. (Pre-grown systems will often include the required fertilization required for establishment.) Temporary watering may also be needed during the first summer, if drought conditions persist. 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.

8.2. Construction Inspection

Inspections during construction are needed to ensure that the vegetated roof is built in accordance with these specifications. 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.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision is needed during several steps of vegetated 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; and

An additional inspection should be conducted at the end of the first or second growing season to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

Upon final inspection and acceptance, log the filtering practice's GPS coordinates and submit them for entry into the local BMP maintenance tracking database.

SECTION 9: MAINTENANCE

9.1. Maintenance Inspections and Ongoing Operations

Maintenance of a vegetated roof must be ensured through written documentation and an enforceable mechanism as per the VSMP regulations (4VAC50-60-112) between the VSMP authority and the property owner or manager. Documentation should include provisions for adequate notification or authorization for access to conduct inspections.

A vegetated 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 5.6** below). In addition, the vegetated 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 five years after the vegetated 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 vegetated roof plant communities.

An example maintenance inspection checklist for Vegetated Roofs can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2nd Edition, 2013).

Table 5.6. Typical Maintenance Activities Associated with Vegetated Roofs

Activity	Schedule
• Water to promote plant growth and survival. • Inspect the vegetated roof and replace any dead or dying vegetation.	As Needed (Following Construction)
• Inspect the waterproof membrane for leaking or cracks. • Annual pH test to determine if fertilization is needed. • Weeding to remove invasive plants. • Inspect roof drains, scuppers and gutters immediately adjacent to the growing media to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. • Inspect the vegetated roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed. • Mow or trim plantings in early April of each year as needed.	Semi-Annually

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Not applicable.

SECTION 11: REFERENCES

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