VR-1. Introduction

Source: WV DEP

Vegetated Roofs (also known as green roofs, living roofs or ecoroofs) are alternative roof surfaces that capture and store rainfall in an engineered growing media designed to support plant growth.

Vegetated Roofs can be used to:

- Manage the first one inch of rainfall on-site
- Meet partial storage requirements for local stormwater detention standards
- Retrofit existing developed areas, especially ultra-urban sites
- Vegetated Roofs DO NOT achieve additional pollutant removal credit beyond that achieved by the volume reduction credit.

A portion of the rainfall captured on a Vegetated Roof evaporates or is taken up by plants, which helps reduce runoff volumes and peak runoff rates on development sites. Vegetated Roofs typically contain a layered system of roofing, which is 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 toward the roof drain outlets.

There are two different types of Vegetated Roof systems: ***Intensive Vegetated Roofs*** 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. ***Extensive Vegetated Roofs*** have shallower growing media (4 inches), which is planted with carefully selected drought tolerant vegetation. Extensive Vegetated Roofs are much lighter and more commonly applied as stormwater management features. While intensive roofs have a deeper growing media and therefore more potential storage volume, they are not credited with greater volume reductions. However, they may provide other ancillary building life-cycle cost benefits, such as heating and cooling.

Vegetated Roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2-yr, 15-yr).

Figure VR-1 illustrates several Vegetated Roof applications. **Figure VR-2** is a typical schematic, and **Figure VR-3** shows typical layers of a Vegetated Roof system. **Tables VR-1 and VR-2** describe the runoff reduction and pollutant removal performance of Vegetated Roofs. **Table VR-3** is a design checklist to help guide the design process for Vegetated Roofs.

VR-1.1. Planning the Practice

Figure VR-1. Example Applications of Vegetated Roofs

Extensive Vegetated Roof (Source: WVDEP)

Intensive Vegetated Roof (Source: University of Virginia)

Figure VR-2. Schematic of typical Vegetated Roof

(Photo credit: Albemarle County, VA)

1. **Elements of Vegetated Roof** – Figure VR-2 & Section VR-4.1
2. **Structural capacity of roof** – Section VR-4.3
3. **Roof drains/overflow** – Section VR-4.5
4. **Plant selection** – Section VR-4.6

VR-1.2. Vegetated Roof Design Options & Performance

Table VR-1 describes the design options for a Vegetated Roof and the associated performance in terms of reducing the volume associated with one inch of rainfall on the site. There is only one design level for a Vegetated Roof. **Table VR-2** summarizes the Total Pollutant Load Reduction for Vegetated Roof designs for the purposes of calculating site-based pollutant load reductions in the context of Total Maximum Daily Loads (TMDLs) and/or watershed plans.

The runoff reduction credit for Vegetated Roof is provided in **Table VR-1**. There is only one design level for this practice. As shown in **Table VR-2**, there is no corresponding pollutant removal credit for Vegetated Roofs.

Table VR-1. Vegetated Roof Design Levels: Descriptions & Performance

Design Level	Design Variation Descriptions	Applications	Performance Achieved Toward Reducing 1" of Rainfall
One Design Level	Standard Design[1] • Soil media ≥ 4" • No more than 20% organic matter	Well-suited to ultra-urban areas and retrofits.	100% volume reduction for the Design Volume of the practice[2]

[1] *All designs must be in conformance with ASTM international standards for Vegetated Roofs referenced in* **Section VR-5**.
[2] *The Design Volume includes the storage volume of the growing media as defined by the porosity of the media (usually 0.25 to 0.35) and the media depth. Additional volume reduction credit is not provided for oversized (deeper) media storage.*

Table VR-2. Total Pollutant Load Reduction1 Performance Values for Vegetated Roofs

Design Level	Total Suspended Solids (TSS)	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)
One Design Level	TSS = 70%	TP = 45% TN = 45%

[1] *Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008). Vegetated Roofs do not achieve pollutant removal; therefore the Total Pollutant Load Reduction is solely a function of volume reduction. The runoff reduction credit awarded in Table 1 corresponds to a 45% annual pollutant load reduction for nutrients, and 70% for TSS.*

VR-1.3. Vegetated Roof Design Checklist

Table VR-3. Vegetated Roof Design Checklist

CHECKLIST

This checklist will help the designer with the necessary design steps for Vegetated Roofs.

- ☐ Check feasibility for site and building– **Table VR-1 and Section VR-3**
- ☐ Complete Design Compliance Spreadsheet to plan and confirm required Vegetated Roof sizing (Design Volume), additional practices needed, and overall site compliance – Design Compliance **Spreadsheet & Chapter 3 of Manual**
- ☐ Check Vegetated Roof sizing guidance and make sure the building has adequate structural capacity – **Sections VR-4.2 and VR-4.3**
- ☐ Check design adaptations appropriate to the site – **Section VR-6**
- ☐ Design Vegetated Roof in accordance with design criteria and typical details – **Sections VR-2 & VR-4**
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes

4.2.9. Vegetated Roofs (VR)

VR- 2. Typical Details

The typical layers of a Vegetated Roof are shown in **Figure VR-3**.

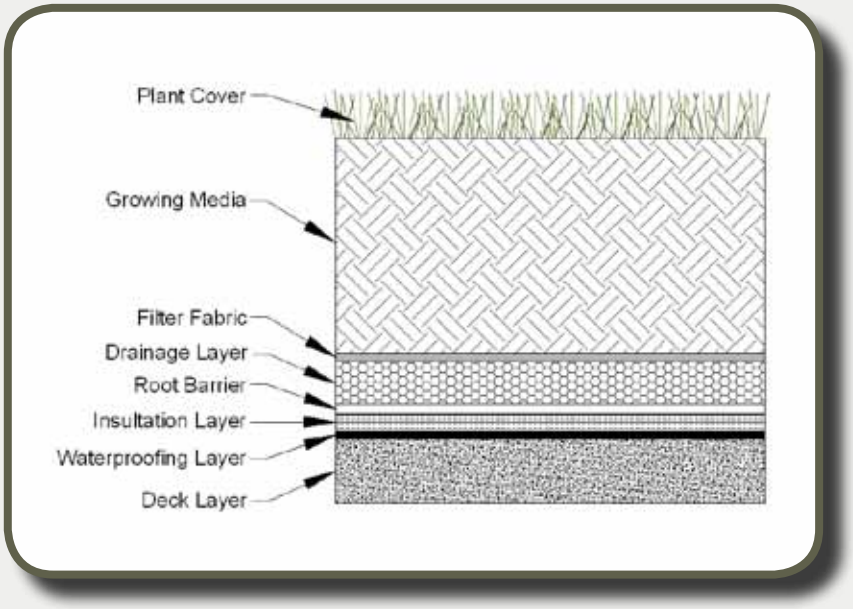

Figure VR-3. Typical Layers for a Vegetated Roof

4.2.9. Vegetated Roofs (VR)

VR-3. Feasibility Criteria and Design Considerations

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. Key constraints with Vegetated Roofs include the following:

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. See Section VR-4.3, Structural Capacity for more information on structural design considerations.

Roof Pitch. Vegetated Roof storage volume 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% if baffles, grids, or strips are used to prevent slippage of the media. These baffles should be designed to ensure the roof provides adequate storage for the design storm.

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 exposed treated wood and uncoated galvanized metal, may not be appropriate for Vegetated Roofs due to pollutants leaching through the media (Clark et al, 2008).

Setbacks. Vegetated Roofs should not be located near rooftop electrical and HVAC systems. A 2-foot wide vegetation-free zone is recommended along the perimeter of the roof, with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may be relaxed for small or low Vegetated Roof applications where parapets have been properly designed.

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 local building codes with respect to roof drains and emergency overflow devices.

4.2.9. Vegetated Roofs (VR)

VR-4. Design Criteria

VR-4.1. 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 (see **Figure VR-3**). 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 Roof systems that arrive at the project fully assembled, including plants. Alternatively, the designer or architect must specify and assemble all the Vegetated Roof system components. Several notable resources for assembling the components of a Vegetated Roof system include Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006), and Dunnett and Kingsbury (2004).

Vegetated Roof design layers include:

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 in the Vegetated Roof system. In general, concrete decks are preferred for Vegetated Roofs, although other materials can be used as long as the appropriate system components are matched to them.

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.

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.

5. **Drainage Layer and Drainage System:** A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The selection of the drainage layer type and thickness is an important design decision that is governed by the required conveyance capacity and the structural capacity of the rooftop. The depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive Vegetated Roof systems. The drainage layer should consist of synthetic or inorganic materials, such as a 1-2 inch layer of clean, washed granular material [American Society for Testing and Materials (ASTM) D 448 size No. 8 stone or lightweight granular mix], or recycled polyethylene 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 leaders. 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 to prevent the media from migrating into the drainage layer and clogging it.

7. **Growing Media:** The next layer in an extensive Vegetated Roof is the growing media, which is typically 3 to 6 inches deep. 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 Appendix D). 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. 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.

8. **Plant Cover:** The top layer of a Vegetated Roof consists of non-native, slow-growing, 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 West Virginia 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 Vegetated Roof. See Section VR-4.6 for additional plant information.

VR-4.2. Overall Sizing

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a BMP plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the contributing drainage area (CDA), as determined by the Design Compliance Spreadsheet. Any given best management practice (BMP) may treat the full Tv or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage within different layers as prescribed in the BMP specification. For Vegetated Roofs, Dv will equal Tv if the CDA is limited to the rooftop itself. However, if the Vegetated Roof is used in conjunction with downstream runoff reduction practices, the Dv of the Vegetated Roof will be a subset of the overall drainage area Tv. In such cases, the sum of the Design Volume in the Vegetated Roof plus that of the other practices in the treatment train should equal the total drainage area Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the permeable pavement being designed.

The minimum 4-inch depth and the porosity of the growing media define the storage volume for the Vegetated Roof to meet the required goal of managing the 1" rainfall event Design Volume (Dv) for the rooftop area. Different commercially available pre-fabricated Vegetated Roof "panels" may include variations on the growing media depth, porosity and hydraulic conductivity, as well as the geometry and the hydraulic capacity of the underlying drainage layer, and other components. Site designers and planners should consult with Vegetated Roof manufacturers and material suppliers for specific sizing guidelines. As a general sizing rule, **Equation VR-1** can be used to determine the water quality treatment storage volume retained by a Vegetated Roof:

Equation VR-1

$$S_v = (RA \times d \times \eta)/12$$

Where, Sv = storage volume (cu. ft.)
RA = Vegetated Roof area (sq. ft.)
d = media depth – minimum 4 inches (in.)
η = media porosity (typically 0.25 to 0.3); consult manufacturer's specifications)

The resulting storage volume can then be compared to the target Dv for the entire rooftop area (including all non-vegetated areas) to determine if it meets or exceeds the required volume.

Vegetated Roofs are not designed to capture large storms (2-year, 10-year frequency, etc.). However, the West Virginia Design Compliance Spreadsheet will provide a Curve Number adjustment for individual design storms based on the total storage volume provided as calculated in **Equation VR-1**.

NOTE: Additional credit (i.e. greater than 100% of the Dv for the area of rooftop) is not awarded for providing a deeper growing media section.

VR-4.3. Structural Capacity of the Roof

The physical capacity of the roof to bear structural loads can limit Vegetated Roofs in terms of the additional weight of the fully saturated soil and plants. The designer should consult with a licensed structural engineer as well as the project 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 25 lbs./sq. ft., which is similar to traditional new rooftops (12 to 15 lbs./sq. ft.) that have a waterproofing layer anchored with stone ballast. For a 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 Roof Systems*.

VR-4.4. Pre-treatment

Pretreatment is not needed for Vegetated Roofs.

VR-4.5. Conveyance and Overflow

The Vegetated Roof drainage layer (refer to **Section VR-4.1**.) should convey flow from under the growing media directly to an outlet or overflow system such as a traditional rooftop downspout drainage system. The Vegetated Roof drainage layer must be adequate to convey the volume of stormwater equal to the flow capacity of the overflow or downspout system without backing water up onto the rooftop or into the Vegetated Roof media. 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. However, an adequate number of roof drains that are not immediately adjacent to the growing media must be provided so as to allow the roof to drain with minimal ponding above the media.

VR-4.6. Planting Plan

Plant selection, landscaping, and maintenance are critical to the performance and function of Vegetated Roofs. Therefore, a planting plan shall be provided for Vegetated Roofs.

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 Roofs 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).

A list of some common Vegetated Roof plant species that work well in West Virginia can be found in **Table VR-4** below. Designers may also want to directly contact the short list of mid-Atlantic nurseries for Vegetated Roof plant recommendations and availability (**Table VR-5**).

- 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 VR-4. Ground Covers appropriate for Vegetated Roofs in West Virginia

Plant	Light	Moisture Requirement	Notes
Delosperma cooperii	Full Sun	Dry	Pink flowers; grows rapidly
Delosperma 'Kelaidis'	Full Sun	Dry	Salmon flowers; grows rapidly
Delosperma nubigenum 'Basutoland'	Full Sun	Moist-Dry	Yellow flowers; very hardy
Sedum album	Full Sun	Dry	White flowers; hardy
Sedum lanceolatum	Full Sun	Dry	Yellow flowers; native to U.S.
Sedum oreganum	Part Shade	Moist	Yellow flowers; native to U.S.
Sedum stoloniferum	Sun	Moist	Pink flowers; drought tolerant
Sedum telephiodes	Sun	Dry	Blue green foliage; native to region
Sedum ternatum	Part Shade-Shade	Dry-Moist	White flowers; grows in shade
Talinum calycinum	Sun	Dry	Pink flowers; self sows

Note: Designers 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.

Table VR-5. Vegetated Roof Plant Vendors in the Mid-Atlantic

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 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 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 West Virginia (which contrasts with native plant recommendations for other stormwater practices, such as Bioretention and Stormwater Wetlands).
- Given the limited number of Vegetated 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 (see **Table VR-5** above for a current list of mid-Atlantic Vegetated Roof plant nurseries).
- When appropriate species are selected, most Vegetated Roofs will not require supplemental irrigation, except for temporary irrigation during dry months as the Vegetated Roof is established. The planting window extends from the • 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 that is self-sustaining and requires minimal mowing, trimming and weeding.

The Vegetated 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.

VR-5. Materials Specifications

Standard 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 ASTM has recently issued several overarching Vegetated Roof standards, which are described and referenced in **Table VR-6** below.

Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" Vegetated Roof systems or modules.

Table VR-6. 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 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	Depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive designs. 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. Designers should consult the material specifications as outlined in ASTM E2396 and E2398. Roof drains and emergency overflow should be designed in accordance with all applicable building 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	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.

4.2.9. Vegetated Roofs (VR)

VR-6. Design Adaptations

VR-6.1. 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.

VR-6.2. 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 Chesapeake 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.

VR-6.3. Acid Rain

Much of the mid-Atlantic area 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.

4.2.9. Vegetated Roofs (VR)

VR-7. Construction & Installation

VR-7.1. Vegetated Roof Installation

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 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), 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. 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 • It generally takes 12 to 18 months to fully establish a Vegetated Roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth. 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.

VR-7.2 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
- 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.

An example construction phase inspection checklist for Vegetated Roofs can be found in **Appendix A**.

4.2.9. Vegetated Roofs (VR)

VR-8. Maintenance Criteria

VR-8.1. Maintenance Inspections and Operations

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 VR-7** 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 according to ASTM E2400 (ASTM, 2006).

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.

Part II, Section C.b.5.ii(C) of the MS4 General Permit requires a maintenance agreement and plan between the property owner or operator and the local program authority (for municipal separate storm sewer systems). This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

Vegetated Roofs must be covered by a drainage easement to allow inspection and maintenance.

An example maintenance inspection checklist for Vegetated Roofs can be found in **Appendix A**.

Table VR-7. Typical Maintenance Activities Associated with Vegetated Roofs

Activity	Schedule
• Water to promote plant growth and survival. • Inspect the roof and replace any dead or dying vegetation.	As Needed (following construction)
• Inspect the waterproof membrane for leaking or cracks. • Annual fertilization (first five years). • Weeding to remove invasive plants (no digging or using pointed tools). • Inspect roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. • Inspect the roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.	Semi-Annually

REFERENCES

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