BMP 6.5.1: Vegetated Roof

An extensive vegetated roof cover is a veneer of vegetation that is grown on and completely covers an otherwise conventional flat or pitched roof ($\leq 30^{o}$ slope), endowing the roof with hydrologic characteristics that more closely match surface vegetation than the roof. The overall thickness of the veneer may range from 2 to 6 inches and may contain multiple layers, consisting of waterproofing, synthetic insulation, non-soil engineered growth media, fabrics, and synthetic components. Vegetated roof covers can be optimized to achieve water quantity and water quality benefits. Through the appropriate selection of materials, even thin vegetated covers can provide significant rainfall retention and detention functions.

Key Design Elements

- 2-6 inches of engineered media; assemblies that are 4 inches and deeper may include more than one type of engineered media
- Engineered media should have a high mineral content. Engineered media for extensive vegetated roof covers is typically 85% to 97% non-organic (wet combustion or loss on ignition methods).
- Vegetated roof covers intended to achieve water quality benefits should not be fertilized
- Irrigation is not a desirable component of vegetated covers used as best management practices
- 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.
- Assemblies planned for roofs with pitches steeper than 2:12 must incorporate supplemental measures to insure stability against sliding.

Structural considerations are required.

Potential Applications

Residential:	Yes
Commercial:	Yes
Ultra Urban:	Yes
Industrial:	Yes
Retrofit:	Yes
Highway/Road:	None

Stormwater Functions

Volume Reduction:	Med/High
Recharge:	None
Peak Rate Control:	Low
Water Quality:	Medium

Water Quality Functions

TSS:	85%
TP:	85%
NO3:	30%

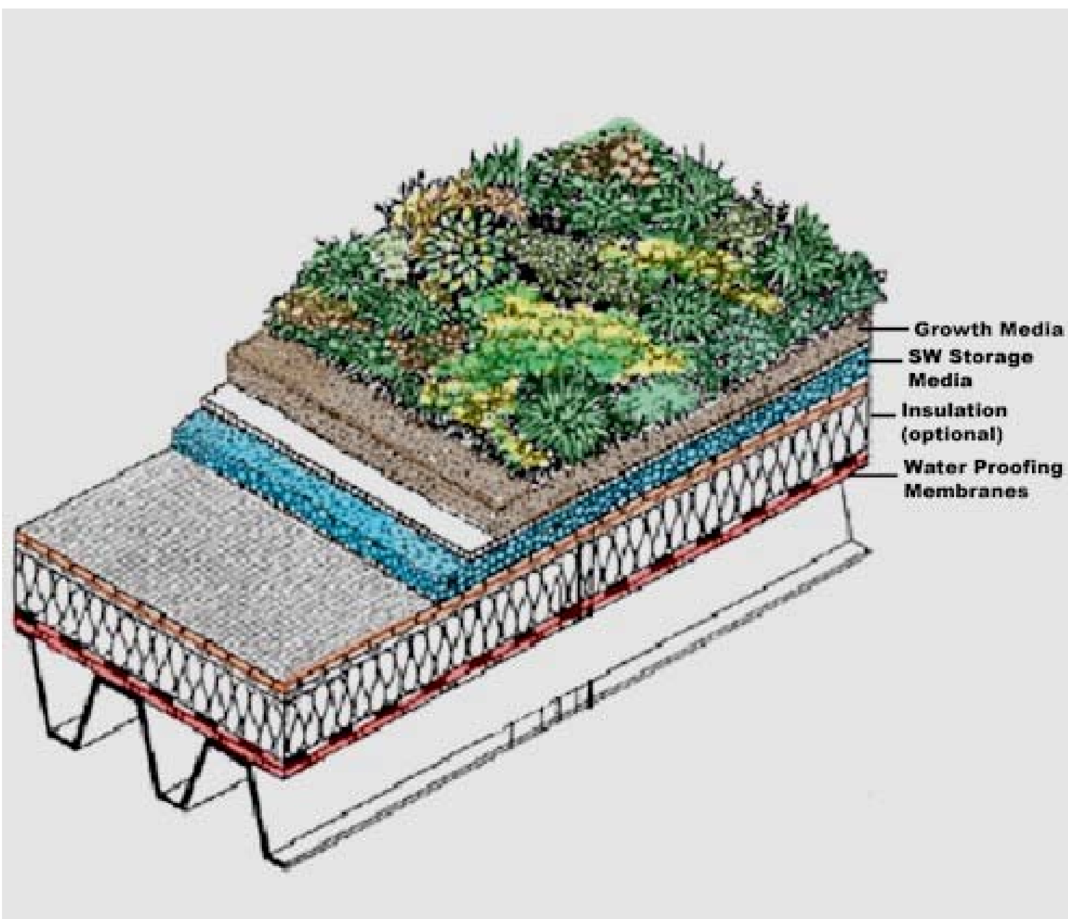
Other Considerations

- The roof structure must be evaluated for compatibility with the maximum predicted dead and live loads. Typical dead loads for wet extensive vegetated covers range from 8 to 36 pounds per square foot. Live load is a function of rainfall retention. For example, 2 inches of rain equals 10.4 lbs. per square foot of live load. It requires 20 inches of snow to have the same live load per square foot.
- The waterproofing must be resistant to biological and root attack. In many instances a supplemental root-fast layer is installed to protect the primary waterproofing membrane from plant roots.
- Standards and guidelines (in English) for the design of green roofs are available from FLL[1], a European non-profit trade organization. In the United States, guidelines are in development by ASTM (American Standard Testing Methods).

Description

Extensive vegetated roof covers are usually 6 inches or less in depth and are typically intended to achieve a specific environmental benefit, such as rainfall runoff mitigation. For this reason they are most commonly not irrigated. While some installations are open to public access, most extensive vegetated roof covers are for public viewing only. In order to make them practical for installation on conventional roof structures, lightweight materials are used in the preparation of most engineered media. Developments in the last 40 years that have made these systems viable include: 1) recognition of the value of vegetated covers in restoring near open-space hydrologic performance on impervious surfaces, 2) advances in waterproofing materials and methods, and 3) development of a reliable temperate climate plant list that can thrive under the extreme growing conditions on a roof.

Vegetated roof covers that are 10 inches, or deeper, are referred to as 'intensive' vegetated roof covers. These are more familiar in the United States and include many urban landscaped plazas. Intensive assemblies can also provide substantial environmental benefits, but are intended primarily to achieve aesthetic and architectural objectives. These types of systems are considered "roof gardens" and are not to be confused with the simple "extensive" design. Benefits beyond the stormwater considerations include temperature moderation and roof longevity.



Variations

Most extensive vegetated roof covers fall into three categories

- Single media with synthetic under-drain layer
- Dual media
- Dual media with synthetic retention/detention layer

All vegetated roof covers will require a premium waterproofing 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 vegetated roof cover system can be adapted to either roofing configuration. In the descriptions that follow, the assemblies refer to the conventional configuration, in which the insulation layer is below the primary waterproofing.

All three extensive roof cover variations can be installed without irrigation. Non irrigated assemblies are strongly recommended. While this may place some limits on the type of plants that can be grown, the benefits are that the assembly will perform better as a stormwater BMP, and the maintenance requirements will be substantially reduced.

Some assemblies are installed in tray-like modules to facilitate installation, especially in confined locations.

Single media assemblies
Single media assemblies are commonly used for pitched roof applications and for thin and lightweight installations. These systems typically incorporate very drought tolerant plants and utilize coarse engineered media with high permeability. A typical profile would include the following layers.

- Waterproofing membrane
- **Root-barrier** (optional, depending on the root-fastness of the waterproofing)
- Semi-rigid plastic **geocomposite drain** or **mat** (typical mats are made from non-biodegradable fabric or plastic foam)
- Separation geotextile
- Engineered **growth media**
- Foliage layer

Pitched roof applications may require the addition of slope bars, rigid slope stabilization panels, cribbing, reinforcing mesh, or similar method minimizing sliding instability.

Flat roof applications with mats as foundations typically require a network of perforated internal drainage conduit to enhance drainage of percolated rainfall to the deck drains or scuppers.

Assemblies with mats can be irrigated from beneath, while assemblies with drainage composites require direct drainage.

Dual media assemblies
Dual media assemblies utilize two types of non-soil media. In this case a finer-grained media with some organic content is placed over a basal layer of coarse lightweight mineral aggregate. They do not include a geocomposite drain. The objective is to improve drought resistance by replicating a natural

growing environment in which sandy topsoil overlies gravelly subsoil. These assemblies are typically 4 to 6 inches thick and include the following layers:

- Waterproofing membrane
- Protection layer
- Coarse-grained **drainage media**
- Root-permeable nonwoven separation geotextile
- Fine-grained engineered growth media layer
- Foliage layer

These assemblies are suitable for roofs with pitches less than, or equal to, 1.5:12. Large vegetated covers will generally incorporate a network of perforated internal drainage conduit.

Dual media systems are ideal for use in combination with base irrigation methods.

Dual media with synthetic retention/detention layer
These assemblies introduce plastic panels with cup-like receptacles on their upper surface (i.e., a modified geocomposite drain sheet). The panels are in-filled with coarse lightweight mineral aggregate. The cups trap and retain water. They also introduce an air layer at the bottom of the assembly. A typical profile would include:

- Waterproofing membrane
- Felt fabric
- Retention/detention panel
- Coarse-grained drainage media
- Separation geotextile
- Fine grained ‘growth’ media layer
- Foliage layer

These assemblies are suitable on roof with pitches less than or equal to 1:12. Due to their complexity, these system are usually 5 inches or deeper.

If needed, irrigation can be provided via surface spray or mid-level drip.

- **Stormwater Volume and Rate Control**
  Vegetated roof covers are an “at source” measure for reducing the rate and volume of runoff released during rainfall events. The water retention and detention properties of vegetated roof covers can be enhanced through proper selection of the engineered media and plants.

- **Runoff Water Quality Improvements**
  Direct runoff from roofs is often a contributor to NPS pollutant discharges. Vegetated roof covers can significantly reduce this source of pollution. Assemblies intended to produce water quality benefits should employ engineered media with 100% mineral content. Following the plant establishment period (usually about 18 months), on-going fertilization of the cover should not be permitted. Experience indicates that it will take five or more years for a water quality vegetated cover to attain its maximum potential pollutant removal efficiency.

- **In Combination with Infiltration Measures**
  Vegetated roof covers are frequently combined with ground infiltration measures. Vegetated roof covers improve the efficiency of infiltration devices by:

  - Reducing the peak runoff rate
  - Prolonging the runoff
  - Filtering runoff to produce a clear effluent

  Roofs that are designed to achieve water quality improvements will also reduce pollutant inputs to infiltration devices.

- **Habitat Restoration/Creation**
  Vegetated roof covers have been used to create functional meadows and wetlands to mitigate the development of open space. This can be accomplished with assemblies as thin as 6 inches.

Design Considerations

1. Live and **dead load** bearing capacity of the roof need to be established. Dead loads should be estimated using media weights determined using a standardized laboratory procedure.[1]

2. **Waterproofing** materials must be durable under the conditions associated with vegetated covers. A supplemental root-barrier layer should be installed in conjunction with materials that are not root-fast.

3. Roof flashings should extend 6 inches higher than the top of the growth media surface and be protected by counter-flashings.

4. The design should incorporate measures to protect the waterproofing membrane from physical damage during and after installation of the vegetated cover assembly.

5. Vegetated roof covers should incorporate internal drainage capacity sufficient to accommodate a two-year return frequency rainfall without generating surface runoff flow.

6. Deck drains, scuppers, or gravel stops serving as methods to discharge water from the roof area should be protected with **access chambers**. These enclosures should include removable lids in order to allow ready access for inspection.

7. The physical properties of the engineered media should be selected appropriately in order to achieve the desired hydrologic performance.

8. Engineered media should contain no clay size particles and should contain no more than 15% **organic matter** (wet combustion or loss on ignition methods)

9. Media used in constructing vegetated roof covers should have a maximum moisture capacity[2] of between 30% and 40%.

10. Plants should be selected which will create a vigorous, drought-tolerant ground cover. In Pennsylvania the most successful and commonly used ground covers for non irrigated projects are varieties of Sedum and Delosperma. In the Pennsylvania climate Delosperma is deciduous. Both deciduous and evergreen varieties of *Sedum* are available. Deeper assemblies (i.e., 4 to 6 inches) can also incorporate a wider range of plants including *Dianthus, Phlox, Antennaria,* and *Carex.*

11. Roofs with pitches exceeding 2:12 should be provided with supplemental measures to insure stability against sliding

Detailed Stormwater Functions

The performance of vegetated roof covers as stormwater best management practices cannot be represented by a simple algebraic expression. Conventional methods are used to estimate surface runoff from various types of surfaces. In the analysis of vegetated roof covers, the water that is discharged from the roof is not surface runoff, but rather underflow, (i.e., percolated water). The rate and quantity of water released during a particular design storm can be predicted based on knowledge of key physical properties, including:

- Maximum media water retention
- Field capacity
- Plant cover type
- Saturated hydraulic conductivity
- Non-capillary porosity

The maximum media water retention is the maximum quantity of water that can be held against gravity under drained conditions. Standards that have been developed specifically for measuring this quantity in roof media are available from FLL and ASTM (draft).

Peak Rate Mitigation

Vegetated roof covers can exert an influence on runoff peak rates derived from roofs.
A general rule is to consider the first portion of the rainfall fills the volume reduction capacity (see below).

Volume Reduction Calculations

All vegetated roof covers have both a retention and a detention volume component. Benchmarks for these volumes can be developed from the physical properties described above (*Detailed Stormwater Functions*).

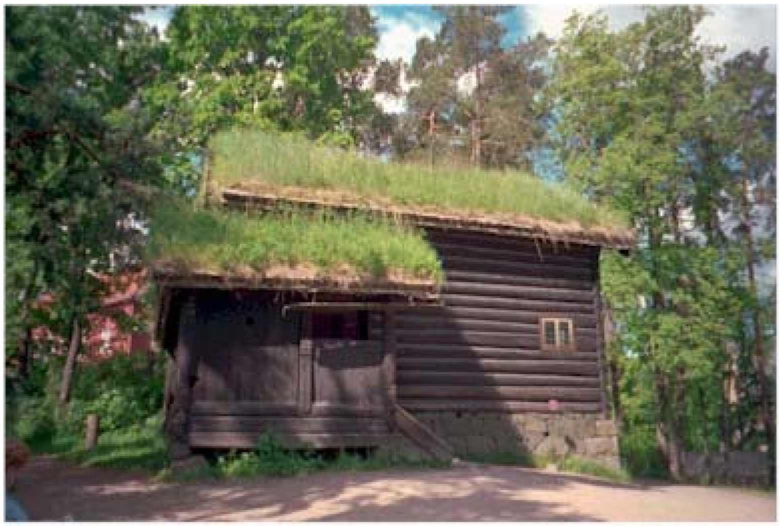
The interaction of retention and detention produce both short-term effects (i.e., control of single storms) and long-term effects (i.e., reductions in total seasonal or annual roof runoff). Continuous simulation using a representative annual rainfall record from a local weather station is required in order to predict the long-term runoff versus rainfall benefit. The effectiveness of vegetated roof covers will vary according to the regional pattern of rainfall.

Using the German RWS program, the designer could generate a table of volume reductions for several regions in Pennsylvania. The table would relate the runoff ratio (runoff/rainfall) based on one or two types of cover assemblies and selected regions in PA for which good weather data is available. For the table to be used, a vegetated cover would have to comply with European guidelines.

Water Quality Improvement

Once the plant cover is established, nutrient additions should be suspended. Experience indicates that the efficiency of vegetated covers in reducing pollutant and nutrient releases from roofs will increase with time. The vegetated cover should reach its optimum performance after about five years.

See Section 8 for Water Quality Improvement methodology that addresses pollutants removal effectiveness of this BMP.



Construction Sequence

1. Visually inspect the completed waterproofing to identify any apparent flaws, irregularities, or conditions that will be interfere with the security or functionality of the vegetated covers system. The waterproofing should be tested for watertightness by the roofing applicator.

2. Institute a leak protection program

3. Introduce measures to protect the finished waterproofing from physical damage

4Install slope stabilization measures (pitched roofs with pitches in excess of 2:12). In some installations slope stabilizing measures can be introduced as part of the roof structure and will be already be in-place at the start of the construction sequence.

5. If the waterproofing materials are not root fast, install a root-barrier layer
6. Layout key drainage and irrigation components, including drain access chambers, internal drainage conduit, confinement border units, and isolation frames (for roof-top utilities, hatches and penetrations)

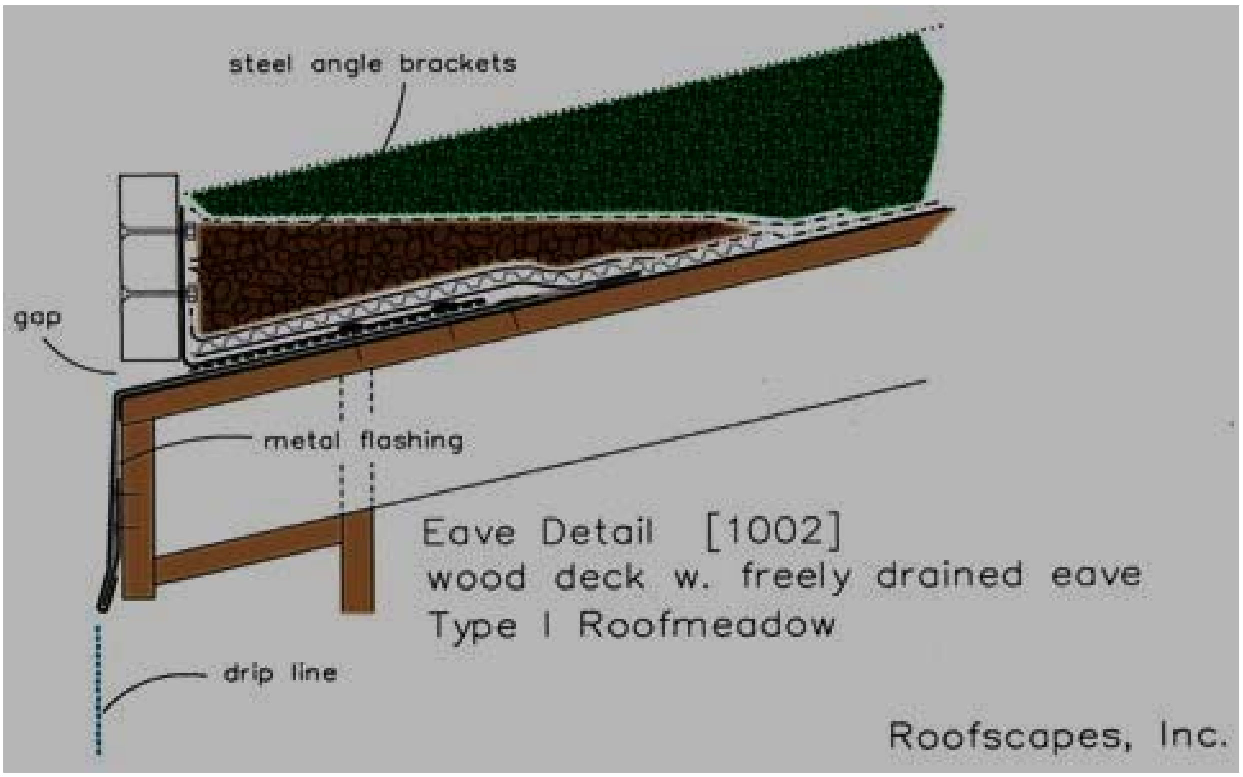
7. Install walkways and paths (projects with public access)

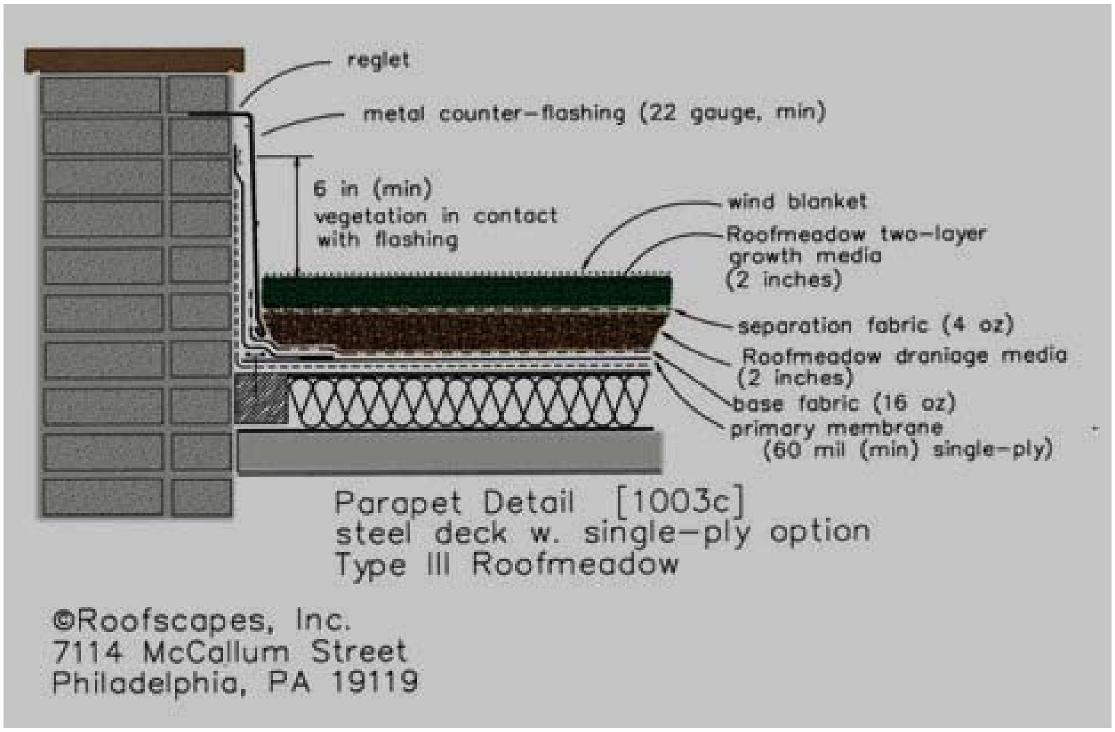
8. Test irrigation systems (as relevant for roof gardens)

9. Install the drainage layer. Depending on the variation type, this could be a geocomposite drain, mat, or course of drainage media.

10. Cover the drainage layer with the separation fabric (in some assemblies, the separation fabric is pre-bonded to a synthetic drainage layer.

11. Install the upper growth media layer (dual media assemblies only)
12. Establish the foliage cover plantings from cuttings, seed, plugs or pre-grown mats
13. Provide protection from wind disruptions as warranted by the project conditions, and plant establishment method.





Maintenance Issues

- During the plant establishment period, periodic irrigation may be required
- During the plant establishment period, three to four visits to conduct basic weeding, fertilization, and in-fill planting is recommended. Thereafter, only two annual visits for inspection and light weeding should be needed (irrigated assemblies will require more intensive maintenance).

Cost Issues

The construction cost of vegetated roof covers can vary greatly, depending on factors such as:

- Height of the building
- Accessibility to the structure by large equipment such as cranes and trailers
- Depth and complexity of the assembly
- Remoteness of the project from sources of material supply
- Size of the project

However, under present market conditions (2004), extensive vegetated covers for roof will typically range between $8 and $15 per square foot, including design, installation, and warranty service. Basic maintenance for extensive vegetated covers typically requires about 3 man-hours per 1,000 square feet, annually.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

Due to the very large variation in assembly types and methods, it is not possible to provide a comprehensive specification. Performance specifications, describing the assembly elements and their physical properties can be obtained from commercial providers of vegetated roof covers. The references provided also offer specific guidance for the selection of materials and methods.

Some key components and associated performance-related properties are as follows:

1. **Root-barriers** should be thermoplastic membranes with a thickness of at least 30 mils. Thermoplastic sheets can be bonded using hot-air fusion methods, rendering the seams safe from root penetration. Membranes that have been certified for use as root-barriers are recommended. At present only FLL offers a recognized test for root-barriers. Several FLL-certified materials are available in the United States. Interested American manufactures can submit products for testing to FLL-certified labs.

2. **Granular drainage media** should be a non-carbonate mineral aggregate conforming to the following specifications:

Saturated Hydraulic Conductivity[2]	25 in/min
Total Organic Matter, by Wet Combustion (MSA)	1%
Abrasion Resistance (ASTM-C131-96)	25% loss
Soundness (ASTM-C88 or T103 or T103-91)	5% loss
Porosity (ASTM-C29)	25%
Alkalinity, CaCO3 equivalents (MSA)	1 %
Grain-Size Distribution (ASTM-C136)	
Pct. Passing US#18 sieve	1%
Pct. Passing ¼-inch sieve	30%
Pct. Passing 3/8-inch sieve	80%

3. **Growth media** should be a soil-like mixture containing not more than 15% organic content (wet combustion or loss on ignition methods). The appropriate grain-size distribution is essential for achieving the proper moisture content, permeability, nutrient management, and non-capillary porosity, and 'soil' structure. The grain-size guidelines vary for single and dual media vegetated cover assemblies.

Non-capillary Pore Space at Field Capacity, 0.333 bar (TMECC 03.01, A)	15% (vol)
Moisture Content at Field Capacity (TMECC 03.01, A)	12% (vol)
Maximum Media Water Retention (FLL)	30% (vol)
Alkalinity, Ca CO3 equivalents (MSA)	2.5%

Total Organic Matter by Wet Combustion (MSA)	3-15% (dry wt.)
pH (RCSTP)	6.5-8.0
Soluble Salts (DTPA saturated media extraction)"(RCSTP)	6 mmhos/cm
Cation exchange capacity (MSA)	10 meq/100g
Saturated Hydraulic Conductivity for Single Media Assemblies (FLL)[3]	0.05 in/min
Saturated Hydraulic Conductivity for Dual Media Assemblies (FLL)	0.30 in/min

Grain-size Distribution of the Mineral Fraction (ASTM-D422)

Single Media Assemblies

Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	5%
Pct. Passing US#60 sieve	10%
Pct. Passing US#18 sieve	5 - 50%
Pct. Passing 1/8-inch sieve	20 - 70%
Pct. Passing 3/8-inch sieve	75 -100%

Dual Media Assemblies

Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	5-15%
Pct. Passing US#60 sieve	10-25%
Pct. Passing US#18 sieve	20 - 50%
Pct. Passing 1/8-inch sieve	55 - 95%
Pct. Passing 3/8-inch sieve	90 -100%

Macro- and micro-nutrients shall be incorporated in the formulation in initial proportions suitable for support the specified planting.

4. <u>Separation fabric</u> should be readily penetrated by roots, but provide a durable separation between the drainage and growth media layers (Only lightweight nonwoven geotextiles are recommended for this function.

Unit Weight (ASTM-D3776)	4.25 oz/yd2
Grab tensile (ASTM-D4632)	90 lb
Mullen Burst Strength (ASTM-D4632)	135 lb/in
Permittivity (ASTM-D4491)	2 sec-1

References

FLL: Guidelines for the Planning, Installation, and Maintenance in Roof Greening, 1995, English Version (*Richtlinen für die Planung, Ausführung und Pflege von Dachbegrünungen*), Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.

ASTM: American Standard Testing Methods

Planting Green Roofs and Living Walls, 2004, Dunnett, N, and Kingsbury, N, Timber Press [ISBN 0-88192-640-X]

Penn State Center For Green Roof Research, http://hortweb.cas.psu.edu/research/greenroofcenter/

FOOTNOTES

1 FLL or ASTM procedures for determining the maximum density and associated moisture content under compressed and hydrated conditions. See ASTM Draft: Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems , and ASTM Draft Standard Practice for Determination of Dead Loads and Live Loads f or Green Roof Systems

2 ASTM Draft: Standard Test Method for Saturated Hydraulic Conductivity of Granular Drainage Media [Falling-Head Method] for Green Roof Systems