





## 9.4 GREEN ROOFS



A green roof, also known as a vegetated roof, is a roof that has been covered with a growing medium and vegetation. Green roofs are effective for reducing the amount of stormwater runoff leaving a site. A green roof consists of vegetation planted in growing media on top of a drainage layer that intercepts stormwater runoff and reduces the total volume of runoff through evapotranspiration.

### N.J.A.C. 7:8 Stormwater Management Rules – Applicable Design and Performance Standards

	Green Infrastructure	Yes
	Stormwater Runoff Quantity	Yes
	Groundwater Recharge	Not Allowed
	Stormwater Runoff Quality	Not Allowed

### Stormwater Runoff Quantity Control Mechanisms and Corresponding Criteria

Volume Reduction*	
Reduced Curve Number	Based on the available water capacity of the growing medium
Growing Medium	Must meet the design criteria specifications. See Pages 6 and 7, plus either Page 9 for Extensive Green Roofs or Page 10 for Intensive Green roofs, as appropriate
Maximum Roof Slope	20%
Evapo-transpiration	
Appropriate Species Selection	See Page 6
Minimum Density of Vegetation	85%

## Introduction

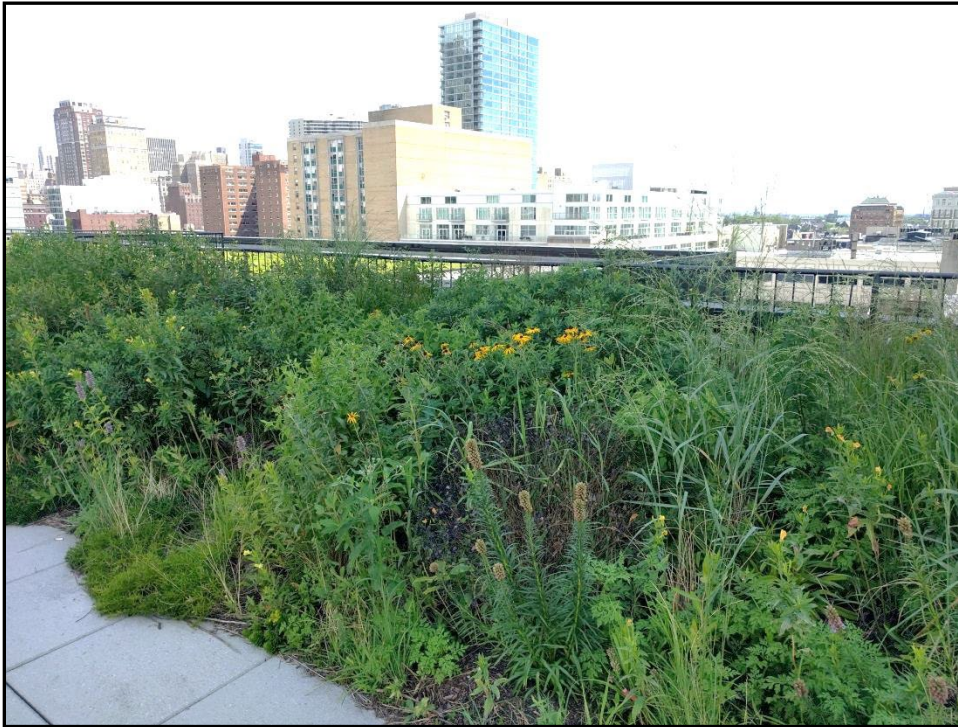
A green roof, also known as a vegetated roof, is a roof that has been covered with a growing medium and vegetation. Green roofs are effective for reducing the amount of stormwater runoff leaving a site, mitigating urban heat island effects and reducing local air pollution, as well lowering energy costs by providing additional insulation. A green roof consists of vegetation planted in growing media on top of a drainage layer that intercepts stormwater runoff and reduces the total volume of runoff through evapo-transpiration. Additionally, studies have indicated that green roofs can extend the lifespan of roofing systems compared to conventional roofs, because the vegetation and growing media protect the roof and the waterproofing layer from physical damage and ultra-violet radiation. Green roofs are generally referred to as either intensive or extensive based on the depth of the growing medium.

Green roofs may be used on newly constructed buildings or on existing structures. Their use may be limited by the bearing capacity of the roof; therefore, it is important to analyze the structural integrity of the roof before deciding whether to use a green roof and what type is most appropriate. Green roofs are most effective on sites where roofs make up the majority of the impervious surface on the site or for sites which have little space available at-grade to build other BMPs. A green roof must have a maintenance plan and must be reflected in a deed notice recorded in the county clerk's office to prevent alteration or removal.

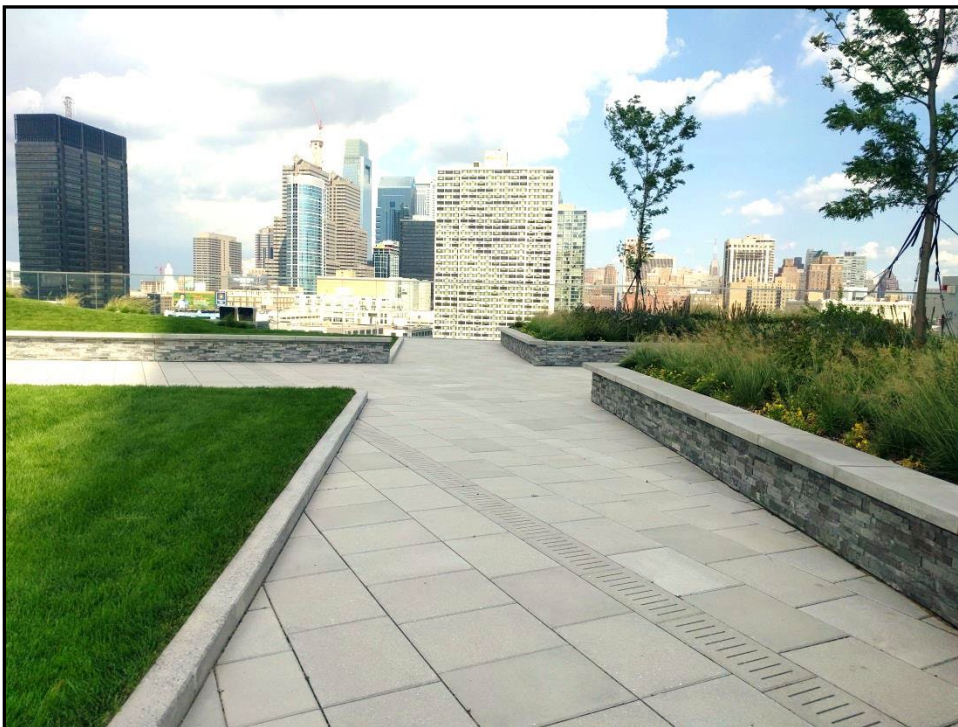
The following series of images depict the variety of vegetation that used on a green roof. Like the main area of the green roof shown below, low-lying vegetation can be planted



or a variety of taller plants can also be used, like that shown below.



It is even possible to use turf grass or trees on a green roof. The photo below shows an example of a green roof with both.



Here is another example of a green roof incorporating a wide variety of plants.



## Applications



Pursuant to N.J.A.C. 7:8-5.2(a)(2), the minimum design and performance standards for groundwater recharge, stormwater runoff quality and stormwater quantity at N.J.A.C. 7:8- 5.4, 5.5 and 5.6 shall be met by incorporating green infrastructure in accordance with N.J.A.C. 7:8-5.3.



Green roofs may be designed to convey storm events larger than the Water Quality Design Storm (WQDS); however, regardless of the design storm chosen, all green roofs must be designed for stability and capacity in accordance with the *Standards for Soil Erosion and Sediment Control in New Jersey*, as required by N.J.A.C. 7:8 Stormwater Management rules.



Green roofs may be designed to reduce peak runoff rates by reducing the the volume of stormwater runoff generated by a clean roof from storm events. For more information on calculating the volume reduction, refer to the methodology beginning on Page 13.

## Design Criteria

### Basic Requirements

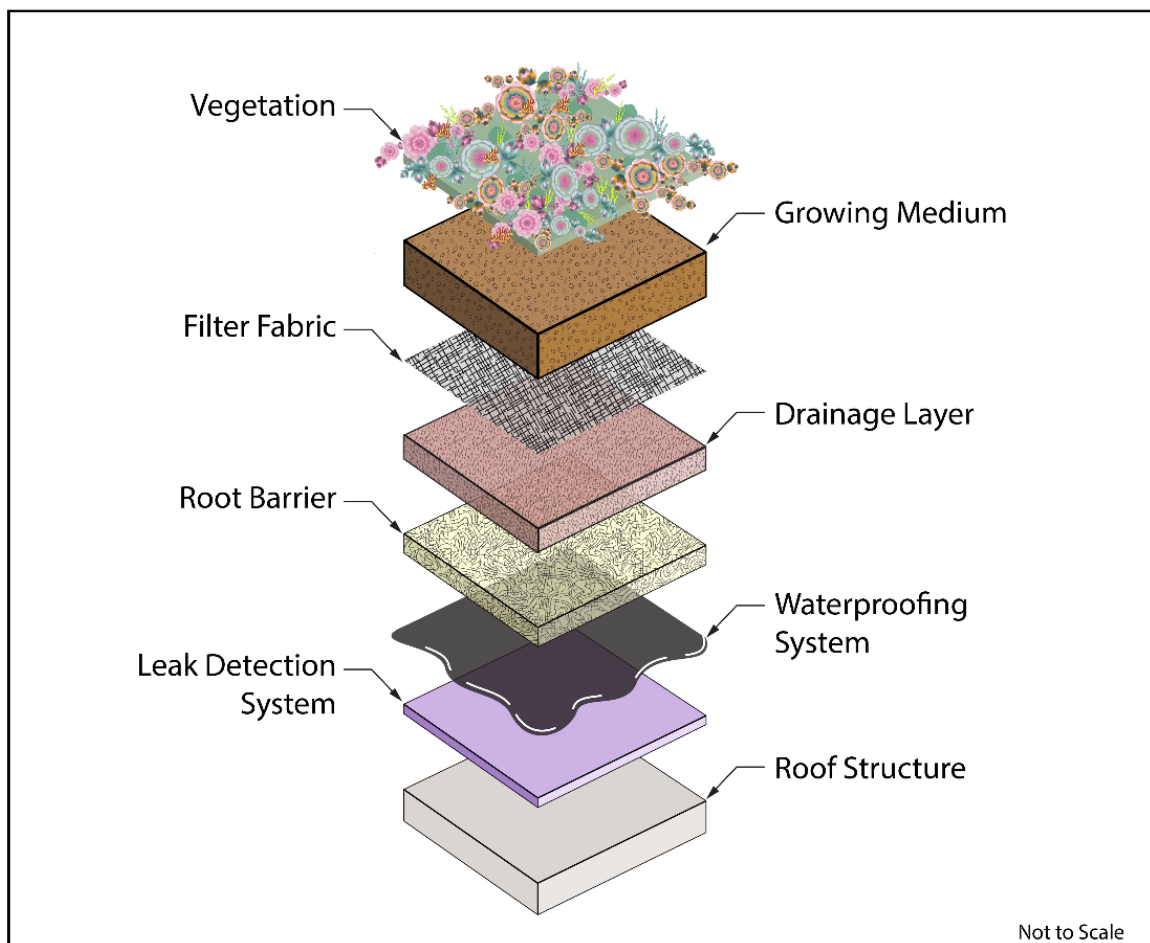
A green roof proposed to meet any of the design and performance standards at N.J.A.C. 7:8-5 must be designed in accordance with the following design criteria.

#### Contributory Drainage Area

A green roof manages the precipitation that falls directly on the vegetated surface and any surrounding walkways, but has no maximum contributory drainage area limitation. Runoff from other surfaces and structures should not be directed onto the green roof.

#### Green Roof Layer Requirements

The following illustration depicts the various component layers typically incorporated into a green roof. Each layer is discussed in the text below and continues further through Page 8.



## Vegetation

Evapo-transpiration by plants makes the vegetation on a green roof one of the most important factors in reducing the volume of runoff. Selected species must be able to tolerate a broad range of conditions, including wide variations in water depth and inundation, high wind speed and extreme temperature fluctuations. Except in rare cases, typical grass species used for lawns are not acceptable species for a green roof. Some other important factors are listed below.

- Native species are preferred, but it is best when choosing plants to select those with the highest prospects for establishing a healthy plant community. Sedums are often chosen for use on green roofs, as are a variety of native plant species. A list of potential native species is available from New York City's Department of Parks and Recreation at:

[https://www.nycgovparks.org/sub\\_about/parks\\_divisions/gnpc/pdf/green\\_roof\\_species\\_list.pdf](https://www.nycgovparks.org/sub_about/parks_divisions/gnpc/pdf/green_roof_species_list.pdf).

Be aware that since this list was developed for New York City, not all of the plants listed are native in all areas of New Jersey.

- The amount of direct sunlight is of particular importance when selecting plant species. The presence or absence of surrounding structures determines which plant species will survive the specific site conditions. When configuring the layout of plants on the roof, analyze the roof to determine the hours of sunlight versus shade. For example, the presence of some types of solar panels, partitions, overhangs and awnings may block plant access to sunlight during certain portions of the day or growing season. The results of this analysis should be used in determining appropriate plant species for the available sunlight.
- The slope of the roof must also be a factor in plant selection and placement. Roofs with higher slopes tend to drain faster and may therefore require plant species that are more drought-tolerant.
- Final plant species selection must be discussed with the reviewing agency to ensure that the selections are appropriate for the area where the green roof will be located.

## Growing Medium

The growing medium affects the ability of the installation to support vegetation, retain stormwater runoff, and provide heat and noise insulation for the building; therefore, the composition of the medium is a crucial design parameter. In general, growing media for green roofs are different from at-grade gardens in that they are light-weight, engineered mixes. Green roof growing media can vary widely in their composition; however, they must also be light-weight and retain sufficient water to sustain vegetation. These mixes are generally composed of approximately 80 - 90%, by weight, lightweight aggregate, such as, but not limited to expanded shale, expanded clay, expanded slate, pumice, zeolite, perlite or vermiculite. The remaining 10 - 20% is composed of stable organic matter. Biochar may also be used as an additive to increase the absorption of water, lighten the weight of the growing medium, aid in the reduction of turbidity, suspended solids and carbon and even assist in decreasing pollutant discharge from green roofs. The growing medium needs sufficient water storage capacity to support vegetation. The growing medium also needs sufficient permeability to prevent ponding or logging. To meet these requirements, the required physical characteristics of the growing medium are as follows:

- The tested permeability of the growing medium must be at least 1 inch per hour, as determined by the method established in ASTM E2399 or in the *Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau*, hereafter referred to as the *FLL*.
- The pH must be between 6 and 8.5.
- No more than 10% by mass of particles of the growing medium shall have a grain diameter less than 0.063 mm to prevent fine particles clogging the filter fabric.
- No grain diameter shall be greater than 12 mm to prevent piping of the runoff through the growing medium.
- Additional physical characteristics specific to one of the different types of green roofs are found on Pages 9 through 11.

#### **Filter Fabric**

- Filter fabric is required and must be installed directly beneath the planting media to prevent the migration of fine particles.
- Any filter fabric used must have sufficient density to physically support the weight of the growing medium. For installations requiring a deeper growing medium depth or on steeply graded roofs, the filter fabric density must be increased to provide increased tensile strength.
- Any filter fabric selected must permit root penetration.

#### **Drainage Layer**

- The drainage layer shall either be made of a non-carbonate, coarse granular material or a synthetic layer.
- The drainage layer must be resistant to freeze-thaw cycles.
- The hydraulic conductivity of the drainage layer must exceed that of the growing medium.

#### **Root Barrier**

- A root barrier must be included in the design to ensure that the growth of roots does not damage the roof.
- The root barrier must not interfere with the roots' access to water.
- The root barrier must be durable and not contain chemicals that will contaminate runoff. Herbicides must not be used.

#### **Waterproofing System**

- A waterproofing system must be included in the design to ensure that water does not damage the roof or leak into the building. An impermeable root barrier or other membrane may act as the waterproofing system.

- A method for detecting leaks must be included in the green roof's maintenance plan. Location of physical leak detection systems will depend on the manufacturer's specifications and shall be placed accordingly. A flood test is generally insufficient for detecting small leaks and must not be used. Electronic leak detection and moisture monitoring systems are recommended.
- It may be necessary to seek additional guidance from a roofing specialist when selecting the waterproofing system.

## **Environmental Constraints**

### **Erosion Protection and Stability Requirements**

- Due to higher wind speeds expected on a rooftop, the effects of wind erosion must be addressed in the design of a green roof. Vegetation must be established as quickly as possible, especially around the perimeter and corners of the roof.
- Temporary erosion protection, such as mats or mesh, must be provided until mature plant cover is established.
- If erosion becomes an issue, permanent stabilization must be installed. All stabilization measures must be included in the maintenance plan.

### **Roof Slope**

- The maximum roof slope is 20%.

## **Safety**

- All green roofs must be designed to safely convey overflows, up to and including the 100-year storm, to downstream drainage systems. The design of any overflow structure must be sufficient to provide safe and stable discharge of stormwater runoff in the event of an overflow. Safe and stable discharge minimizes the possibility of adverse impacts, including erosion and flooding in down-gradient areas.
- All drains and scuppers must be protected to prevent clogging; one such method is a gravel apron, as shown in the image below.



## Types of Green Roofs

There are two main types of green roofs:

1. Intensive Green Roofs
2. Extensive Green Roofs

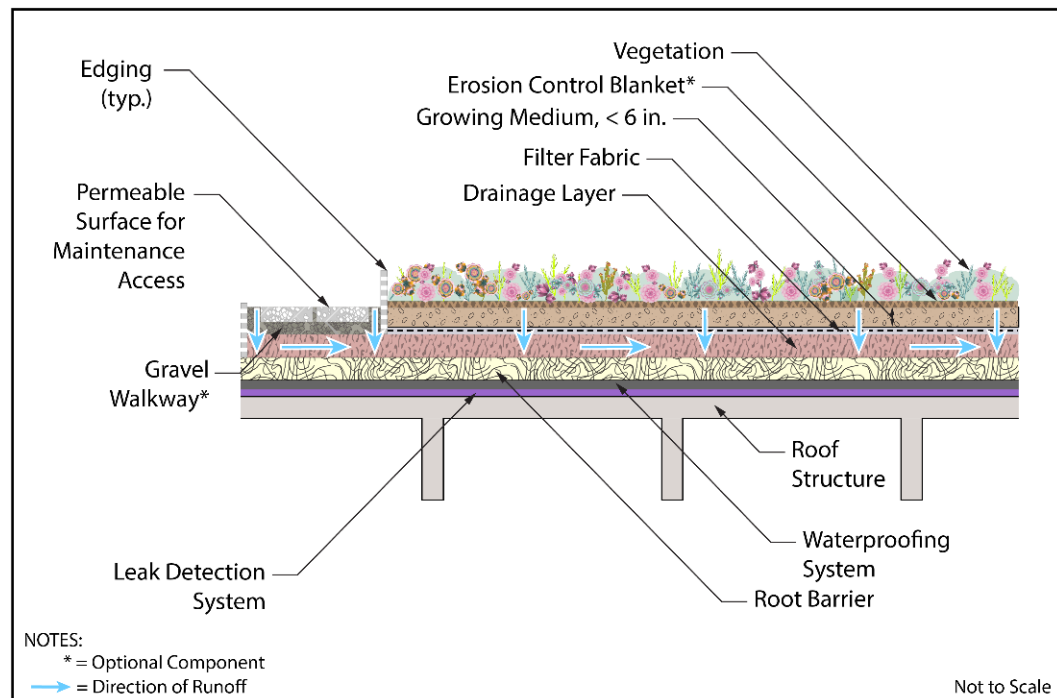
## Individual Types of Green Roofs

The following section provides detailed design criteria for each type of green roof; the illustrations show possible configurations and flow paths and are not intended to limit the design.

### Extensive Green Roofs

Typically, extensive green roofs are the least expensive type of green roof, and they may be more suitable for retrofits. The illustration below depicts a cross-sectional view of an extensive green roof for which the growing medium layer must be designed to be six (6) inches or less in depth. This shallow depth of growing medium generally makes extensive green roofs the lowest in unit weight when compared to the various other types of green roofs and typically limits the variety of vegetation that may be selected. When designing an extensive green roof, it is crucial that the growing medium depth be sufficient to support the selected vegetation.

**Extensive Green Roof – Cross-Section View:**



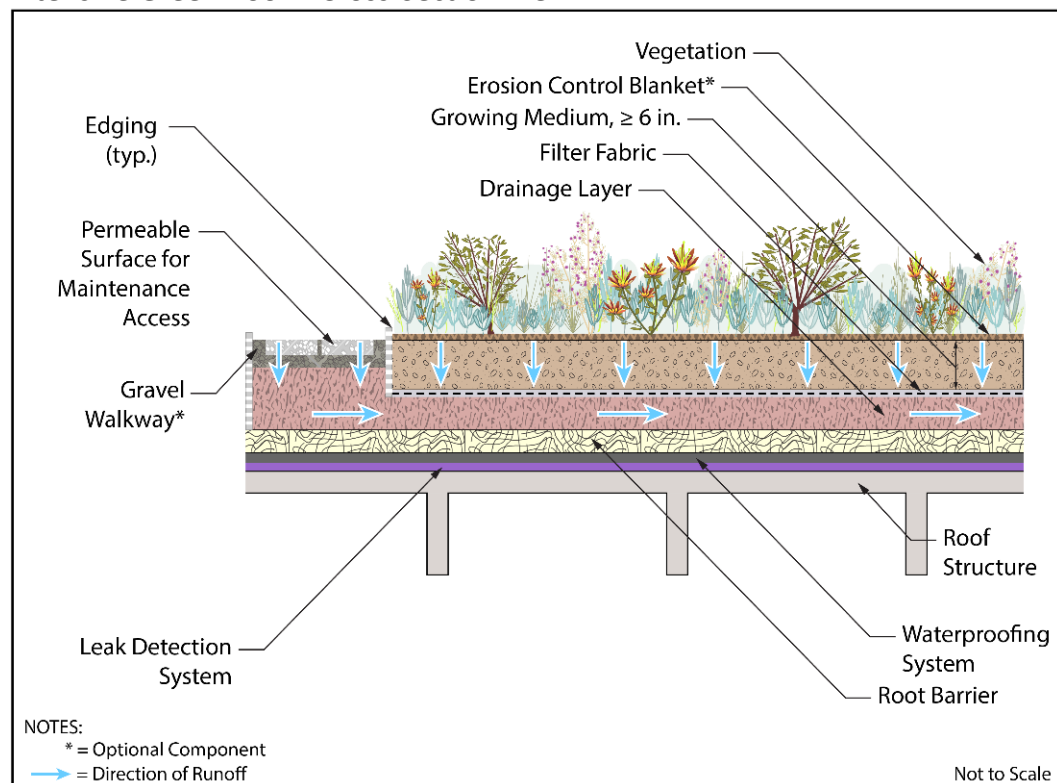
The following growing media design criteria apply only to extensive green roofs:

- The tested maximum media water retention, when using the ASTM E2399 method, or the maximum water capacity, when using the FLL method, must be at least 35% by volume but no greater than 65%, also by volume.
- The organic content must be less than 4.06 pounds per cubic foot or 65 grams per liter.

## Intensive Green Roofs

Unlike extensive green roofs, intensive green roofs are designed with a growing medium layer six (6) inches or greater in depth, which allows this type of green roof to support a wide variety of vegetation, including shrubs and trees. Due to the increased overall depth, intensive green roofs provide significant benefits for stormwater management, habitat creation and heat and noise insulation; however, this additional depth also adds significant weight to this type of roof. Therefore, intensive green roofs may not be suitable for retrofit projects. Additionally, intensive green roofs may also require more irrigation than extensive green roofs to maintain vegetation; therefore, prior to selection of this type of green roof, the structural integrity of the building and access to water must be analyzed. The illustration below depicts a cross-sectional view of an intensive green roof.

**Intensive Green Roof – Cross-Section View:**



The following growing media design criteria apply only to intensive green roofs:

- The tested maximum media water retention, when using the ASTM E2399 method, or the maximum water capacity, when using the *FLL* method, must be at least 45% by volume but no greater than 65%, also by volume.
- The organic content must be less than 5.62 pounds per cubic foot or 90 grams per liter.

**Note that the maximum media water retention and maximum water capacity are used only as indicators for growing medium selection. They cannot be used as the parameters to calculate the runoff to be retained in the growing media.** For the calculation of stormwater runoff volume reduction, refer to the subsection regarding Volume Reduction beginning on Page 13.

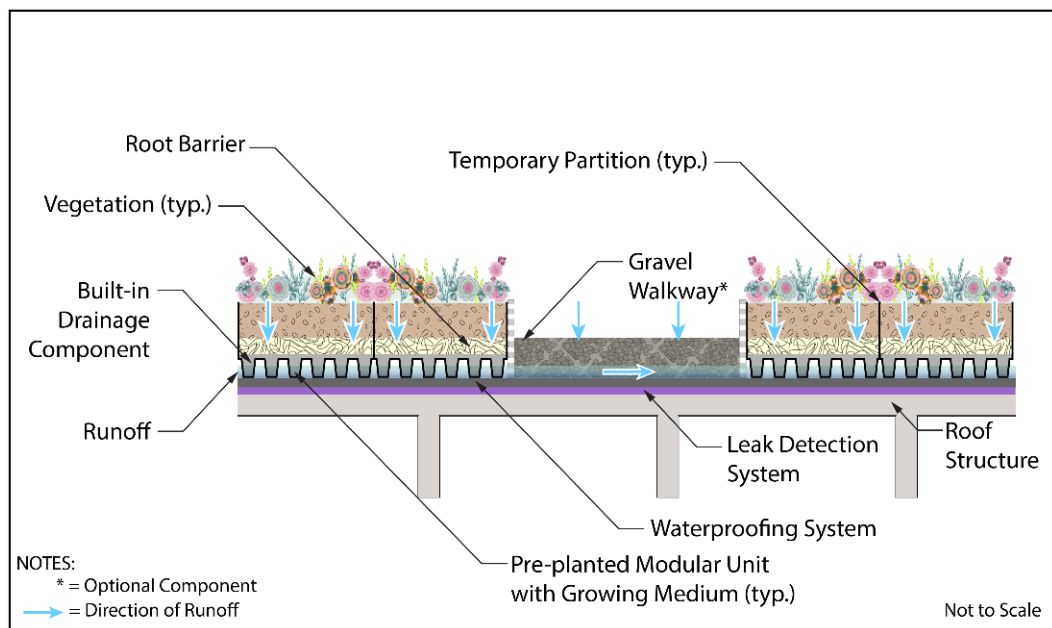
## Green Roof Design Options

Green roofs are versatile, and there are a number of options that make the construction of green roofs feasible in on most projects.

### Modular Green Roofs

Modular green roofs are either extensive or intensive and consist of pre-fabricated trays, or units, containing green roof components that can be placed on a traditional roof in a variety of configurations. Modular systems tend to be easy to install, are easily removed for roof maintenance and the vegetation is typically established in the units prior to installation. The illustration below depicts a cross-sectional view of a modular green roof. The gravel walkway between units is optional. The temporary partitions serve to keep the contents of an individual module intact during placement.

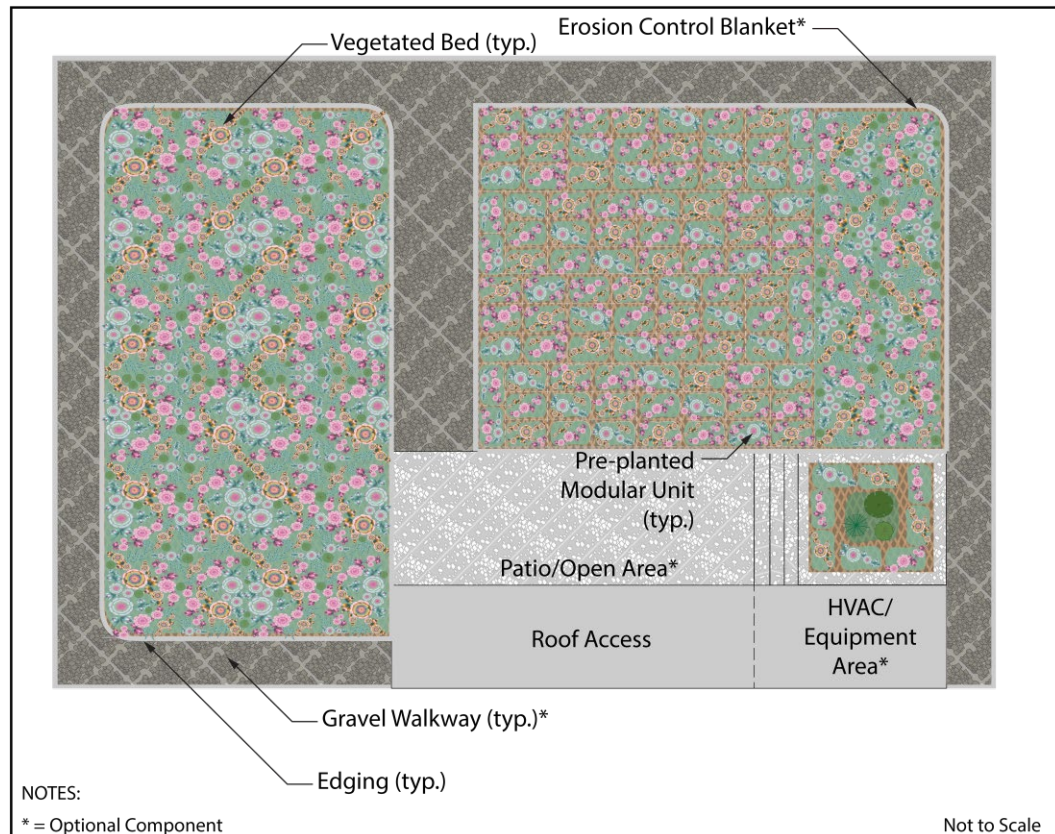
#### Modular Green Roof – Cross-Section View:



## Combination Green Roofs

Depending on site specific conditions, the individual types of green roofs may be combined to create a functional and aesthetically pleasing open space area. The following illustration incorporates intensive and extensive green roof design with modular zones; however, it is only a suggested approach and is not meant to limit the design in any way. Access walkways are shown, along with an open area and a stepped planter box which serves as a wind screen for the open area.

**Combination Green Roof – Plan View:**



## Volume Reduction

The growing medium on a green roof will absorb and retain a portion of the rainfall that lands on it, thus reducing the volume of runoff that will reach downstream stormwater facilities. For the calculation of runoff retention, the available water capacity for runoff reduction is the difference in the water content between the *field capacity* and the *wilting point*, both of which are defined below. Therefore, the values for field capacity and the wilting point of the selected growing medium must be obtained either from a published research article or tested in accordance with either the ASTM D-6836 method or the Soil Survey Investigations Report No. 42, Kellogg Soil Survey Laboratory Methods Manual, published by NRCS. The field capacity is tested at -10 KPa, for sandy material, or -0.33 KPa, for other materials. The wilting point is tested at 1,500 KPa under the ASTM D-6836 method or Kellogg Soil Survey Laboratory Methods Manual by NRCS. Information regarding some examples of growing media mixes are provided below.

Growing Medium and Composition (% by Volume)	*Effective Porosity (cf/cf)	*Field Capacity (cf/cf)	*Wilting Point (cf/cf)	Maximum Water Capacity, Using FLL Method, (% by Volume)	Maximum Available Water Capacity For Runoff Retention (cf/cf)
<ul style="list-style-type: none"> <li>20% 1-7 mm pumice</li> <li>60% 4-10 mm pumice</li> <li>20% composted pine bark fines</li> </ul>	0.30	0.349	0.118	49.6	0.231
<ul style="list-style-type: none"> <li>50% 4-10 mm pumice</li> <li>30% 1-8 mm zeolite</li> <li>20% composted pine bark fines</li> </ul>	0.30	0.295	0.053	46.6	0.242
<ul style="list-style-type: none"> <li>70% 4-10 mm pumice</li> <li>10% zeolite &lt;3 mm</li> <li>15% pine bark fines + mushroom compost</li> <li>5% sphagnum peat</li> </ul>	0.35	0.358	0.069	63	0.289

\*Note: *Effective porosity* is the porosity available to fluid flow and is typically less than the total porosity.

*Field capacity* is the water content of the soil after free drainage has ceased.

*Wilting point* is the minimum soil moisture required by a plant to not wilt.

Note the assumption that the maximum available water capacity for runoff retention assumes the growing medium has dried to the wilting point of the plants between each storm event. In many storm events, especially in the case of back-to-back storms, the green roof may not provide the full calculated volume reduction, as stormwater runoff from the first storm may still be retained within the growing medium

when the second storm occurs. Therefore, a lower value of the maximum available water capacity for stormwater runoff retention may be needed when modeling back-to-back storm conditions.

The steps to calculate the adjusted CN, after considering the available water capacity for stormwater runoff retention, are as follows:

**Step 1: Calculate the runoff retention of the green roof**

$$S_v = \frac{SA \times [(d \times \eta_1) + (DL \times \eta_2)]}{12 \text{ in/ft}}, \text{ where:}$$

$S_v$  = storage volume (cf)

$SA$  = green roof area (sf)

$d$  = media depth (in)

$\eta_1$  = available water capacity for runoff retention

$DL$  = drainage layer depth (in)

$\eta_2$  = drainage layer field capacity

**Step 2: Calculate the discharged runoff volume**

- a. Calculate stormwater runoff volume produced by the Water Quality Design Storm (WQDS), 2-, 10- and 100-year storms using the method described in the NRCS Methodology section of *Chapter 5: Stormwater Management Quantity and Quality Standards and Computations*. Note that the Rational and Modified Rational Methods cannot be used for this calculation.
- b. Subtract the storage volume,  $S_v$ , in Step 1 from the stormwater runoff volume for the different storm events. The result is the runoff volume to be discharged from the green roof during the different storm events.

**Step 3: Calculate the direct runoff depth**

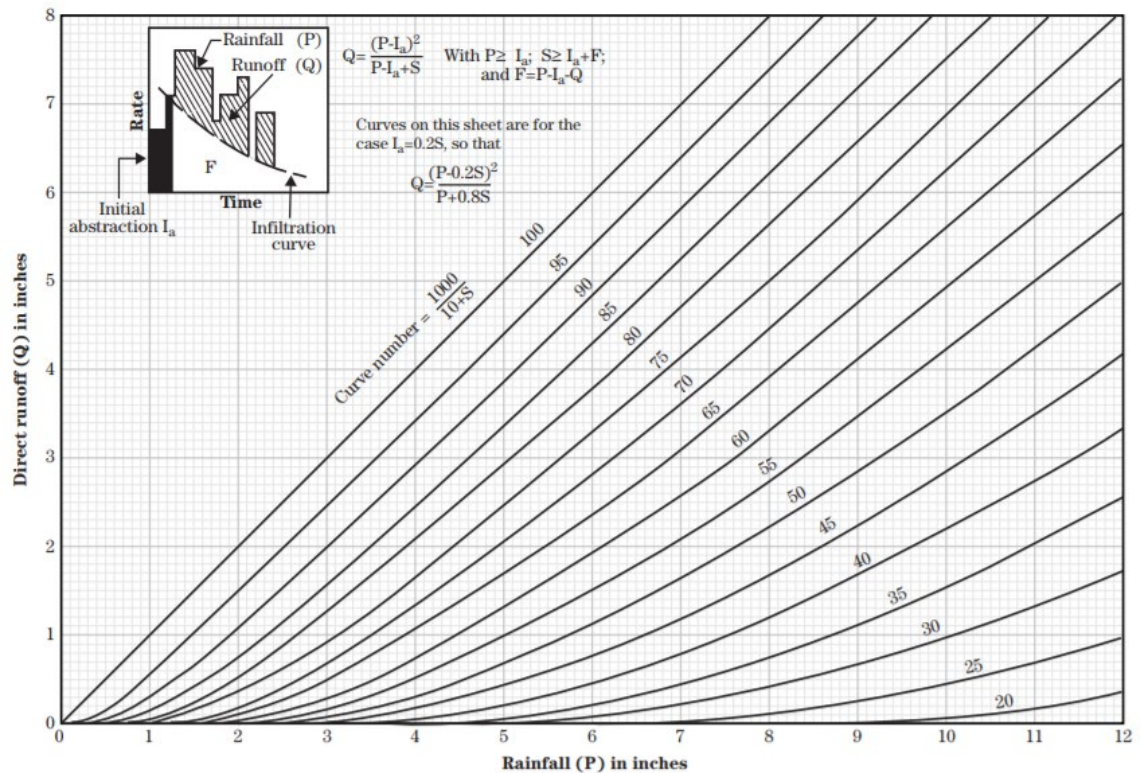
Divide the discharged runoff volume for each of the storm events calculated in Step 2b by the green roof area. The result is the direct runoff,  $Q$  (in), in the NRCS method or in equation 10-11 of the *National Engineering Handbook, Part 630, Hydrology (NEH)*.

$$Q = \frac{\text{reduced runoff volume (cf)} \times 12 \text{ in/ft}}{\text{green roof area (sf)}}$$

**Step 4: Determine the Adjusted Curve Number**

Use the direct runoff,  $Q$ , calculated in Step 3 and the rainfall precipitation for each of the storm events,  $P_n$ , to find corresponding CN value in Figure 10-2 from the *NEH*, as reproduced on the following page:

**Figure 10–2** ES-1001 graphical solution of the equation  $Q = \frac{(P - 0.2S)^2}{P + 0.8S}$



#### Step 5: Caculate Peak Flow Rates by Adjusted Curve Number

Calculate the time of concentration and use it along with the adjusted curve numbers determined in Step 4 to calculate the peak flow rates of each of the storm events using NRCS methodology.

Note that the time of concentration of a green roof must be calculated based on the vegetation condition, roof slope and drainage path. A green roof with dense vegetation and a milder slope may provide a longer time of concentration, which will slow down the discharge of the roof runoff and lower the peak rate of the runoff. The time of concentration must be calculated in accordance with the velocity method described in the *NEH, Chapter 15 - Time of Concentration*.

## Incorporation with other BMPs

Green roofs may be incorporated with other BMPs to retain the entire roof runoff from the WQDS or to reduce roof runoff produced by larger storms. For example, dry wells may be designed to receive and infiltrate some discharge from the downspouts of a green roof in order to achieve retention of the entire WQDS volume. Cisterns, rain gardens and pervious paving systems may also be incorporated with green roofs. Note that if the discharge from a green roof is mixed with runoff that must be treated to reduce the total suspended solids (TSS), the entire mixed runoff volume is subject to the 80% removal rate for TSS.

## Designing a Green Roof

The following example illustrates how to use a green roof to reduce the volume of runoff generated by the WQDS, plus the 2-, 10- and 100-year storms. The example shows a possible configuration and flow path and is not intended to limit the design.

**Example:** A 1 acre roof of a building in Camden County is to be designed as a green roof based on the following parameters, assuming the entire roof is vegetated:

Roof Area:	1	acre
WQDS rainfall, $P_{WQ}$ :	1.25	inches
2-year storm rainfall, $P_2$ :	3.31	inches
10-year storm rainfall, $P_{10}$ :	5.06	inches
100-year storm rainfall, $P_{100}$ :	8.52	inches
Drainage layer depth:	6	inches
Drainage layer field capacity:	0.02%	by volume
Slope	2.5%	
Vegetation	dense native grass	

### Growing Medium:

The growing medium has a composition of 20% 1 - 7 mm pumice by volume, 60% 4 - 10 mm pumice by volume, and 20% composted pine bark fines by volume. The characteristics of the growing medium are as the follows:

Growing medium depth:	6	inches
Field capacity:	0.349%	by volume
Wilting point:	0.118%	by volume
Available Water Capacity for Stormwater Runoff Retention	0.231%	by volume

### Step 1: Calculate the stormwater runoff retention by the green roof

The volume of rainfall stored in the green roof system is calculated using the following equation:

$$S_v = \frac{SA \times [(d \times \eta_1) + (DL \times \eta_2)]}{12 \text{ in/ft}}, \text{ where:}$$

$S_v$  = storage volume (cf)  
 $SA$  = green roof area (sf)  
 $d$  = media depth (in)  
 $\eta_1$  = available water capacity for runoff retention  
 $DL$  = drainage layer depth (in)  
 $\eta_2$  = drainage layer field capacity

The storage volume, which is also the maximum stormwater runoff volume reduction, is then calculated as follows:

$$S_v = \frac{43,560 \times [(6 \times 0.231) + (6 \times 0.02)]}{12} = 5,467 \text{ cf}$$

### Step 2: Calculate the discharged runoff volume

Using the storage volume calculated above, the discharged runoff volume for each storm is calculated by subtracting the storage volume calculated in Step 1 from the stormwater runoff volume from a traditional roof of the same area, as shown in the following table:

Storm Event	(A) Runoff Volume (cf) (Impervious Surface)	(B) Storage Volume (cf)	(A)-(B) Discharged Runoff Volume (cf) (Green Roof)
WQDS	3,755	5,467	0
2-year	11,170	5,467	5,703
10-year	17,508	5,467	12,041
100-year	30,056	5,467	24,589

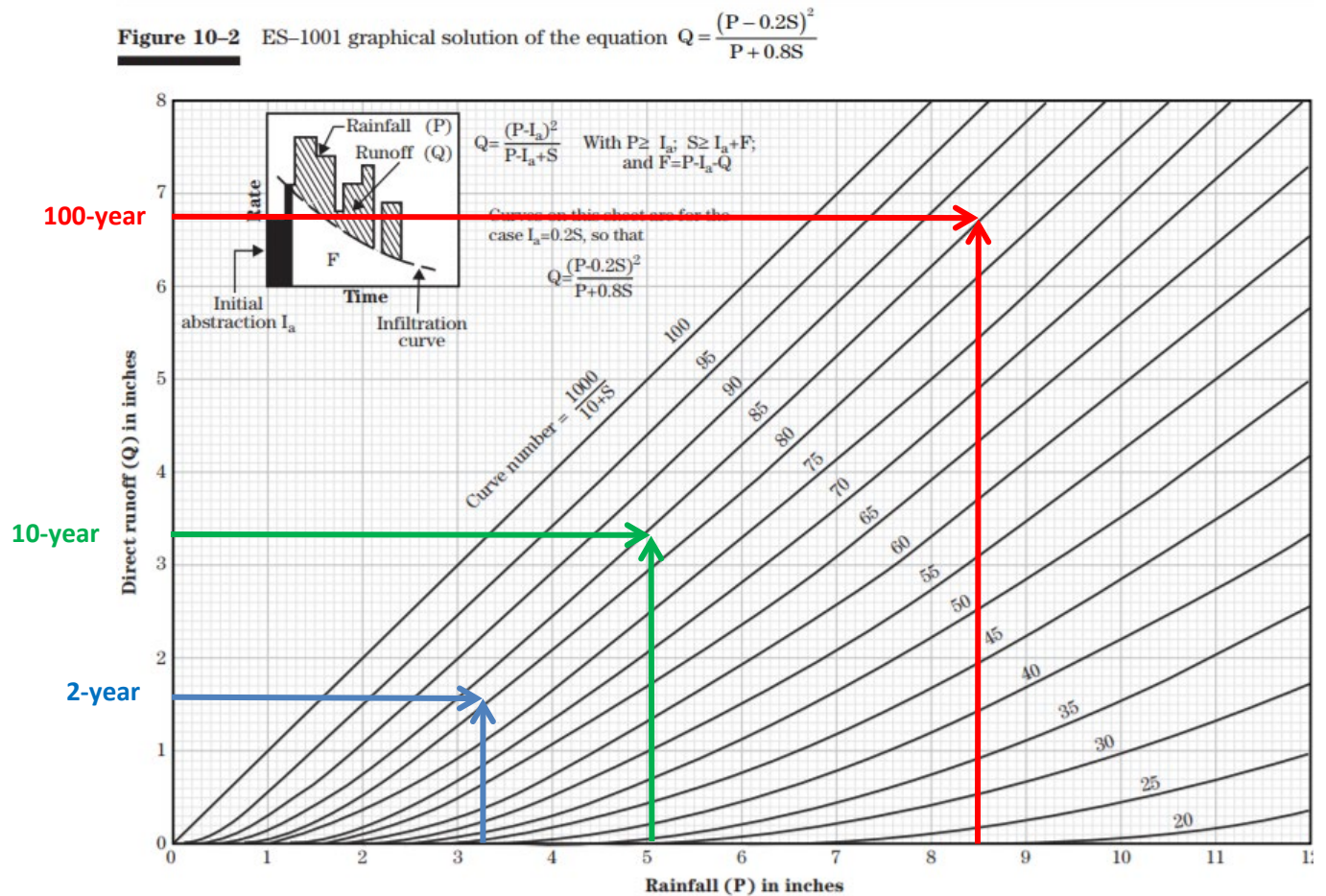
### Step 3: Calculate the direct runoff depth

Next, the direct runoff depth,  $Q$ , is calculated by dividing the discharged runoff volume by the roof area, yielding the following results:

Storm Event	Discharged Runoff Volume (cf) (Green Roof)	Green Roof Area (sf)	Direct Runoff Depth (in)
WQDS	0	43,560	0
2-year	5,703	43,560	1.57
10-year	12,041	43,560	3.32
100-year	24,589	43,560	6.77

#### Step 4: Determine the Adjusted Curve Number

From Figure 10-2 in the *NEH*, the adjusted curve number can be found using the rainfall depths and the stormwater runoff depths calculated in Step 3 for each storm, as depicted below, in blue, green and red for the 2-, 10- and 100-year storms, respectively.



From the figure above, the adjusted curve numbers for the 2-, 10- and 100-year storm events are approximately 81, 84 and 85, respectively. For the WQDS, there is no runoff, so the curve number should be 61, which produces no runoff in the WQDS.

Storm Event	Rainfall Depth (in)	Direct Runoff Depth (in)	Adjusted Curve Number
WQDS	1.25	0	61
2-year	3.31	1.57	81
10-year	5.06	3.32	84
100-year	8.52	6.77	85

### Step 5: Calculated Peak Flow Rates by Adjusted Curve Number

Next, the peak flow rate can be calculated by using the adjusted curve number with the NRCS method. The time of concentration must be calculated based on the vegetation condition, roof slope and drainage path. In order to avoid potential erosion that may result from the concentration of flow on the rooftop, drains are located on the roof so that the maximum flow length is 100 feet. The Manning's roughness for sheet flow is 0.24. Under these conditions, the green roof will have a time of concentration of 12.8 minutes. Note that the time of concentration for a traditional impervious surface under the post-construction condition has a default value of 6 minutes.

The peak flow rates for different storms under the adjusted curve numbers and estimated time of concentration were calculated by hydrologic modeling software and the results are as follows:

Storm Event	Adjusted CN	Runoff Volume Discharged from the Green Roof (cf)	Peak Flow (cfs)
WQDS	61	0	0
2-year	81	5,703	1.45
10-year	84	12,041	3.11
100-year	85	24,589	6.10

Compare these results with that from an impervious roof:

Storm Event	CN	Runoff Volume Discharged From an Impervious Roof (cf)	Peak Flow (cfs)
WQDS	98	3,755	2.93
2-year	98	11,170	3.22
10-year	98	17,508	4.95
100-year	98	30,056	8.37

## Considerations

A number of factors should be considered when using a green roof to manage stormwater runoff.

### Structural Strength

Green roofs can add a significant amount of weight to a roof including the dead load of the green roof layers, as well as the added live loads as a result of rainfall, pedestrians, maintenance personnel and equipment. Therefore, the structural load capacity of the roof is a crucial consideration when designing a green roof.

## **Access**

Green roofs, like all other stormwater BMPs require maintenance; therefore, it is important all maintenance personnel are able to access the roof. Additionally, if the roof is open to the public, measures should be included to ensure public safety. Many large buildings use the roof as the access point for window washing; therefore, the green roof should be designed to provide access and safe working conditions for maintenance personnel.

## **Physical Impacts**

The ability of the green roof vegetation to absorb moisture, undergo evapotranspiration and survive depend upon the architectural features of the building. If a green roof is adjacent to reflective surfaces, for example, the additional reflected heat may jeopardize the ability of the plants to thrive. Similarly, high wind velocities across or shading of the planting bed caused by adjacent roof structures may damage plants. Therefore, practicality and aesthetics must be properly balanced for successful green roof design.

## **Longevity**

When designing a green roof, it is important to consider the longevity of all parts of the system, as well as the roof and all structural supports. The waterproofing layer of a green roof is especially important, as failures can create serious structural problems. Care should be taken during construction to ensure that the waterproofing membrane is not damaged.

## **Irrigation**

In some instances, green roofs may require irrigation to maintain vegetative cover. Intensive green roofs tend to require more irrigation than extensive green roofs. If the vegetative cover fails to establish or cannot be maintained by rainfall alone, irrigation should be installed. Rainwater harvesting from unplanted areas may be an option to consider.

## **System Monitoring**

Monitoring may be necessary to ensure the percentage of organic material in the growing medium does not increase over time. Too high a percentage of organic material may conflict with fire regulations regarding smoldering burns. Additionally, although a high percentage of organic material may support a more diverse plant population on a given green roof, it tends to increase moisture storage and hence weight. Too much organic material may also promote the growth of less drought-tolerant species and lead to the growth of aggressive species, thereby lowering plant diversity in the long term.

## **Use of Non-Native Plant Species**

While native plants are preferred, in some cases a non-native plants may be needed. If they are used, extra care should be taken to ensure that these non-native plants do not spread to surrounding sites. Deadheading or other measures to control the spread of seeds should be implemented.

## Maintenance

Regular and effective maintenance is crucial to ensure effective green roof performance. A green roof used to meet any State requirement must have a maintenance plan. For projects that are major developments, there are a number of required elements in all maintenance plans, pursuant to N.J.A.C. 7:8-5.8; these are discussed in more detail in *Chapter 8: Maintenance of Stormwater Management Measures*. Furthermore, maintenance activities are required through various regulations, including the New Jersey Pollutant Discharge Elimination System (NJPDES) rules, N.J.A.C. 7:14A. Specific maintenance activities for green roofs are presented below; these activities must be included in the green roof's maintenance plan. Detailed inspection and maintenance logs must be maintained.

### General Maintenance

- Green roofs must be inspected at least four times annually and after every storm event exceeding 1 inch of rainfall. Check for and clear debris, sediment, dead vegetation, and check whether the growing medium has eroded or been transported to the drainage gutter or outlets.
- All structural components must be inspected for cracking, subsidence, spalling, erosion and deterioration at least once annually.
- Disposal of debris, trash, sediment and other waste material must be done at suitable disposal/recycling sites and in compliance with all applicable local, state and federal waste regulations.
- Access points for maintenance are required on all green roofs; these access points must be clearly identified in the maintenance plan. In addition, any special training required for maintenance personnel to perform specific tasks must be included in the plan.
- A detailed, written log of all preventative and corrective maintenance performed on the green roof must be kept, including a record of all inspections and copies of maintenance-related work orders. Additional maintenance guidance can be found online at:

<https://dep.nj.gov/stormwater/maintenance-guidance/>.

### Vegetated Areas

- Bi-weekly inspections are required when establishing/restoring vegetation.
- A minimum of one inspection during the growing season and one inspection during the non-growing season is required to ensure the health, density and diversity of the vegetation. Additional inspections are required after major weather events, such as but not limited to, high wind events and lightning strikes.
- Trimming of the vegetation must be performed on a regular schedule based on specific site conditions.
- Vegetative cover must be maintained at 85%; damage must be immediately addressed through replanting in accordance with the original specifications.

- Vegetated areas must be inspected at least once annually for erosion, scour and unwanted growth; any unwanted growth must be removed with minimum disruption to the remaining vegetation.
- All use of fertilizers, pesticides, mechanical treatments and other means to ensure optimum vegetation must not compromise the intended purpose of the green roof.

## **Drain Time**

- Water ponding on the surface and the drainage layer of green roofs must fully drain within 72 hours; ponding in excess of 72 hours may render the green roof ineffective and may result in anaerobic conditions, odor and both water quality and mosquito breeding issues.

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