19. Rooftop Runoff Management

Description

Rooftop runoff management is the deployment of vegetated roof covers and roof gardens (also known as green roofs), roof ponding areas and cisterns to detain and promote evapotranspiration of runoff originating from roofs.

Regulatory Credits

Pollutant Removal

0%	Total Suspended Solids
0%	Nitrogen***
0%	Phosphorus***

Water Quantity

possible	Peak Attenuation*
possible	Volume Capture**

Feasibility Considerations

High	Land Requirement
High	Cost of Construction
Med	Maintenance Burden
Low	Treatable Basin Size
Low	Possible Site Constraints
High	Community Acceptance

* Green roofs shall receive peak attenuation credit. A Rational C Coefficient of 0.65 shall be used for the green roof peak runoff calculation.

** Green roofs shall receive volume reduction credit. The Simple Method shall be used to calculate volume. The impervious fraction for the green roof will be 50% of the impervious fraction for a standard roof. The SCS Method can not be used because a curve number has not been specified.

*** Green roofs shall not receive nutrient credit. When using the Neuse and Tar-Pamlico nutrient export models, the green roof shall be entered as "roof impervious".

Advantages

- Useful in wide range of applications.
- Provides effective stormwater management for small to mid-size events.
- Conserves space.
- Thought to extend life expectancies of roofs, primarily by shielding from UV and temperature.
- Insulates sound; 5 inches of green roof medium can reduce sound by 40 decibels (dB).
- Reduces heat island effects caused by impervious surfaces, and reduces heating and cooling costs of the building covered.
- Proven track record in Europe and numerous applications in North America.
- Adds aesthetic value to residential and commercial property; provides attractive textures and colors and creates habitat for birds and insects.

Disadvantages

- Can be difficult to retrofit.
- Main disadvantage is the potential need to provide additional structural strengthening.
- Normal garden maintenance is required for roof gardens, but the location may make it more difficult to inspect and correct problems.
- Rooftop detention may lead to leaks through the roof.
- Sediment can accumulate near the outlet and cause clogging if not cleaned out periodically.
- Cost - These are among the most expensive practices per square foot of treated area.

Major Design Elements

Required by the NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements.	
1	A vegetation plan prepared by a horticulturalist versed in green roof vegetation is required.
2	A structural engineer must be consulted and verify roof and structure strength.
3	Access to the roof is required for inspection and maintenance.
4	On a roof slope greater than 20 degrees, horizontal strapping or other support systems must be installed to avoid slippage and slumping of the growing medium and plants.

19.1. General Characteristics and Purpose

Roofs are an important source of concentrated runoff from developed sites; therefore, rooftop runoff management can provide substantial benefits in highly urbanized settings where space for other BMPs is limited. Rooftop runoff management BMPs are typically applied on flat or gently sloping roofs (see Figure 19-1); however, this BMP can also be applied with steep roofs. The techniques can be retrofitted to many conventionally constructed buildings. If roof runoff is at least partly controlled at the source, the size of other BMPs throughout the site can be reduced. Although rooftop runoff management is generally more effective in controlling small storms, since the vast majority of rain events are in this category, rooftop runoff management can be important in planning for comprehensive stormwater management. By retaining this rainfall for evaporation or plant transpiration, some rooftop runoff management measures, such as vegetated roof covers, can achieve significant reductions in total annual runoff.

Although rooftop runoff management BMPs are currently not extensively used in the United States, they do have a proven track record in Europe. In an effort to reduce overloading of sewer systems, several German cities (including Stuttgart, Berlin, Cologne, Dusseldorf, and Hamburg) provide incentives for homeowners to install vegetated roof covers or roof gardens. In addition, numerous applications do exist in North America including Vancouver, BC; Portland, OR; Chicago, IL; Atlanta, GA, and several locations in North Carolina.

The location of the green roof is very important in the design, which is influenced by factors such as height above ground, wind exposure, and sunlight and shade by surrounding buildings. Climate of the area and the expected microclimate created by the roof have a bearing on plant species. For roofs with public access, visual appearance is also important.

Rooftop runoff management not only provides detention and promotes evapotranspiration, rooftop runoff management effectively increases the time of concentration, delaying runoff peaks and lowering runoff discharge rates. It can also be aesthetically and socially beneficial and may provide improved air quality, energy saving, and temperature reduction benefits.

The main drawback is it can sometimes be very costly for the amount of stormwater quality and quantity improvements it provides. This is because of the possibly small fraction of overall site stormwater that can be treated by the rooftop runoff management BMP, as well as the additional cost to the building for construction of the BMP and possible reinforcement of the structure.

Figure 19-1

Rooftop Garden (Photo courtesy of Dr. Bill Hunt, NCSU BAE Dept.)

It should also be noted that safety is a big concern with rooftop runoff management BMPs. Construction and maintenance are obviously performed in a location with potential for dangerous falls. In addition, some rooftop runoff management BMPs, most often roof gardens, are designed to have public access. Other safety concerns include high temperatures, becoming trapped on the roof, and the possibility of the roof structure becoming unsound and causing a fall. Designs should take all safety issues related to the BMP being constructed on a roof into consideration and attempt to reduce as much as possible the level of risk and exposure.

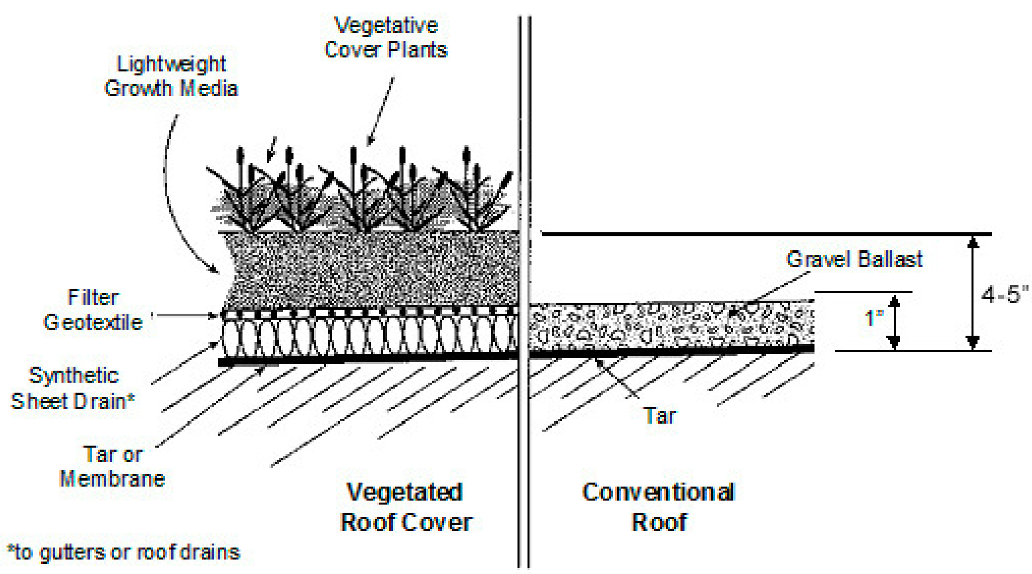
This Section discusses three techniques of rooftop runoff management: vegetated roof covers, roof gardens, and roof ponding areas. Each of these is described briefly below.

Vegetated Roof Covers

Vegetated roof covers (which are also called extensive green roofs and can not be walked on) involve blanketing roofs with a layer of living vegetation. Vegetative roof covers are particularly effective when applied to extensive roofs, such as those commonly used on commercial, multifamily, and institutional buildings. However, they can be applied to virtually any building, including single-family residences. Vegetated roof covers are an effective means of retarding runoff from roof surfaces. Initially during a rainfall event, nearly all precipitation striking the foliage is intercepted. As rain continues, water percolates into and begins to saturate the growth media and root zone of the cover. Significant quantities of water do not begin to drain from the roof until the field capacity of the medium is filled. For small rainfall events, little runoff occurs and most of the precipitation eventually returns to the atmosphere by evaporation and transpiration. For larger storms, vegetated roof covers can delay and attenuate the runoff peak significantly. See Figure 19-2 for a comparison of a conventional roof system and a vegetative roof cover.

Figure 19-2

Comparison Between Vegetative Roof Cover and Conventional Roof System



Roof Gardens
Roof gardens (which are also called intensive green roofs and can be walked on) are landscaped environments that may include planters and potted shrubs and trees. Roof gardens can be custom-made naturalized areas, designed for outdoor recreation, and perched above congested city streets. Because of the special requirements for access, structural support, and drainage, roof gardens are found most frequently in new construction. The services of a professional engineer are required to evaluate the structural and drainage constraints associated with roof garden design.

Roof Ponding Areas
Roof ponding is applicable where the increased load of impounded water on a roof will not increase the building costs significantly or require extensive reinforcement. Water ponding will increase structural costs. Roof ponding generally is not viable for large-area commercial buildings where clear spans are required. Special consideration must be given to ensuring that the roof will remain watertight under a range of adverse weather conditions. Low-cost synthetic membranes can be used to construct an impermeable liner for the containment area.

19.2. Meeting Regulatory Requirements

A listing of the major design elements is provided on the first page of this section. At a minimum, any rooftop runoff management system must meet the major design elements indicated as being from the North Carolina Administrative Code. To receive credit for reduction of volume or peak flow listed in the front of this Section, the rooftop runoff management system must meet all of the major design elements listed in the beginning of this Section. Runoff volume and peak flow calculation methods are discussed in Chapter 3. Green roofs seeking runoff volume reduction credit will use the Simple Method to quantify the credit. Designers shall use an impervious fraction for a green roof equal to half the impervious fraction for a standard roof. Green roofs seeking peak flow reduction shall use a Rational C Coefficient equal to 0.65. Green roofs shall not receive nutrient reduction credit. When using the Neuse and Tar-Pamlico nutrient export models, the BMP designer will enter one of the following land uses into the model; transportation impervious, roof impervious, managed pervious, wooded pervious, or area taken up by the BMP. Each of these land uses has an associated nutrient loading value associated with it. Impervious areas have higher nutrient export values than pervious areas. Because green roofs do not receive nutrient credit, their areas shall be entered into the model as "roof impervious". If they were entered as one of the other land uses with a lower nutrient export value, then they would indirectly receive nutrient credit. This is not permissible.

Pollutant Removal Calculations
Rooftop runoff management BMPs do not provide active pollutant removal and are therefore given 0% pollutant removal rates as shown in the beginning of this Section.

Volume Control Calculations
Some rooftop runoff management BMPs can be designed with enough storage to meet the specific stormwater program volume control requirements (calculations for which are provided in Section 3.4). Others do offer some active storage volume, so if used in series with another BMP with volume control capabilities, they might be able to meet the requirements. All rooftop runoff management BMPs provide some passive volume control capabilities by providing pervious surface (any planted area measured on a horizontally projected footprint basis) and therefore reducing the total runoff volume to be controlled. However, volume control calculations shall not result in a reduction in the nutrient loading.

19.3. Design

19.3.1. Vegetated Roof Covers

Because of recent advances in synthetic drainage materials, vegetated roof covers are now feasible on most conventional flat and gently sloping roofs. A lightweight, efficient drainage layer is placed between the growth medium and the impermeable membrane protecting the roof surface. This layer rapidly conveys water off the roof surface and prevents it from ponding on the roof. Vegetated roof covers also serve to protect roof materials and prolong their life, primarily by shielding from UV and temperature extremes. European data show that green roofs can double the life span of a roof.

Although vegetative roof covers are most effective during the growing season, they are also beneficial during the winter months if the vegetative matter from the dead or dormant plants is left in place and intact.

The emphasis of the design should be to promote rapid roof drainage and minimize the weight of the system. It is advisable to obtain the services of specialized installers because of the many factors that may influence the design.

19.3.1.1. Waterproof Roof Liner

In some instances, the impermeable lining can be the watertight tar surface, which is conventional in flat-roof construction. However, where added protection is desired, a layer of plastic or a rubber membrane can be installed immediately beneath the drainage net or sheet drain.

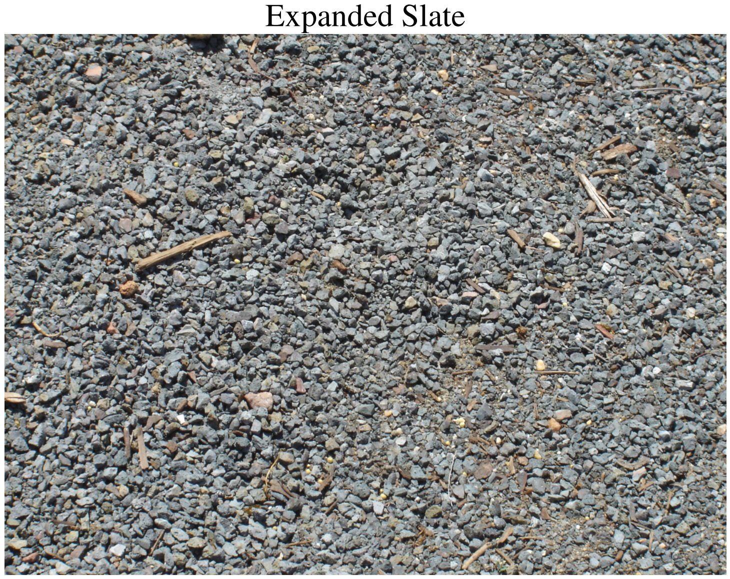
19.3.1.2. Drainage Net or Sheet Drain

The drainage net or sheet drain is a continuous layer that underlies the entire cover system. A variety of lightweight, high-performance drainage products function well in this environment. The product selected should be capable of conveying the discharge associated with the design storm without ponding water on top of the roof cover. The drainage layer must have a good hydraulic connection to the roof gutters, drains, and downspouts. To prevent the growth medium from clogging the drainage layer and to prevent roots from penetrating the roof surface, a geotextile should be installed immediately over the drainage net or sheet drain. Some products have the geotextile bonded to the upper surface of the drainage material. A root retardant (such as copper sulfate) is typically included in this geotextile.

19.3.1.3. Lightweight Growth Medium

The depth of the growth medium should be as small as the cover vegetation will allow, which is typically 3 to 6 inches. Low-density substrate materials with good water-retention capacity (e.g., mixtures containing expanded slate, expanded shale, expanded clay, and terra cotta) should be specified. Media appropriate for this application will retain 40 to 60 percent water by weight and have bulk dry densities between 35 and 50 lb/ft^3. The make up of the media will vary depending on the types of plants used, but an example media make up would be 55% expanded Slate, 30% root zone sand, and 15% compost. Care should be taken when specifying compost because it will eventually break down over time and the depth of the media will therefore decrease. A photograph of expanded slate is provided in Figure 19-3. Earth and topsoil are too heavy for most applications, as well as being too wet for succulent and other recommended vegetation and too dry for grasses.

Figure 19-3
Expanded Slate



19.3.1.4. Vegetation

A limited number of plants can thrive in the roof environment where periodic rainfall alternates with periods that are hot and dry. Effective plant species must: tolerate mildly acidic conditions and poor soil, prefer very well-drained conditions and full sun, tolerate dry soil, and be vigorous colonizers. It should also be noted that conditions can be much wetter for longer periods near a gutter or drain and dryer near the peaks. Succulents have shown to be very successful in vegetative roof covers, and are preferred to grasses. Both annual and perennial plants can be used. Vegetative roof covers may need provisions for occasional watering (e.g., conventional lawn sprinklers) during extended dry periods. A vegetation plan prepared by a horticulturalist versed in green roof vegetation is required.

19.3.1.5. Hydraulics

Vegetative roof covers influence the runoff hydrograph in two ways: intercepting rainfall during the early part of a storm, and limiting the release rate. Hydrologic properties are specific to the growth medium. If information is not provided by the supplier, prospective media should be laboratory-tested to establish:

- Porosity
- Moisture content at field capacity
- Moisture content at the wilting point
- Saturated hydraulic conductivity

Rainfall retention properties are related to field capacity and wilting point. Appropriate media for this application should be capable of retaining water at the rate of 40 percent by weight, or greater. The medium must be uniformly screened and blended to achieve its rainfall retention potential. During the early phases of a storm, the media and root systems of the cover intercept and retain most of the rainfall, up to the retention capacity. For instance, a 3-inch cover with 40 percent retention potential effectively controls the first 1.2-inch of rainfall. Although some water percolates through the cover during this period, this quantity is generally negligible compared to the direct runoff rate without the cover in place. Studies on several green roofs in North Carolina show capture volumes ranging from 0.5” to 1.2” (Moran et al, 2005). Capture rates are dependent on rainfall intensity, antecedent rainfall, time of year, evapotranspiration, and roof pitch. Green roofs on pitches steeper than 1:12 do not function as well as for water quality and quantity control. Vegetated roof covers should be kept on slopes of 8 percent or less, if they are being used to mitigate water quality or quantity.

Once the field capacity of the cover is attained, water drains freely through the medium at a rate that is approximately equal to the saturated hydraulic conductivity of the medium. The maximum release rate from the roof can be controlled by selecting the appropriate medium. The medium is a mechanism for “buffering” or attenuating the peak runoff rates from roofed areas. The attenuation can be important even for large storms. By using specific information about the hydraulic properties of the cover medium, the effect of the roof cover system on the runoff hydrograph can be approximated with numerical modeling techniques. As appropriate, the predicted hydrographs can be added into site-wide runoff models to evaluate the effect of the vegetative roof covers on site runoff. The hydraulic analysis of roof covers requires the services of a properly licensed design professional experienced in this type of drainage design.

Drainage nets or sheet drains with transmissivities of 15 gallons per minute per foot or higher are recommended. When assessing a drainage layer design, designers should evaluate the roof topography to establish the longest travel distances to a roof gutter, drain, or downspout. If flow converges near drains and gutters, the design unit flow rate should be increased accordingly. The drainage layer should be able to convey the design unit flow rate at the roof grade without water ponding on top of the cover medium.

For storms larger than the design storm, direct roof runoff will occur. The design flow rates should be based on the largest runoff peak attenuation considered in the design of the vegetated roof cover.

19.3.1.6. Weight Considerations

Roof designs are dictated by state and local building codes and standards. They must account for maximum design loads contributed by dead loads, live loads, and snow or water accumulation. The design of a vegetative roof cover can alter the dead loads to the system and it should therefore be closely coordinated with the structural design of the building. Dead loads for vegetated roof covers include the planting medium, vegetation, drainage system, and water in the pore space. However, the additional weight is partly offset by the removal of the gravel ballast.

By using appropriate materials, the total weight of fully saturated vegetated roof covers can readily be maintained below 35 pounds per square foot (psf). Vegetative roof covers in North Carolina tend to weigh between 30 and 35 psf in addition to other dead, live and/or snow loads.

It is also possible that the minimum weight design focus for the vegetated roof cover might be too light to satisfy the ballast requirements for flat tar roofs. As required, deepening the medium can increase the weight of the cover system.

19.3.2. Roof Gardens

Roof gardens generally are designed to achieve specific architectural objectives. The load and hydraulic requirements for roof gardens vary according to the intended use of the space. Intensive roof gardens typically include design elements such as planters filled with topsoil, decorative gravel or stone, and containers for trees and shrubs. Complete designs also may detain runoff ponding in the form of water gardens or storage in gravel beds. A wide range of hydrologic principles may be used to achieve stormwater management objectives, including runoff peak attenuation and runoff volume control.

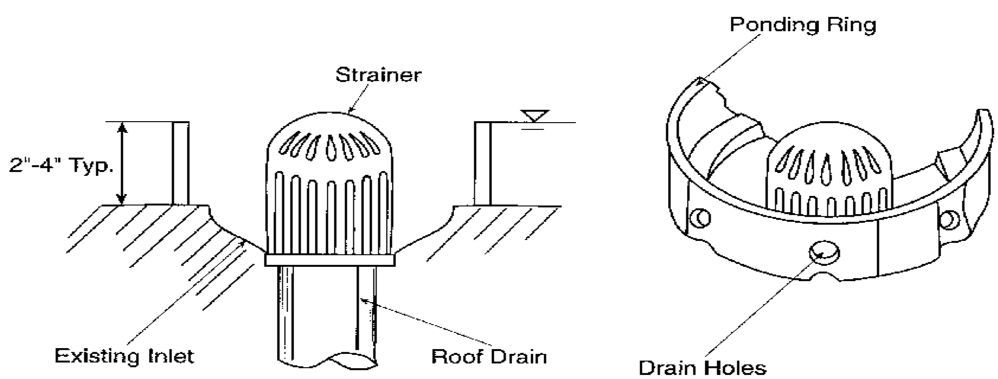
Effective designs ensure that all direct rainfall is cycled through one or more devices before being discharged to downspouts as runoff. For instance, rainfall collected on a raised tile patio can be directed to a medium-filled planter where some water is retained in the root zone and some is detained and gradually discharged through an overflow to the downspout.

19.3.3. Roof Ponding Areas

Roof ponding measures can be designed for rainfall events of all sizes. However, the structural loads associated with the impounded runoff may impose limitations on their use. This is especially true if ponding areas must also accommodate runoff derived from adjacent roof surfaces.

Flat roofs can be converted to ponding areas by restricting the flow to downspouts. Figure 19-4 shows a simple device that can be used to modify downspout inlets. The device features drain holes that retard outflow as the water level rises and a weir ring that allows free drainage once the design ponding level is attained. It is essential that a structural engineer verify that the existing roof can carry this extra weight. Some form of emergency overflow is advisable and can be as simple as a free overflow through a notch in the roof parapet wall.

Figure 19-4
Modification of Downspout Inlet (Adapted from Tourbier, 1974)



The inputs needed for analysis of roof ponding systems are similar to those needed for design of dry ponds and other runoff peak attenuation facilities. The necessary inputs are:

- Input hydrograph
- Depth-storage function
- Depth-discharge function

Because the roof is impermeable, the runoff hydrograph is simply the rainfall distribution for the design storm multiplied by the area of the roof.

The depth to storage relationship can be computed from the topography of the roof. For perfectly flat roofs, the storage volume of a ponding level is equal to the roof area times the ponding level.

The depth-discharge relationship is unique to the outlet device used. For simple ponding rings, the following discharge equation can be used:

$$O = 3.141\ CD(d - H)^{3/2}$$

where:

- O = outflow rate (cfs)
- D = diameter of the ring (ft)
- d = depth of ponding (ft)
- H = height of the ring (ft)
- C = discharge coefficient (typically 3.0 but may vary depending on the shape of the flow device)

With this information, the attenuation effectiveness of the roof ponding system can be predicted by using the Modified Puls or other storage-routing procedure. The performance of the ponding area can be adjusted by changing the height or diameter of the ponding ring.

19.3.4. Cisterns

Cisterns, or rainbarrels, are a method of collecting and storing rainwater for future use. Uses include irrigation, vehicle washing, toilet flushing, and laundry operation. Cisterns are effective for reducing runoff if they are used correctly. Cisterns must be designed to capture an appropriate volume of water that will be re-used onsite on a regular basis. Cisterns that are not used regularly will remain full, not collect rainfall from future storms, and not reduce runoff. Cistern pumps can be included in a design where an increase in water pressure is needed. Pumps should be designed to accommodate the necessary pressure and flow for the system.

19.4. Construction

The main construction guideline is to engage professionals who are experienced with rooftop runoff management BMP installation, and preferably who can undertake all phases of the project from waterproofing to planting.

Additional loading is one of the main factors controlling the feasibility and cost of a rooftop runoff management BMP. New extensive green roofs can be accommodated in building design for a minor additional cost. Rooftop runoff management BMPs on an existing building need to consider the bearing capacity of the structure. It is also possible to use roof areas where point loading can be increased over columns or along a bearing wall, to allow areas for deeper growing medium and larger plants. A structural engineer must be consulted and verify roof and structure strength.

Access to the roof is required for inspection and maintenance. For example, materials need to be carried to the roof for soil and plant replacements. Suitable exterior or interior access or elevator stops need to be provided to allow this access. For 1 to 3 story structures, blower trucks or shingle lifts may be used.

A waterproof membrane is an essential component of a rooftop runoff management BMP. It is recommended that a membrane be installed as the rooftop runoff management BMP is deployed. In addition, good drainage must be provided to prevent extended contact with water and reduce the possibility for leaks and for plant mortality due to drowning or rotting. Roof appurtenances such as parapets, skylights, mechanical systems, and vents should be well protected with a gravel skirt, and when necessary, weep drains.

If the waterproof membrane contains organic material (e.g., bitumen) plant roots may penetrate it. Also, the chemical composition of the membrane should be compatible with the surfaces with which it will be in contact. Membranes developed specifically for rooftop runoff management BMPs contain a root-deterring chemical or metal foil at the seams to prevent root damage (Peck and Kuhn, 2004).

On a roof slope greater than 20 degrees, horizontal strapping or other support systems must be installed to avoid slippage and slumping of the growing medium and plants.

The timing of planting depends on the local climate and season. Planting in the summer may require additional irrigation. Fall planting depends on the availability of plants and whether there is sufficient time to allow for the plants to become established before late winter. Mid-spring planting (Feb – Apr) is recommended for much of North Carolina. Rooftop runoff management BMPs constructed in the mountains are best planted Mar – May.

19.5. Maintenance

19.5.1. Common Maintenance Issues

Please refer to Section 7.0, General BMP Maintenance, for information on types of maintenance, typical frequency, and specific maintenance tasks that are common to all BMPs. The following information is maintenance that is specific to rooftop runoff management BMPs.

Two to three yearly inspections are recommended to check for weeds and damage. After installation, weekly visits may be needed to ascertain the need for irrigation.

Both plant maintenance and maintenance of the waterproofing membrane are required. All rooftop runoff management measures must be maintained periodically. Furthermore, the vegetative measures require routine care and maintenance typical of any planted area. The maintenance includes attention to plant nutritional needs, irrigation as required during dry periods, and occasional weeding. The cost of maintenance can be significantly reduced by judiciously selecting hardy plants that will out-compete weeds. In general, fertilizers must be applied periodically. Fertilizing usually is not a problem on flat or gently sloping roofs where access is unimpeded and fertilizers can be uniformly broadcast. However fertilization is not recommended if the roof is to be used for water quality improvement. Treading on the cover system should not damage properly designed vegetated roof covers. Maintenance contracts for routine care of the vegetative cover frequently can be negotiated with the installer.

Retrofits of existing roofs must incorporate easy access to gutters, drains, spouts, and other components of the roof drainage system. Foreign matter, including leaves and litter, should be removed promptly.

19.5.2. Sample Inspection and Maintenance Provisions

Important inspection and maintenance procedures:
- The plants will be watered during extended periods of dry weather.
- Fertilize only once per year as long as the rooftop runoff system is not intended for nutrient removal.

The rooftop runoff management system will be inspected **once a quarter and within 24 hours after every storm event greater than 1.0 inches (or 1.5 inches if in a Coastal County)**. Records of inspection and maintenance will be kept in a known set location and will be available upon request.

Inspection activities shall be performed as follows. Any problems that are found shall be repaired immediately.

BMP element:	**Potential problem:**	**How to remediate the problem:**
The plants materials	Weeds are present.	Remove the weeds by hand.
	Vegetation is dead or diseased.	Try to determine the cause of the problem (may wish to consult an expert). Correct the problem and replace the plants.
The flow diversion structure	The structure is clogged.	Unclog the conveyance and dispose of any sediment off-site.
	The structure is damaged.	Make any necessary repairs or replace if damage is too large for repair.
Gutters, drains and spouts	Clogging has occurred.	Remove leaves, debris, and other foreign matter and dispose of in a manner that will not impact streams or the BMP.
	Damage has occurred.	Repair or replace the damaged conveyances.

September 28, 2007 Changes:

1. Major Design Elements: Reformatted to include numbered requirements.
2. Regulatory Credits: Specified that the Simple Method must be used to calculate volume.