Aerial view of Chicago City Hall

GREEN ROOFS

Definition: Green roofs are simply a layer of vegetation grown on a layer of soil on a rooftop above layers of drainage where rain water is stored for a small period of time.
Purpose: Green roofs are constructed to create green space for public benefit, energy efficiency, and stormwater retention and detention. Green roofs also mitigate effects of urbanization on water quality by filtering, absorbing or detaining pollutants in rainfall.

Components and Mechanisms:

- Plant level – drought-resistant and robust plants selected specifically for the intended soil depth and climate region
- Growing medium layer – roof planting soil adapted to the plant level; either lightweight or heavier weighted soil is used
- Filter sheet and drainage layer – prevents fine particles from being washed out of the substrate soil and retains water for dry periods
- Moisture retention/protection mat and root barrier – provides protection and retains moisture and nutrients while preventing roots from affecting the waterproofing efficiency

Benefits:

- Prevent airborne pollutants from entering the storm drain system
- Help reduce volume and peak rates of stormwater
- Reduce summer air conditioning cost

Limitations:

- Higher cost than traditional roofing systems
- Requires 'intense' initial maintenance
- Leaks can cause significant damage and can be hard to locate and repair

Design Considerations:

- 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
- Access to the roof is required for inspection and maintenance
- A structural engineer must be consulted and verify roof and structure strength

POLLUTION REDUCTION (%)

80 – 90	TSS (Sediments)
20 – 85	TP (Total Phosphorus)
30 – 95	TN (Total Nitrogen)
65	Pathogens
50 – 80	Metals
NA	Hydrocarbons
50 – 90	Runoff Volume/Peak

SITING CONSIDERATIONS

- Residential
- Commercial
- Ultra Urban
- Industrial
- Retrofit
- Can be C & D soil types with modifications (underdrains)

FEASIBILITY AND COST

√	Replace roof membrane
√	Inspection for drainage
√	Inspection for leaks
High	Land Requirement
High	Construction Cost
Median	Maintenance burden
High	Community Acceptance

A. GENERAL DESCRIPTION

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. However, this BMP can also be applied with steep roofs. 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.

There are two classes of roof top vegetation systems: extensive and intensive. Each of these types can be further classified as accessible or inaccessible greenroofs. Extensive systems, also known as low-profile, performance, or ecoroofs, are composed of a waterproof membrane covered with a shallow layer (4-6 inches) of growing medium and low growing vegetation. Intensive systems, also known as high profile or roof gardens are heavier weight systems that consist of a waterproof membrane covered with a deeper layer (6 to 24 inches) of growing medium and a variety of vegetation including some deeper-rooted vegetation (even trees). Either of these types of greenroofs can be made accessible to the residents or users of a building or the general public and provide a green space and amenity to the users. However, it is more common for intensive greenroofs to be designed as accessible space, while extensive greenroofs are often only accessed for inspections and maintenance.

B. COMPONENTS

Figure 7.1 – 7.2 illustrate Green Roofs. Green Roofs consist of:

(1) Structural roof
- Support greenroof weight

(2) Waterproof membrane
- Waterproofing
- Moisture control
- Prevents breakdown from UV rays.

(3) Root barrier, if not integral to membrane.
- Prevent root migration into the waterproofing system
- Protect waterproofing system

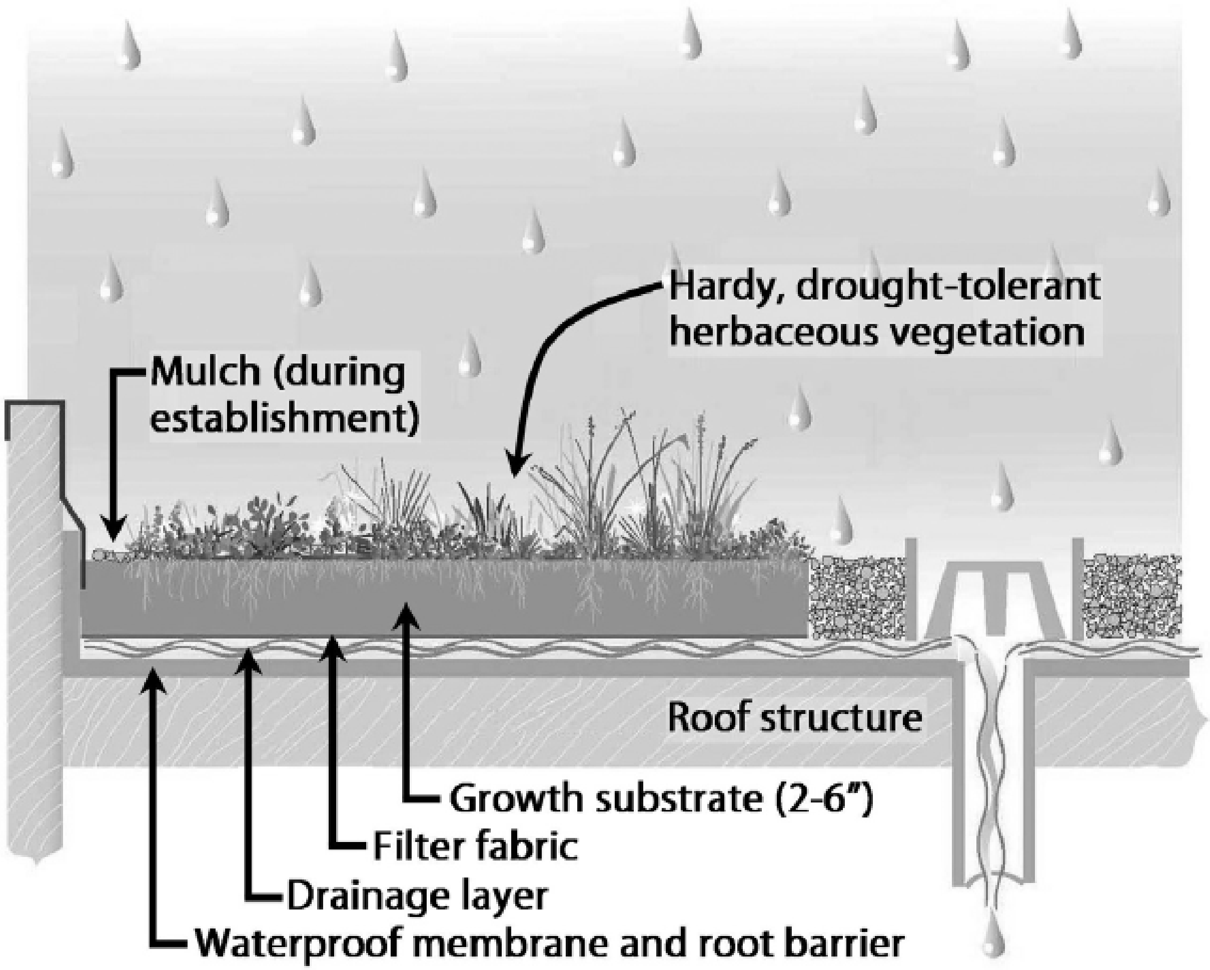
(4) Drainage layer
- Prevents damage to the waterproof membrane by draining excess rainfall off the roof through roof drains.
- Keeps the vegetation from drowning or rotting.

(5) Filter fabric between the drainage layer and the growing medium
- Prevents clogging.

(6) Growing medium
- Prevents clogging.
- Support a viable growing and water-control substrate for decades

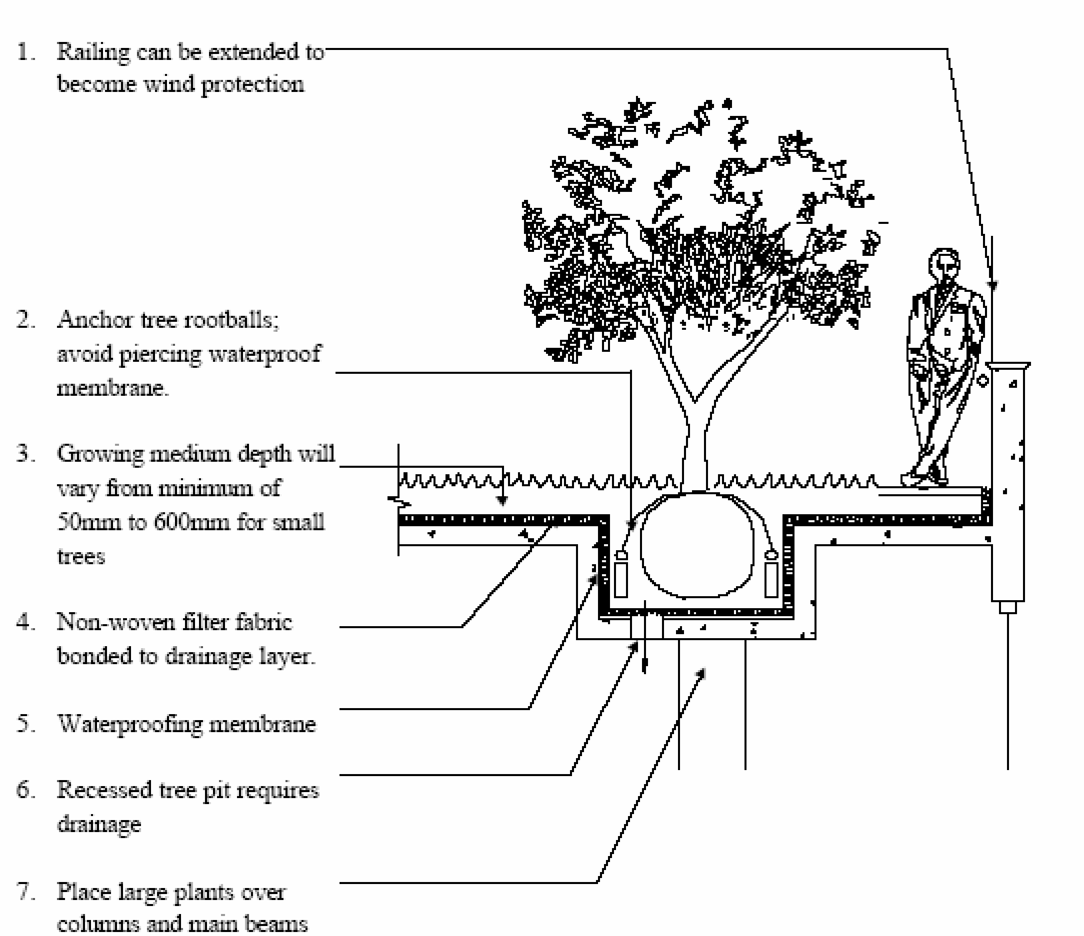
(7) Vegetation

- Cleaning the air by taking up smog forming chemicals such as oxides of nitrogen and sulfur, as well as carbon dioxide.
- Lower rooftop temperatures.
- Helping to reduce the urban heat island effect because less heat is radiated to the surrounding environment
- Creating wildlife habitat
- Reducing sound reflection and transmission



(Source: Massachusetts Law Impact Development Toolkit)

Figure 7.1 Extensive Green Roof (4 to 6 inches of growth medium)



(Source: Public Works and Government Services Canada, 2002)

Figure 7.2 Intensive Green Roof (6 to 24 inches of growth medium)

C. VARIATIONS AND APPLICATIONS

Most extensive vegetated roof covers fall into three categories: (1) Single media with synthetic under-drain layer, (2) Dual media, and (3) 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

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

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

D. POLLUTION REDUCTION CAPABILITIES AND MECHANISMS

Volume Control Capabilities

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. 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

A general rule for vegetated roof covers is that rate of runoff from the covered roof surface will be less than or equal to that of open space (i.e., NRCS curve number of 65) for storm events with total rainfall volumes equal to 3 times the maximum media water retention of the assembly. For example, a representative vegetated roof cover with a maximum moisture retention of 1 inch will react like open space for storms up to and including the 3-inch magnitude storm.

Pollutant Removal Capabilities

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.

Pollutant Removal Mechanisms

Wind, insulation and evaporation create the extreme drying conditions on roof tops mean that runoff from green roofs are often negligible. The vegetation and soil system provide similar treatment to that achieved by other soil filtration systems such as rain gardens, green roofs provide both water quantity and water quality benefits. Through a variety of physical, biological and chemical treatment processes that filter pollutants and reduce the volume of precipitation runoff, green roofs reduce the amount of pollution delivered to the local drainage system and, ultimately, to receiving waters.

Green roofs contribute to improved water quality not only by retaining and filtering the rainwater through the soil and root uptake zone, but also through:

- The vegetation, which slows down the water through friction and root absorption.
- The foliage in particular, which collects dust, transpires moisture and provides shade.
- The binding of potential pollutants to clay and organic matter in the roof top soil matrix (Dramstad, et al, 1996).

In addition, the temperature of the water not retained on the rooftop is moderated before draining downstream.

Green roofs, beyond their use for stormwater management, provide a number of ecological amenities. They can help to preserve habitat and biodiversity and provide an oasis of life in an otherwise sterile urban environment. Even in densely populated areas, birds, bees, butterflies and other insects can be attracted to green roofs and gardens up to 20 stories high (The London Ecology Unit, 1993). Some of the ecological and environmental amenities of green roofs are summarized as follows:

- Green rooftops can provide a micro 'stepping stone' habitat for birds and insects, connecting natural isolated habitat pockets with each other, or provide an 'island' habitat above those at ground level.
- Green roofs can be specifically designed to resemble endangered ecosystems or habitats, i.e., prairie grasslands or desert xeriscapes.
- A green roof designed for minimal maintenance is very protected and can provide habitat to both plants easily damaged by walking and/or to ground nesting birds.
- Green roofs can improve air quality through increased evapotranspiration and the filtering and shading effect of their foliage, thus helping to ameliorate the urban heat island effect, especially in sparsely vegetated areas.

Table 7.1 Pollutant removal efficiency of Green Roofs

Parameter	Removal Efficiency (%)
Total Suspended Solids	80 - 90
Total Phosphorus	20 – 85
Total Nitrogen	30 – 95
Pathogens	65
Heavy Metals	50 – 80
Hydrocarbons	NA
Runoff Peak Flow	50 – 90

E. PLANNING AND DESIGN CRITERIA

The following design and implementation considerations must be incorporated into greenroofs:

Design and Site Considerations

- The structural capacity of the building must be sufficient to support the saturated weight of the greenroof system. On new construction, it is relatively inexpensive to incorporate the structural requirements of the green roof at the outset. An existing building should be able to hold an additional 10 to 30 psf (for an extensive greenroof). Structural retrofits to existing buildings can be costly.
- The maximum slope for a roof with a vegetated system should be 15 percent. Studies have shown that gently sloping or flat roofs retain more runoff and thus fulfill the intended stormwater functions better. Note that steeper roofs require that the planting medium and vegetation layers do not slump or slip under their own weight, especially when wet, through the use of strapping or other methods.
- The intended function of the greenroof affects design. Greenroofs in Metro should be designed to perform stormwater functions of retention, peak flow attenuation, and filtration. It may also be desired that greenroofs serve as green space, in which case accessibility and aesthetics will also be important design considerations.
- The microclimate on the roof, which is affected by the height of the roof, wind exposure, orientation to the sun, shading by other buildings, rainfall, temperatures, and humidity are important factors in greenroof design, particularly in vegetation selection.
- The waterproof membrane is a crucial component of the greenroof system. Membranes come in various materials: bitumens, synthetic thermoset, hypalon and reinforced thermoplastic resin. If the membrane contains any organic material (bitumen is most common), a root barrier is necessary to prevent root penetration and destructive micro-organic activity. Many roof membranes are manufactured with root repellant as an integral component. Membranes with pesticides as an integral component are not permitted.
- Although greenroofs retain a great deal of stormwater, drainage from the entire system is still a necessary design component so that the roofing membrane is not compromised and so that the vegetation does not drown or rot. Proper drainage can be provided in a number of ways. Commonly, drainage mat systems with pockets for water storage are used. The drainage layer must be protected by filter fabric. The drainage layer directs excess rainfall off of the roof through roof drains and downspouts. When impervious areas drain to the roof, flow directed to the greenroof from these areas must be distributed evenly to prevent scour.
- Parapets, edges, flashing, skylights, vents, chimneys, and mechanical systems must be well protected with a gravel skirt, and sometimes with a weep hole.
- Growing medium should be a lightweight mineral-based mix. Common components include pumice perlite, expanded clay, sand, shale, compost, and coir.
- Vegetation must be suitable for harsh rooftop climates unless shading, irrigation, and fertilization will be provided. Plants must thoroughly cover the soil, at least 90% coverage. On extensive roofs, it is most practical to install hardy and indigenous plants such as succulents, sedums, mosses, semperviviums, and festucas that can survive with little maintenance aside from watering and fertilization in the short term, while the plants establish themselves. On intensive greenroofs, a wide variety of plants, bushes, and even

trees can make up the vegetation. Intensive greenroofs require more maintenance than extensive greenroofs.

Vegetation Installation
There are common methods of establishing vegetation on greenroofs:

Table 7.2 Common methods of establishing vegetation on Green Roofs

Method	Description/Advantages	Disadvantages
Vegetation Mats	Sod-like mats with pregerminated seeds. Provide full coverage, erosion control, with little maintenance or weeding requirements	Little flexibility in design
Plugs or potted plants	Well-rooted seedlings raised in a nursery and then planted on the greenroof.	Take longer to achieve coverage, erosion control, need more watering and weeding.
Springs	Cuttings that are hand broadcast	More maintenance than mats.
Seeds	Can be hand broadcast or hydroseeded	More maintenance than mats

- Access to the greenroof is important, not only for maintenance but for the initial installation of the greenroof. Materials including the membrane, drainage materials, growing medium, and plants will need to be brought up to the roof. This will be easiest if there is an elevator that goes to the roof. Otherwise, material must be hauled up via stairs, utility ladders, or even a crane. New buildings should be designed with easy access to the roof.

If the greenroof is designed to be accessible, the access must not only be convenient for installation and maintenance purposes but also must adhere to Metro Building Codes and other regulations for access and safety.

- It is best to choose a roof installer who has experience in working with greenroof systems. Because an industry has built up around greenroofs, it is possible to find companies that specialize in greenroofing. Some companies specialize in handling the whole greenroofing process from re-roofing to installation and initial maintenance, some have experience with design of greenroofs, while others have created special components for use on greenroofs.

F. CONSTRUCTION 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:

Root-barriers

- 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 FLLcertified materials are available in the United States. Interested American manufactures can submit products for testing to FLL-certified labs.

Granular drainage media

A non-carbonate mineral aggregate conforming to the following specifications:

Saturated Hydraulic Conductivity	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%

Growth media

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)	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.

Separation fabric

It 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

G. OPERATION AND MAINTENANCE REQUIREMENTS

Common Maintenance Issues

The O&M Agreement is to be used by the BMP owner or owners in performing routine inspections. The owner is responsible for the cost of maintenance and annual inspections, and the BMP owner must maintain and update the BMP operations. 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.

Sample Inspection and Maintenance Provisions

Important 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 sand filter 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.

Table 7.3 Sample Inspection and Maintenance Agreement for Green Roofs

BMP element:	**Potential problems**	**How to remediate the problems**
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.
	Damaged has occured	Repair or replace the damaged conveyances.

H. CONSTRUCTION AND MAINTENANCE COSTS

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.

I. DESIGN PROCEDURE

Step 1. Investigate the feasibility of the installation of a green roof. A Structural Engineer should verify that the roof will support the weight of the green roof system. It is important to consider the wet weight of the roof in the design calculations.

Step 2. Determine the portion of roof that will have a green roof.

Step 3. Extensive green roofs that have an engineered media at least 3 inches thick are permitted a DCIA reduction equal to the entire area of the green roof.

Step 4. The green roof is not considered impervious area when determining whether a redevelopment project has reduced DCIA by 20%.

Step 5. The area of the green roof is not included in the calculation of the Water Quality Volume, because it is not considered DCIA.

Step 6. The area of the green roof is not included in the calculation of the Channel Protection Volume, because it is not considered DCIA.

Step 7. The green roof area can be considered pervious open space in good condition with moderate soils when determining post-development flow rates for the Flood Control Requirement.

Step 8. Although green roofs are not considered as impervious surfaces when determining stormwater management requirements, they are not zero discharge systems. The roof drainage system and the remainder of the site drainage system must safely convey roof runoff to the storm sewer, combined sewer, or receiving water.

Step 9. Green roofs with a media thickness less than 3 inches can only be considered pervious if the designer can demonstrate that the initial abstraction of the green roof will be 0.5 inches or greater.

Step 10. Develop planting plan based on the thickness of the planting media.

Step 11. Complete construction plans and specifications.