Green Roof

Stormwater BMP Type

Pretreatment BMP	☐
Infiltration BMP	☐
Filtering BMP	☐
Stormwater Pond BMP	☐
Stormwater Wetland BMP	☐
Water Quality Conveyance BMP	☐
Stormwater Reuse BMP	☐
Proprietary BMP	☐
Other BMPs and Accessories	■

Stormwater Management Suitability

Retention	■
Treatment	☐
Pretreatment	☐
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**Moderate**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**Varies**

Description

Green roofs, also known as eco-roofs or vegetated roofs, consist of layers of soil and vegetation installed on building rooftops. Green roofs are typically multilayered systems that consist of a waterproof membrane, a synthetic drainage layer, a root barrier topped with a lightweight soil media, and a selection of plants suited to harsh rooftop conditions. Green roofs reduce runoff volumes and peak discharge rates by retaining runoff and creating longer flow paths. Rainwater is either intercepted by vegetation and evaporated to the atmosphere or retained in the substrate before being returned to the atmosphere through evapotranspiration.

The ability of a green roof to absorb and/or retain stormwater depends primarily on the type of plant material and soil medium but also depends on the drainage layer, the roof slope, the size of the roof and the season and climate. Green roofs may be used on newly constructed buildings or as retrofits of existing buildings. The structural integrity of the building is an important consideration for evaluating the feasibility of a green roof for a given application.

A green roof's ability to influence the water quality of runoff depends on the chemical composition of the rain falling on it, the materials used to promote plant growth such as fertilizer, and the type of plants. While the soil media and vegetation of green roofs can reduce pollutants in stormwater, green roofs are generally not used for stormwater treatment because they capture rainwater, which is typically relatively clean. Green roofs primarily slow the flow of stormwater or intercept rainwater and supply it for non-potable uses like flushing toilets and irrigation. In addition to reducing the amount of stormwater runoff leaving a site, green roofs can mitigate heat island effects, reduce local air pollution, and lower building energy costs by providing additional insulation, among other benefits.

Advantages

- Can reduce the peak rate of runoff by 50-90% as well as delay the peak rate by up to three hours as compared to runoff from a conventional impermeable roof.
- Can reduce stormwater runoff volumes by retaining a portion if not all the rainfall in a storm event by releasing it back into the atmosphere via evaporation and evapotranspiration. (Unplanted "Blue Roofs" are designed specifically to retain water and slowly release it back via managed release of runoff and/or evaporation.)
- Can moderate the temperature of runoff.
- Can be used in densely developed areas where the use of other stormwater management practices is limited due to space constraints.
- Can improve runoff water quality if planted with material that naturally takes up contaminants from the soil.
- Can buffer the effects of acid rain by filtering it through a growth medium with a basic pH.
- Can contribute to air quality improvements by reducing carbon dioxides levels, binding airborne particulates and sequestering greenhouse gases.
- Can provide habitat for birds and pollinators and thus promote biodiversity.
- Can reduce the "urban heat island" effect by helping to regulate air temperature.
- Can extend the life of the conventional roof below.
- Can contribute to building's energy efficiency by providing additional insulation and reducing heat loss in the winter and cooling the roof in the hot summer months.
- Can provide sites for recreational amenities or even urban agriculture.
- Can increase the property's marketability or that of surrounding properties by improving views from neighbors into the site.

Limitations

- Can be expensive to design and construct.
- Construction can be challenging and require gardening and roofing experts to work together.
- Roof system must be designed to support the green roof under fully saturated conditions.
- Inadequate or improperly maintained drainage can cause the system to underperform or in extreme cases exceed the capacity of the load-bearing structure supporting it.
- Sloped-roof applications require additional erosion control measures.
- Historic buildings and building codes/standards can increase regulatory requirements and cost.
- More frequent maintenance required than for a conventional roof.
- Can contribute nutrient pollutant loads if fertilizer is used.
- Leaks can damage the building it is sited on.

- Damage to materials under the plantings such as the root barrier or waterproofing materials can be difficult to repair or replace.
- Plants can be difficult to establish and even once they are established, they can expire from the harsh conditions and need replacement.
- Soils can erode if soil levels are not maintained as organic matter deteriorates or if soils are washed out by a rain event.

Siting Considerations

- **Potential Locations:** Green roofs are appropriate for all types of structures and uses from commercial, institutional to residential. Wide, relatively flat roof areas are preferred but not necessary as green roofs can be installed in narrow areas and on slopes. Green roof technology makes it possible to install a green roof in a wide variety of locations where stormwater flow reduction is desired. Green roofs can be incorporated into new construction and can often be added to existing structures.

- **Drainage Area:** A green roof has no maximum contributing drainage area limitation because it only manages the precipitation that falls on the vegetated roof surface. Runoff from other surfaces and structures should not be directed onto the green roof.

- **Roof Slope:** Roof slope can affect the overall cost and performance. The flatter the roof the easier it is to retain water and stabilize planted areas. When roofs are sloped it is necessary to consider the different requirements for upslope and downslope conditions, which will tend to collect more water and will require plant, depth of soil media, and structural considerations to accommodate those conditions. Green roofs are difficult to install on structures with a pitch in excess of 45 degrees and it is recommended that green wall technology be implemented in those situations. Sloped roofs do not necessarily result in increased peak flows in comparison to flat roofs as long as the green roof system is designed to accommodate the flow of water down the slope of the conventional roof. Gravel ballast, wrapped in filter fabric, can be used along the perimeter of the roof to promote drainage and prevent soil medium migration. [89]

- **Roof Size:** Roof size is a factor that contributes to the overall performance. Larger green roof installations tend to have a higher capacity to reduce runoff volumes, peak flow rates, and time of runoff concentration than smaller roof areas.

- **Seasons and Climate:** Season and climate should be considered in Connecticut where conditions differ dramatically throughout the year. Green roofs tend to retain more stormwater during the growing months and less when plants are dormant. Additionally, evaporation rates are higher during the warmer months. Green roofs also typically work more effectively during low-impact short-term rain events in comparison to high-intensity

[89] Landscape Development and Landscaping Research Society e.V., Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL). 2018 Edition. Guidelines for the Planning, Construction and Maintenance of Green Roofs.

events or storms that have a long duration. Micro-climatic conditions such as seasonal shade, seasonal wind shifts, etc. can affect the performance of a green roof. Height of the rooftop and orientation can create stronger winds requiring tree staking and special mulching

- **Use with Other BMPs:** Green roofs can be sited so that runoff from them feeds into other BMPs, which can provide additional retention, treatment, peak runoff attenuation, or stormwater reuse. Pairing a green roof with cisterns and other structural stormwater BMPs can improve the overall system's ability to achieve stormwater quality and quantity objectives for the range of storm conditions that can be expected in Connecticut.

Types of Green Roofs

A variety of green roof designs exist, which fall into two major categories based on the type of construction, the program, and related specifically to the depth of the growing medium (Table 13-15):

- **Extensive:** Typically less complex and less expensive than an intensive system, these installations usually include a planted area sometimes accessible only to maintenance personnel and do not typically require irrigation after the initial establishment of plant material. Extensive green roofs can be used on flat or sloped roofs.

- **Intensive:** or, roof gardens, are typically designed to provide amenity spaces and accommodate varied planting designs, and thus deeper planting media is typically necessary to accommodate larger plant material, like trees. Intensive green roofs can be designed to provide more environmental services than extensive roofs, but tend to cost more than extensive green roofs. Intensive green roofs are typically used on flat roofs. In addition to garden spaces, intensive green roofs can be used for urban agriculture or even turf sports fields.

The following photographs are examples of extensive and intensive green roofs in Connecticut. Figure 13-32 provides schematics of common types of extensive and intensive green roofs showing the differences in the various layers that comprise each type.

Extensive Green Roof, Laurel Hall, Storrs, CT

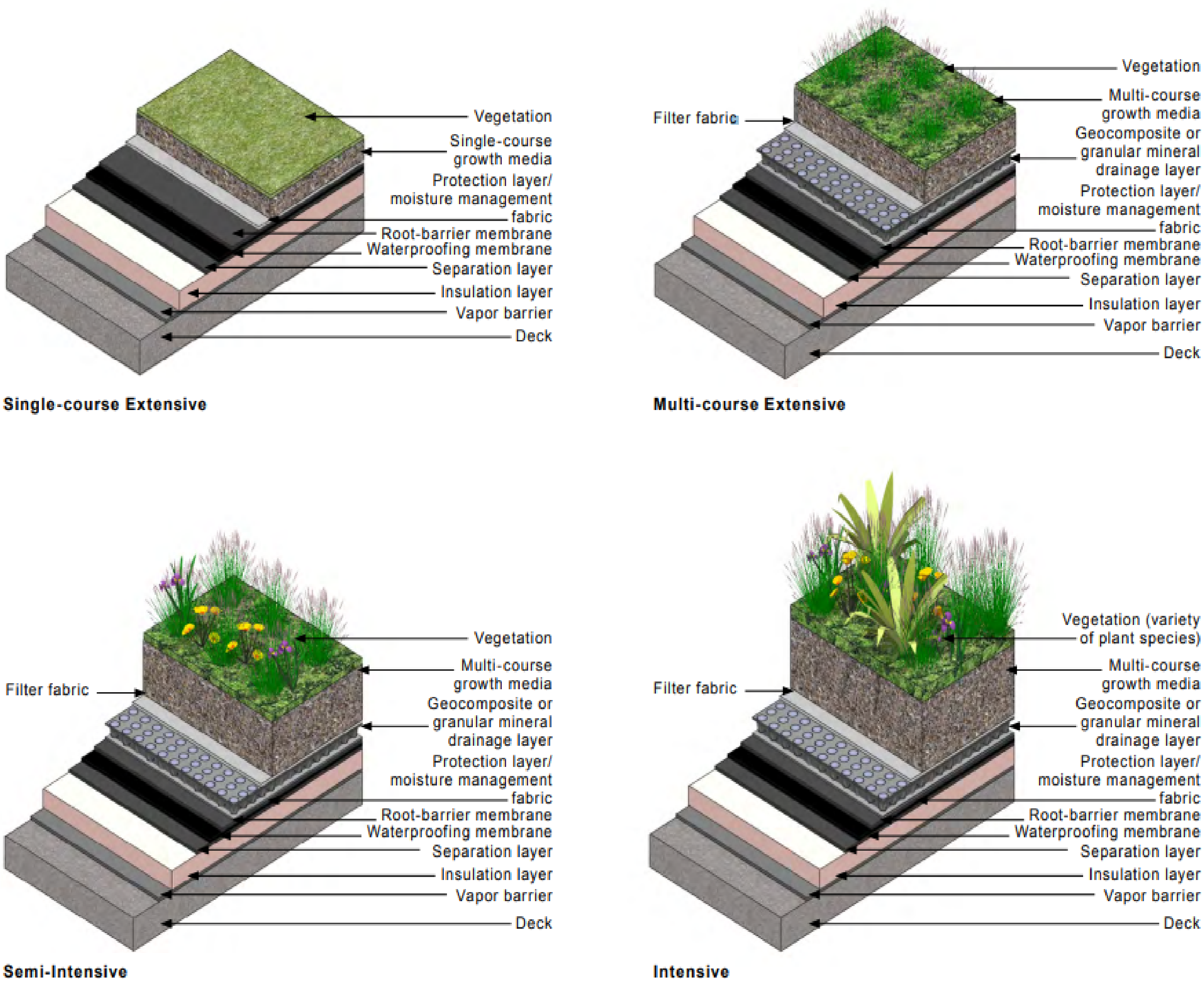
Simple Intensive Green Roof, Storrs Hall, Storrs, CT

Modular Green Roof, Gant Plaza, Storrs, CT

Intensive Green Roof, Stamford Government Center, Stamford, CT

Source: [UConn NEMO Program]

Figure 13-32. Typical Green Roof Types



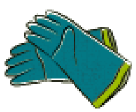
Source: GSA, 2011[90]

[90] U.S. General Services Administration (GSA). 2011. The Benefits and Challenges of Green Roofs on Public and Commercial Buildings: A Report of the United States General Services Administration. May 2011, p.18. https://www.gsa.gov/cdnstatic/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.pdf

Table 13-12. Comparison of Extensive and Intensive Green Roof Systems

	Extensive		Intensive	
Typical Feature	**Single Course**	**Multi Course**	**Simple**	**Full**
Relative Cost	$ Least Expensive			Most Expensive $ $
Thickness	3-4"	4-6"	6-12"	>12"
Establishment	As short as one growing season	1-3 growing seasons	Depends on plant selection	Intensive care throughout
 **Vegetation**	Self-sustaining, adapted to extreme site conditions with a high regeneration rate such as succulents, sedums, moss, or a native meadow seed mix appropriate to the site's USDA hardiness zone and local biotope.	Self-sustaining, adapted to extreme site conditions with a high regeneration rate such as succulents, sedums, moss, or native herbaceous material; other plants as possible, such as grasses, depending on the USDA hardiness zone and the availability of supplemental irrigation when required.	A variety of species can be supported with the right blend of soil medium and moisture. Species include herbaceous and smaller woody meadow perennials, turf grasses, and other ornamentals. Plants that can withstand extreme site conditions should be given preference.	Depending on the roof garden's micro-climate, plantings can be implemented similar to ground-level installations. Due to micro-climates on rooftops, plants that can withstand heat, wind and fluctuations in moisture are more likely to thrive and will require less maintenance.
 **Growth media**	Light-weight coarse growing media integrated with a drainage media	Light-weight, typically finer-grained media over a discrete drainage layer	Multi-course growth media overlaid on a discrete drainage layer	Growth media must be compiled at sufficient depths and composition to support the plant's needs. Higher levels of organics might be necessary and their effects on the water storage and density of the media must be considered when designing the structural support system. For trees a minimum planting depth 30 inches is required. The use of structural soil or soil cell system will be required for larger trees integrated with pavement areas

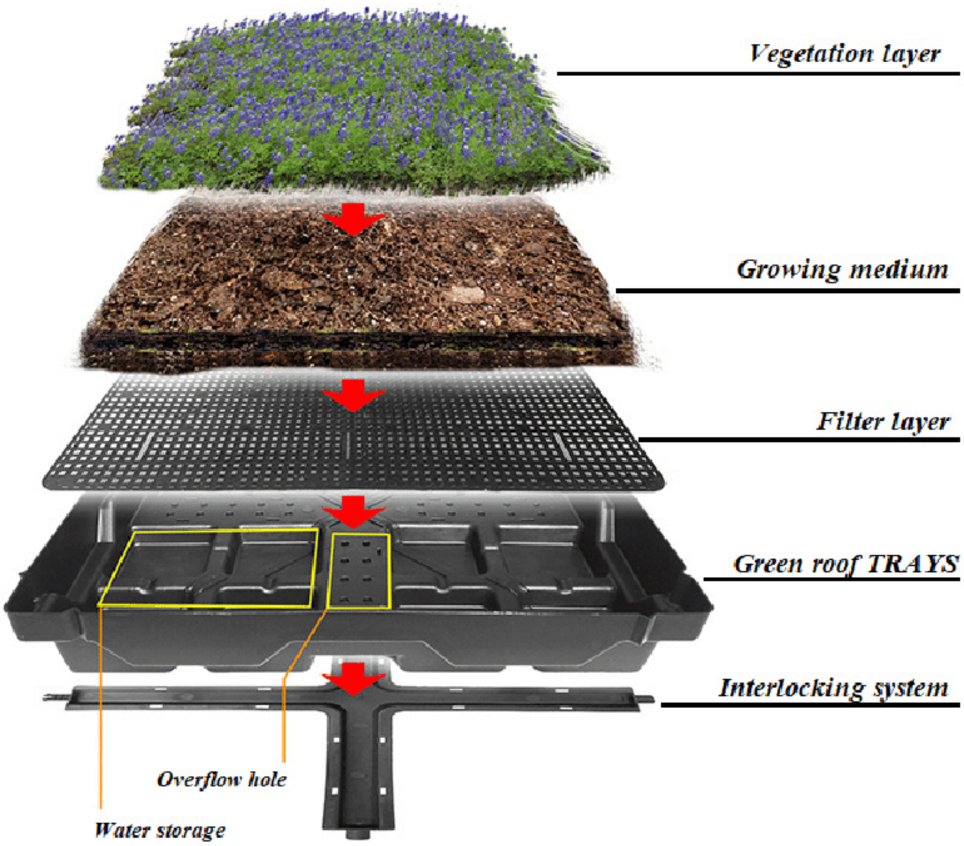
	Extensive		Intensive	
Typical Feature	Single Course	Multi Course	Simple	Full
Relative Cost	$ Least Expensive	→	→	Most Expensive $ $
Thickness	3-4"	4-6"	6-12"	>12"
Establishment	As short as one growing season	1-3 growing seasons	Depends on plant selection	Intensive care throughout
Drainage & Other Layers	Least complex layer structure. Drainage is integrated into soil media.	Potential for a less-complex layer structure. Typically a geocomposite is used but specific selection is related to the composition of the soil media, the types of plants selected, and regional climate and micro-climate conditions	Complex layer structure. Discrete drainage layer: either geocomposite or drainage media such as sand or gravel wrapped in a filter fabric or underlain with drainage board	Most complex layer structure. Discrete drainage layer is essential: either geocomposite or drainage media such as sand or gravel wrapped in a filter fabric or underlain with drainage board
Irrigation	None	Usually provided to establish vegetation; used to supplement as needed afterwards	Usually provided to establish vegetation; used to supplement as needed afterwards; required to maintain a turf grass installation	Typically required to supplement rainfall. Must be regulated to maintain the roof's ability to attenuate stormwater during a rain events

	Extensive		Intensive	
Typical Feature	Single Course	Multi Course	Simple	Full
Relative Cost	$ Least Expensive			Most Expensive $ $
Thickness	3-4"	4-6"	6-12"	>12"
Establishment	As short as one growing season	1-3 growing seasons	Depends on plant selection	Intensive care throughout
 Maintanence	Minimal: regular weeding, plant replacement as necessary, regular material inspection to insure functionality. If the material is planted in a certain pattern or design additional maintenance to retain the desired pattern will be required.	Minimal: regular weeding, plant replacement as necessary, seasonal removal of spent plant material (such as cutting back meadow grasses); regular material inspection of hardscape layers to insure functionality	Intensive: regular weeding, plant care, mulching, pruning and typical garden maintenance; irrigation as necessary; regular material inspections, care, and maintenance	Intensive: regular weeding, plant care, mulching, pruning and typical garden maintenance; irrigation as necessary; regular material inspections, care, and maintenance

Created with Canva.com

- **Modular Green Roofs:** Modular green roof systems are either extensive or semi- intensive and can be used with new installations and building retrofits. These prefabricated systems consist of interlocking modules (trays or units) containing plants and soil medium. The modules typically have established vegetation prior to installation and can be easily installed and removed/replaced, thereby facilitating roof maintenance and repair. These systems can be more expensive than the built-in-place systems, and aspects of modular construction can interfere with the optimal performance of the green roof to achieve stormwater benefits. Figure 13-33 is a schematic cross-section of a modular green roof.

Figure 13-33. Typical Modular Green Roof Assembly



Source: www.sedumgreenroof.co.uk

Design Recommendations

Pretreatment

No pretreatment is required for direct rainfall onto the green roof surface.

Sizing and Dimensions

- Green roofs should be designed to retain without bypass or overflow the Required Retention Volume (100% or 50% of the roof's Water Quality Volume or WQV).
- Maximum roof slope: 20%

Green Roof Elements

The elements of a green roof are all interdependent and must be carefully selected and detailed to work together to achieve the desired goal of the green roof installation. For example, a green roof designed to maximize the interception of stormwater might rely on large-leafed plants to maximize evapotranspiration. Those types of plants will require a deeper growth medium than plants with lower evapotranspiration rates, which will present a larger load that the structure will need to support. Alternatively, a roof garden that uses a water-retention system such as hydrogel will require a structure that will bear the load of the material when it is fully saturated.

Vegetation

Plant choices must be appropriate to the USDA growing zone as well as the rooftop microclimate, balanced with the roof's capacity to support their needs for growth medium and moisture as well as with the project's overall budget for installation and ongoing maintenance. Evaluating the rooftop for site-specific conditions such as reflections, thermal loading and/ or shade from adjacent structures, specific air quality resultant from co-located utilities, as well as wind tunnel effects due to adjacent structures, is critical when identifying species that will succeed.

Plants that succeed are typically:

- Hardy in a harsh rooftop microclimate:
    - Able to survive intense temperature fluctuation
    - Able to endure freeze-thaw cycles
    - Capable of withstanding the impact and desiccation from high winds
    - Tolerant of droughts as well as deluges
    - Adapted to urban air quality
- Self-sustaining with a high rate of regeneration
- Low growing for extensive, but can be all different sizes in an intensive application
- Fire-resistant
- Low maintenance

Plants that take up water through roots more readily can help maximize the performance of the green roof, but those species are often not low-maintenance or suited for rooftop conditions and thus require more care. Sedums and other succulents, like Delosperma (ice plant) or Sempervirums, as well as creeping thyme, Allium, Anntenaria, Ameria and Abretia along with urban-tolerant meadow grasses, such as Ammophilia brevigulata are typically selected for rooftop installations because they are highly tolerant of droughts and desiccating winds and have a high capacity for absorbing stormwater.

Evapotranspiration rates for all plants vary depending on the species, climate, and localized environmental conditions. Plants with higher evapotranspiration rates increase the stormwater absorption rates but they tend to require deeper growth medium and potentially could require a supplemental irrigation system. Adding an irrigation system requires monitoring so that the roof is not already saturated, and thus unable to retain and reduce runoff when a rain event occurs.

Vegetation should be kept back from roof edges so that drainage is not inadvertently conveyed over the edge of a building.

Growth Medium

- Particle sizes, type of material and depth of medium must be balanced as together they affect the overall performance of a green roof. The soil medium must support the vegetation and retain stormwater without overburdening the structural system. The shallower the growth medium, the more diminished the water retention capacity and the less nutrients necessary to support plants.

- Smaller particles, with more surface area, have a higher capacity for retaining stormwater, but smaller particles can retain too much water or get washed out during heavy storm events and end up clogging the drainage system. It is recommended that no grain diameter be smaller than 0.063 mm as smaller material will clog typical filter fabrics.

- The organic content must be balanced to promote plant growth without causing negative effects. As organic material decomposes it can contribute phosphorus and nitrogen to the runoff and it can also lose volume which would need to be replaced to sustain root masses. Deeper soil medium can retain more water, but the bearing capacity of the roof must be designed to accommodate a higher load, which can greatly increase project costs. A typical planting medium for a green roof will consist of 80-90% lightweight aggregate and 10-20% stable organic matter.

- For extensive green roofs, use 2 to 6 inches of lightweight growth substrate consisting of inorganic absorbent material such as perlite, clay shale, pumice, or crushed terracotta, with no more than 5% organic content.

- The pH of the planting medium should be between 6 and 8.5.

- Tested permeability (hydraulic conductivity) of the growing medium to be at least 1 inch per hour. The permeability can be determined by following the test method outlined in ASTM E2399.

- The following growth media design criteria apply to extensive green roofs: (NJDEP, 2021)
    - The tested maximum media water retention, when using the ASTM E2399 method, or the or the maximum water capacity, when using the *FLL* method, should be at least 35% by volume but not greater than 65% by volume.
    - The organic content should be less than 4.06 pounds per cubic foot or 65 grams per liter.

- The following growth media design criteria apply to intensive green roofs: (NJDEP, 2021)
    - The tested maximum media water retention, when using the ASTM E2399 method, or the maximum water capacity, when using the *FLL* method, should be at least 45% by volume but not greater than 65% by volume.
    - The organic content should be less than 5.62 pounds per cubic foot or 90 grams per liter.

- Consider adding biochar to the soil medium to (NJDEP, 2021):
    - Increase water absorption
    - Manage the weight of the soil medium
    - Decrease the pollution discharge including decreasing the suspended solids in runoff

Drainage Layer

- Overall, the drainage layer should be dimensioned and implemented with consideration of the roof pitch, unevenness on the roof surface, and to tie into roof drains.

- The hydraulic conductivity of the drainage layer should exceed the planting medium's hydraulic conductivity to promote positive conveyance of runoff.

- Factors to consider include:
    - Structure and layer stability/ compatibility with other materials
    - Compressive performance (i.e., will it still perform under compression)
    - Water permeability
    - Water storage capacity
    - Plant compatibility (phytotoxicity safety)
    - Root penetrability
    - Particle distribution/ mesh width
    - Resistance to freeze-thaw cycles
    - pH value (should match the growing medium or, at a minimum avoid a deleterious effect on it)

  - Salt content
  - Weatherability/ vulnerability to erosion
  - Chemical stability (tendency to leach)
  - Resistance to micro-organisms/ rot potential

- Multi-course systems should consist of either a coarse aggregate material like sand or gravel wrapped in a filter fabric or a synthetic geocomposite made from plastic or filaments. Aggregate materials tend to resist the horizontal flow of stormwater and so they delay peak runoff effectively. However, even though they tend to promote root development, they tend to be heavier and store less water than geocomposites. Fabricated from synthetic polymers, geocomposites are typically designed to achieve a specific goal such as stormwater storage, promotion of drainage, or the reduction of hydrostatic pressure on the waterproofing layer.

- Drainage can be addressed with multiple layers. It can be useful to install a geocomposite directly above the waterproofing membrane in addition to a multi-course drainage layer directly under the growth medium.

- Vegetated and non-vegetated areas should be drained and often require different drainage design and separate overflow mechanisms. At least one drain and one emergency overflow are recommended for each drainage field.

- Ideally, the system should be designed so that the pressure of the rainwater flow through the system will self-clean the mechanisms so that maintenance and inspections can be minimized.

- Calcareous materials, such as recycled concrete aggregate, should not be used in drainage layers as they can lead to efflorescence in the drainage system which can damage the system in the long term.

- Drainage such as gravel strips should be installed at the edge of green roofs to convey water at the edges to the designed system and to avoid allowing runoff to flow over the edge of the building.

- While roots can grow in the drainage layer, drainage infrastructure, such as scuppers, drains, and other conveyances for stormwater should be kept clear of vegetation and protected from clogging with debris with a filter screen or mesh coordinated with the particle sizes of the growth medium and/or gravel used in the drainage layer.

- Drainage must be considered at all thresholds to the green roof installation and can require special detailing that includes:
  - A heated channel drain at the threshold
  - Splash protection/ protection from snow accumulation

- Doors with special sealing functions
- Additional waterproofing and drainage in the interior of the threshold

Moisture Management Layer

- Separation fabric can directly affect drainage and should be selected and installed so that it achieves the desired design goal.

Root Barrier/ Protective Layer

- Can consist of:
  - A layer of perforated plastic sheets
  - A thin layer of gravel that prevents root growth from advancing but does not interfere with the drainage or the roots' ability to access water
  - A full surface coating or liquid sealant on the roof material below
- Can be combined with the waterproofing layer
- The required strength of the barrier is directly related to the type of root growth of the specified plant species. For example, bamboos with aggressive rhizome growth may require extra-strength protection.
- Special root protection treatment may be required at transition points, roof penetrations and joints in the roofing material.
- Thinner growth medium can cause an increase in competition among plants which respond with more aggressive root growth and can require additional protection.
- Should arrest the advancement of root growth to prevent damage to the waterproof membrane, the leak detection system below it, and the roof itself.
- Root barriers containing chemical root-growth-blockers and/or herbicide should be avoided as they will contaminate the runoff from the green roof.
- Some installations, such as waterproof concrete roofs, or roofs constructed from welded metal sections, do not require a root barrier because the material is already resistant to root penetration.
- Special care should be taken when installing the root barrier layer as many are UV-sensitive and can deteriorate if left exposed during construction. Also, protection for the material may be necessary when installing it over a rough surface below.
- Root protection layers can be manipulated to establish pockets of water in areas of the garden where they are needed to support plant material but should be installed carefully to prevent unwanted ponding from occurring.

- On sloped roofs, root protection should be installed and pinned as necessary to prevent it from sliding relative to a waterproof membrane below it.

Waterproof Membrane

- Typically made of materials such as bitumen, synthetic rubber (such as EPDM), hypolan (CPSE), or reinforced PVC. Adhesives used to bind panels of the membrane together should be impermeable.
- An impermeable root barrier sometimes doubles as a waterproofing membrane.
- The waterproofing must be extended at all transitions, particularly at the edge of the roof where it should wrap around and overlap with the wall waterproofing.
- The waterproof membrane should be reviewed by both the roof expert and the garden expert to be certain that it meets the physical requirements for the structure below and the green roof installation above.

Leak Detection System

- Many options for electronic leak detection and moisture monitoring systems exist in the market. A leak detection system should be used under the waterproof membrane and above the roof so that leaks can be detected quickly before damage to the underlying roof structure occurs.

Roof Materials

- Transition points
  - Special care is needed to secure root barriers and waterproofing where roof materials or slopes transition. Snow accumulation at these points should also be considered.
- Separation Layer(s)
  - Can be installed as needed between the green roof layers or under the green roof materials and above the traditional roof materials.
  - Should be compatible with other materials in the installation.
  - Should be resistant to mechanical, thermal, and chemical stresses of the green roof installation
  - Should be resistant to rotting from exposure to biological factors present in a living green roof system.
  - Should not off-gas or leach pollutants into the stormwater released from the green roof.
- Insulation Layer
  - Needed if there is an occupied space directly under the green roof.

- Vapor Barrier

- Roof Deck or Membrane
  - If not separated from the stormwater conveyance system:
    - Concrete roofing can leach carbonates
    - Asphalt roofing can leach polycyclic aromatic hydrocarbons (PAHs) and hydrocarbons

Safety Considerations

- All green roofs will require access whether just for maintenance personnel or for recreational users. Safety measures, such as proper tie-off points for fall protection, will need to be installed to enable maintenance of all green spaces.

- All synthetic materials layered in the green roof installation should be chosen to be chemically compatible with one another so as to avoid leaching or off-gassing of pollutants. Additionally, materials should be evaluated to be certain that they are not toxic to the plant species.

Stormwater Quantity Control Design – Adjusted Runoff Curve Number

- Green roofs reduce the volume of runoff from building roofs and therefore result in a reduced NRCS Runoff Curve Number (CN), which should be used for hydrologic and hydraulic routing calculations that are required for stormwater quantity control design.

- Determine adjusted CN values for the green roof by the following method:

  1. Calculate the volume of stormwater retained by the green roof based on the available water capacity of the planting/growing media using the methodology presented in the New Jersey Stormwater Best Management Practices Manual.
  2. Calculate the stormwater runoff volume produced by the water quality storm and the 2-, 10-, and 100-year, 24-hour design storms as described in Chapter 4 of this Manual.
  3. Subtract the volume of stormwater retained by the green roof from the stormwater runoff volume for the various design storm events. The result is the runoff volume that will be discharged from the green roof during each design storm event.
  4. Convert the volume of stormwater retained by the green roof to an equivalent retention depth (in inches) by dividing the volume retained by the area of the green roof.
  5. Convert the volume of stormwater discharged from the green roof to an equivalent discharge depth (in inches) by dividing the volume discharged by the area of the green roof.

6. Determine the adjusted CN values for each design storm using one of the following two approaches:
   - Intensive green roofs should use the runoff CNs for Woods, Brush, or Grass, depending on the specific plant communities used. Extensive green roofs should use the adjusted CN values listed in Table 13-16 based on the calculated retention depth in inches.
   - Using the calculated discharge depth described above and the precipitation for each design storm event, calculate the adjusted CN values using the equation or graphical solution (Figure 2-1 from TR-55) presented in Appendix D of this Manual (i.e., Graphical Peak Discharge Method).

Table 13-13. Adjusted Curve Numbers for Extensive Green Roofs

Retention Depth (inches)	Adjusted Curve Number (CN)
0.6	94
1.0	92
1.2	90
1.4	88
1.6	86
1.8	85
2.0	82
2.2	81
2.4	77

Adapted from Maryland Department of the Environment, Stormwater Design Guidance – Green Roofs, March 2018.

- Once the adjusted CN values are determined, also calculate the time of concentration and either follow the remaining steps in the Graphical Peak Discharge Method in Appendix D or use a stormwater hydrologic/hydraulic routing model based on the NRCS Curve Number method (e.g., HydroCAD or similar software) to calculate peak discharge for each design storm event.

Green Roof Retrofit Assessment

- Where a green roof is proposed as a retrofit, perform a site assessment of the existing building and roof integrity necessary to support the proposed green roof.

  - Structural Analysis
    - For the roof to be considered viable for green roof installation, the structural analysis must indicate that the roof structure is capable of supporting the additional load from the proposed green roof(s) when saturated in addition to any other live loads expected as part of the project.
    - Connections to building systems, such as plumbing (for irrigation), drainage, electrical, etc. should be carefully considered so as to not compromise those systems or to create issues.
  - Roof Membrane Assessment
    - Evaluate the condition of the existing roof membrane and confirm the remaining years on its warranty, if any.
    - If there are remaining year(s) on the warranty, contact the roof membrane manufacturer and confirm the necessary steps required to protect the membrane before installing the proposed green roof.
    - Confirm if the manufacturer cannot continue to honor the warranty if a green roof is installed.
    - Note major or numerous roof penetrations by pipes, ducts, equipment, or other features.
  - Historic Structure Considerations
    - Evaluate historic structure code requirements and any limitations of prohibitions relative to the use of green roofs. Can the historic character of the building be maintained? For example, green roofs on federal buildings cannot be visible from public thoroughfares.

Outlet & Overflow

- Runoff exceeding the retention capacity of the green roof system should be safely conveyed to the drainage system or another structural stormwater BMP. Design the outlet/overflow in accordance with the Inlet and Outlet Controls section of this Manual.

- The green roof system should safely convey runoff from the 100-year, 24-hour storm to a downgradient drainage system to avoid erosion or flooding.

- Roof drains and scuppers should be protected to prevent clogging through the use of a stone/gravel apron surrounding the drain or similar measures.

Other Considerations

- The following ASTM standards should be used for design of a green roof system:
  - ASTM E2396 – Standard Testing Method for Saturated Water Permeability of Granular Drainage Media (Falling-Head Method) for Green Roof Systems
  - ASTM E2397 – Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems

- ASTM E2398 – Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems
- ASTM E2399 – Standard Test Method for Maximum Media Density for Dead Load Analysis
- ASTM E2400 – Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems
- ANSI/SPRI VF-1 – External Fire Design Standard for Vegetative Roofs
- ANSI/ SPRI Standard for Wind Design- method for designing wind uplift resistance of green roofs
- ANSI/ SPRI Fire Design Standard- method for designing external fire resistance for green roofs
- ANSI/ SPRI Standard for Preventing Root Penetration- in development

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.
- The designing qualified professional should inspect the installation after placement of each roof layer, plantings, modular units, and outlet/overflow structures.
- The designing qualified professional r should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.
- The green roof planting media should be tested prior to placement according to the specifications in this section. The designing qualified professional should certify that the planting media meets the specifications based on soil testing results and soil weight requirements.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- Temporary erosion protection, such as mats or mesh, should be provided until plant cover is well established.
- Vegetation can be installed as vegetation mats, plugs, sprigs, seeds or as potted plants. Mats tend to be the fastest to establish, but the material is expensive even though it requires lower labor costs to install. In comparison, potted plants can establish coverage quickly but are expensive to purchase and install. Sprigs can be cost effective but often require irrigation, weeding and can be difficult to establish and often require replacement.

Maintenance Needs

- Green roof systems should be designed with easy access to the building roof and all components of the system for maintenance purposes. Refer to Chapter 7 for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- A method for detecting leaks should be included in the green roof's maintenance plan.
- Maintenance should be detailed in a legally binding maintenance agreement.

Recommended Maintenance Activities

- Plan for extra maintenance, often labor-intensive work like hand-watering and weeding, while plants establish.
- Perform inspections 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 planting medium has eroded or been transported to the drainage gutter or outlets.
- Remove organic litter, cutting herbaceous material back and pruning woody material two to three times annually.
- Provide extra maintenance to retain the desired aesthetic of a detailed planting.
- Perform periodic weeding, sometimes every other week during the growing season.
- Replace plants as needed. Maintain a minimum 85% vegetative cover at all times.
- Replace organic matter as it deteriorates.
- Fertilize to maintain plant health only as needed. Avoid use of fertilizer or over-fertilization to minimize nutrient export from the roof.
- Provide seasonal irrigation when necessary.
- Periodically maintain outflows (unclogging if debris enters) and inspect them two times a year at a minimum.
- Inspect roof materials for any problems, particularly the underlying membrane for deterioration.

- Relatively low-cost electronic grids can be installed under the membrane to help pinpoint leaks if they occur.

Other References

Massachusetts Low Impact Development Toolkit. *Fact Sheet #9 Green Roofs*. Metropolitan Area Planning Council. https://www.mapc.org/wp-content/uploads/2017/11/LID_toolkit_factsheets_7-9.pdf

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U.S. Environmental Protection Agency (EPA). 2018. *Estimating the environmental effects of green roofs: A case study in Kansas City, Missouri.* EPA 430-S-18-001. www.epa.gov/heat-islands/using-greenroofs-reduce-heat-islands

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