2.4 Green Roof

Photo credit: Elizabeth Hiser, Cuyahoga SWCD

Description

While a conventional roof sheds nearly all rainfall as runoff, a green roof reduces stormwater runoff quantity, peak flows, and pollutant load by retaining a portion of the rainfall within an engineered media to be used by plants or evaporate.

There are two general types of green roofs: 1) intensive green roofs with a deep planting media that can support shrubs and trees, often planned for uses such as gardening or rooftop patios; and 2) extensive green roofs designed with lightweight, low-profile materials for stormwater management, water recycling, and/or thermal advantages. This chapter details the stormwater management design objectives of an extensive green roof.

Many extensive green roof configurations are possible, including proprietary built-in-place and modular systems. Most consist of the following components layered over the roof deck: a waterproofing layer, an insulation layer, a drainage layer, a root barrier, and shallow (four- to six-inch deep) growing media planted with drought-tolerant vegetation. Rainfall not absorbed by the planting media or taken up by plants discharges through standard roof scuppers or drains.

Planning and Feasibility

Green roofs of many types and purposes, including the green roof depicted above, are built on structures throughout Ohio. Consider installing a green roof on ultra-urban developments with limited ground space available stormwater management or when seeking further environmental, sustainability, and economic performance benefits. A green roof is particularly effective at reducing the imperviousness of a previously developed site such that additional stormwater quality management practices may not be necessary.

Roof Pitch

A flat or slightly pitched (less than five percent) roof maximizes the runoff storage capacity within green roof media. Pitched roofs may subject the engineered media to erosion from wind and flowing water. Installing a green roof on a roof sloped greater than five percent requires baffles or other methods to ensure adequate retention of the design rainfall volume and to prevent the media from sliding downslope. The maximum roof pitch allowable for water quality credit is 2:12 or 9.5 degrees.

Roof Access

Adequate access to the roof must be available for both personnel and materials needed to conduct routine (monthly to bi-weekly) maintenance activity such as weeding, plant replacement, and wind-borne debris removal. This access must be a permanent feature of the building, such as a pilot house, roof hatch, or exterior stairs to the green roof. Unsecured ladders should not be needed to access a green roof for maintenance.

Access to Water

Locate an easily accessible water source with sufficient pressure and volume at the green roof level for irrigation during establishment and extended droughts.

Roof Microenvironment

Each urban rooftop presents a unique microenvironment that must be considered when planning and designing a green roof. A well-designed green roof should withstand extreme seasonal and daily climate variations as well as high winds that occur on an elevated surface. Evaluate possible solar reflection or shade from nearby buildings that can unexpectedly harm green roof vegetation. Prevent vented exhaust from killing plants or eroding the planting media.

Design Criteria

A green roof is subject to structural and other engineering criteria that are beyond stormwater management function and the scope of this chapter. Designers must consult applicable structural engineering standards and adhere to applicable State and local building code. Other industry-accepted resources serve as a more comprehensive design guide that cannot be replicated here. The following table of green roof design resources is not exhaustive but is provided for reference.

Table 2.4.1 Potential Green Roof Design Standards and References

- National Roofing Contractors Association. 2017. *The NRCA Vegetated Roofing Systems Manual*. Third Edition. Rosemont, IL.
- Green Roofs for Healthy Cities. 2016. *Green Roof Design and Installation Resource Manual*. Toronto, Ontario, Canada.
- Landscape Development and Landscaping Research Society [Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau] e.V. (FLL). 2018. *Green Roof Guidelines – Guidelines for the Planning, Construction, and Maintenance of Green Roofs*. Bonn, Germany.
- ANSI/SPRI. RP-14: Wind design standard for vegetative roofing systems.
- ANSI/SPRI. VF-1: External fire design standard for vegetative roofs.
- ANSI/SPRI. VR-1: Procedure for investigating resistance to root penetration on vegetative roofs.
- ASTM E2396 / E2396M – 15. Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Vegetative (Green) Roof Systems.
- ASTM E2397 / E2397M – 15. Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems.
- ASTM E2398 / E2398M - 15a. Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetative (Green) Roof Systems.
- ASTM E2399 / E2399M – 15. Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems.
- ASTM E2777-20 - Standard Guide for Vegetative (Green) Roof Systems.
- ASTM E2400 / E2400-19 - Standard Guide for Selection, Installation, and Maintenance of Plants for Vegetative (Green) Roof Systems.

In addition, the specialized design and materials associated with a green roof warrant both the designer and installer have proper experience and training. *Green Roof Professional* (greenroofs.org) or another applicable professional accreditation or certification is recommended.

Roof Coverage

For water quality credit, an extensive green roof with planted media should cover at least 90 percent of the available roof surface. Area excluded from the green roof often includes setbacks for safety, access, leak prevention, and fire protection. This is commonly around the roof perimeter, mechanicals, access points, roof penetration points, skylights, erosive exhaust vents (unless deflectors are installed), and otherwise incompatible or inaccessible area.

Water Quality Volume

The amount of rainwater retained within the green roof planting media is the product of the water holding capacity and the depth of the planting media layer (d_{media}). The water holding capacity of the media is represented in soil science and horticulture terminology as the plant available water (PAW). The PAW is the difference between the field capacity (moisture remaining after gravity drainage has occurred) and permanent wilting point (water remaining in the media that cannot be transpired by plants) for the design media.

Assume the PAW to be 0.25 in/in (based on the retention of water in typical green roof media). Use a PAW greater than 0.25 only if data for the selected planting media blend is supported by either an independent testing laboratory using standard measurement procedures (ASTM D-6836 or USDA-NRCS documented methods) or as published findings in a peer-reviewed research journal through academic study.

A green roof designed to the PAW and d_{media} criteria within this chapter supplies the required water quality volume (WQv) for the green roof area. The WQv provided with a green roof is:

$$WQv_{gr} = PAW \times d_{media} \times A_{gr} / 12 \qquad \text{(Equation 2.4.1)}$$

where WQv_{gr} = water quality volume of a green roof (ft^3),

PAW = plant available water (in/in) with an assumed value of 0.25 in/in,

d_{media} = media depth (in) with a minimum of four inches and a maximum value of six inches, and

A_{gr} = area of green roof (ft^2).

Extensive green roofs should not require regular irrigation. If irrigation beyond the establishment or extended drought periods is expected, reduce the PAW by 50 percent and provide a stormwater treatment practice, such as rainwater harvesting, to treat any remaining WQv.

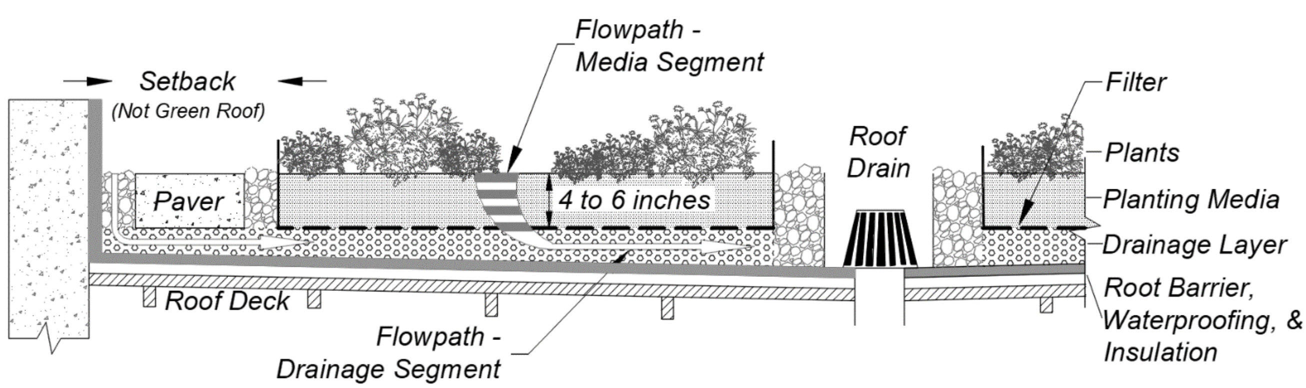

Figure 2.4.1 Typical Cross-section of an Extensive Green Roof for Stormwater Control (not to scale)

Conveyance and Overflow

A drainage layer underneath the planting media must freely convey runoff to an outlet or overflow system when the water holding capacity of the planting media is exceeded. This prevents the buildup of water which might adversely impact the plants and structural loading of the building. The drainage layer may consist of a prefabricated system or granular material such as a one- to two-inch layer of clean, washed aggregate or synthetic material. A minimum grade of two percent is recommended.

The drainage layer typically outlets to a traditional rooftop drainage system. This could include drains built into the roof deck as well as scupper assemblies that pass through a roof parapet and drain into a downspout. The system must include an adequate number of drains with sufficient capacity to drain the entire roof without ponding water above the media and meet applicable building code. Protect all roof drains from clogging, especially those within or near the planting media. Include emergency overflows within the green roof to prevent inundation and surface erosion when heavy rainfall events exceed the storage and transmission capacity of the planting media.

Any material or filter fabric separating the planting media and the drainage layer must not impede the downward migration of water into the drainage layer. Root barriers that come into contact with water shall be free of chemicals that could leach into stormwater runoff.

Planting Media

A specially designed planting media supports vegetation with a permeability and pore space volume necessary for stormwater management. It is typically a manufactured blend of lightweight mineral aggregate and organic matter. The lightweight aggregate may be coarse sand, slate, expanded shale or clay, volcanic rock, pumice stone, scoria, zeolite, vermiculite, perlite, diatomaceous earth, or other similar materials. The planting media must be free of excess fine (clay or silt) particles that will increase weight, decrease permeability, and potentially clog drainage elements and filter fabrics. No more than 10 percent by mass of the planting media may have a grain diameter less than 0.06 mm and 100 percent by mass shall be less than 12.5 mm (1/2 inch). The full particle size distribution of the planting media may vary by manufacturer.

Organic matter may be supplied by adding peat moss, composted bark, shredded wood waste, coconut coir fiber, or other acceptable organic matter to the lightweight aggregate to be later supplemented by decomposing roots and foliage. All supplied organic matter must have a nutrient content that will limit nitrogen or phosphorus leaching, be free of pathogens, weed seeds, herbicide residue, excess salts, and excess heavy metals. Garden soil or harvested topsoil is not recommended due to its weight. Organic content is expressed as a percentage of the total blend as determined by a loss-on-ignition test. An organic content of four- to eight-percent of the total blend is usually adequate for extensive green roofs.

The planting media layer must be a minimum of four inches thick. Plants may have difficulty surviving in less than four inches of planting media, especially during dry periods. Media with synthetic amendments or other components to increase the media's water hold capacity must include a plant survivability report demonstrating plant survival equals that of a non-irrigated four-inch standard green roof growing media. Although the constructed depth may be deeper, the maximum d_{media} eligible for RRv credit is six inches. A media thickness greater than six inches may not dry out as quickly, creating a non-uniform moisture distribution in the soil and no significant increase in retention storage potential. Use a planting media with a minimum saturated hydraulic conductivity of 1.5 inches per hour to limit the ponding and freezing of stormwater on the green roof.

Plants

A full and vigorous cover of low-maintenance, self-sustaining (requiring minimal fertilizer and irrigation) perennial vegetation 1) protects the planting media from wind erosion, 2) increases the amount of stormwater managed through evapotranspiration, 3) dries out the media for upcoming storms, and 4) minimizes maintenance cost and effort. Use plants capable of surviving in shallow, predominately dry planting media as well as withstanding the severe wind, temperature, and other weather conditions encountered on a roof. Native plants such as wild onion, sedges, and certain grasses may grow well on green roofs, however low-growing succulents may offer greater fire resistance and require less irrigation. A plant community composed of at least three species of succulent plants is recommended. Plant selection guides for green roofs are available from several sources including:

- Getter, Kristin and D. Bradley Rowe. 2008. Selecting Plants for Extensive Green Roofs in the United States. Extension Bulletin E-3047. Michigan State University Extension.

Plan a plant palette to achieve vegetative cover over 80 to 90 percent of the green roof media within two years of installation. An initial density of a minimum of two succulent plantings per square foot is recommended for a green roof planted with plugs or short root trainers. Plant area coverage will be attained quicker by planting at higher density, including in the plant palette some plants with high growth rates, and using hardened off plants raised in green roof media and allowed to acclimate to outside conditions for a few weeks prior to installation. Use pre-grown mats or modular trays to achieve instant plant coverage.

Specify erosion control measures to protect the plugs and underlying planting media from wind and rain erosion during the establishment period.

Consult with a landscape architect, horticulturalist, green roof supplier, or other professional experienced with green roofs to select a plant palette appropriate for the growing media depth, roof exposure, shading, solar reflection, wind, roof pitch, roof access, and other factors. Include the planting plan in the stormwater pollution prevention plan (SWP3).

Design Considerations

Peak Flow Attenuation

The design criteria in this chapter focus on water quality primarily as a product of annual runoff volume reduction, but research suggests that a green roof is also capable of attenuating runoff peak discharge rates. A study in Pennsylvania (Jarrett, 2016) concluded that a particular green roof was able to attenuate synthetic rainfall events to a pre-development level within a 2- to 100-year event return period. Similarly, a study in London, Ontario, Canada (Simms, 2019) found the 50- to 100-year return period storm event drainage was reduced to about a 10-year storm event by a green roof primarily for short (less than eight hour) duration events. However, green roofs are considered effective at reducing the peak runoff rates of smaller precipitation events but less so for larger events. Note that the addition of a storage reservoir to a green roof has been shown to be more efficient at reducing peak discharge than increasing the media depth (Li, 2016).

The conversion of rainfall to runoff for a statistical event can be difficult to predict due to the variability of the water holding capacity of the various types of media and heavily influenced by the antecedent moisture conditions. If a characteristic runoff equation cannot be determined for a green roof assembly, it may be possible to use the NRCS Curve Number methodology usually reserved to predict the hydrologic response of natural ground. Various CN values for extensive green roofs are reported in research and publications. Table 2.4.2 presents CN values developed by the Maryland Department of the Environment for various retention volumes (determined by the design planting media's PAW and depth) that are recommended for use here.

Table 2.4.2 Effective Curve Number for Extensive Green Roofs (from Maryland, 2018)

PAW × d_{media} (in):	0.6	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
CN:	94	92	90	88	86	85	82	81	77

Estimating peak stormwater runoff rates may be best determined through *EPA SWMM*[1] or similar stormwater management models. The flow path (see Figure 2.4.1) through an extensive green roof should include 1) a vertical segment though the planting media controlled by its saturated conductivity (k_{sat}) and depth and 2) a horizontal component through the drainage layer.

[1] EPA SWMM is common domain software available free from U.S. EPA. Similar proprietary software are also available.

Additional Benefits of Green Roofs

In addition to stormwater management, a green roof offers many other benefits, some of which are listed in Table 2.4.3, that may influence the decision to select a green roof, its overall design, and its bottom-line cost.

Some of these benefits produce direct economic returns while others, such as the usable space shown in Figure 2.4.2, may provide marketable or functional value. A developer may find it necessary to quantify potential financial gains from these benefits to represent the true cost of a green roof in comparison to other potential stormwater management practices. The Living Architecture Performance Tool (Green Infrastructure Foundation, 2019) or other calculators are freely available to help planners identify and appraise these various benefits.

Figure 2.4.2 University of Toledo (Photo Courtesy of Cuyahoga SWCD)

Table 2.4.3 Potential Non-stormwater Benefits

Private Benefits	Community Benefits

• extended service life of the roof
• increased heating and cooling energy efficiency
• noise dampening
• architectural feature that:
  ○ positively affects resident or employee health and well-being
  ○ improves sale or rental marketability
  ○ improves view from higher floors
• credit toward certifications (LEED, Green Globes, SITES, etc.) or local stormwater fees
	• reduced urban heat island effect
	• urban biodiversity and pollinator habitat
	• improved air quality
	• carbon sequestration
	• waste diversion (when using recycled materials)
	• reduces combined sewer overflow (CSO) discharges

Maintenance Considerations

All roof drains should be easily accessible for routine and emergency maintenance. Design drains to prevent vegetation, debris, or growing media from obstructing them.

Fall protection may be needed for maintenance activity. Plan railing, anchor points, and other safety features during the design process.

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