Green Roofs (GR)

Green roof at UAB Hulsey Center; Birmingham, AL

Site Selection

Quantity Control	possible
Drainage Area	small
Space Required	med-large

Works with:

Steep Slopes	---
Shallow Water Table	---
Poorly Drained Soils	---

General Significance

Construction Cost	high
Maintenance	med
Community Acceptance	high
Habitat	low
Sun / Shade	sun to p. shade

Synonyms: Vegetated roof cover, vegetated roof tops, roof gardens, landscaped roofs, eco-roofs, living roofs

Green roofs are landscaped roofs that use a specialized growing substrate, storage, drainage mat, and vegetation that is tolerant of extreme climates experienced on rooftops. Green roofs mitigate stormwater runoff, reduce the heat island effect of impervious surfaces from rooftops, extend roof membrane life, conserve energy, reduce noise and air pollution, provide wildlife habitat in urbanized settings, and improve fire resistance of buildings. These systems have been used in Europe for decades and are becoming more prevalent in the U.S. as stormwater retention practices that provide aesthetic value. As a stormwater control measure (SCM), green roofs are more effective at reducing runoff volumes resulting from small storms rather than providing pollutant load reductions from impervious surface runoff.

Long-term Investment: Green roofs are considered a long-term investment because they are one of the most expensive structural low impact development (LID) practices per square foot to construct. Depending on the depth of substrate and volume of runoff retained, vegetated roofs can be quite heavy. Construction alone is considered an expensive capital cost when building structure reinforcement is needed. Although green roofs are an expensive practice, the layer of vegetation and substrate protect the roof membrane from ultraviolet (UV) radiation and harsh temperatures, and can extend the lifespan of roofing membranes. In the absence of green roofs, roofing membranes experience sharp temperature fluctuations causing them to expand and contract, resulting in damage and eventual replacement. Data from Europe have shown green roofs to double the life span of roofing membranes.

Table 4.7.1
Site Selection: Constraints and Limitations for Green Roofs

Constraint	Recommendations
Water Quality	If pollutant load reductions are the primary objective, use another practice.
Slope	A roof slope of 8% or less is recommended and flatter slopes work best
Limited Volume Control	Green roofs may have reduced capacity for large quantity retention. No curve number (CN) is assigned and Discrete Curve Number Method cannot be used.
Roof Pitch	Pitches greater than 1:12 do not function for water quantity treatment
Building Code	State and local building codes may prevent retrofit or use of green roof

Site Selection

Footprint: Green roofs have been used on industrial, commercial, and residential rooftops. The installation of a green roof is well-suited to ultra-urban areas because it offers stormwater benefits and ecosystem services, but does not result in any additional land usage.

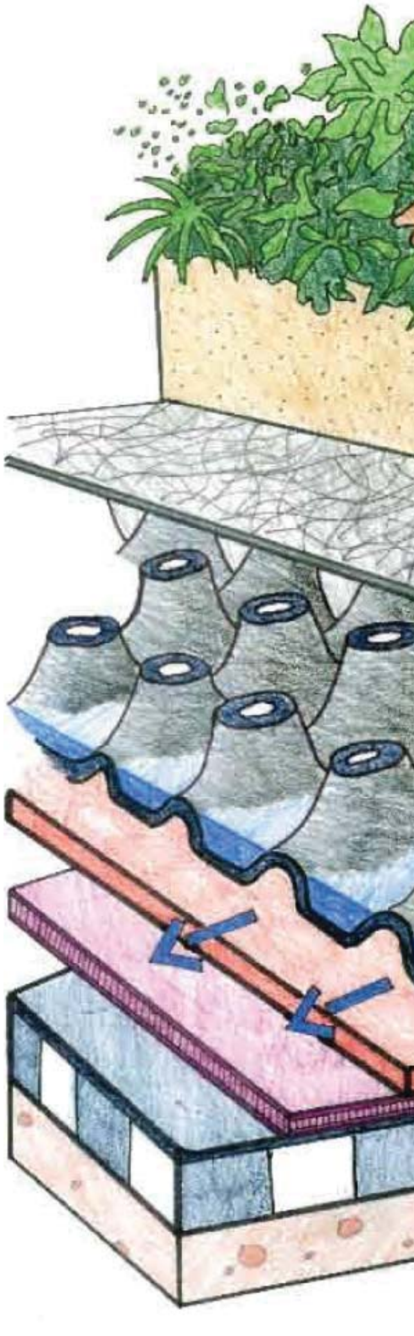
Slope: The ability of a green roof to retain rainwater will decrease with increasing roof slope, typically flat roofs are used for green roofs. A roof slope of 8% or less is recommended when green roofs are planned for water quantity or potential water quality benefits. Green roofs at < 2% slope are not recommended because of poor drainage resulting in standing water that can damage vegetation and increase the need for structural support.

Retrofits: Not all retrofit applications will require structure reinforcement, and it is critical to consult with a structural engineer to determine this early in the planning process. Most flat-roofed buildings can bear the load of an extensive green roof retrofit. Building height, location, sun exposure, and wind exposure should all be considered when planning a green roof installation or retrofit. Surrounding buildings may shade the green roof surface and this has the potential to impact vegetation selection and evapotranspiration rates. A shaded green roof retains water for longer periods of time and could result in stress to the building structure because of heavy, water-soaked substrate.

Common Green Roof Variations

Intensive Green Roofs: Intensive green roofs are similar to landscapes found at ground level. Intensive green roofs have a substrate depth usually > 8" and can support a diverse plant community with deeper root systems. Although intensive green roofs are generally more attractive due to their garden-like appearance, they are also more expensive and require the building to support the increased weight of the substrate depth. Maintenance tends to be more expensive for this type of green roof due to overall aesthetics and maintenance required by the diverse plant community. Intensive green roofs can be designed to accommodate foot traffic and used as an outdoor space with garden paths throughout. Visitor access not only makes aesthetics an important amenity, but also means that safety concerns should be addressed early in the design process. Extreme temperatures of green roofs can be a hazard for humans using it as a recreational space.

Extensive Green Roofs: An extensive green roof installation is more common because it is ideal for retrofits and less expensive. An extensive green roof system requires less structural support because its substrate depth is usually < 8". The typical substrate depth ranges from 3 – 5" thick with 4" of substrate recommended in the Southeast. Extensive green roofs offer all the environmental benefits associated with intensive green roofs but are designed to be low maintenance and do not usually allow public access. These systems can provide undisturbed habitat for insects, birds, and microorganisms because access is limited.



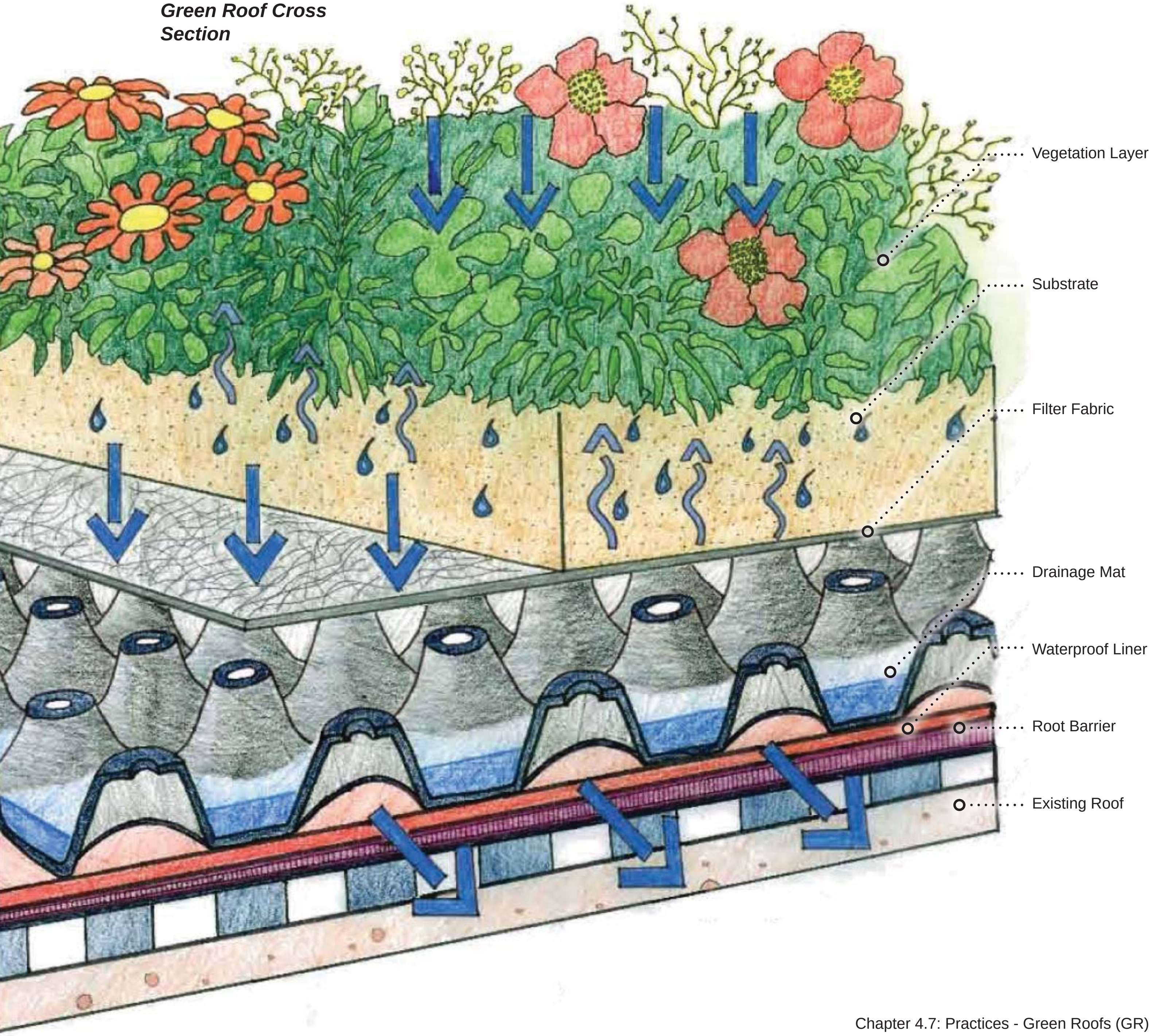
Design

This handbook focuses on the design and construction of extensive type green roofs due to its growing popularity and decreased costs.

Components

Substrate: A green roof substrate should be relatively lightweight, retain nutrients for plant growth, and be persistent. Topsoil should not be used as a green roof growing medium because it is too heavy and remains too wet. The substrate should be composed of a lightweight mineral compound such as shale, slate, clay, or terra cotta. The substrate should hold approximately 40 to 60% water by weight and have a bulk density (dry) range of 35 to 50 lb/ft^3. Though vegetation roots and shoots intercept rainfall, the substrate should manage the release rate of stormwater. A target water holding capacity of 40 to 60% is ideal for plant survival and to release and drain enough water to maintain the appropriate weight on the building structure. Capture volumes ranging from 0.5" to 1.2" have been reported on several green roofs.

Green Roof Cross Section



Substrate Depth: Substrate depth is largely based on local climate and precipitation patterns. Although research out of Michigan shows substrate depths of at least 2.75" can successfully support succulents and provide adequate coverage, 4" of substrate is recommended in Alabama to support succulents and perennials. It should also be noted that when irrigation is installed, decreased substrate depths have been successful.

Substrate Organic Matter: Organic matter in the substrate should be 15% or less. High organic matter components are not recommended because of increased decomposition resulting in substrate shrinkage. Substrate replacement is expensive and not practical, therefore, the substrate components should have minimal decomposition rates.

Fertilizer: Some fertilization is needed for plant establishment, however too much can result in nutrient leaching and increased levels of nutrients in stormwater runoff. Controlled release fertilizers (CRF) have shown to be effective for plant establishment at rates as low as 3.5 oz per 20ft^2 (13N-6P-11K).

Compost: Other research has utilized low rates of compost (up to 20%) in the substrate mix to provide nutrients and organic matter. High rates of compost in green roof substrate may leach nitrogen and phosphorus, which can be problematic in nutrient-sensitive watersheds. Future research at the University of Alabama at Birmingham is planned to analyze water quality impacts associated with the use of both compost and fertilizer.

Filter Fabric: A layer of geotextile filter fabric is placed between the substrate and drainage mat. The filter fabric protects the drainage mat by preventing the substrate from clogging it and deterring root growth into the mat and roof surface.

Drainage Mat: The drainage mat, layer, or net prevents water from ponding by conveying it off the roof to protect and preserve the roof surface. Rapid drainage of the substrate will reduce the weight of the green roof. The drainage mat selected should adequately drain the roof from the design storm. Drainage mats should drain at a rate of 15 gal/min/ft or higher.

Membrane/Waterproof Liner: The impermeable roof membrane is made of tar or another waterproofing liner that creates watertight conditions between the drainage mat and the building structure. This layer is similar to conventional roofing liners. If the membrane contains organic matter, there is danger of roots penetrating it and eventually growing into the underlying structure.

Design Guidance

It should be noted that the design presented in this handbook is limited for Green Roofs because of structural standards that limit their application. A licensed structural engineer should be consulted to verify the use of a Green Roof. Structural upgrades can be cost-prohibitive to a project.

Roof Weight: Green roof weight should be considered during the design process. The weight of saturated media, live or dead loads, and any snow accumulation should be scrutinized to ensure that structural support requirements are met. Dead loads for green roofs consist of the substrate, drainage mat, and water in the pore spaces. These loads must meet state and local building codes. The State of Alabama conforms to the International Building Code (IBC). Under IBC Table 1607.1, roofs used for gardens or assembly purposes must be designed for a 100 pounds per square foot (psf) uniform live load. The substrate used must have the capacity for rainfall retention and balance runoff retention with loading (weight).

1. Calculate Runoff Volume

The Discrete Curve Number Method cannot be used because a curve number has not been specified for green roofs.

However, the Simple Method can be used to calculate the volume of water necessary for water quantity and volume reduction. The Simple Method uses two equations (EQNs 4.7.1 and Y.2) to calculate the runoff coefficient.

Typically, when calculating the **runoff coefficient (R_v)**, **impervious fraction (I_a)** is determined as the impervious area divided by total area. However, in this case, the **impervious fraction (I_a)** is 50% of the impervious fraction for a standard roof and this is a standard assumption for green roof design.

Once the **runoff coefficient (R_v)** is calculated, it

EQN 4.7.1

$$Q = CiA$$

C = Runoff coefficient
i = Rainfall intensity (in/hr)
A = Watershed area (ac)
Q = Peak flow (ft^3/s)

EQN 4.7.2

$$R_v = 0.05 + 0.9 * I_a$$

R_v = Runoff coefficient
I_a = Impervious fraction

EQN 4.7.3

$$V = 3630 * R_d * R_v * A$$

V = Peak runoff volume (ft^3)
R_d = Design rainfall depth (in)
R_v = Runoff coefficient
A = Rooftop area (ft^2)

can be used in EQN 4.7.3 to determine the **total runoff volume (V)**.

The hydrologic properties specific to the substrate or growing medium are used to determine the capacity for rainfall retention. Porosity, moisture content at field capacity, moisture content at wilting point, and saturated hydraulic conductivity (K_{sat}) are all needed to determine water retention and the rational runoff coefficient.

R_d is the design rainfall depth (in), R_v is the rational runoff coefficient (in/in), and A is area in acres.

Forty percent by weight or greater retention is needed to intercept and retain the water quality storm event. This characteristic is imperative for peak attenuation. A runoff hydrograph and numerical modeling can be approximated using these properties. For storms larger than the design storm, runoff will occur and downspouts should be designed accordingly.

Construction

Check Membrane: Prior to installation, the water-proofing membrane should be checked to determine that it is leak-free. Although this may be a time-consuming task, it should be done as a preventative maintenance measure. If leaks to the membrane are found following installation, complete vegetation and substrate removal may be required to mitigate leaks.

Preventing Root Penetration: Membranes or waterproof liners specific for green roof applications should contain a root deterrent chemical or metal foil at membrane seams. Although not required, a copper-based root retardant can also be included in the filter fabric to prevent root growth beyond the substrate layer.

Irrigation: Irrigation should be installed for plant establishment and periods of extreme drought. Hand watering or overhead irrigation has been used effectively during plant establishment, but irrigation for seasonal drought conditions should use micro-irrigation emitters. Soil moisture probes or sensors can be an inexpensive investment for the irrigation system and they ensure that irrigation only occurs during extreme drought conditions.

Roof Access: Frequent roof access will be necessary for inspection and maintenance operations following installation. Substrate loading and unloading or plant replacement to and from the rooftop surface may be labor intensive. Exterior or interior elevators are helpful to carry materials to the roof. A blower truck or shingle lift can be used for 1 – 3 story buildings.

Safety: Safety can be a concern both during construction and after installation due to the possibility of a fall. Safety issues may include high temperatures, being trapped on the roof, and decreased roof structure integrity causing injury.

Vegetation

Plant Characteristics: Vegetation suggested for extensive green roofs are native perennials, grasses, or succulents. Plants for these systems are typically low growing, establish quickly, and are cold, heat, and drought tolerant. Vegetation selection can be difficult due to decreased rooting depth available to plants. Green roof plants that are readily established, spreading, and propagate easily have shown to be successful. Annual and perennial plants can be used, although perennial plants are preferred as the sustainable choice. Other preferred characteristics include persistent plants that are long-lived, self-propagate, or reseed themselves.

Stress Tolerance: Selecting plants for green roofs can be difficult due to the extreme weather conditions experienced on a rooftop. Required stress tolerances results in vegetation that is low-growing, compact, mat-forming, tough foliaged, and any other characteristics that allow plants to efficiently avoid drought. Most green roof vegetation will need to tolerate mildly acidic and poor soil conditions present in the growing substrate.

Irrigation: Irrigation of extensive green roofs is not required, but irrigation has proved effective in aiding in plant establishment as well as plant survival during periods of long-term drought. The initial cost of irrigation system installation is usually less than replacing vegetation.

Plant Placement: Vegetation near gutters and downspouts may remain wet for longer periods of time and should include plants that are tolerant of extended wet conditions. A horticulturist or landscape architect should be consulted for specific vegetation recommendations.

Examples of Green Roof Vegetation at the University of Alabama at Birmingham; Birmingham, AL

Additional Vegetation Design Guidelines

- Areas of the green roof that will remain wet or dry for longer periods of time should be planted with the appropriate species for these conditions.
- The nursery or plant supplier should be contacted prior to green roof design to determine species and quantities that are available.
- Although native species are preferred for LID practices, a mixture of nonnative succulents and native perennials may be necessary to ensure adequate coverage.
- Follow plant label instructions for spacing recommendations.
- Succulents appear to be more suited to extensive green roof environment, but native perennials and grasses can be used in conjunction to provide aesthetic appeal.

Table 4.7.2
Green Roof Plant List*

This is a suggested plant list for green roofs in Alabama.

Botanical Name	Common Name	Native	Habit	Seasonal Irrigation
Antennaria plantaginifolia	pussytoes	yes	perennial	yes
Coreopsis auriculata	mouse-ear tickseed	yes	perennial	yes
Elymus hystrix	Eastern bottlebrush grass	yes	grass	yes
Phemeranthus calycinus	limestone fameflower	yes	perennial	yes or no
Phlox bifida	starry glade phlox	yes	perennial	yes
Sedum album 'Jellybean'	'Jellybean' white stonecrop	no	succulent	yes or no
Sedum album 'France'	'France' white stone-crop	no	succulent	yes or no
Sedum kamtschaticum	orange stonecrop	no	succulent	yes
Sedum rupestre 'Angelina'	'Angelina' stonecrop	no	succulent	yes or no
Sedum spurium 'Fuldaglut'	'Fuldaglut' two-row stonecrop	no	succulent	yes or no
Viola egglestonii	Eggleston's violet	yes	perennial	yes

*Adapted from Price et al., 2011

Maintenance

Access: Maintenance can prove difficult simply due to the location of the practice. Access to the roof is imperative and walkways or paths for maintenance purposes are recommended for ease of plant inspection, weeding, or irrigation system maintenance.

Vegetation Maintenance: Plant maintenance is expected since the majority of the green roof will be covered by vegetation. Dead plants should be removed and replaced during early spring. Dead vegetation should remain over winter months as cover for the roof before being replaced in the spring. Most vegetation for green roofs will undergo winter dormancy, but should experience bud break when temperatures warm. Maintenance professionals and horticulturists can assist in determinations of whether plant replacement is necessary.

Troubleshooting Roof Ponding: Because the green roof is designed to retain stormwater, leaks are possible and may be challenging to repair. If ponding occurs on the substrate surface, the source of ponding should be quickly determined. Substrate or surface ponding can damage vegetation through extended saturation that may promote fungal growth and plant dieback. In addition, sediment tends to collect in the outlet causing it to clog and should be periodically cleaned out to avoid roof flooding. Ponding may also occur due to clogging of the gutters or drainage layer. Complete substrate removal and replacement should be a last resort and only occur when all other ponding causes have been refuted.

Table 4.7.3
Maintenance Schedule

Task	How Often	Comments
Inspection of Green Roof	Once a quarter	Inspections should be made once a quarter or within 24 hours following a 0.5" or greater rain event. This is especially important during plant establishment.
Inspect Outlet for Sediment and Debris	As Needed	Drainage spouts, gutters, and other components of the roof drainage system should be cleaned out as debris appears. If clogged, the substrate can remain too wet and damage vegetation.
Inspect for Weeds	Every Two Weeks Until Establishment, Then Twice a Year	Vegetation should be inspected for weeds and if present, weeds should be removed by hand. Weeding is most important during plant establishment and should be done every two weeks to minimize plant competition.
Inspect Vegetation	Weekly then 2 or 3 times per year	Inspect vegetation for insects or disease. Replace dead plants at the appropriate time of year (early spring for sedum).
Irrigation	During plant establishment and periods of drought	Weekly inspections are necessary to determine the need for supplemental irrigation.

Pollutant Removal

Practice Pairing: Currently, green roofs are not considered a stand-alone water quality practice primarily because there are not documented reductions in nutrients and other pollutants. However, routing green roof discharges into other structural SCMs such as bioretention has the potential to provide both water quantity and quality treatment.

Retention: Green roofs can be utilized to effectively decrease runoff and peak flows through the retention of stormwater. Rooftop runoff can be even further reduced through evapotranspiration, especially during small storms when the majority of rain absorbed is released back into the atmosphere. Discharge or runoff from the green roof should occur only when the growing medium or substrate has reached field capacity.

Nutrient Leaching: Higher percentages of compost in the substrate can lead to nutrient leaching. Even with low rates of 15% compost, both nitrogen and phosphorus have been leached and were significantly higher compared to rainfall from a conventional rooftop. It is possible that determining the ideal recipe or formula for the growing media could eventually result in water quality benefits or at the very least, a leveling off of nutrient leaching.

Energy Use Reduction: Besides retention of stormwater, green roofs can also provide other benefits. A reduction in energy consumption is provided because green roofs insulate the building through the use of vegetation and substrate that dissipates solar radiation to buffer temperature extremes. Green roofs cool through an increase of reflectivity, or albedo. Heat reduction can be high as 70 – 90% during the summer. Energy savings may be even greater for retrofitted green roofs on buildings that have poor insulation.

Noise Reduction: Green roofs also reduce external noise; five inches of green roof media can reduce noise from building surroundings by 40 decibels.

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Riparian Buffers (RB)

Aerial photo of streamside forest, courtesy of Greg Jennings

Synonyms: Filter strips, streamside vegetation, streamside forest, aquatic buffers, corridors, greenways, riparian zones, engineered buffers, buffer strip, water pollution hazard set backs, vegetated buffers, biological buffer zones

Site Selection

Quantity Control	---
Drainage Area	small-med
Space Required	med-large

Works with:

Steep Slopes	---
Shallow Water Table	✔
Poorly Drained Soils	✔

General Significance

Construction Cost	med
Maintenance	low
Community Acceptance	high
Habitat	med-high
Sun / Shade	sun to p. shade

Riparian buffers are permanently vegetated transition zones that connect upland areas to streams. Prior to development, most streams in the Southeast had naturally occurring riparian buffers. These streamside forests slow runoff velocity, create diffuse flow, and reduce nonpoint source (NPS) pollution concentrations before runoff enters nearby streams or other water bodies. Buffers filter pollutants from agricultural, urban, suburban, and other land cover through natural processes such as deposition, infiltration, adsorption, filtration, biodegradation, and plant uptake. Riparian buffers also stabilize streambanks and provide food and shelter to wildlife to connect otherwise fragmented wildlife communities in a watershed. Riparian buffers are often recommended as part of a holistic watershed management plan aimed at reducing NPS pollution.

Site Selection

Riparian buffers are sited adjacent to surface waters such as perennial, intermittent, and ephemeral streams. To be considered a LID practice, a riparian buffer should be restored and enhanced. Restored riparian buffers work well in high density, urban areas, such as residential subdivisions and can be used in conjunction with other stormwater control measures (SCMs) that help reduce flashy urban flows.

Permanent Easements: A long term or permanent easement is recommended to protect the restored buffer from development, clearing, or unnecessary extensive plant maintenance that might limit buffer functionality.

Right of Way: The restored riparian buffer should not be in a current right of way (ROW) for sewer, power, or other infrastructure.

Buffer Width: Buffer width may be a function of surrounding land use, land availability, or topography and may vary throughout the watershed. Check local ordinances on buffer width as these regulations can vary across the state from 25’ to 150’. Narrower buffers can be just as effective as wider buffers in removing sediment in environments where rainfall events are consistently light; however, buffers in regions that experience heavy or frequent rain events in urbanized settings may require wider buffers to adequately reduce sediment and other pollutants.

Slope: Slope can greatly affect buffer width and a slope of < 6% is recommended to slow runoff through riparian buffers. Steeper slopes may require larger buffer widths due to increased runoff velocities that decrease residence