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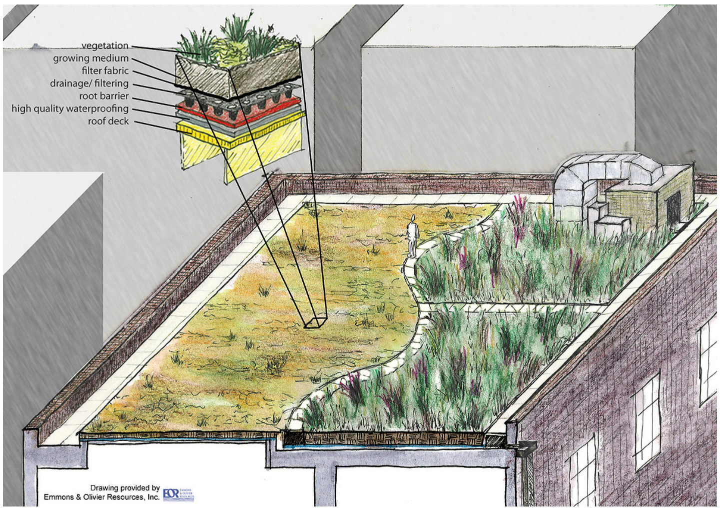
Overview for green roofs

Green roofs consist of a series of layers that create an environment suitable for plant growth without damaging the underlying roof system. Green roofs create green space for public benefit, energy efficiency, and stormwater retention/ detention.

For a literature review of green roof benefits, see .

Function within stormwater treatment train

Green roofs occur at the beginning of stormwater treatment trains. Green roofs provide filtering of suspended solids and pollutants associated with those solids, although total suspended solid (TSS) concentrations from traditional roofs are generally low. Green roofs provide both volume and rate control, thus decreasing the stormwater volume being delivered to downstream Best Management Practices (BMPs).



Schematic showing the different components of a green roof. Thicknesses of some layers vary with the design (e.g. extensive vs. intensive roofs).

MPCA permit applicability

One of the goals of this Manual is to facilitate understanding of and compliance with the MPCA Construction General Permit [1] (CGP), which includes design and performance standards for permanent stormwater management systems. Standards for various categories of stormwater management practices must be applied in all projects in which at least one acre of new impervious area is being created.

Green roof on the Target Center in Minneapolis Minnesota. Note the vegetation free zones. Image Courtesy of The Kestrel Design Group, Inc.

Although few roofs will meet or exceed the one acre criteria, roofs can contribute to the one acre determination at a site. Therefore, green roofs can be used in combination with other practices to provide credit for combined stormwater treatment, as described in Part III.D.1 of the permit. Due to the statewide prevalence of the MPCA permit, design guidance for green roofs is presented with the assumption that the permit does apply. Also, although it is expected that in many cases the green roof practice will be used in combination with other practices, standards are described for the case in which it is a stand-alone practice.

Retrofit suitability

Green roofs are an ideal and potentially important BMP in urban retrofit situations where existing stormwater treatment is absent or limited. Green roofs can be particularly important in ultra-urban settings.

Special receiving waters suitability

The following table provides guidance regarding the use of green roofs in areas upstream of special receiving waters. This table is an abbreviated version of a larger table in which other BMP groups are similarly evaluated. The corresponding information about other BMPs is presented in their respective sections of this Manual.

Summary of green roof design restrictions for special waters.

Link to this table

BMP Group	Stormwater Management Category				
	A Lakes	B Trout Waters	C Drinking Water	D Wetlands	E Impaired Waters
Filtration	NOT RECOMMENDED due to poor P removal	RECOMMENDED	RECOMMENDED	RECOMMENDED	RECOMMENDED for non-nutrient impairments

Water quantity treatment

A portion of rain that falls on green roofs is stored in the green roof media and eventually lost to evapotranspiration. Green roofs therefore provide water quantity treatment.

Green roof hydrology

Rain that falls on a green roof soaks into the soil (growing media) and

- is evaporated or transpired from the growing media and plants back into the atmosphere, or
- percolates through the growing medium into the drainage layer under the growing medium and eventually to the roof drains.

Surface runoff almost never occurs on a green roof except during massive rainfalls. The FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.v. [2]) guidelines for saturated hydraulic conductivity of growing medium for multi-course extensive green roofs, for example, is 0.024 to 2.83 inches per minute. Green roofs are analogous to thin groundwater systems. Discharge from a green roof is best understood as ‘groundwater baseflow’ from this system. This is apparent when you consider the time delay between rainfall peaks and discharge peaks on green roofs. For a green roof area of 5,000 square feet the delay may be 60 minutes, versus 15 minutes if a surface flow ‘time of concentration’ was calculated using the Manning formula, or similar. Green roofs do not have curve numbers, since nothing infiltrates.

Times of concentration in the context of TR-55 [3], do not apply to green roofs. There should be no surface flow under normal conditions. Rather, the rate at which water is discharged from the roof depends on the design of the subsurface drainage zone. The appropriate parameter is transmissivity.

The water storage and evapotranspiration (ET) potential of the green roof growing media are dynamic. The pattern of water uptake and release from the surface media can be summarized as follows.

1. Initially all moisture is absorbed and no underflow occurs.
2. After about ½ of the maximum water capacity (MWC) is satisfied, the first ‘break through’ of precipitation occurs and underflow begins.
3. The media continues to absorb more water, with increasing efficiency, even as percolation continues.

4. Finally, the capacity of the media to hold water is overwhelmed and the underflow rate will approach rainfall rate for the first time.
5. As the rainfall rate decreases, the moisture content will continue to drop until it attains the MWC (typically 30 to 40 percent by volume).
6. After the rainfall has stopped, water will continue to bleed out of the green roof for an extended period. At the same time water is continuously lost to the atmosphere via direct evaporation and plant evapotranspiration. Depending on the type of media, this process may last for days.
7. Eventually, underflow will end. The moisture remaining at this point is associated with field capacity (typically 15 to 20 percent by volume). This water will be slowly removed from the media through evapotranspiration of the plants (adapted from Miller, 2003).

ET rates also vary over time, depending on climatic conditions, soil moisture, and vegetation vigor, cover, and species. Several studies have shown rapid water loss through ET immediately after a rain event and much slower ET rates starting 5 to 10 days after soil was saturated, when plants need to start conserving water to survive (Voyde et. al., 2010; Rezaei et. al., 2005).

Preliminary research results indicate that transmissivity of the drainage layer significantly affects how much rain a green roof retains and evapotranspires. Transmissivity of typical geocomposite drain sheets ranges from 0.050 to 0.200 square meters per second ([ASTM [4]] D4716 and ASTM 2396), which is 50 times greater than that of a typical 2 inch granular drainage layer (0.001 to 0.004 square meters per second). Lower transmissivity results in longer residence times for rainfall in the green roof. This translates to more efficient water absorption and longer delay in peak runoff rate. Preliminary research results indicate that green roofs that have a drainage layer with lower transmissivity have significantly higher ET rates.

A model that accounts for these dynamic processes is needed to accurately reflect green roof hydrology. However, studies and field experience have found that [Green roofs terminology and glossary maximum media water retention] (MMWR), the quantity of water held in a media at the [Green roofs terminology and glossary maximum media density] of the media using the ASTM E2399 [5] standard testing procedure, provides a very approximate estimate of event green roof runoff retention potential. The aggregated effect of storage and ET processes in green roofs can result in annual runoff volume reductions of 60 percent or more. However, the increase in retention storage potential with increasing soil depth is not linear. This is a consequence of the non-uniform moisture distribution in the soil column. Consequently increasing media thickness above 4 to 6 inches does not provide significant increase in retention storage potential in many instances.

Water retention by green roofs

Studies show that, compared to traditional hard roofs, green roofs:

- decrease runoff peak discharge (eg. Berghage et. al., 2010; Carter and Rasmussen, 2006);
- delay peak runoff (eg. Carter and Rasmussen, 2006; Van Woert et. al., 2005; Berghage et. al., 2010); and
- reduce runoff volume (eg. Carter and Rasmussen, 2006; Teemusk and Mander, 2007; Van Woert et. al., 2005)

Green roof stormwater performance is affected by regional climatic conditions, storm size, rain intensity, frequency, and duration, antecedent moisture in the soil, transmissivity of drainage layer, vegetation species and diversity, length of flow path, roof size, growing medium composition and depth, and roof age.

For small rainfall events (typically less than ½ inch) little or no runoff will occur (e.g. Rowe et. al., 2003; Miller, 1998; Simmons et. al., 2008; Moran et. al., 2005). Lower intensity storms also result in greater stormwater retention than high intensity storms (Villarreal and Bengtsson, 2005). For storms of greater intensity and duration, a vegetated roof can significantly delay and reduce the runoff peak flow that would otherwise occur with a traditional roof.

Annual runoff volume reduction in northern temperate regions is regularly measured to be 50 to 70 percent when the media thickness is 3 to 6 inches (e.g. Berghage et. al., 2010; Carter and Rasmussen, 2006; Van Woert et. al., 2005; Moran et. al., 2005; Van Seters et. al., 2007; Berghage et. al., 2009). While no green roofs have been monitored for annual stormwater retention in Minnesota, green roofs in Minnesota's climate (with shorter storms, and generally enough time to allow evapotranspiration to renew much of the soil water holding capacity between rain events) are expected to retain about 70 percent of annual runoff. Berghage et al (2010), studying an extensive green roof with 3 inches of growing medium in Chicago IL and a climate similar to Minnesota's climate, found 74 percent annual retention over a 2 year study period that included 106 precipitation events. Higher reductions are attainable by maximizing design for stormwater retention and evapotranspiration (e.g. Compton and Whitlow, 2006).

Water quality treatment

When considering the influence of green roofs on runoff water quality, emphasis should be placed on the total mass of pollutants that may be released. Rainwater is generally considered non-polluted, but can contain substantial nitrates, as well as traces of other pollutants, such as heavy metals and pesticides (Berndtsson, 2010). Generally, organic material in green roofs can be very effective in binding heavy metals (e.g., zinc, arsenic, cadmium, lead, and copper). Consequently, green roofs are excellent practices where airborne pollution by heavy metals is important. Green roofs can also immobilize complex organic pollutant molecules.

While many research studies have found an increase in nutrients in green roof runoff compared to conventional roofs, several have found green roofs to be beneficial even for nutrient reduction. Studies of nutrients released from green roofs are a good example of the importance of studying total mass of pollutants released rather than percent removal in the effluent, or concentration in the effluent. For example, USEPA (2009) reports higher concentrations for most nutrients and ions in the green roof runoff compared to runoff from the conventional roof, but total mass released was less than from the conventional roof because the green roofs retain more rain than the conventional roof.

Primary sources of nutrients in green roof runoff are atmospheric deposition and leaching from the growing medium and fertilizers. Aggregates, organic materials and amendments used in formulating green roof media should be tested for nutrients to insure that they will not be a potential long-term sources for contaminants. For mature green roofs, the mass of major nutrients (e.g., total nitrogen, total phosphorus, potassium, and magnesium) released during the course of one year will be approximately equal to the mass of nutrients contributed by atmospheric deposition and fertilization over the same period. Green roofs that are efficient in detaining and cycling nutrients will require less fertilization and therefore be less of a concern for water quality.

Through professional management of soil fertility, both the concentration and the total mass of nutrients released can be minimized. To maintain plant vigor, critical nutrients should be restored by periodic fertilization when needed to maintain plant vigor based on soil tests. Fertilization rates should be adjusted to replenish the nutrient 'reserves' and stabilize the concentration of soluble nutrients at minimum recommended levels. Fertilize only when needed to maintain plant vigor, and do not include P in fertilizer unless plants need additional P to thrive.

Rowe (2011) concluded "Overall, it appears that green roofs can have a positive effect on water quality. Based on the data available, green roofs that were a source of pollutants tended to be new, whereas those that were older with established vegetation were not a problem. The initial nutrient load likely is due to decomposition of organic matter that was incorporated into the original mix. Established vegetation and substrates can improve the water quality of runoff by absorbing and filtering pollutants. Of course, water quality of the effluent is dependent on several factors such as substrate composition, substrate depth, plant selection, age of the roof, fertilization and maintenance practices, the volume of rainfall, local pollution sources, and the physical and chemical properties of those pollutants. Also, the use of soluble conventional fertilizers should be avoided due to the adverse impact on stormwater runoff. If nutrient loading is a problem green roofs could be coupled with other low impact development practices such as rain gardens and bioswales."

Until more data is available showing more consistent nutrient reduction from green roofs, green roofs should be used in conjunction with BMPs that are effective for nutrient removal on sites where nutrient reduction is needed. Alternatively, runoff from the green roof could be harvested and re-used on site.

See also Literature review of pollutant removal by green roofs [6]

Related pages

- Green roofs
- Overview for green roofs
- Types of green roofs
- Design criteria for green roofs
- Construction specifications for green roofs
- Assessing the performance of green roofs
- Operation and maintenance of green roofs
- Cost-benefit considerations for green roofs
- Plant lists for green roofs
- Case studies for green roofs
- Links for green roofs
- References for green roofs
- Supporting material for green roofs
- Green roofs terminology and glossary
- Green roof fact sheet
- Requirements, recommendations and information for using green roofs as a BMP in the MIDS calculator

References

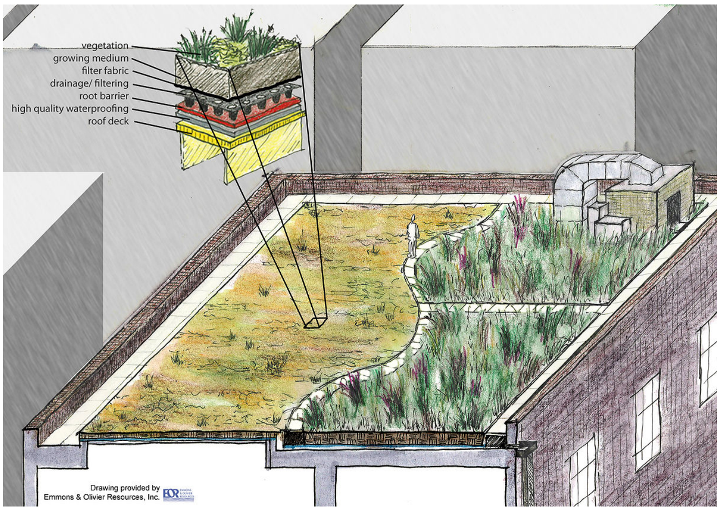
[1] http://www.pca.state.mn.us/water/stormwater/stormwater-c.html
[2] http://www.fll.de/
[3] http://www.cpesc.org/reference/tr55.pdf
[4] http://www.astm.org/
[5] http://www.vegetalid.us/media/downloads/public/5.ASTM_E2399.pdf
[6] http://stormwater.pca.state.mn.us/index.php/File:Green_roof_pollutant_removal.docx

Types of green roofs

Structural load capacity, how much weight the roof can hold, is a major factor in determining roof design and construction. Green roofs are therefore typically defined as being either extensive or intensive.

- Extensive green roof: an extensive green roof has growing medium that is 6 inches or less deep
- Intensive green roof: an intensive green roof has growing medium that is more than 6 inches deep

Semi-intensive green roofs represent a roof design intermediary between extensive and intensive roof. The following table summarizes characteristics of the different types of green roofs.



Schematic showing the different components of a green roof. Thicknesses of some layers vary with the design (e.g. extensive vs. intensive roofs).

General characteristics of extensive and intensive green roofs (adapted from Green Roofs for Healthy Cities and the Cardinal Group, 2006).

Link to this table.

Characteristic	Extensive	Semi-intensive	Intensive
Growing medium depth	6 inches or less	Portions of the green roof above and below 6 inches, with a minimum of 25% of green roof area above or below 6 inches	More than 6 inches
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully saturated weight	Low: 10 to 35 lb/ft^2 (48.8 to 170.9 kg/m^2)	Varies: 35 to 50 lb/ft^2 (170.9 to 244.1 kg/m^2)	High: 35 to 300 lb/ft^2 (170.9 to 1464.7 kg/m^2)
Plant diversity	Lower	Greater	Greatest
Cost	Low	Varies	High
Maintenance	Varies, but generally lower than for intensive green roofs	Varies	Varies, but generally higher than for extensive green roofs
Stormwater management	Best cost-benefit balance	More growing medium and more vigorous plant growth provides marginally greater stormwater volume benfits	More growing medium and more vigorous plant growth provides marginally greater stormwater volume benefits

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Design criteria for green roofs

The information in this section is not intended to be a comprehensive green roof design manual. The primary reason for not providing design specifications is that each green roof is unique and needs to be designed considering the factors discussed in this article. Poor design can lead to structural failure of a green roof. The main goals of this article are therefore to provide a detailed list of design considerations and examples of issues to consider when designing a green roof, as well as factors that will affect stormwater treatment performance.

In addition to the information provided on this page, we recommend the following references, which address green roof design.

- ANSI/SPRI RP-14 Wind Design Standard for Vegetated Roofing Systems [1]
- ANSI/SPRI VF-1 External Fire Design Standard for Vegetative Roofs [1]
- ANSI/GRHC/SPRI VR-1 Procedure for Investigating Resistance to Root Penetration on Vegetative Green Roofs [1]
- Cantor, S. L. 2008. Green Roofs in Sustainable Landscape Design. W.W.Norton, NY.
- Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL) Richlinien für die Planung, Ausführung and Plege von Dachbegrünung (Guideline for the Planning, Construction and Maintenance of Green Roof –Green Roofing Guideline: developed by the German Research Society for Landscape Development and Landscape Design), latest English Edition
- Greenroofs.com [2]
- Green Roofs Tree of Knowledge [3] (TOK): database on research and policy related to green roof infrastructure at
- Green Roofs for Healthy Cities and The Cardinal Group. 2006. Green Roof Design 101: Introductory Course. Second Edition Participant's Manual.
- Green Roofs for Healthy Cities. No publication year given. Green Roof Infrastructure: Design and Installation 201.
- Living Architecture Monitor, A Quarterly Green Roofs for Healthy Cities Publication [4].
- Mandel, L., 2013, EAT UP; The Inside Scoop on Rooftop Agriculture
- National Institute of Building Sciences. Whole Building Design Guide [5]

- Snodgrass, E.C., and L.L. Snodgrass. 2006. Green Roof Plants. Timber Press, Portland OR.
- Snodgrass, E.C., McIntyre, L, 2010, The Green Roof Manual
- Weiler, S.K., Scholz-Barth, K., Green Roof Systems
- Dunnett, N., and N. Kingsbury. 2004. Planting Green Roofs and Living Walls. Timber Press, Portland OR.

Readers can also consult with a professional skilled in green roof design for design guidance.

Design steps

A progression for design of a typical green roof consists of the following 12 steps.

1. Determine project budget
2. Assemble design team
3. Establish goals
4. Estimate design, installation and maintenance goals
5. Conduct lifecycle cost analysis
6. Determine project timeline
7. Determine green roof financial incentives available for project site, such as stormwater utility fee credits or grants
8. Site analysis
9. Determine type of green roof desired based on goals, constraints and budget
10. Design green roof
11. Refine project design, installation and maintenance, and lifecycle costs based on green roof plan, specifications and detail
12. Adjust design to fit budget if estimated capital or maintenance costs exceed budget

These steps are explained in greater detail below. Adjust these steps as needed to suit your project. Some projects will not need all these steps, some projects may need additional steps, and the order may need to be changed for some projects.

Determine project budget

Project budget will be crucial to inform project feasibility and design. Design decisions that can be greatly affected by the project budget include

- how deep the growing medium will be;
- whether or not additional structural support is financially feasible if needed; and
- whether or not the green roof will be accessible to the building occupants or the public.

This initial project budget should be updated at strategic points during the design process.

Assemble design team

The following table shows roles of various players that can be involved in green roof design and construction. Assemble a team to fit project budget and goals and level of complexity. Depending on the project, additional roles not shown in the table may be needed.

Potential roles in green roof design.

Link to this table

Actor	Definition	Potential roles
Client	An individual or company (i.e. building owners, developers, consortiums, or government entities) that requests the service of professionals to create a green roof / green building. The owner is the ultimate authority on any project. Their participation in the design process can help to ensure green roof installation.	• Determines scope and budget of project. • Defines project expectations. • Maintains the primary contractual relationship with both the prime design professional and general contractor. • Issues payment. • Inherits the completed project and on-going maintenance responsibilities.
Building architect	An architect is a person licensed in the art of planning, designing and overseeing the construction of buildings. They are the designer of a scheme or plan.	• Acts as prime professional and design team leader. • Responsible for the design of interface between the building, waterproofed roof, and the green roof (degree of systems integration). • Paper work associated with the green roof (e.g. grants, review of shop drawings, and permits). • Assumes primary liability for the design and structural integrity of the project. • Acts as Project Manager responsible for coordination of the design team. • Cost estimation. • Monitors construction compliance with plans and specifications. • Reviews Contractor proposals.
Landscape architect	A landscape architect is a person licensed in the art of planning, designing and management of the built or natural environment. Landscape Architects are responsible for the design of the natural environment similar to the way architects are responsible for the design of a building or structure. Some landscape architects are skilled in the integration of building requirements and ecological and environmental design issues	• Analysis of Site. • Designs green roof system components above roofing membrane • Paper work associated with the green roof (grants, review of shop drawings, permits, etc). • Prepares maintenance plan. • Cost Estimation. • Reviews Contractor proposals. • Tagging and inspecting vegetation. • Construction observation and administration
Structural engineer	Structural engineers determine the loading requirements of a roof to resist live loads, forces such as snow, rainwater, rooftop equipment, green roofs, and maintenance crews, as well as dead loads, the basic roofing structure and materials.	• Conducts Site Analysis to determine required structural loading capacity. • Reviews plans for material transportation to roof. • Reviews the distribution of material and equipment during construction. • Plans for reinforcement of roof. • Reviews plans for structural safety. • Reviews green roof plans to increase available loading.
Civil engineer	Civil engineers work closely with architects and landscape architects to design and oversee site utilities including, storm drainage, sewer, electric, water, gas and communications supply.	• Produces drainage and utility drawings. • Determines drainage capacity of roof. • Assesses impact on stormwater. • Supervises construction of site utilities. • Designs water conveyance system in accordance with local infrastructure/ regulation. • May conduct site analysis to reduce or eliminate internal drains.

Mechanical engineer	Mechanical engineers design the heating, cooling, and ventilation systems for a building.	• Optimizes design of HVAC system. • Conducts energy modeling analysis to reduce HVAC requirements. • Drawings for drainage and water inside the building. • Creates drawings for the location and placement of penetrations and mechanical equipment on the roof deck. • Designs water distribution to irrigation system.
Electrical engineer	Electrical engineers deal with electrical power transmission.	Provides electricity needed on the green roof for irrigation as well as anything else that required electricity on the roof.
Roofing consultant	An independent roofing professional who provides information pertaining to the roof membrane, waterproofing, and determines what system would be best suited to the roof.	• Advises architect in selection and installation of a roofing system including waterproofing, insulation, flashing and parapet details, and works with engineers to optimize drainage of the green roof. • Evaluates suitability of existing waterproofing for green roof. • Determines the condition of the roof membrane and provides recommendations regarding roof repairs, in existing structures. • Determines potential areas of roof penetration. • Inspects roof installation on behalf of the architect for quality control. • Provides vital technical data (i.e. stormwater retention calculations and estimates, noise reduction estimates, and roofing details).
Cost estimator	A cost estimator calculates how much the green roof will cost during construction and during a determined maintenance period.	• For smaller projects, other members of the design team generally fulfill this role. • Provides technical information on the cost of construction (market prices, labor, materials, transportation, etc). • Conducts Life Cycle cost analysis. • Estimates operational costs.
Irrigation specialist	Specialists retained to design irrigation.	Design and construction observation of irrigation systems.
Regulatory bodies	Public entities responsible for reviewing a project for compliance with local, state/provincial and federal codes and ordinances. Because green roof technology is new to the North American market, city officials may not be familiar with the systems requirements and considerations. When applying for a permit you may have to educate the reviewer about green roofs.	• Review of proposed design to ensure that it meets municipal requirements. • Ensuring that installation is carried out in accordance with local standards and incentive program performance requirements (if available). • Issue permits. • Determines occupancy requirement for fire codes.

Establish goals

Project goals can include

- specific stormwater management, such as reducing pollutant load or volume and rate control;
- aesthetics;
- research and monitoring;
- specific uses, such as food production, gathering spaces;
- minimizing building energy usage for heating and cooling;
- establishing wildlife habitat;
- marketing and branding as part of an overall green building strategy; and
- green building certification (eg. LEED [6] or B3 [7]).

Estimate design, installation and maintenance costs

See the section on Cost-benefit considerations for green roofs.

Conduct lifecycle cost analysis

See the section on Cost-benefit considerations for green roofs.

Determine project timeline

The ideal window for planting green roofs in Minnesota is from after last frost until four weeks before first frost. Planting during extremely hot weather, above 90^{o} F degrees or so, generally has long term negative impacts on plant health and should be avoided. Other issues to consider are discussed in the section on construction sequencing.

Determine green roof financial incentives available for project site

Examples include stormwater utility fee credits or grants. For example, Philadelphia businesses can apply for a Green Roof Tax Credit [8] that will provide a rebate for 25 percent of green roof costs up to $100,000. New York City [9] provides a similar credit for green roofs.

Site analysis

Evaluate factors that affect roofing design, such as

- climate and microclimate (sun and wind exposure, precipitation, proximity to and reflection from glass curtain walls);
- type and condition of existing waterproofing, deck, and parapet if retrofit;
- roof slope (see Design green roof for implications of roof slope);
- dead and live load structural capacity;
- views of the roof;
- access points;
- roof height;
- roof drain locations and type;
- building HVAC systems, including nature of intakes and exhausts onto the roof surface and presence of ondensate releases; potential impacts on vegetation; impact on potential building heating and cooling energy savings;
- water storage and supply (spigot and tap availability);
- opportunities for rainwater harvesting and storage;
- source of power if needed for irrigation or installation;
- elevations of existing or planned parapets, door thresholds, sills of curtain walls;
- building code and insurance requirements; and

- criteria presented by LEED, Sustainable Sites Initiative, Passive House, Living Building Challenge, etc.

Determine type of green roof desired based on goals, constraints, and budget

The following table describes characteristics of extensive, semi-intensive, and intensive green roofs. In summary, intensive green roofs typically have slightly higher stormwater volume benefits, but also have higher installation and maintenance costs and require more structural capacity compared to semi-intensive and extensive green roofs.

General characteristics of extensive and intensive green roofs (adapted from Green Roofs for Healthy Cities and the Cardinal Group, 2006).

Link to this table.

Characteristic	Extensive	Semi-intensive	Intensive
Growing medium depth	6 inches or less	Portions of the green roof above and below 6 inches, with a minimum of 25% of green roof area above or below 6 inches	More than 6 inches
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully saturated weight	Low: 10 to 35 lb/ft^2 (48.8 to 170.9 kg/m^2)	Varies: 35 to 50 lb/ft^2 (170.9 to 244.1 kg/m^2)	High: 35 to 300 lb/ft^2 (170.9 to 1464.7 kg/m^2)
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Cost	Low	Varies	High
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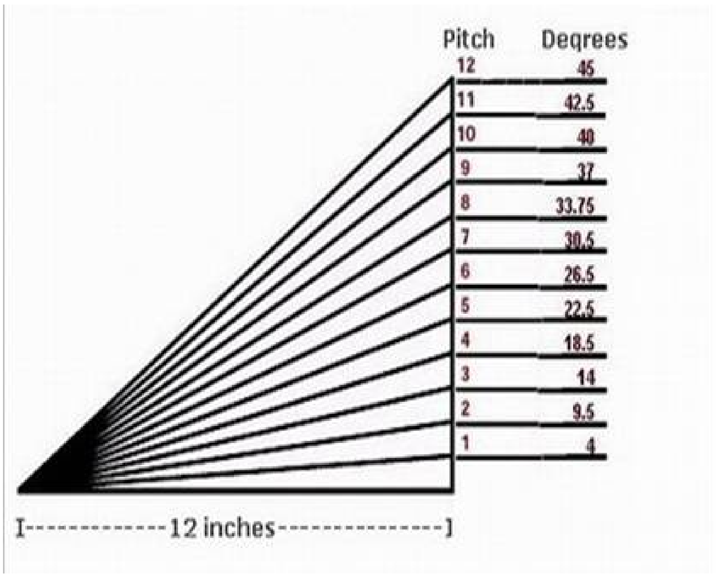
Stormwater management	Best cost-benefit balance	More growing medium and more vigorous plant growth provides marginally greater stormwater volume benfits	More growing medium and more vigorous plant growth provides marginally greater stormwater volume benefits

Design green roof

This section provides a discussion of issues to consider in green roof design.

Determine implications of roof slope

Specialized reinforcement is needed to protect green roofs from sliding on slopes steeper than 2:12. Even with reinforcement, slopes should be limited. The German FLL standards, which are widely accepted in the US, recommend that green roofs should not be installed on slopes steeper than 40 degrees.



Comparison of roof slope expressed as roof pitch vs. roof slope in degrees. Pitch and degrees on same line express same roof slope. For example, a 1:12 slope is a 4 degree roof slope.

The systems used to stabilize green roof installations on slopes greater than 2:12 depend on the underlying structural capacity and design, and the steepness of the roof. Examples range from geotechnical matting systems like Enkamat, to slope restraint systems, cable grids, and mechanically attached structural grids. An engineered slope stability analysis should be performed for green roofs with slopes above 2:12 (10 degrees).

Several research studies have been performed on the impacts of roof slope on green roof stormwater performance, with mixed results. See, for example, Berndtsson (2010) for an overview of slope impact on stormwater performance of green roofs. While some studies found no significant correlation between green roof slope and stormwater runoff (Bengtsson 2005; Mentens et al 2006), others found greater stormwater retention at lower roof slopes (e.g. Getter et al. 2007; Van Woert et al., 2005). Two examples from the literature are summarized below.

- Getter et al. (2007) studied 12 green roof platforms at varying slopes and varying rain intensities and found mean retention to be greatest (85.6 percent) at the lowest slope (2 percent) studied and least (76.4 percent) at the greatest slope studied (25 percent). Retention was also greatest for light rain events (94 percent) and least for heavy rain events (63 percent).
- Van Woert et al. (2005) observed greatest retention (87 percent) at the lowest slope studied (2 percent slope), and least retention (65.9 percent) at the greatest slope studied (6.5 percent slope).

Determine what areas of roof can be vegetated and what areas need to remain vegetation free

Green roofs may include vegetation free zones designed to

1. resist wind uplift and scour;
2. reduce fire risk associated with air intakes or proximity to flammable materials and equipment;
3. provide access for roof maintenance related issues;
4. provide enhanced flow path toward drains out scuppers for runoff sheeting off walls and parapets; and
5. in areas where exhausts onto the roof surface or presence of condensate releases would negatively affect plant growth.

Vegetation free zones at Target Center Green Roof, Minneapolis, MN. Image courtesy of The Kestrel Design Group, Inc.

These vegetation free zones are most often located at a minimum around the roof perimeter and around roof drains and other roof penetrations.

The ANSI/SPRI VF-1 External Fire Design Standard for Vegetative Roofs [10] provides guidance for minimizing the risk of fire on green roofs, including recommendations for location and width of vegetation free zones for fire safety.

ANSI/SPRI RP-14 Wind Design Standard for Vegetative Roofing Systems [11] provides guidance for minimizing risk of wind uplift on green roofs, including recommendations for location and width of vegetation free zones in areas of the roof particularly vulnerable to wind uplift and scour. Guidelines for locations and widths are also included in the FLL Green Roofing Guideline [12].

Currently available guidelines, with the exception of the FLL Green Roofing Guideline, are based on very limited field data. Designers and practitioners should stay abreast of updated recommendations and guidelines as more reliable field information becomes available.

If the green roof will be used to help meet water quantity of water quality goals, determine green roof size needed to meet stormwater and other goals

For projects where stormwater goals for volume or pollutant reduction are the primary driver of roof size, use Minimal Impact Design Standards (MIDS) or other credits calculator to determine green roof size needed to meet the goals.

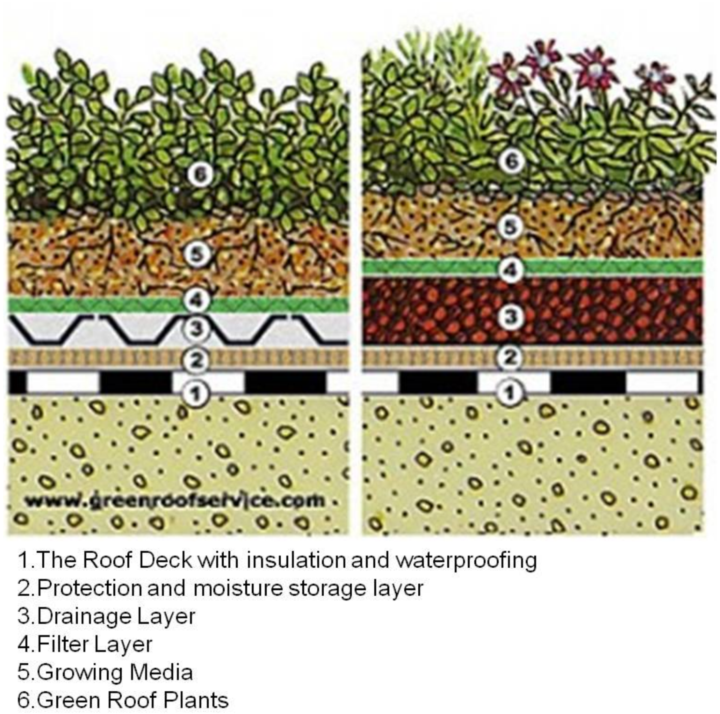
Determine project components desired and requirements for components

The following components are part of almost all green roofs. Each of these is discussed in greater detail below.

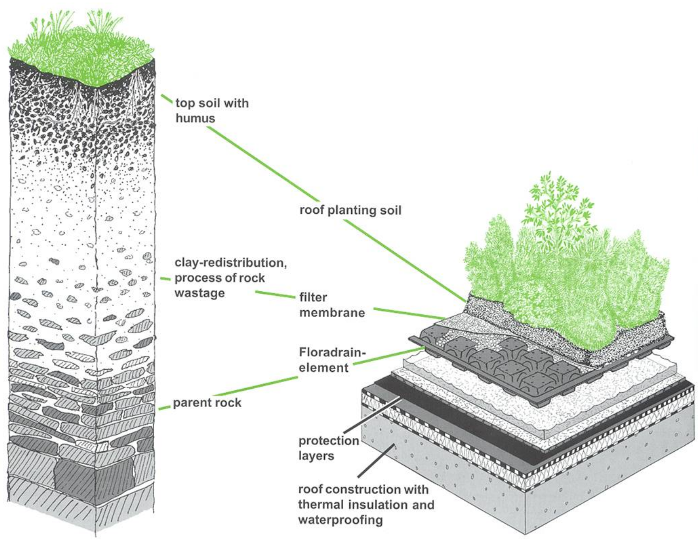
- Waterproofing assembly
- Root barrier (thermoplastic and thermoset membranes frequently do not require a root-barrier)
- Protection layer
- Drainage components
- Filter layer
- Growing medium
- Wind or surface runoff erosion protection
- Vegetation

Examples of optional green roof components are listed below. These are also discussed in greater detail below.

- Leak detection system
- Water retention layer
- Irrigation system
- Edging
- Vegetation free zone
- Railing
- Worker safety anchor systems
- Amenities: for example, walkways, gathering areas, site furniture, water features, lighting, interpretive materials, other structural elements such as trellises and arbors



Typical green roof sections. Images from http://www.greenroofservice.com



Typical native soil versus typical green roof profile. Images from ZinCo [13]

Waterproofing assembly

Choosing a durable, quality waterproofing assembly is crucial for green roofs, since the waterproofing assembly is buried under the green roof, so repairing or replacing the waterproofing is more costly and more complicated than for a traditional roof. Consult with a roofing consultant or other qualified professional to design the waterproofing assembly for a new roof, or to evaluate an existing roof on which the green roof will be installed.

Caution: It is highly recommended that the waterproofing membrane is tested for leaks (see leak detection system) both after the waterproofing is installed as well as after all construction traffic on the green roof is complete, including, for example, installation of mechanical equipment, or windows on adjacent walls.

Testing right after waterproofing is installed allows for correction of any leaks prior to installing the green roof. Testing after all construction traffic on the roof is complete will detect whether or not any leaks developed between the time of the first leak detection test and the completion of all subsequent work on the roof. The Importance of preserving an option for post-construction leak surveys will, however, influence the green roof design. Leak detection of green roof assemblies that incorporate root-barriers is very challenging, if not impossible in most instances.

Roof Membrane Installation at Target Center Green Roof, Minneapolis, MN, Image courtesy of The Kestrel Design Group, Inc.

Workmanship and proper construction sequencing are the factors mostly closely correlated to waterproofing success. Leak testing, while a prudent precaution and check, is not a substitute for craftsmanlike installation of the waterproofing layer.

Root barrier

A root barrier prevents plant roots from damaging the waterproofing membrane. When using waterproofing membranes that are root resistant, such as, for example, PVC, TPO and EPDM membranes, a separate root barrier may not be needed. While some waterproofing membranes can resist roots on their own, many will require an additional component to protect the waterproofing membrane from root damage. When plants with vigorous roots are selected, an additional root barrier layer is often installed above root resistant membranes. Common materials used for root barriers include PVC, TPO, and polyethylene. The root barrier is sometimes part of the drainage board. It is recommended to use a root-barrier that successfully passed the VR-1 test, a standardized method to evaluate root resistance of both waterproofing and root-barrier products (ANSI/GRHC/SPRI VR-1 Procedure for Investigating Resistance to Root Penetration on Vegetative Green Roofs [1]).

Root Barrier Welding. Image courtesy of Roofscapes

Protection layer

In most applications a cushioning layer will be installed on top of the waterproofing or root-barrier to resist strains induced by point loads or puncture from sharp protections. This protection layer is a water-permeable, synthetic fiber material with good puncture resistance. It is often part of the drainage panel.

Drainage components

While green roofs are designed to retain and detain stormwater and supply vegetation with the water they need, drainage components are also needed to remove excess water. Inadequate drainage can result, for example, in structural loading problems, major damage to the building, as well as problems with plant health. Drainage capacity must also account for vertical sheet flow from adjacent facades or tall parapets.

Aggregate Drainage Layer. Image courtesy of Roofscapes

Drainage components typically include the following.

Drain Access Chambers at Phillips Eco-Enterprise Green Roof, Minneapolis, MN, Image courtesy of The Kestrel Design Group, Inc.

- **Drainage layer**. Drainage layers, such as drainage aggregate, drainage sheets, and drainage mats, convey water across the roof surface under the growing medium and filter fabric, and are available in a range of different materials and drainage capacities. The choice of the drainage layer will have a significant impact on the peak rate and time delay of discharges from the green roof (Taylor and Gangnes, 2007).
- **Roof drains and overflow drains**. Roof drains must comply with building codes and regulations and are typically designed by a professional engineer. Vegetation free zones are typically installed around drains to provide easy access, an enhanced pathway for surface water flow to enter the drain, and to improve the transition of subsurface flow into the drain.
- **Drain access chamber**. Removable drain access chambers are typically installed around the drains to protect the drains from clogging while still allowing for easy access to the drains.

Filter layer

"A light-weight, rot-proof material placed over or included as a part of the drainage layer to keep the growing medium in place and thereby prevent fine particles from blocking the drainage system." (Green Roofs for Healthy Cities and the Cardinal Group, 2006). In most assemblies, a fabric is selected that will freely admit plant roots.

Growing medium

"A combination of organic and inorganic matter than anchors plant roots, drains water from the roof, and sustains plant growth." ([[References for green roofs|Green Roofs for Healthy Cities and the Cardinal Group, 2006) Growing medium characteristics that affect stormwater performance include the following.

- Nutrients in growing medium affect green roof runoff water quality.
- Permeability affects how quickly water moves through the growing medium.
- Water holding capacity affects how much water the growing medium can hold.
- Percent fines affects how quickly water moves through the growing medium.

Erosion protection

Green roofs need to be protected from erosion during all phases of construction and maintenance. Some techniques that can be used to protect soil from eroding include erosion control blanket, mats, or soil tackifier.Care must be taken not to damage waterproofing membrane when securing erosion control fabric. Once a roof is fully covered with vegetation, the vegetation typically protects soil from erosion.

Erosion control blanket and native plant plugs at Minneapolis City Hall Green Roof, Minneapolis, MN. Image courtesy of The Kestrel Design Group, Inc.

Plugs during installation and one year later at Phillips Eco-Enterprise Green Roof, Minneapolis, MN. Image courtesy of The Kestrel Design Group, Inc.


Sedum Cuttings. Image courtesy of Roofmeadow

Vegetation - plant selection.

Plant selection should be informed by

- climate and microclimate (e.g. sun and wind exposure, precipitation, proximity to and exposure associated with glass curtain walls);
- growing medium depth and composition;
- irrigation availability and type;
- project goals: e.g. stormwater, wildlife, aesthetics, food production;
- maintenance labor and budget;
- building code and insurance requirements, where applicable;
- availability; and
- fire resistance.

Green roofs with a diverse plant palette are usually more resilient than those with very few species and also generally provide greater stormwater and other ecological benefits. If winter aesthetics are of concern, be sure to include some species with winter interest.

Vegetation - methods of installing green roof vegetation.

A number of different techniques can be used to install green roof vegetation, each with its own advantages and disadvantages. Choice of technique used to install green roof vegetation will depend on

- project goals;

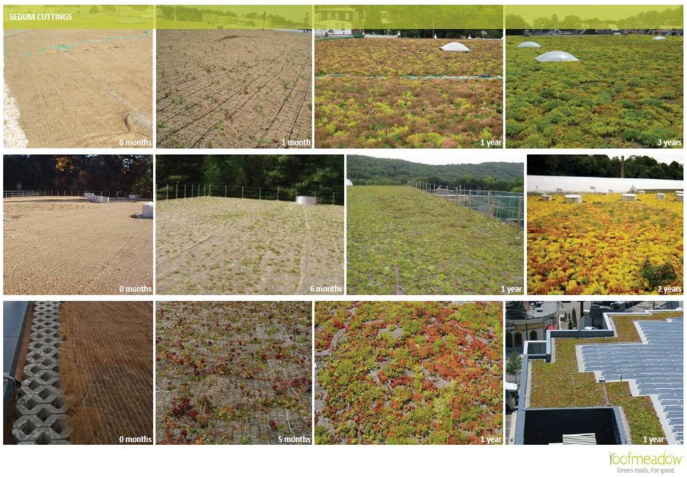
- how soon full vegetation cover is desired;
- budget;
- species; and
- maintenance labor, accessibility, and budget

The following table shows some of the pros and cons of some potential green roof vegetation installation techniques.

Comparison of most common extensive green roof planting methods

Link to this table

Planting method	Description	Survival rate	Installation labor	Maintenance requirements	Expense	Establishment time	other pros, cons, notes
Plugs	Plants in small pots	High	Medium	Low	Low-medium	Quick, 1-2 years depending on species, plug size, and initial planting density	Allows for most flexible and controlled planting design; can be added to green roofs started from cuttings or to pre-grown mats to increase species diversity
Cuttings	Small pieces of sedums that are spread across or mixed into growing medium	Good	Low	Low	Low - More than plugs, less than seed	Quick, 1-2 years	Less control over final look than with plugs
Seed	Seed	Good	Lowest	Higher	Lowest - Less than plugs or cuttings	Longer than plugs or cuttings – typically 2-5 years depending on species	Less control over final look than with plugs; seed cannot be allowed to dry out until germinated; more bare soil can result in higher weed pressure; need more erosion protection during establishment since soil is bare; only a limited number of species can germinate from seed on a green roof
Pregrown Mats	Plants delivered to the site pre-grown into an erosion control mat with growing medium	Good	Low	Low	Low-Medium	Almost instant green	Instant erosion protection if fully vegetated; precise plant composition difficult to predict; less control over final look; less species diversity possible than with plugs, can be combined with plugs to increase species diversity
Modular Systems	Plastic, metal, or degradable trays filled with growing medium and delivered to site pre-grown	Good initially	Low	High	High	Almost instant green	Allow for greater precision of design, some may require frequent plant replacement due to edge effect; some trays may retain heat and cause soil to dry out faster, negatively affecting plant health



Progression of sedum cuttings installation over three years. Image courtesy of Roofmeadow.

A combination of techniques can be used to combine benefits of several techniques as well as to maximize vegetation resilience. Examples include the following.

- If seed is installed on a roof planted with plugs, and some patches of plugs die, some of this seed may germinate in areas where plugs died. Including self-sowing plant species in the plant palette similarly increases resilience.
- Plug accents can be planted into green roofs started with cuttings or pre-grown mats to increase species diversity.

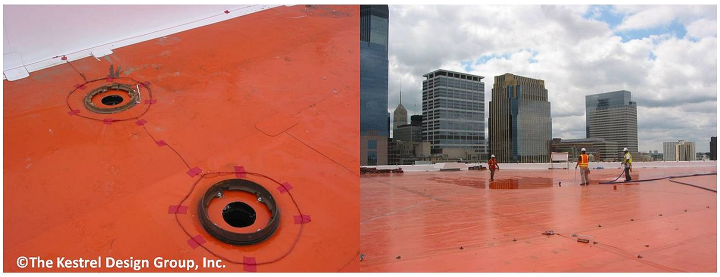
Installation of pregrown sedum mat. Image courtesy of The Kestrel Design Group, Inc.

Installation of pregrown mats at Target Center Green Roof. Minneapolis, MN. Image courtesy of The Kestrel Design Group, Inc.

Leak detection system

Leak detection systems allow for pinpointing the exact location of leaks and can also detect small imperfections in the waterproofing. Milestones when leak detection testing is especially valuable include the following.

- Test integrity of the membrane once installation of the waterproofing membrane is complete before installing the growing medium, so any leaks or imperfections can be fixed before the growing medium and vegetation are installed



Electronic leak detection at Target Center Green Roof, Minneapolis, MN. Images courtesy of The Kestrel Design Group, Inc.

- After installation of the vegetation, and all other construction traffic on the green roof is complete, ensure no leaks were caused during any of the construction phases after the first leak test (Note: Applies to green roofs without root-barriers)
- Test for leak before the warranty expires, to ensure the waterproofing membrane is sound just before the warranty expires.
- Periodically check the roof for leaks as part of a maintenance program.
- Check when there is evidence of a leak that needs to be located.

Several types of leak detection systems are available, including high and low voltage surface surveys and built-in time-domain reflectometer (TDR) sensors. High voltage methods cannot be used in wet environments and therefore are useful only as constructon-phase quality control approach. Low voltage and TDR methods rely on the facts that: 1) the waterproofing membrane is an electrical insulator, and 2) water is an electrically conductive medium. The low voltage method is a survey technique that can be applied to green roof that are designed to enable this approach. For this reason there are few, if any, initial capital costs. TDR sensor arrays must be built into the roofing system. Unlike the low voltage method, however, these systems can provide real-time on-demand information about the waterproofing status and alarm owners if a problem is detected. Descriptions of these techniques are provided in ASTM Standard Methods D6747 and D7007.

Low voltage systems are currently the most commonly used leak detection system.

If leak detection is desired, ensure green roof system is designed to be compatible with leak detection, as leak detection of green roof assemblies that incorporate root-barriers is very challenging, if not impossible, in most instances.

Water retention layer

Typically a water holding fabric or a plastic sheet with cup-like depressions, the water retention layer holds water for later use by plants. Water retention layers are available in a range of water holding capacities, typically between 0.06 gal/ft2 and 0.16 gal/ft2

Irrigation system

Irrigation installation at Minneapolis Central Library Green Roof, Minneapolis, MN. Image courtesy of The Kestrel Design Group, Inc.

While not all extensive green roofs require permanent irrigation, almost all green roofs require irrigation during the establishment period (unless adequate rainfall occurs), often several times a day. Overhead watering is usually needed immediately after installing plugs, seeds, or cuttings. Even green roofs with underground drip irrigation systems will need overhead watering until the roots have grown enough to reach water from the irrigation driplines. It is therefore essential to ensure access to water will be available during the plant establishment period.

Many different types of irrigation systems exist, including manual or automated spray systems, drip, and flood irrigation systems.

While a simple manual overhead system is less expensive, drip systems are typically more water efficient than overhead systems and provide more uniform coverage. Once vegetation is mature, introducing water from as low as feasible in the growing medium typically also results in the most resilient plants, as it draws plant roots to grow deeper.

A variety of controllers and sensors are available that can be used to maximize water efficiency and stormwater holding capacity. For example: Soil moisture sensors can be used to program irrigation to only be activated when soil is dry and plants need water controllers are available that time irrigation based on weather forecast and predicted evaporation rates, e.g. can be programmed to not irrigate for set length of time before rain is predicted

Potential irrigation water sources include:

- runoff harvested from impervious surfaces[2];
- water harvested from air conditioning effluent[2];
- grey water harvested from baths, showers, and sinks[1], [2];
- municipal water; and
- well water.

[1]When using grey water for irrigation, a non-contact irrigation method should be selected. Additional codes may apply when using grey water for irrigation

[2]More information on stormwater reuse is available, for example, in the Metropolitan Council's Stormwater Reuse Guide at http:/ / www. pca. state. mn. us/ index. php/ water/ water-types-and-programs/ stormwater/ stormwater-minimal-impact-design-standards-mids. html, also include link to Stormwater Manual re-use chapter.

To irrigate or not to irrigate

While almost all green roofs will need water during the plant establishment period, extensive green roofs can be designed without permanent irrigation. Intensive green roofs almost always need a permanent irrigation system, depending on factors such as project goals and plant palette.

Efficient irrigation is not expected to decrease stormwater benefits of green roofs, since lusher vegetation and moister soils provide greater evapotranspiration.

Advantages of irrigating extensive green roofs include

- increased cooling of space below;
- lusher vegetation and moister soils provide greater evapotranspiration;
- sustainable use of stormwater harvested from hard surfaces, where harvested water is available;
- aesthetics: plants look greener more of the time; and
- if no bare spots develop during drought, there is less chance of weed invasion.

Advantages of not irrigating extensive green roofs include the following.

- Plants exposed to seasonal moisture variations may be more resilient.
- If irrigation does not use harvested water, not irrigating will be advantageous to lower water use and costs.

Edging, curbs, or borders

Edging, curbs, or borders are often included to separate vegetated areas from non-vegetated areas. Curbs or borders are also sometimes used to provide a firebreak or protection from wind uplift (Green Roofs for Healthy Cities and The Cardinal Group, 2006).

Vegetation free zones

Vegetated roofs generally also include vegetation free zones, for example, in areas prone to high wind uplift, where firebreaks are needed, for protection in areas where icicles are likely to fall, for easier access to roof flashings, or for other maintenance related issues. These vegetation free zones are most often located at a minimum around the roof perimeter and around roof drains and other penetrations. The surface of the vegetation free zones can consist, for example, of roof ballast or pavers. Under the roof ballast or pavers, the assembly is typically the same as for the green roof.

Green roofs dominated by succulent plant varieties and installed with media containing low organic matter content will qualify as Class A fire resistant surfaces based on ASTM E108. Consequently, Sedum-based extensive profiles may qualify as 'fire breaks' on otherwise intensive green roof projects.

Railings

Railings are often required by code.

Worker safety anchor systems

Worker safety anchoring systems may also be desired and/or required.

Amenities

On accessible roofs, amenities include walkways, gathering areas, site furniture, water features, lighting, other structural elements such as trellises and arborwalkways.

Produce green roof plan, details, and specifications in accordance with project goals and constraints developed in previous steps

Because many different green roof systems are often available that meet project goals, performance specifications (insert hyperlink to definition) can often result in more competitive pricing than descriptive specifications (insert hyperlink to definition), since performance specifications allow for more systems to meet the specifications than descriptive specifications. Performance specifications also allow for the most innovation. Performance specifications typically include required physical and chemical properties of green roof components and the green roof system as a whole, as well as required performance goals. Examples of performance goals are listed below.

- Minimum system dead load of ___psf (pounds per square foot) (determined according to ASTM [14] E 2397 – 05 and E 2399 – 05).
- Maximum system dead load of ___psf (determined according to ASTM E 2397 – 05 and E 2399 – 05).
- Vegetated roofs shall retain a minimum of "x" c.f. (cubic feet) of water as determined according to ASTM E2397).
- Roof shall balance drainage and water retention to meet drainage requirements but retain as much rain as possible while still meeting drainage and maximum wet weight dead load requirements.

- Green roof shall provide suitable drainage and water retention capacity to support healthy vegetation cover according to specified vegetation performance standard as provided in this specification Section under “Inspection and Acceptance”.
- Green roof shall have a Rational runoff coefficient of "x", for storms with durations of X hours and return frequency of X years.
- Green roofs shall achieve a peak-to-peak delay of "x" hours for rainfall runoff
- Media shall retain its horticultural and drainage properties during the specified warranty period, and not require refreshing with new media or amendments other than conventional nutritional supplements, such as fertilizer and compost.
- Green roof products shall be fully compatible with the waterproofing system and shall be installed in a manner that does not negatively impact waterproofing assembly in any way.
- Green roof products shall protect waterproofing system from damage, including but not limited to damage caused by UV (ultraviolet) radiation, hail, physical abuse or tears, rapid temperature fluctuation, or water vapor.
- No potential phytotoxicity shall be introduced through any of the temporary or permanent green roof materials or installation methods.
- Green Roof shall be able to withstand basic 10-second wind gusts of "x" miles per hour (MPH) without erosion or wind uplift (consult ASCE 07, Minimum Design Loads for Buildings and Other Structures [15].

Other key elements of green roof specifications typically include, but are not limited to the following:

- list of required submittals and when the submittals are due, including submittals related to materials as well as contractor qualifications;
- list of green roof performance requirements;
- materials specifications for all green roof related components;
- installation specifications;
- maintenance specifications;
- warranty requirements; and
- mockup requirements.

Related pages

- Green roofs
- Overview for green roofs
- Types of green roofs
- Design criteria for green roofs
- Construction specifications for green roofs
- Assessing the performance of green roofs
- Operation and maintenance of green roofs
- Cost-benefit considerations for green roofs
- Plant lists for green roofs
- Case studies for green roofs
- Links for green roofs
- References for green roofs
- Supporting material for green roofs
- Green roofs terminology and glossary
- Green roof fact sheet
- Requirements, recommendations and information for using green roofs as a BMP in the MIDS calculator

References

[1] http://www.spri.org
[2] http://www.Greenroofs.com
[3] http://www.greenroofs.org/grtok/
[4] http://livingarchitecturemonitor.com/
[5] http://www.wbdg.org
[6] http://www.usgbc.org/leed
[7] https://mn.b3benchmarking.com/
[8] http://www.phillywatersheds.org/whats_in_it_for_you/residents/green-roofs
[9] http://www.tectaamerica.com/archives/63-new-york-green-roof-property-tax-credit-up-to-100000
[10] http://www.greenroofs.org/resources/ANSI_SPRI_VF_1_Extrernal_Fire_Design_Standard_for_Vegetative_Roofs_Jan_2010.pdf
[11] http://www.greenroofs.org/resources/ANSI_SPRI_RP_14_2010_Wind_Design_Standard_for_Vegetative_Roofing_Systems.pdf
[12] http://www.greenrooftechnology.com/fll-green-roof-guideline
[13] http://www.zinco.ca/
[14] http://www.astm.org/Standard/index.shtml
[15] https://secure.asce.org/files/estore/896/40809_40809.pdf

Construction specifications for green roofs

Green roof construction can be complex and involve many different trades working in a small space. A pre-construction meeting is recommended prior to beginning any construction on the roof to ensure construction sequencing will maximize efficiency and minimize conflicts between the various trades that need to access the roof. The meeting should include all green roof related installers and designers. Installers present at the meeting should include roofing, green roof, irrigation, leak detection, lightning protection, electrical, glaziers, mechanical, and general contractor, as well any others involved in the green roof project. Designers should include roofing consultant, green roof designer, irrigation designer, electrical and mechanical engineers as well any others involved in the green roof project.

Key factors in determining construction sequencing include the following.

- Do not begin installation until required submittals are approved.
- Staging: stay within load limits throughout installation
- Protect all materials on roof from wind and erosion at all times
- Perform leak detection test after installation of membrane and again after all work on roof is done. If there is signficant construction traffic on the roof after leak detection, from green roof contractor or any other trades, leak detection shall be repeated.
- Ensure there will be a means to keep vegetation watered during and after vegetation installation.
- Whenever possible, install green roof only after there will be no more traffic by other trades, such as, for example, window installers or mechanical equipment installers.

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Assessing the performance of green roofs

Because exact maintenance requirements vary from roof to roof, we do not recommend developing maintenance specifications, but recommend developing example maintenance performance requirements, as described below.

For acceptance of installation

Set the following requirements for, for example, 30 days after Substantial Completion, for roofs established using cuttings, pre-grown modules, or mats:

- minimum percent cover of specified plant species required;
- maximum percent cover and patch size of weed species (if any);
- maximum square feet of bare area allowed; and
- minimum thickness of media.

All areas that do not meet Performance Standards 30 days after installation shall be re-planted with original plant species and densities within 14 days of notification unless weather conditions are not suitable for planting as determined by Owner’s Representative.

Set the following requirements for, for example, 30 days after Substantial Completion, for roofs established using plugs, or pots:

- minimum percent of plants that are healthy as determined by Owner’s Representative;
  - crowns of plants level with top of media;
  - vigorous foliage;
- root balls broken and integrated into the soil;
- maximum square feet of area of bare area allowed (excluding any areas that have been established from seed alone); and
- minimum thickness of media

All areas that do not meet Performance Standards 30 days after installation shall be re-planted with original plant species and densities within 14 days of notification unless weather conditions are not suitable for planting as determined by Owner’s Representative.

For acceptance of maintenance

Set the following requirements for acceptance of maintenance:

- minimum percent cover of specified plant species required for each year of the maintenance period;
- minimum number of species present on the roof each year of the maintenance period; can also specify desired minimum percent cover needed to count as species diversity if desired;
- maximum percent cover and patch size of weed species (if any); and
- maximum square foot of bare area allowed each year of the maintenance period.

Vegetation will be replaced with species and densities acceptable by Owner’s Representative anytime vegetated cover requirements are not met during the maintenance period.

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Operation and maintenance of green roofs

Native plants on Minneapolis City Hall green roof, Minneapolis, MN. Image Courtesy of The Kestrel Design Group, Inc.

This article addresses green roof vegetation maintenance only. Consult with a roofing consultant or manufacturer for roof membrane maintenance requirements.

Green roof maintenance is particularly important during the first five years after green roof installation to ensure vegetation becomes well established. It is recommended that the first 5 years of maintenance are included in the installation contract. Once the vegetation is well established (i.e. once most of the green roof surface is covered with desired plants, invasive species are minimal, and there are very few areas of bare ground) maintenance is still crucial, but maintenance needs typically decrease. Depending on the density, condition and species of vegetation planted, climate, and level of maintenance, a green roof is typically well established within 2 to 5 years after planting.

Level of maintenance needed is influenced by many factors, such as, for example, project goals, and project location (e.g. proximity to weed sources, views of the roof), rainfall and irrigation, and growing medium depth. Because some maintenance will always be needed on a green roof (and also on a traditional roof), it is crucial to budget for maintenance and maintenance inspections during the project planning stages and identify responsibilities for that maintenance.

The plants and soil conditions that characterize green roofs are unfamiliar to most landscape service contractors. Therefore, it is always preferable to look for a contractor with experience in green roof services. Typical green roof maintenance tasks include the following.

Weeding

While some weeding will always be necessary on a green roof, as green roofs will always be exposed to weed seeds, for example, via wind and birds, weeding is particularly important during the establishment phase when the roof is not yet fully vegetated and there is more open ground in which weeds can germinate. If weeds are left to spread uncontrolled, they can choke out desirable plants and compete with desirable plants for nutrients and water. Since tree roots can damage roofing components, timely tree seedlings removal is especially crucial.

Weeds that are especially common on green roofs include, for example:

- Poplar seedlings, *Populus* species
- Clover species, *Trifolium* species
- Spotted Spurge, *Euphorbia maculata*
- Horseweed, *Conyza Canadensis*
- Dandelion, *Taraxacum officinalis*

- Foxtail, *Setaria* species

Do not use herbicides, pesticides or any other chemicals that could negatively affect the roofing membrane or warranty. Vegetation free zones as well as vegetated areas will require weeding.

Maintenance specifications should state performance requirements. Control invasive species to the required maintenance specifications.

Once the vegetation is established, a green roof typically needs to be weeded 2 to 3 times a year if done strategically at times just before weeds go to seed. Green roofs should be weeded more frequently if needed to prevent weeds from setting seed, or if tree seedlings or any other species threaten the integrity of the roofing assembly. Pulling weeds when they are small and before they set seed will maximize weeding efficiency. Weed cycles on the roof should be noted and weeding schedules adjusted to maximize effectiveness. If frequent observations of the roof condition are not practical, then more frequent weeding should be scheduled.

Plant Replacement

Some plant mortality is normal during the green roof establishment period. Good maintenance specifications will state how much plant mortality is acceptable, as well as required plant cover and diversity every year of the maintenance. Maintenance tasks need to include replacing plants as needed to meet project requirements.

In many instances, areas with disappointing or sparse plant coverage or diversity can be remedied by harvesting cuttings, seed, or healthy plants from other areas of the roof and transplanting. Micro-climatic factors can have dramatic effects on plant success. Over a space of years, it will become obvious which plant species are most stable on the various areas of the roof and the green roof can be nudged toward the plant assemblages that perform best on the roof.

Irrigation

Almost all green roofs require irrigation during the establishment period (unless adequate rainfall occurs). Overhead watering is usually needed immediately after installing plugs, seed, or cuttings. Even green roofs with underground drip irrigation systems will need overhead watering until the roots have grown enough to reach water from the driplines.

Irrigation of installation at Minneapolis Central Library green roof, Minneapolis, MN. Image Courtesy of The Kestrel Design Group, Inc.

After the vegetation is well established irrigation requirements will depend on the plant species chosen, project goals, and the water holding capacity of the green roof growing medium and other components. Extensive green roofs planted with drought tolerant vegetation such as Sedums typically do not need irrigation once established if adequate growing medium depth is provided.

During the establishment period and after vegetation is established, initial estimates of seasonal irrigation demand should be adjusted based on field observation. During each maintenance visit the moisture conditions should be investigated at the bottom of the profile (usually the level of the filter fabric). During dry weather conditions, media on irrigated roofs should be moist and cool to the touch, but not saturated. Fabrics exposed at drains should be wet, but little or no water should be escaping at the drain.

If plants are irrigated with harvested water, consult with an irrigation consultant or other professional to determine whether periodic testing of irrigation water may be recommended.

Fertilization

Green roofs may need periodic fertilization. To minimize leaching of fertilizer into stormwater runoff, fertilize only when soil tests or plant health indicates lack of nutrients. Fertilizing only when fertilizing is needed also lessens weed growth and maintenance needs. If fertilizing a green roof, use slow release, organic fertilizer in the spring. Avoid using compost derived from animal waste, which may leach excessive nitrogen and phosphorus (Hathaway et al., 2008). Generally, phosphorus-containing fertilizers can be avoided entirely. See soil tests below for guidance on determining whether or not fertilization is needed.

Soil tests

Annual green roof soil tests are recommended to manage soil for maximum plant vigor while also minimizing nutrient leaching. Based on over 740 soil samples from Penn State, Berghage (no publication year given) recommends the following soil test ranges for green roof media using the modified (DTPA)saturated paste extract (SME)test method. The ranges are for mature green roofs. Higher nitrogen levels are recommended for green roofs during establishment.

Recommended green roof growing medium parameter ranges

Link to this table

Parameter	Extensive green roofs	Intensive green roofs
pH	6.5 to 7.8	6.5 to 7.8
Nitrate-N (mg/L)	1 to 4	2 to 32
Ammonium-N (mg/L)	0.1 to 0.8	0.1 to 0.8
Nitrogen (total) (mg/L)	2 to 8	2 to 32
Phosphorus (total) (mg/L)	2 to 10	2 to 15
Potassium (mg/L)	8 to 32	8 to 64
Calcium (mg/L)	100 to 300	100 to 300
Magnesium	10 to 80	10 to 80
Iron (mg/L)	8 to 32	8 to 32
Manganese	1 to 8	1 to 8
Boron (mg/L)	0.04 to 0.6	0.04 to 0.6
Sodium (mg/L)	<20	<20
Zinc (mg/L)	1 to 10	1 to 10
Soluble salts (mmhos/cm)	0.4 to 1.2	0.4 to 1.2
Sodium Absorption Ratio (SAR)	<2	<2

Spring cleanup

If dried vegetation from the previous season is thick or tall enough that it will negatively affect spring growth, remove dried vegetation using a scythe, trimmer, or weed-whip prior to spring growth flush.

Other factors to consider during green roof maintenance period

Ensure that activities not directly related to green roof maintenance do not negatively impact green roof vegetation. Ensure, for example, that green roof vegetation is not damaged by activities such as power washing, any activities related to rooftop equipment, or use of any cleaning agents or other chemicals.

Maintenance inspections

Maintenance inspections should monitor whether or not project requirements are being met. Inspections should be conducted at least once a year, and should be conducted more frequently during the establishment phase and should also be conducted more frequently as needed beyond the establishment phase, for example, if the roof is not meeting project requirements. Written reports of inspections should be reviewed prior to each subsequent inspection. A sample maintenance inspection checklist is shown below.

Green roof maintenance inspection checklist

Photographical record

Photograph the green roof at each maintenance inspection for historical documentation of roof condition over time. Photos taken from the same location and view are recommended to track change over time. Photos of areas in need of maintenance are also recommended for a photographical record of effectiveness of maintenance practices (e.g. weeding, supplemental planting).

If dried vegetation from the previous season is thick or tall enough that it will negatively affect spring growth, remove dried vegetation using a scythe, trimmer, or weed-whip prior to spring growth flush.

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Cost-benefit considerations for green roofs

Evaluating lifecycle costs is crucial when comparing cost of a green roof to a conventional roof since green roof lifecycle costs can be lower for green roofs than for conventional roofs, even though the capital cost of green roofs is much higher.

Green roof capital costs

Green roof capital costs vary widely. Examples of important factors that influence green roof capital costs include:

- roof size: all other factors being equal (location, ease of access, etc), per square foot cost would typically decrease by a factor of at least 3 as size increases from a 1,000 square foot roof to a 20,000 square foot roof;
- location;
- availability of labor force experienced in green roof installation;
- ease of access for installation and maintenance;
- growing medium depth;
- whether or not additional structural support is needed; and
- type of warranty.

Based on local projects, extensive green roofs in Minnesota typically range from $10 to $30 per square foot for the components above the waterproofing assembly and a simple irrigation system. These costs are consistent with costs noted in the literature (e.g. TRCA, 2007; Green Roofs for Healthy Cities, 2005; Peck and Kuhn, 2002). Intensive green roofs cost significantly more.

Green roof maintenance costs

Green roof maintenance is crucial, especially in the first 5 years after establishment. Maintenance of the green roof for the first 5 years after installation is often included in a green roof installation contract.

Maintenance costs for extensive green roofs in Minnesota typically range from $0.10 to $1.00 per square foot per year after the first five years. Factors that affect maintenance costs include, for example, project size, level of maintenance needed, and proximity of the maintenance crew to the project site.

Green roof lifecycle cost-benefit analysis

Evaluating lifecycle costs is crucial when comparing cost of a green roof to a conventional roof since green roof lifecycle costs can be lower for green roofs than for conventional roofs, even though the capital cost of green roofs is much higher. Factors that generally have the biggest influence on green roof lifecycle costs are estimated roof lifespan and policy and financial incentives to install green roofs.

Estimated roof lifespan

While green roofs cost more up front than traditional roofs, they have the potential to increase the lifespan of the roofing membrane by protecting them from thermal stress from high temperatures and greatly reducing diurnal temperature fluctuations.

Green roofs and conventional roofs can vary greatly in cost, but in very general terms, installing a green roof costs about twice as much as a conventional roof. However, based on experience in Germany, where green roofs have been widely used since the 1970’s, green roofs are expected to at least double the lifespan of a comparable roof without greening (Porsche and Kohler, 2003). If that is the case, two traditional roofs would need to be installed to equal the lifespan of one green roof.

Policy and financial incentives to install green roofs

Local policy incentives to install green roofs, such as stormwater fee reductions, tax abatements, and direct financial incentives, can also render installation of a green roof financially attractive.

Miller et al. (2010) compared the return on investment (ROI) of green roofs in 5 municipal regulatory environments and concluded "Local policy initiatives, however, can create direct incentives that result in positive ROI, and in some cases, first cost savings … Those cities that offer attractive polices for green roofs are often doing so in order to reduce the massive outlays that will be associated with infrastructure upgrades required to comply with the NPDES Part II (Clean Water Act) requirements. For these cities, the cost of incentives such as tax abatements and fee reductions are outweighed by the savings achievable by downsizing or delaying infrastructure improvements. This has been the largest driving factor behind the green roof phenomenon in Germany and the United States."

Methods to evaluate green roof lifecycle costs and benefits

A number of different approaches have been taken to evaluate green roof lifecycle costs and benefits. Two examples are provided below.

Comparing costs and benefits of a green roof to a comparable dark or reflective roof for a certain study period

The most common way to evaluate lifecycle costs and benefits of a green roof is to compare all the costs and benefits of the green roof over the duration of the study period to all the costs and benefits of an alternative roof type(s), typically a comparable dark and/or reflective roofing membrane.

The Athena Institute, supported by Tremco, has developed the Greensave Calculator [1] for Green Roofs for Healthy Cities to "compare roofing alternatives over a specific time period to determine which has the lowest life-cycle cost. It is excellent for determining whether higher initial costs are justified by reducing such future costs as operating, maintenance, repair or replacement costs and/or producing additional benefits, such as energy savings."

Based on user-defined input on costs, benefits, and other relevant financial investment information, the calculator compares lifecycle costs, simple payback period, and internal rate of return on investment of up to 3 roofing scenarios.

Cost input includes capital, maintenance, replacement costs, and lifespan. Benefit input includes information needed to determine stormwater savings, energy savings, HVAC downsizing capital savings, development fee reduction, UHI effect mitigation capital cost savings, annual increase in revenue due to productivity and health, and increased property value. Many of these benefits will not be relevant to all projects and the user should only enter input for those applicable to the project evaluated. Additional annual costs and benefits that are not included in the calculator can also be entered manually. Other relevant financial investment information includes, for example, inflation rate, and applicable discount rate.

Comparing costs and benefits of a green roof to a comparable dark or reflective roof plus an at grade bmp to treat stormwater that would otherwise be treated on the green roof

Another way to evaluate green roof return on investment is to compare the lifecycle cost of a green roof to the lifecycle cost of a comparable non-greened roof PLUS another BMP that would be used instead of the green roof to meet stormwater regulations, such as, for example, permeable pavement or a raingarden. Green roof related policy and incentives and cost of land are especially significant influences on such analyses.

Example green roof lifecycle cost-benefit analysis calculations can be found in:

- Carter, Timothy, and Andrew Keeler. 2008. *Life-Cycle cost–benefit Analysis of Extensive Vegetated Roof Systems*. Journal of environmental management 87:350-363.
- David Evans and Associates, Inc. and ECONorthwest. 2008. *Cost Benefit Evaluation Of Ecoroofs*. Prepared for: City of Portland Bureau of Environmental Services Sustainable Stormwater Group.

- Miller, C., Weeks, K, Bass, B. Berghage, R. Berg, S. 2010. *Stormwater Policy As A Green Roof (Dis)Incentive For Retail Developers*. Cities Alive 8th Annual Green roof &Wall Conference, Vancouver, November 30-December 03, 2010.
- Porsche, U. and M. Kohler. 2003. *Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil.* Presented at the World Climate and Energy Event. December 1-5, Rio de Janeiro, Brazil.
- Toronto and Region Conservation. An Economic Analysis of Green Roofs: Evaluating the Costs and Savings to Building Owners in Toronto and Surrounding Regions [2]. Sustainable Technologies Evaluation Program. July.

Depending on the approach to the lifecycle cost analysis and project specifics, some of the above found green roofs to have the lowest lifecycle costs, while others found the traditional roof to have the lowest lifecycle costs, and still others found them to have comparable lifecycle costs.

In those cases when the green roof lifecycle costs are lower than those of a traditional green roof, the payback period is often (but not always) significantly more than 5 years, which is the maximum payback period acceptable to many developers. But for long-term property owners, green roofs can make financial sense depending on project conditions and local stormwater policy and green roof incentives. And under some local policies, payback for green roofs can even come close to 5 years.

Miller et al (2010), for example, compared payback for a green roof compared to a traditional roof with pervious pavement to meet stormwater regulations, as well as to a traditional roof with a raingarden to meet stormwater regulations in five different municipal regulatory environments, represented by five major metropolitan areas. While the green roof never pays back for itself in one of the cities studied, it paid back for itself in just 6 years compared to a traditional green roof with a raingarden in Minneapolis.

References

- Carter, Timothy, and Andrew Keeler. 2008. *Life-Cycle cost–benefit Analysis of Extensive Vegetated Roof Systems*. Journal of environmental management 87:350-363.
- David Evans and Associates, Inc. and ECONorthwest. 2008. Cost Benefit Evaluation Of Ecoroofs [3]. Prepared for: City of Portland Bureau of Environmental Services Sustainable Stormwater Group.
- Green Roofs for Healthy Cities (GRHC) [4]. 2005. Green Roof Design 101 Introductory Course Participant Manual. Green Roofs for Healthy Cities and the Cardinal Group Inc.
- Miller, C., K. Weeks, B. Bass, R. Berghage, and S. Berg. 2010. *Stormwater Policy As A Green Roof (Dis)Incentive For Retail Developers*. Cities Alive 8th Annual Green roof &Wall Conference, Vancouver, November 30-December 03, 2010.
- Peck, S.W. and M.E. Kuhn, 2002. Design Guidelines for Green Roofs [5]. Report prepared for the Ontario Association of Architects and the Canada Mortgage and Housing Corporation, Toronto, Ontario.
- Porsche, U. and M. Kohler. 2003. *Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil*. Presented at the World Climate and Energy Event. December 1-5, Rio de Janeiro, Brazil.
- Saiz, S., et al. 2006. *Comparative Life Cycle Assessment of Standard and Green Roofs*. Environmental Science and Technology 40: 4312-4316.
- Toronto and Region Conservation.An Economic Analysis of Green Roofs: Evaluating the Costs and Savings to Building Owners in Toronto and Surrounding Regions [2]. Sustainable Technologies Evaluation Program. July.

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References

[1] http://www.greenroofs.org/index.php/component/content/article/20-system-notices/237-living-architecture-toolbox
[2] http://www.sustainabletechnologies.ca/Portals/_Rainbow/Documents/GR_Econ_Full%20document.pdf
[3] http://www.portlandoregon.gov/bes/article/261053
[4] http://www.greenroofs.org/
[5] http://www.cmhc-schl.gc.ca/en/inpr/bude/himu/coedar/upload/Design-Guidelines-for-Green-Roofs.pdf

Case studies for green roofs

Target Center Arena Green Roof

View of the Target Center Arena green roof, located in downtown Minneapolis, Minnesota. Image by Bergerson Photography, Courtesy of The Kestrel Design Group, Inc., INSPEC, and Leo A Daly.

Vegetation on the Target Center Arena green roof. vegetation consisted of a pregrown Sedum mat supplemented with 22 species of plugs and 16 species of seed native to Minnesota's bedrock bluff prairies. Image Courtesy of The Kestrel Design Group, Inc.

When Minneapolis' Target Center Arena needed a new roof, the City of Minneapolis chose to model a sustainable building and stormwater management approach by re-roofing with a green roof. At 113,000 square feet, the Target Center Arena green roof was the 5th largest extensive green roof at the time of design and the first green roof installed on an arena in North America. The green roof mitigates the urban heat island effect, provides greens views from above, provides wildlife habitat, and improves urban air quality on a scale that is not feasible at grade in an ultra-urban area like the site of the Target Center Arena in downtown Minneapolis. It also mitigates stormwater runoff from a significant amount of previously impervious surface in a downtown location where space does not permit use of other Low Impact Development (LID) techniques for stormwater management at grade. Such positive impacts on local water bodies are valuable in a city that prides itself on its legendary waterbodies - The City of Lakes in the Land of 10,000 Lakes. (For more information on stormwater management in Minneapolis see http:/ / www. minneapolismn. gov/ publicworks/ stormwater/).

The design process began with a quantitative and qualitative lifecycle cost benefit analysis that enabled the City of Minneapolis to decide with confidence that replacing the conventional roof on the Target Center with a green roof was the most cost effective and ecologically sound decision over the lifespan of the proposed roof. Quantitative financial lifecycle cost benefit analysis showed that over a 20 year study period, a green roof is more cost effective than a white reflective or a traditional roof.

A state-of-the-art waterproofing membrane was used to withstand constant dampness, high alkalinity, and exposure to plant roots, fungi and bacterial organisms as well as varying hydrostatic pressures. To test for leaks and facilitate pinpointing the exact location of leaks throughout the roof's lifespan so that the amount of overburden removed can be minimized, an Electro Field Vector Mapping (EFVM) leak detection system was installed.

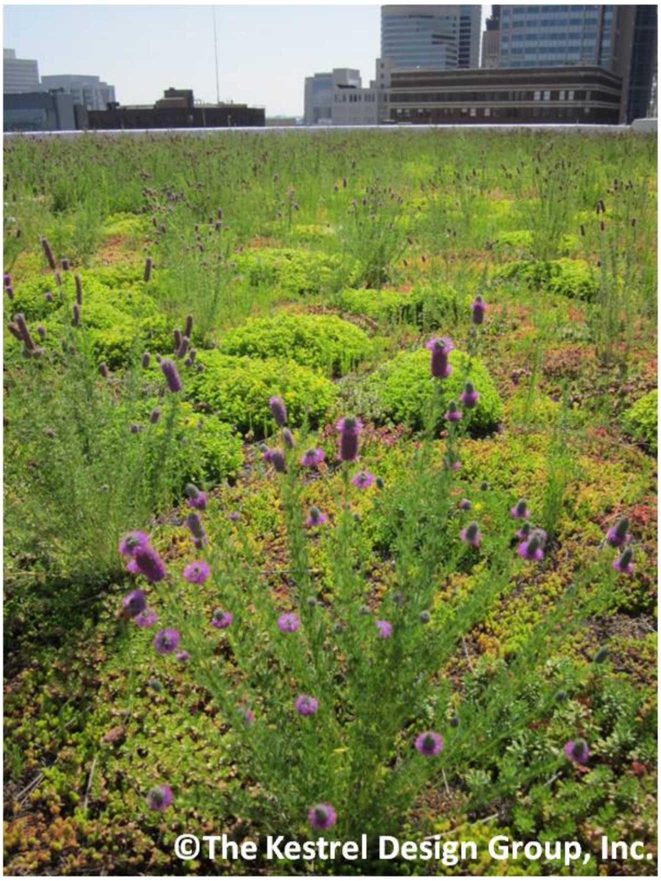


Photo showing the sedum mat with additional plants. Image Courtesy of The Kestrel Design Group, Inc.

One of the most difficult challenges at this site was structural. At 17.4 pounds per square foot on most of the roof, the Target Center's dead load capacity is much lower than that of a typical green roof. The designers aimed to maximize stormwater holding capacity and plant resilience on a roof with very limited structural capacity. Because this is a public, highly visible project, designing an aesthetically captivating roof that succeeds right away was another especially important objective.

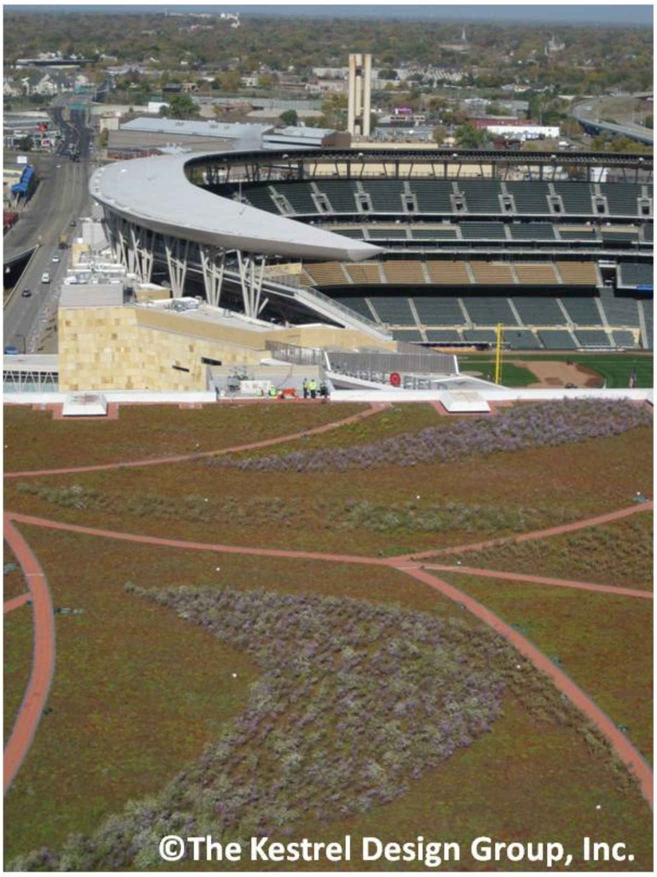
Aerial view of the Target Center Arena green roof, chowing vegetation-free zones and some of the patterns incorporated into the roof for aesthetic purposes. Image Courtesy of The Kestrel Design Group, Inc.

Design strategies used to achieve these design objectives include:

- choosing a mat pre-grown at grade to allow plants to establish before facing the harsh conditions on the roof, as well as to maximize plant cover and wind resistance 150 feet up in the air;
- requiring a lightweight growing medium;
- including drip irrigation and a water retention layer to compensate for the minimal soil depth available to hold water;
- maximizing plant diversity and adding native plugs and seed to maximize resilience to climate extremes, diseases, and pests;
- adding bold sweeps of native plant plugs to not only increase resilience and ecological benefits, but also make a bold aesthetic statement; and

- shaping the firebreaks as a metaphorical leaf, river, or basketball, to not only meet functional requirements prescribed by the insurance company, but also add a powerful aesthetic element.

The Target Center green roof consists of a 2.75 inch deep growing zone in the center of the main arena roof structure and a deeper 3.5 inch growing zone around the perimeter where the structural capacity is greater. The pregrown Sedum mat was supplemented with 22 species of plugs and 16 species of seed native to Minnesota's bedrock bluff prairies, a plant community with harsh growing conditions similar to the growing conditions on the Target Center Green Roof. As of 2012, the green roof's 4th growing season, a diversity of sedum species, plugs, as well as species germinated from seed were thriving on the roof.



Aerial view of the Target Center Arena green roof, illustrating the use of different vegetation to create patterns in the roof. Image Courtesy of The Kestrel Design Group, Inc.

Year built: 2009

Location: Minneapolis, MN, USA

Building Type: Public

Green Roof Type: Extensive

Size: 113,000 square feet (2.6 acres)

Slope: 1 percent

Materials used in and components of the green roof (above membrane):

- 80 millimeter PVC waterproofing membrane
- insulation
- coverboard
- leak detection system
- pavers
- extensive growing medium
- drainage sheet of post-industrial recycled polypropylene drainage core of fused, entangled filaments and a geocomposite fabric bonded to each side
- capillary drip irrigation system that uses capillary action to evenly distribute water throughout the growing medium
- Soil moisture sensor to inform when growing medium is dry enough to need watering
- pregrown Sedum vegetation mat
- 22 species of plugs and 16 species of seed native to Minnesota's bedrock bluff prairies, a plant community with harsh growing conditions similar to the growing conditions on the Target Center Green Roof

Plant list: The pregrown Sedum mat was supplemented with 22 species of plugs and 16 species of seed native to Minnesota's bedrock bluff prairies, a plant community with harsh growing conditions similar to the growing conditions on the Target Center Green Roof.

Documented maintenance practices: weeding, irrigation, and plant replacement as needed

Unit cost: $15 per square foot, includes green roof, irrigation, and leak detection; excludes maintenance costs

Owner: City of Minneapolis

Designers and installers:

- Landscape Architect/Greenroof Designer: Kestrel Design Group, Inc.
- Roofing Consultant: Inspec
- Architect: Leo Daly
- Irrigation: Hydrologic Design
- General Contractor: Stock Roofing, a Tecta America Company
- Electric Field Vector Mapping (EFVM): International Leak Detection (ILD)
- Irrigation: KISSS

Access: Not accessible

Additional information:

- greenroofs.com [1] project database
- Minnesota Green Roofs Council [2] case studies

Minneapolis Central Library

The Minneapolis Central Library has three green roofs that each have very different microclimates:

- 15,868 square feet of green roof on the building's top (5th) floor, exposed to full sun;
- 2436 square feet of green roof on the building's 2nd floor, facing south, exposed to full sun plus reflection from an adjacent glass curtain wall; and
- 363 square feet of green roof facing northwest, with only partial sun exposure.

Minneapolis Central Library 5th floor green roof, Minneapolis, MN. Image Courtesy of The Kestrel Design Group, Inc.

Minneapolis Central Library 2nd floor south facing green roof, Minneapolis, MN. Image Courtesy of The Kestrel Design Group, Inc.

The plant palette and irrigation system of each roof is tailored to the growing conditions on that roof - drought tolerant species were planted on the 2nd floor roof that faces south, while shade tolerant species were used on the 2nd floor roof facing northwest.

To maximize irrigation efficiency, a drip irrigation system was used on the 5th floor and the 2nd floor roof that faces northwest. On the 2nd floor roof that faces south, adjacent to a south facing glass curtain wall, a popup sprinkler system is used to help cool plants in addition to watering them. Visitors to the library can view one of the green roofs from windows on 2nd floor, and all roofs are visible from surrounding buildings.

The primary driver behind these green roofs was their ability to provide sustainable stormwater management on a site where little space is available for stormwater management at grade. Further minimizing negative effects of roof runoff on downstream water bodies, the Central Library green roof is equipped with an irrigation system that utilizes a 7,500 gallon capacity cistern system to collect, store, and distribute harvested rainwater for use by the plants. This irrigation system is powered by a solar pump, and is intended for use on the green roof only during the plant establishment period and during periods of extreme drought. When the roof does not need watering, roof runoff collected in the cisterns is used to irrigate at grade landscape.

Minneapolis Central Library 2nd floor northwest facing green roof, Minneapolis, MN. Image Courtesy of The Kestrel Design Group, Inc.

Minneapolis Central Library aerial view of south facing 2nd floor roof and 5th floor roof green roof, Minneapolis, MN.

Minneapolis Central Library cisterns in an underground parking garage. The cisterns harvest stormwater runoff for irrigation

The conceptual design for the Minneapolis Central Library's green roof connects culture and nature, weaving together local cultural and natural patterns. The concept emphasizes the influence of the Mississippi River on Minneapolis' street grid and building design, as the flow of the Mississippi River is emulated by waves created across plant palettes of varying, undulating heights, with 20 to 30 species in each palette. Wave patterns change as different waves will be more apparent at different times of the year when prominent species are in bloom. A seasonal wave movement is also superimposed on 3D wave patterns by a purple/pink burst of color that moves west to east from spring to fall in accordance with the flow of Mississippi River. The planting design also complements the frit patterns and geometry of the library windows. The metaphorical connection of the green roof design to the Mississippi River highlights the positive impact of the green roof as it mitigates the effect of storm water runoff from the roof on the Mississippi River.

Year built: 2005

Location: Minneapolis, MN

Building Type: Public

Green Roof Type: Extensive

Size: 18,667 square feet.

Slope: 1 percent

Materials used in and components of the green roof (above membrane):

- root barrier/synthetic drainboard/filter fabric composite
- 4 inches depth of extensive growing medium, which is the maximum depth that could be accommodated by the roof's structural capacity
- erosion control blanket
- pop-up irrigation system and temperature sensor on the roof with the most extreme sun exposure
- drip irrigation on both the other green roofs; soil moisture sensors on all roofs

Plant list: 18 sedum species, which are traditionally used on European green roofs, were combined with 41 grasses and forbs that are native to Minnesota's bluff prairies, a habitat template similar, in many ways, to conditions found on extensive green roofs.

Documented maintenance practices: irrigation and weeding as needed

Unit cost: $28 per square foot (includes fall protection, paving, and other atypical green roof costs)

Owner: City of Minneapolis

Designers and installers:

- The Kestrel Design Group, Inc., Landscape Architect/Green Roof Designer
- Cesar Pelli & Associates Architects: Design Architect
- Architectural Alliance: Architect of Record

- Ambe, Ltd.: Roofing Consultant
- Hydrologic, Irrigation Design
- Mortensen/Thor: Construction Manager
- Rosenquist Construction: Green Roof Contractor
- Berwald Roofing: Roofing Contractor
- Aloha Landscaping: Green Roof Plants Installation

Edgewater Condominiums

Located in a very urban location adjacent to Lake Calhoun, the largest lake in Minneapolis' Chain of Lakes, sustainable stormwater management was especially important when the Edgewater Condominiums, a luxury condo project with 23 condos, was designed and constructed in 2006.With little open space at grade, the Edgewater Condominiums' green roof serves both to provide sustainable stormwater management as well as an urban oasis on the roof. Each of the three 5th floor condominium owners has access to its own private green roof deck, with views of Lake Calhoun as well as the Downtown Minneapolis Skyline.

Edgewater green roof, Minneapolis, MN, illustrating the view of nearby Lake Calhoun. Image Courtesy of The Kestrel Design Group, Inc.

The building's name and concept are expressed using a greenroof design that creates a calm, luxurious, resort-like atmosphere at each roof terrace, projecting an 'edge of water' sensibility for its residents. Short, white vegetation (3 to 6 inch tall traditional white sedums) in 3 inches of growing medium represents water/oasis in form and color. A diverse mix of traditional sedums of various colors and short native bedrock bluff prairie plants in 4 to 5 inches of growing medium represents land/beach around the "water". Together, the plant communities visually express the water connection between the green roof and adjacent Lake Calhoun. Variation in depth of growing medium also enhances wildlife habitat value of the green roof. Wave-like trellised fence panels planted with vines enhance the metaphorical connection to the nearby lakes and screen rooftop equipment.

Year built: 2006

Location: Minneapolis, MN, USA

Building Type: Multi-Family Residential

Green Roof Type: Extensive

Size: 3480 square feet

Slope: 1 percent

Materials used in and components of the green roof (above membrane):

- mix of Sedums and prairie plants native to Minnesota on the green roof; native and annual vines on green wall.
- coconut fiber erosion control blanket
- extensive green roof growing medium
- drip irrigation system
- EFVM electronic leak detection system
- dimpled polymeric sheet drainage layer/root barrier/filter fabric composite

Documented maintenance practices: weeding, irrigation, and plant replacement as needed

Designers and installers:

- Landscape Architect/Green Roof Designer: Kestrel Design Group
- Irrigation Consultant: Hydrologic
- Architect: Elness Swenson Graham Architects
- Vegetation Installation: Minnesota Native Landscapes
- Irrigation Installation: Green Acres
- Waterproofing Installation: Berwald Roofing

For more information, see Minnesota Green Roof Council [3] project database.

Edgewater green roof, illustrating the use of native prairie plants and vines (background) Image Courtesy of The Kestrel Design Group, Inc.

Edgewater green roof in late summer. Image Courtesy of The Kestrel Design Group, Inc.

St. Paul Firestation Headquarters

Located on a roof directly outside of the St. Paul Firestation over a parking ramp, the St Paul Firestation green roof includes a wide range of plants: over 100 species of native plants and ornamental plants, no-mow turf, a small pond, and even a vegetable garden where firefighters grow herbs and vegetables for their meals. Amenities include benches, lighting, interpretive signage, a pond, steel trees, and steel trellis structures. Water runoff from the entire building is collected in a 6,000 gallon cistern and used by the green roof subsurface drip irrigation system. A Green Roof Interpretive Center and Garden Classroom, a teacher's guide and student activity book, along with interpretive materials on the roof, are available for interpretation and environmental education (Minnesota Green Roof Council [2]).

St Paul Firestation green roof, St. Paul, MN. note areas where plants are being established. Image Courtesy of Angie Durhman, AD Greenroofs

St Paul Firestation green roof, illustrating vegetation-free zones and walking paths with informational kiosks. Image Courtesy of Angie Durhman, AD Greenroofs

Year built: 2010

Location: St Paul, MN

Building Type: Firestation

Green Roof Type: Intensive and extensive

Size: 8,100 square feet, 6,000 of which is vegetated

Slope: Flat, 1 percent to drains

Materials used in and components of the green roof (above membrane): root barrier, composite filter and retention mat, growing medium, drip irrigation.

Plant list: over 100 species of native plants and ornamental plants, no-mow turf, a small pond, vegetables and herbs

Documented maintenance practices: weeding and automated watering as needed, perennials get cut back and biomass is removed at the end of the year, pond and irrigation maintenance.

Unit cost: $35 per square foot (does not include roofing membrane)

Owner: City of St. Paul

Designers and installers:

- Green Roof Designer: Abraham and Associates
- Architect of Record: Collaborative Design Group
- Installer: TectaGreen
- General Contractor: Cost, Planning & Management International, Inc, (CPMI)

Access: The green roof and patio are accessible to the public during regular weekly hours.

Vegetables being grown on the St Paul Firestation green roof. Image Courtesy of Angie Durhman, AD Greenroofs

For more information

- St Paul Firestation [4] website
- Minnesota Green Roofs Council [5] project database

St. Simon Stock R.C. Elementary School green roof

When Father Nelson arrived at St. Simon Stock school, an elementary school in New York City's Bronx, the roof had many leaks. Impressed with the green roof movement in Chicago, Father Nelson spearheaded re-roofing part of the roof with a 3,500 square foot green roof. Aside from providing stormwater benefits, other goals of this green roof project included cleaning the air to reduce the high incidence of asthma, providing space where the school's inner city students could grow fresh vegetables, conducting science experiments, and enjoying open space. Father Nelson notes that the school's heating bills have also gone down since the installation of the green roof.

St. Simon Stock R.C. Elementary School Green Roof, Images Courtesy of Jeannette Compton

About half of the roof is planted with native plants, and the other half is planted with edible crops. Bees and butterflies are commonly seen in this urban oasis.

This green roof uses an innovative engineered green roof growing medium, developed by New York's Gaia Institute. The growing medium contains shredded polystyrene coated with pectin, compost, and native clay in 90:10:1 ratio by volume. This growing medium not only turns a waste product into a resource, it is also 75 percent lighter than other engineered green roof growing media, so it allows for a deeper growing media profile and has higher water holding capacity and cation exchange capacity.

Runoff from higher impervious roofs that surround the green roof is collected in rain barrels on the green roof and used by part of the green roof's drip irrigation system.

Twelve planted bins were installed on the green roof to test evaporation rate and water holding capacity of a zero discharge green roof (i.e. without a drainage layer). Species selected for the bins are able to tolerate both droughty and flooded conditions, and can evapotranspire high volumes of water when water is available. Half the bins were planted with Prairie Cord Grass, and the other half with Canada Goldenrod. Half of each species was in bins with a traditional green roof soil, and the other half in a growing medium made of shredded recycled polystyrene modified to improve water holding capacity and cation exchange capacity, mixed with clay and compost. The water holding capacity of the bins ranged from 75 percent to 112 percent of a 2 year storm, which is a 3 inch storm in 24 hours in New York City. "… ET from all treatments eliminated free standing water within 8 days, with much of the water loss occurring in the first three days. Evaporative losses were greater than those of the evaporation pan during the first three days. Crop coefficients compare the water loss of the plants to that of an evaporation pan. Solidago averaged 3.86 and 3.80, and the Spartina 3.42 and 3.38 during Trials 1 and 2, respectively" (Compton and Whitlow 2006). These crop coefficients are an order of magnitude greater than those published for a free-draining green roof planted with Sedums (Van Woert et al 2005).

Native plants being grown on St. Simon Stock R.C. Elementary School's green roof. Images Courtesy of Jeannette Compton

Year built: 2005

Location: Bronx, NY, USA

Building Type: Educational

Green Roof Type: Extensive, Test/Research

Size: 3,500 square feet

Slope: 1 percent

Materials used in and components of the green roof (above waterproofing assembly):

Green roof:

- root barrier
- water retention and drainage mat
- filter fabric
- 10 centimeter (4 inch) growing medium containing shredded polystyrene coated with pectin, compost, and native clay in 90:10:1 ratio by volume.
- 5 centimeters of bound coconut fiber, jute, and straw matting, a layer of compost, and a layer of shredded wood mulch
- drip irrigation system

Students planting the St. Simon Stock R.C. Elementary School green roof. Images Courtesy of Jeannette Compton

Test bins:

- Fiberglass tubs were installed level with growing medium, with a removable lysimeter in each tub.
- Open bottom ¾ inch schedule 40 PVC was installed vertically in each tub as an observation well to allow measurement of free water depth.

- Each bin was lined with filter fabric and installed at a slight angle to allow drainage towards a hole drilled at one end. Male adapter barbs attached to flexible PVC tubing was brought to the surface and clamped shut, permitting drainage if necessary, as well as sampling of leachate.
- Half the bins had traditional green roof growing medium consisting of 3/8 inch graded expanded shale, coarse ground perlite, and compost in a 2:1:1 ratio by volume.
- The other half of the bins had growing medium containing shredded polystyrene coated with pectin, compost, and native clay in 90:10:1 ratio by volume

Students planting vegetables on the St. Simon Stock R.C. Elementary School green roof. Note the rain barrel that collects rainwater used to irrigate plants on the roof. Images Courtesy of Karen Argenti

Both growing media had the same compost and were installed with the same of bound coconut fiber, jute, and straw matting, a layer of compost, and a layer of shredded wood mulch as the rest of the roof.

Plant list: Prairie Cordgrass (*Spartina alterniflora*) and Canada Goldenrod (*Solidago Canadensis*) in the research bins, with a wide diversity of native species and edible plants, including, for example, strawberries, lettuce, and tomatoes, on the remainder of the roof.

One goal of the St. Simon Stock R.C. Elementary School green roof was to provide educational opportunities for students, as illustrated in this photo. Images Courtesy of Karen Argenti

Documented maintenance practices: maintenance tasks include operating the automated drip irrigation system, weeding, supplementing growing medium as needed, and planting annual crops, and harvesting crops. Maintenance tasks are performed by the students from St. Simon Stock School, together with Smartroofs [6], "a social enterprise developed by Sustainable South Bronx (SSBx). SSBx has an award-winning job training program called the Bronx

Environmental Stewardship Training (BEST) Academy that prepares residents of the South Bronx and other New York City neighborhoods for "green" careers. The SmartRoofs social enterprise undertakes projects that enable BEST Academy graduates to obtain resume-building job experience while simultaneously earning income -- and making New York City healthier and greener" (Argenti, 2013).

Unit cost: $57 per square foot

Owner: The Archdiocese of New York

Designers and installers:

- Green Roof: Barrett Company
- Ecological and Horticultural Engineering Consultant: Dr. Paul Mankiewicz, The GAIA Institute
- Ecological and Horticultural Engineering Consultant: Karen Argenti
- Graduate Student: Jeanette Compton, Cornell University
- Roof Contractor: Tony Lado, Bulado Construction

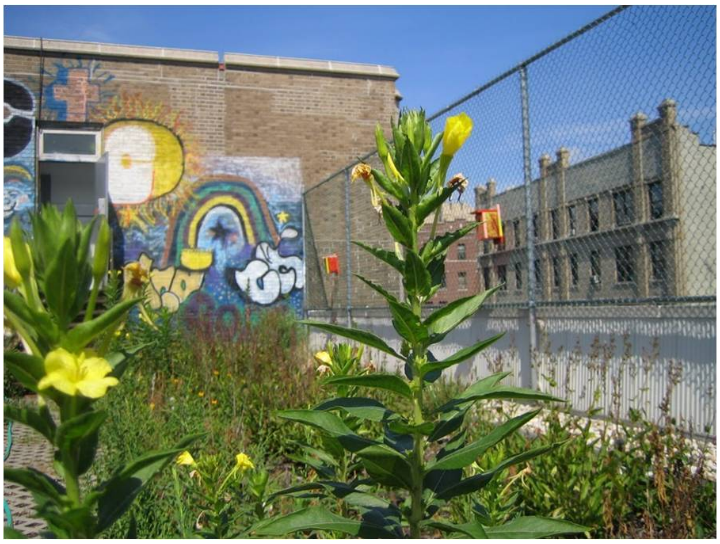
For more information see Greenroofs.com [7] project database.

Vegetables grown on the St. Simon Stock R.C. Elementary School green roof. Images Courtesy of Karen Argenti

The growing medium on the St. Simon Stock R.C. Elementary School green roof consists of shredded polystyrene coated with pectin, compost, and native clay. Images Courtesy of Karen Argenti

Hunt Utilities Group green roof

The Hunt Utilities green roof is an example of a green roof outside of the Metro area, and is also unique in that it was not planted, but the owners just let it be colonized by whatever plants came in naturally.



St. Simon Stock R.C. Elementary School green roof, located in an ultra-urban area in the Bronx, New York City. Images Courtesy of Karen Argenti

Hunt Utilities Group green roof, which was not planted but allowed to vegetate naturally. Image Courtesy of Ryan Hunt

“When the Hunt Utilities Group's Resilient Living Campus needed a prototyping and fabrication shop, we decided on a living roof for it, primarily so we could gain the experience and demonstrate it. The additional, unique green space and limiting water run off was also an interest. We learned that it requires some serious structure, and that making sure it is all done extremely well to prevent expensive, hard to find leaks is critical. Fortunately, we have not experienced any leaks, yet. We have found the space useful for solar panel testing and watching shooting stars” (Ryan Hunt).

Hunt Utilities Group green roof. Image Courtesy of Ryan Hunt

Year built: 2005

Location: 2330 Dancing Wind Road, Pine River, MN 56474

Building Type: (public or private) Private

Green Roof Type: Semi-intensive (Approximately 6 inches deep)

Size: approximately 15,000 square feet

Slope: Flat

Materials used in and components of the green roof (above membrane): multi-layer system by Carlisle

Plant list: Whatever grew there

Documented maintenance practices: None

Unit cost: The cost was about $22 per square foot including additional structural support.

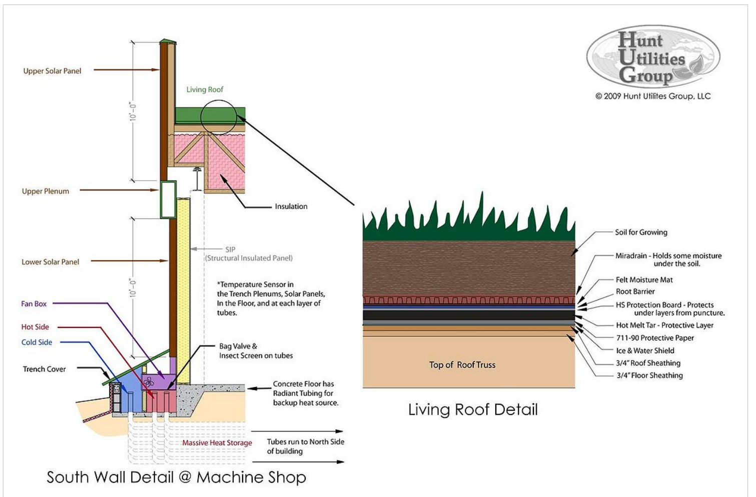
Owner: Hunt Utilities Group

Designers and installers:

- Multi-layer system designed by Carlisle
- Architect: Paul Hirst
- Installed by: Hunt Utilities Group

For more information:

- [8]
- [9]



Hunt Utilities Group green roof details. Courtesy of Ryan Hunt

Additional case studies

- Minnesota Green Roofs Council Website: [2]
- International green roof database on greenroofs.com [10]

References

- Compton, J. S., and T. H. Whitlow. 2006. A Zero Discharge Green Roof System and Species Selection to Optimize Evapotranspiration and Water Retention. Greening Rooftops for Sustainable Communities, Boston, MA, May 11-12, 2006.
- Compton, Jeannette. 2006. Rethinking the Green Roof. Biocycle, September: 38-41.
- Greenroofs.com project database at http://www.greenroofs.com/projects/pview.php?id=514, downloaded 05/28/2013

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References

[1] http://www.greenroofs.com/projects/pview.php?id=1000
[2] http://www.mngreenroofs.org/
[3] http://www.mngreenroofs.org/2012/02/edgewater-condominiums/
[4] http://www.stpaul.gov/index.aspx?NID=4140
[5] http://www.mngreenroofs.org/2012/02/st-paul-fire-headquarters/
[6] http://www.ssbx.org/smart-roofs/
[7] http://www.greenroofs.com/projects/pview.php?id=514
[8] http://www.brockwhite.com/0p23pj96/green-roofing-system-manufacturing-facility-of-hunt-utilities-group/
[9] http://www.cleanenergyresourceteams.org/sites/default/files/publication_files/CS_HUG_2008.pdf
[10] http://www.greenroofs.com/projects/

Links for green roofs

Fact sheets

- Minnesota Stormwater Manual
- RAND Engineering & Architecture [1]
- Atlantic Council utilities Authority [2]
- Massachusetts Metropolitan Area Planning Council [3]
- EPA [4]
- Metro Health Hospital [5]

Technical documents

- Virginia DCR Stormwater Design Specification No. 5 [6]
- Pomegranate Center Green Roof Manual [7]
- New York City Department of Environmental Protection [8] (see Chapter 4)

Research

- Pennsylvania State University [9]
- Michigan State University [10]
- NASA [11]
- Texas A & M University [12]
- The University of Auckland [13]

General

- EPA, Green Roofs for Stormwater Runoff control [14]
- Green Roofs for Healthy Cities [4]

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References

[1] http://www.randpc.com/improve/cis_GreenRoofFactSheet.html
[2] http://www.acua.com/acua/uploadedFiles/Home/ACUA_Information/Files/Fact_Sheets/green%20roof%20fact%20sheet%20with%20links.pdf
[3] http://www.mapc.org/sites/default/files/LID_Fact_Sheet_-_Green_Roofs.pdf
[4] http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=114
[5] http://metrohealth.net/_files/webfm/file/pdfs/Green_Roof_Fact_Sheet.pdf
[6] http://vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/DCR%20BMP%20Spec%20No%205_VEGETATED%20ROOF_Final%20Draft_v2-3_03012011.pdf
[7] http://www.pomegranate.org/wp-content/publications/Pomegrante-Center-Greenroof-Manual-2005.pdf
[8] http://www.nyc.gov/html/dep/pdf/green_infrastructure/stormwater_guidelines_2012_final.pdf
[9] http://plantscience.psu.edu/research/centers/green-roof
[10] http://www.hrt.msu.edu/greenroof/
[11] http://www.nasa.gov/agency/sustainability/greenroofs.html
[12] http://faculty.arch.tamu.edu/bdvorak/
[13] http://www.engineering.auckland.ac.nz/uoa/living-roofs
[14] http://www.nps.gov/tps/sustainability/greendocs/epa%20stormwater-sm.pdf

References for green roofs

References

- ASTM [4]. 2005. *Method E2399-5, Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems.* ASTM International, West Conshohocken, PA.
- Bengtsson, L., L. Grahn, and J. Olsson. 2005. *Hydrological function of a thin extensive green roof in southern Sweden*. Nordic Hydrol. 36 (3), 259–268.
- Berghage, R. Penn State Center for Green Roof Research [9]. *Green Roof Media Nutrient Testing, Nutrient Management, and Runoff Water Quality*. Presentation to NASA Workshop.
- Berghage, R.D., D.Beattie, A. R. Jarrett, C. Thuring, F. Razaei, and T. P. O'Connor. 2009. Green Roofs for Stormwater Runoff Control [1]. National Risk Management Research Laboratory Office Of Research And Development U.S. Environmental Protection Agency Cincinnati, OH 45268. EPA/600/R-09/026.
- Berghage, R. D., and A. R. Jarrett. 2007. Quantifying Evaporation and Transpirational Water Losses from Green Roofs and Green Roof Media Capacity for Neutralizing Acid Rain [2]. National Decentralized Water Resources Capacity Development Project, Penn State University.
- Berghage, R., C. Miller, B. Bass, D. Moseley, and K. Weeks. 2010. *Stormwater Runoff from a Large Commercial Roof in Chicago*. Proceedings Cities Alive Conference. Vancouver, Canada. Nov 30-Dec 3.
- Berndtsson, J. C. 2010. Green roof performance towards management of runoff water quantity and quality: A review. Ecological Engineering, 36, 351-360.
- Butler, C., and C.M. Orians. 2011. *Sedum cools soil and can improve neighboring plant performance during water deficit on a green roof*. Ecological Engineering,37(11): 1796–1803.
- Cantor, S. L. 2008. *Green Roofs in Sustainable Landscape Design*. W.W.Norton, NY.
- Carpenter, D.D., Kaluvakolanu, P. 2011. *Effect of roof surface type on stormwater run-off from full-scale roofs in a temperate climate*. Journal of Irrigation and Drainage Engineering 137:161-169.
- Carter, Timothy, and Andrew Keeler. 2008. Life-Cycle cost–benefit Analysis of Extensive Vegetated Roof Systems. Journal of environmental management 87:350-363.
- Carter, T., Rasmussen, T. 2006. *Hydrological behavior of vegetated roofs*. Journal of the American Water Resources Association 42, 1261-1274.
- Compton, J. S., and T. H. Whitlow. 2006. *A Zero Discharge Green Roof System and Species Selection to Optimize Evapotranspiration and Water Retention*. Greening Rooftops for Sustainable Communities, Boston, MA, May 11-12, 2006.
- David Evans and Associates, Inc. and ECONorthwest. 2008. Cost Benefit Evaluation Of Ecoroofs [3]. Prepared for: City of Portland Bureau of Environmental Services Sustainable Stormwater Group.
- Durhman, A.K. D. B. Rowe, and C. L. Rugh. 2007. *Effect of Substrate Depth on Initial Growth, Coverage, and Survival of 25 Succulent Green Roof Plant Taxa*. HORTSCIENCE 42(3):588–595. 2007.
- Durhman, A.K., D.B. Rowe, and C.L. Rugh. 2006. *Effect of watering regimen on chlorophyll fluorescence and growth of selected green roof plant taxa*. HortScience 41:1623–1628.
- Dvorak, B, and K. Carroll. 2008. *Chicago City Hall Green Roof: Its Evolving Form and Care*. Greening Rooftops for Sustainable Communities Conference Proceedings, Baltimore, MD.
- Dvorak, B., and A. Volder. 2010. *Green Roof Vegetation for North American Ecoregions: A Literature Review*. Landscape and Urban Planning 96: 197-213.
- Fassman, E. and Simcock, R. 2012. *Moisture Measurements as Performance Criteria for Extensive Living Roof Substrates*. J. Environ. Eng., 138(8), 841–851. doi: 10.1061/(ASCE)EE.1943-7870.0000532
- Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL) *Richlinien für die Planung, Ausführung and Plege von Dachbegrünung* (Guideline for the Planning, Execution and Upkeep of Green-Roof Sites: developed by the German Research Society for Landscape Development and Landscape Design)

- Getter, K.L.; Rowe, D.B. 2008. Selecting Plants for Extensive Green Roofs in the United States [3]. Michigan State University Extension Bulletin E-3047.
- Getter, K.L., Rowe, D.B., Andresen, J.A., 2007. Quantifying the effect of slope on extensive green roof stormwater retention. Ecological Engineering, 31, 225-231.
- Green Roofs for Healthy Cities [4] and The Cardinal Group. 2006. *Green Roof Design 101: Introductory Course*. Second Edition Participant's Manual.
- Green Roofs for Healthy Cities [4]. No publication year given. *Green Roof Infrastructure: Design and Installation 201*.
- Green Roofs for Healthy Cities (GRHC) [4]. 2005. Green Roof Design 101 Introductory Course Participant Manual. Green Roofs for Healthy Cities and the Cardinal Group Inc.
- Lundholm J, J.S. MacIvor, Z. MacDougall, and M. Ranalli. 2010. Plant Species and Functional Group Combinations Affect Green Roof Ecosystem Functions [4]. PLoS ONE 5(3): e9677. doi:10.1371/journal.pone.0009677.
- Magnuson Klemenic Associates. 2007. *Technical Memorandum: Stormwater Control Potential for Seattle Green Roof Retrofits*. Seattle Public Utilities Green Roof Retrofit Study.
- Mandel, L.. 2013. *EAT UP; The Inside Scoop on Rooftop Agriculture*. New Society Publishers: Gabriola Island, BC, Canada.
- Mentens, J., Raes, D. & Hermy, M. 2006. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning, 77, 217-226.
- Miller, C. 2003. *Moisture management in green roofs*. In: Proc. of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities. The Cardinal Group. Toronto, Chicago, IL, 29–30 May 2003. p. 177–182.
- Miller, C., K. Weeks, B. Bass, R. Berghage, and S. Berg. 2010. Stormwater Policy As A Green Roof (Dis)Incentive For Retail Developers. Cities Alive 8th Annual Green roof &Wall Conference, Vancouver, November 30-December 03, 2010.
- Monterusso, M.A., D.B. Rowe, and C.L. Rugh. 2005. *Establishment and persistence of Sedum spp. and native taxa for green roof applications*. HortScience 40:391–396.
- Moran, A., B. Hunt, and J. Smith. 2005. *Hydrologic and water quality performance from green roofs in Goldsboro and Raleigh, North Carolina,* p. 512-525. In Proc. of 3rd North American Green Roof Conference: Greening rooftops for Sustainable Communities. Washington, DC. 4-6 May 2005. The Cardinal Group, Toronto.
- National Institute of Building Sciences. Whole Building Design Guide [5].
- Peck, S.W. and M.E. Kuhn, 2002. Design Guidelines for Green Roofs [5]. Report prepared for the Ontario Association of Architects and the Canada Mortgage and Housing Corporation, Toronto, Ontario.
- Porsche, U. and M. Kohler. 2003. Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil. Presented at the World Climate and Energy Event. December 1-5, Rio de Janeiro, Brazil.
- Rezaei, F., A.R. Jarrett, R.D. Berghage, and D.J. Beattie. 2005. *Evapotranspiration Rates from Extensive Green Roof Plant Species*. ASAE Meeting Presentation Paper Number 052150. Written for presentation at the 2005 ASAE Annual International Meeting Sponsored by ASAE, Tampa Convention Center. Tampa, FL 17-20 July 2005.
- Rowe, B.D. 2011. *Green roofs as a means of pollution abatement*. Environmental Pollution 159: 2100-2110.
- Rowe, D.B., C.L. Rugh, N. VanWoert, M.A. Monterusso, and D.K. Russell. 2003. *Green roof slope, substrate depth, and begetation influence runoff*. p. 354-362 In Proc. Of 1st North American Green Roof Conferences: Greening rooftops for Sustainable Communities, Chicago. 29-30 May 2003. The Cardinal Group, Toronto.
- Rowe, D. Bradley, Kristin L. Getter, and Angela K. Durhman. 2012. *Effect of green roof media depth on Crassulacean plant succession over seven years*. Landscape and Urban Planning (Elsevier) 104: 310-319.
- Rowe, D.B., C.L. Rugh, and A.K. Durhman. 2006. *Assessment of substrate depth and composition on green roof plant performance*. Proc. of 4th North American Green Roof Conference: Greening Rooftops for Sustainable

Communities. Boston, Mass. 10–12 May 2006. The Cardinal Group, Toronto.

- Saiz, S., et al. 2006. Comparative Life Cycle Assessment of Standard and Green Roofs. Environmental Science and Technology 40: 4312-4316.
- Simmons, M.T., B. Gardiner, S. Windhager, and J. Tinsley. 2008. *Green roofs are not created equal: the hydrologic and thermal performance of six different extensive green roofs and reflective and non-reflective roofs in a sub-tropical climate*. Urban Ecosyst. 11, 339–348.
- Sinclair, T.R.; N.M. Holbrook, and M.A. Zwieniecki. 2005. *Daily Transpiration Rates of Woody Species on Drying Soil*. Tree Physiology 25: 1469-1472. Victoria Canada.
- Snodgrass, E.C. and L.L. Snodgrass. 2006. *Green Roof Plants: A Resource and Planting Guide*. Timber Press. Portland, OR.
- Sutton, R.K.; J.A. Harrington; L. Skabelund; P. MacDonagh; R. R. Coffman; and G. Koch. 2012. *Prairie-Based Green Roofs: Literature, Templates, and Analogs*. Journal of Green Building 7(1):143-172.
- Sutton, R.; B. Rowe;G. Acomb; J. Lambrinos; P. MacDonagh; R. Hawke. 2012. *New Plant Performance for 21st Century Green Roof Ecosystems*. Cities Alive Conference, Chicago IL.
- Taylor, B. L. and D. Gangnes. 2007. *Technical Memorandum: Stormwater Control Potential for Seattle Green Roof Retrofits*. Seattle Public Utilities Green Roof Retrofit Study.
- Teemusk, A., and U. Mander. 2007. “Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events.” Ecol. Eng., 30(3), 271–277.
- Toronto and Region Conservation.An Economic Analysis of Green Roofs: Evaluating the Costs and Savings to Building Owners in Toronto and Surrounding Regions [2]. Sustainable Technologies Evaluation Program. July.
- Torrance, S.; B. Bass, S. MacIvor and T. McGlade in conjunction with Toronto City Planning Division. No publication year given. City of Toronto Guidelines for Biodiverse Green Roofs [5].
- Ulrich, R.S. 2002. *Health Benefits of Gardens in Hospitals*. Paper for Conference, Plants for People, International Exhibition Floriade.
- Van Seters, T., L. Rocha, and G. MacMillan, G. *Evaluation of the runoff quantity and quality performance of an extensive green roof in Toronto, Ontario*. Proceedings of the Greening Rooftops for Sustainable Communities, Minneapolis, 2007.
- VanWoert, N.D., D.B. Rowe, J.A. Andresen, C.L. Rugh, and L. Xiao. 2005. *Watering regime and green roof substrate design affect Sedum plant growth*. HortScience 40:659–664.
- Villarreal, E. L. and L. Bengtsson (2005). *Response of a sedum green-roof to individual rain events*. Ecological Engineering 25(1): 1-7.
- Voyde, E., E. Fassman, R. Simcock, and J. Wells. 2010. ”Quantifying Evapotranspiration Rates for New Zealand Green Roofs.” J. Hydrol. Eng. 15, SPECIAL ISSUE: Low Impact Development, Sustainability Science, and Hydrological Cycle, 395–403.
- Whittinghill, L.J. and D.B. Rowe. 2012. *The role of green roof technology in urban agriculture*. Renewable Agriculture and Food Systems 27(4):314-322.
- Whittinghill, L.J., D.B. Rowe, and B.M. Cregg. 2013. *Evaluation of vegetable production on extensive green roofs*. Agroecology and Sustainable Food Systems 37(4):465-484.
- Whittinghill, L.J.; D.B. Rowe, 2011. *Salt tolerance of common green roof and green wall plants*. Urban Ecosystems 14(4):783-794.

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References

[1] http://www.epa.gov/ord
[2] http://www.decentralizedwater.org/documents/04-dec-10sg/04-dec-10sg.pdf
[3] http://www.hrt.msu.edu/greenroof/PDF/08%20GetterRoweExtensionBulletin.pdf
[4] http://www.plosone.org/article/info:doi/10.1371/journal.pone.0009677
[5] http://www.toronto.ca/greenroofs/pdf/biodiversegreenroofs_2013.pdf

Green roofs terminology and glossary

Glossary

- Ballast: A material used to hold loose laid roofing materials in place [4]
- Built in place green roof: in a built-in-place green roof, the layers of the green roof are installed on-site, as opposed to green roof trays or mats, which are delivered pre-assembled
- Cation exchange capacity: The quantity of positive ions (cation) that can be absorbed by growing medium. [4]
- Compaction: increase in growing medium density
- Curtain wall: A non-structural outer wall, often of glass or steel
- Dead load: All permanently placed materials on and below the roof (e ,g. green roof materials, green roof plants, ceiling fans) [4]
- Descriptive Specifications: Require specific products and methods of installation. Compared to performance specifications, these give the designer the most control, but since they allow the contractor less flexibility and innovation, they can also be less cost effective.
- Drain access chamber [1]: removable cover installed around roof drains to protect the drains from clogging while still allowing for easy access to the drains
- Drainage layer [2]: Drainage layers, such as, for example, drainage aggregate, drainage sheets, and drainage mats, convey water across the roof surface under the growing medium and filter fabric, and are available in a range of different materials and drainage capacities The drainage layer must be selected to drain well enough so as to not compromise underlying waterproofing or building, but also retain water in a manner that meets stormwater management and vegetation goals. The choice of the drainage layer will have a significant impact on the peak rate and time delay of discharges from the green roof (Taylor and Gangnes, 2007)
- Erosion protection layer: erosion control blanket, netting, or tackifier adequate to protect green roof from wind and water erosion.
- Evapotranspiration: water conveyed to the atmosphere through evaporation and plant transpiration.
- Extensive green roof [3]: an extensive green roof has growing medium that is 6 inches or less deep
- Filter fabric [4]: a lightweight, rot-proof material laid over or included as part of a drainage layer to keep the growing medium in place and thereby prevent fine particles from blocking the drainage system. [4]
- Flashing: the weatherproof material installed between roof sheathing (or wall sheathing) and the finish materials to help keep moisture away from the sheathing [4]
- Growing medium: the particulate matter or substrate that anchors the plant roots to sustain the plant growth [4]
- Intensive green roof [3]: an intensive green roof has growing medium that is more than 6 inches deep
- Irrigation system [5]: Systems which deliver moisture to the growing medium making it available for plant use [4]
- Leak detection system [6]: Leak detection systems allow for detecting and pinpointing the exact location of leaks in the waterproof membrane
- Lifecycle cost: The capital and operational cost of a construction item or system during the estimated useful life of the building [4]
- Live load: All equipment and people on the roof. They are not permanent elements [4]
- Maximum media density: the density of a mixed media material determined after it has been subjected to a specific amount of compaction and hydrated by immersion to simulate prolonged exposure to both foot traffic and rainfall (ASTM [4] E 2399-05)
- Maximum Media Water Retention (MMWR): terminology used in ASTM E 2399-05 for FLL Maximum Water Capacity (MWC); the quantity of water held in a media at the maximum media density. This is a useful measure of the capacity of a media to hold water under drained conditions.
- Maximum Water Capacity (MWC): terminology used in FLL guidelines for Maximum Media Water Retention (MMWR); the quantity of water held in a media at the maximum media density. This is a useful measure of the

capacity of a media to hold water under drained conditions.
- Membrane protection layer: A material used to protect the waterproofing membrane and/or insulation layer during the installation of a green roof [4]
- Modular green roof: A green roof system which combines one or more layers in a single pre-manufactured product (e.g. drainage, growing medium, and plants) [4]
- Performance Specifications: allow the contractor to choose what products to install and how to install them as long as specified performance goals are met. Performance specifications allow the contractor more flexibility and innovation compared to descriptive specifications, and therefore often result in more economical bids.
- Pre-grown mats [7]: Mats filled with growing medium and delivered to the site pre-grown with green roof vegetation, typically Sedums. Pre-grown mats are delivered in rolls like sod. The mats can be biodegradable or permanent
- R factor: The measure of thermal resistance. $R = K{\cdot}m^2/$ [4]
- Root barrier: green roof component that prevents plant roots from damaging the waterproofing membrane. (link to description in 5E)
- Water Permeability: the coefficient, which when multiplied by the hydraulic gradient will yield the apparent velocity with which water, at 68°F (20°C) will move through a cross-section of media. The conditions created in this method apply to freely-drained media where the free water surface is level with the upper surface of the media layer (such as, impending accumulation of water above the surface of the media).
- Water retention layer: Typically a water holding fabric or a plastic sheet with cup-like depressions, the water retention layer holds water for later use by plants.
- Wind uplift: a net upward force that occurs when the pressure below a roof is greater than above it.

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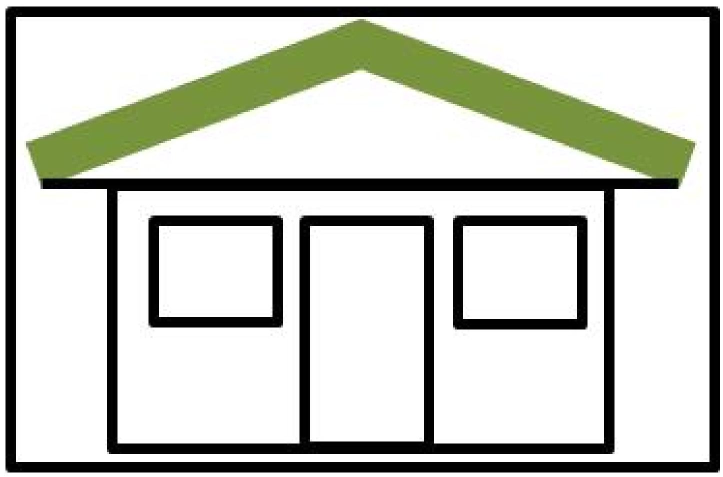
[1] http://stormwater.pca.state.mn.us/index.php/File:Drain_Access_Chambers_at_Phillips_Eco-Enterprise_Green_Roof,_Minneapolis,_MN.jpg
[2] http://stormwater.pca.state.mn.us/index.php/File:Aggregate_Drainage_Layer.jpg
[3] http://stormwater.pca.state.mn.us/index.php/Types_of_green_roofs
[4] http://stormwater.pca.state.mn.us/index.php/File:Typical_green_roof_sections_2.jpg
[5] http://stormwater.pca.state.mn.us/index.php/File:Irrigation_Installation_at_Minneapolis_Central_Library_Green_Roof,_Minneapolis,_MN.jpg
[6] http://stormwater.pca.state.mn.us/index.php/File:Electronic_Leak_Detection_at_Target_Center_Green_Roof,_Minneapolis,_MN.jpg
[7] http://stormwater.pca.state.mn.us/index.php/File:Installation_of_Pregrown_Sedum_Mat.jpg

Requirements, recommendations and information for using green roofs as a BMP in the MIDS calculator

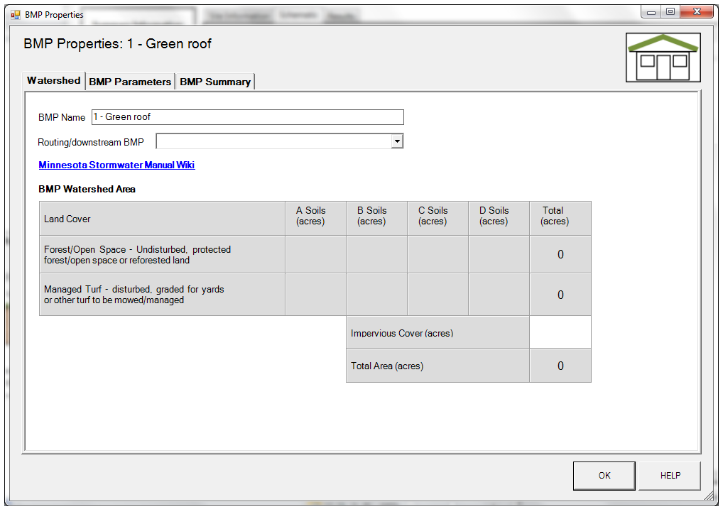
For a green roof system, stormwater that is captured and stored within the soil is removed from the system through evapotranspiration. The green roof does not provide phosphorus (P) reduction and reduces outflow total suspended solid (TSS) concentrations to 2.25 milligrams per liter.



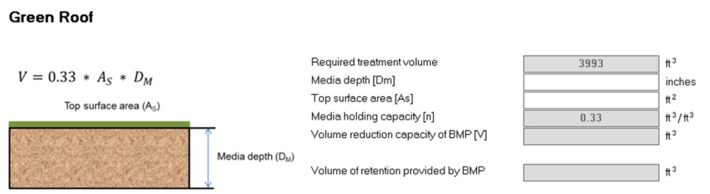
MIDS calculator symbol for green roofs

MIDS calculator user inputs for green roof

For green roof systems, the user must input the following parameters to calculate the volume and pollutant load reductions associated with the BMP.



Screen shot of the watershed tab for green roofs



Screen shot of the MIDS calculator BMP Parameters tab for green roofs

- **Watershed tab**
  - BMP Name: this cell is auto-filled but can be changed by the user.
  - Routing/downstream BMP: if this BMP is part of a treatment train and water is being routed from this BMP to another BMP, the user selects the name of the BMP from the dropdown box to which water is being routed. All water must be routed to a single downstream BMP. Note that the User must include the BMP receiving the routed water in the Schematic or the BMP will not appear in the dropdown box.
  - BMP watershed areas: Impervious area is the only land use that can contribute to the watershed of a green roof. The area of the green roof itself must be included in the impervious watershed area. A traditional roof can be included in the impervious area if water from the traditional roof is routed to the green roof. The area of the traditional roof cannot exceed the area of the green roof. Units are in acres.
- **BMP Parameters tab**
  - Media surface area (A_M): The surface area of the green roof. The user inputs this value in square feet. The calculator will display the surface area in acres for comparison with the watershed areas entered.
  - Media depth (D_M): The depth of the media, equal to the distance from the bottom of the media (i.e., top of underlying drainage layer) to the top of the media. The user inputs this value in inches.
  - Media holding capacity: Moisture content at the maximum media density. This value is in cubic feet per cubic feet and is often expressed as percent volume. The value represents the amount of water that the soils are able to hold onto instead of percolating into the drainage layer. This value is restricted to 0.33 cubic feet per cubic feet (33 percent).
- **BMP Summary Tab**: The BMP Summary tab summarizes the volume and pollutant reductions provided by the specific BMP. It details the performance goal volume reductions and annual average volume, dissolved P, particulate P, and TSS load reductions. Included in the summary are the total volume and pollutant loads received by the BMP from its direct watershed, from upstream BMPs and a combined value of the two. Also included in the summary, are the volume and pollutant load reductions provided by the BMP, in addition to the volume and pollutant loads that exit the BMP through the outflow. This outflow load and volume is what is routed to the downstream BMP if one is defined in the Watershed tab. Finally, percent reductions are provided for the percent of the performance goal achieved, percent annual runoff volume retained, total percent annual particulate phosphorus reduction, total percent annual dissolved phosphorus reduction, total percent annual TP reduction, and total percent annual TSS reduction.

Model input requirements and recommendations

The following are requirements or recommendations for inputs into the MIDS calculator. If the following are not met, an error message will inform the user to change the input to meet the requirement.

- Green roof media depth must be 4 inches or less
- Green roof area cannot be greater than the total impervious area routed to the green roof
- The contributing impervious area cannot be more than 2 times the surface area of the green roof. Since the green roof itself is treated as an impervious surface in the calculator, the maximum run-on area to a green roof from a traditional roof must be equal to or less than the area of the green roof. For example, a 10,000 square foot green roof can also have 10,000 square feet or less run-on area from a traditional roof. In this example, the maximum impervious area input to the calculator is 20,000 square feet.

Methodology

Required Treatment Volume

Required treatment volume, or the volume of stormwater runoff delivered to the BMP, equals the performance goal (1.1 inches or user-specified performance goal) times the impervious area draining to the BMP. This stormwater is delivered to the BMP instantaneously following the Kerplunk method.

Volume Reduction

The volume reduction achieved by a BMP compares the capacity of the BMP to the required treatment volume. The *Volume reduction capacity of BMP* (or volume reduction credit) is calculated using BMP inputs provided by the user. For this BMP, the “Volume reduction capacity” is equal to the amount of stormwater that can be instantaneously captured by the BMP in the soils of the green roof. The capture volume (V) is given by

$$V = A_M * D_M * 0.33$$

Where:

AM is the media surface area; and

DM is the media depth; and

0.33 is the media holding capacity.

The *Volume of retention provided by BMP* is the amount of volume credit the BMP provides toward the performance goal. This value is equal to the lesser of the *Volume reduction capacity of BMP* calculated using the above method or the *Required treatment volume*. This check makes sure that the BMP is not getting more credit than necessary to meet the performance goal. For example, if the BMP is oversized the user will only receive credit for the *Required treatment volume* routed to the BMP, which corresponds with meeting the performance goal for the site.

Pollutant Reduction

Pollutant load reductions are calculated on an annual basis. For this BMP, the annual total phosphorus load reduction is restricted to 0 percent. This means that the total load of phosphorus (both particulate and dissolved) calculated to enter the green roof will exit the green roof without being removed. The total suspended solids (TSS) removal is based on the outflow event mean concentration (EMC). The outflow concentration of TSS from the green roof is set at 2.25 milligrams per liter. The remaining TSS load is filtered in the green roof and removed from the system. This results in an outflow load from the green roof equal to the outflow water volume times a concentration of 2.25 milligrams per liter. For more information see the water quality treatment section in the green roofs overview and the literature review of pollutant removal by green roofs.

NOTE: The user can modify event mean concentrations (EMCs) on the *Site Information* tab in the calculator. Default concentrations are 54.5 milligrams per liter for total suspended solids (TSS) and 0.3 milligrams per liter for total phosphorus (particulate plus dissolved). The calculator will notify the user if the default is changed. Changing the default EMC will result in changes to the total pounds of pollutant reduced.

Routing

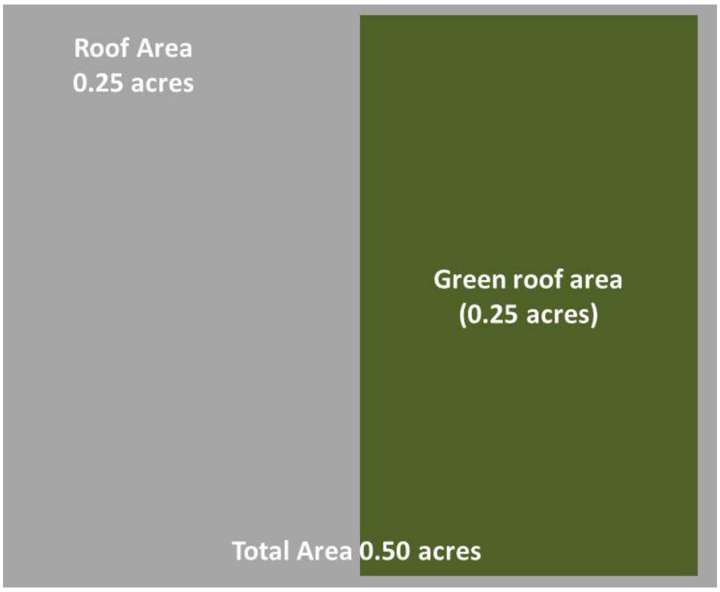
A green roof can be routed to any BMP except for a swale side slope. Only another green roof BMP can be routed to a green roof BMP unless it results in water being rerouted back to the original green roof.

Assumptions

The following general assumptions apply in calculating the credit for a green roof. If these assumptions are not followed the volume and pollutant reduction credits cannot be applied.

- The green roof is properly designed
- The green roof was properly constructed, consistent with the design criteria
- The green roof is properly maintained. The performance of the green roof should be regularly assessed

Example application in the MIDS calculator (Version 2)



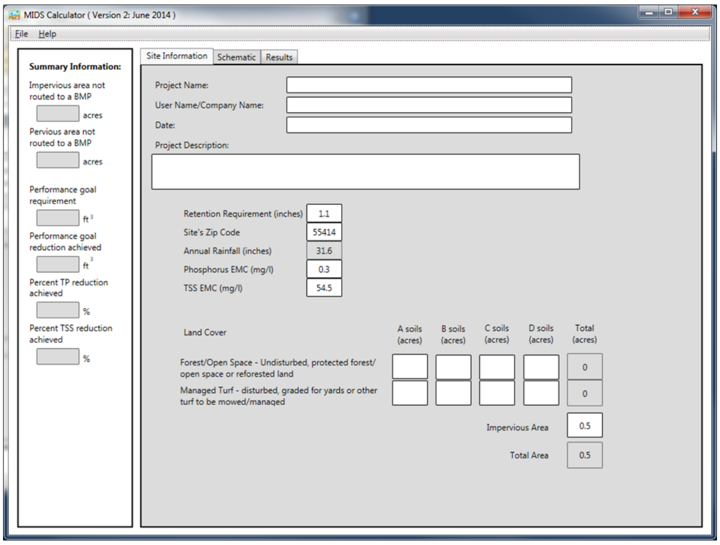
Schematic used for the green roof example. in this example, a 0.25 acre traditional roof is routed to a 0.25 acre green roof, for a total impervious area of 0.50 acres. See Step 1.

A green roof is going to be constructed on an existing 0.5 (21,780 square feet) acre roof. The green roof will cover half (10,890 square feet) of the existing roof and contain media with a depth of 4 inches above the drainage system. Runoff from the entire roof will drain through the green roof. The following steps detail how this system would be set up in the MIDS calculator.

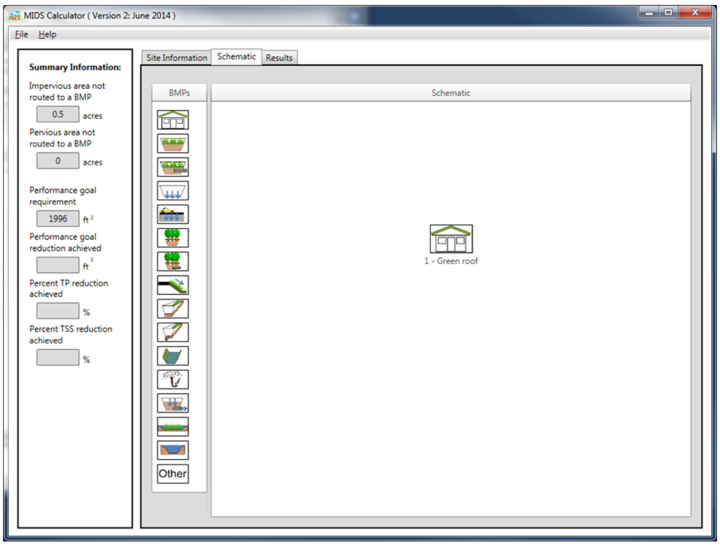
Step 1: Determine the watershed characteristics of your entire site. For this example we have a 0.5 acre site with all 0.5 acres being impervious (this is because the green roof portion is included in the impervious surface area).

Step 2: Fill in the site specific information into the *Site Information* tab. This includes entering a Zip Code (55414 for this example) and the watershed information from Step 1. Zip code and impervious area must be filled in. Other fields on this screen are optional.

Step 3: Go to the Schematic tab and drag and drop the “Green Roof” icon into the *Schematic Window*.



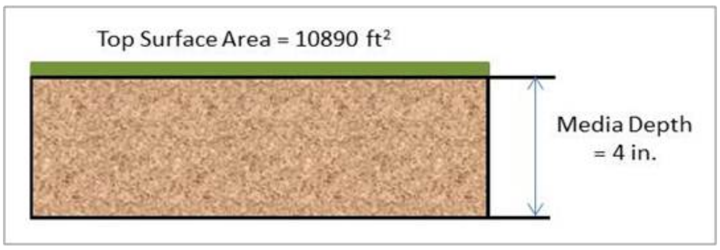
Screen shot of the site information tab for the green roof example. The User enters the zip code and site impervious area, which is 0.5 acres. See Step 2.



Screen shot of schematic tab for the green roof example.

Step 4: Open the BMP properties for the green roof by right clicking on the green roof icon and selecting *Edit BMP properties*, or by double clicking on the green roof icon.

Step 5: If help is needed, click on the *Minnesota Stormwater Manual Wiki* link or the *Help* button to review input parameter specifications and calculation specific to the Green roof BMP.



Schematic cross-section used for the green roof example for the MIDS calculator. See Step 7.

Step 6: Determine the watershed characteristic for the green roof. For this example the entire site is draining to the green roof therefore the watershed parameters include a 0.5 acre site with all 0.5 acres of impervious area. There is no routing for this BMP. Fill in the BMP specific watershed information, which is 0.5 acres of impervious cover.

Step 7: Click on the *BMP Parameters* tab and enter in the BMP design parameters. Green roof requires two entries.

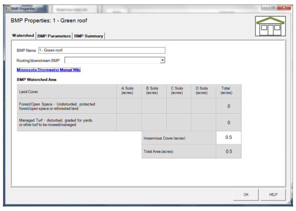
- The media depth, which is 4 inches in this example
- The surface area of the green roof, which is 0.25 acres or 10890 square feet. Note this is the area of the green roof, not the entire roof area draining to the green roof.

Step 8: Click on *BMP Summary* tab to view results for this BMP.

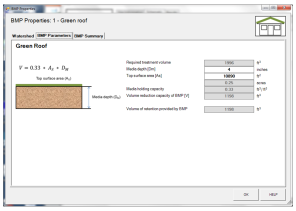
Step 9: Click on the *OK* button to exit the BMP properties screen.

Step 10: Click on *Results* tab to see overall results for the site.

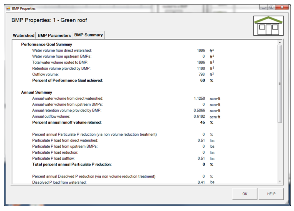
MIDS calculator screen shots for green roofs. Click on an image for enlarged view.



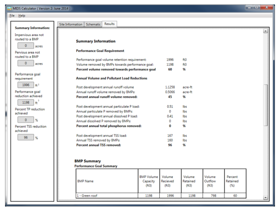
Screen shot of the watershed tab for the green roof example. See Step 6.



Screen shot of the BMP Paraemters tab for the green roof example. See Step 7.



Screen shot of the BMP Summary tab for the green roofs example. See Step 8.



Screen shot of the Site Results tab for the green roof example. See Step 10.

Information

Information: The following information may be useful in determining inputs for the MIDS calculator

- Information on green roof design
- Guidance on characteristics of different types of green roofs
- Information on green roof construction

Links to MIDS pages

- Overview of Minimal Impact Design Standards (MIDS)
- Performance goals for new development, re-development and linear projects
- Design Sequence Flowchart-Flexible treatment options
- Community Assistance Package
- MIDS calculator
- Performance curves for MIDS calculator
- Training and workshop materials and modules
- Technical documents

Related pages

- Green roofs
- Overview for green roofs
- Types of green roofs
- Design criteria for green roofs
- Construction specifications for green roofs
- Assessing the performance of green roofs
- Operation and maintenance of green roofs
- Cost-benefit considerations for green roofs
- Plant lists for green roofs
- Case studies for green roofs
- Links for green roofs
- References for green roofs
- Supporting material for green roofs
- Green roofs terminology and glossary
- Green roof fact sheet
- Requirements, recommendations and information for using green roofs as a BMP in the MIDS calculator

Plant lists for green roofs

Given adequate growing medium depth and irrigation, just about any plants, even trees, can be grown on green roofs. The plant list discussions below pertain to extensive green roofs.

While most of the first extensive green roofs in the US were planted with non-native succulent species, mostly Sedum species, the plant palette for green roofs in the United States, and in Minnesota, is rapidly expanding to include many herbaceous plants and grasses.

Species included on the plant lists below may not be appropriate for all projects. Suitability can vary with climate, microclimate, project goals, and maintenance budget. Many of these green roof species have not yet been tested in all of Minnesota. While a considerable number of green roofs have been installed in the Twin Cities area, few green roofs have been installed to date in more northern parts of Minnesota that have a harsh climate that will be challenging for green roof vegetation. The section on design criteria for green roofs provides guidance on factors that affect green roof plant selection.

Growing sedums and other succulent plants on green roofs

Sedums and other succulent plants are often used on green roofs because they are tolerant of the dry conditions found on most roofs. For example, Durhman et al (2006) found some Sedum species could survive and maintain active photosynthetic metabolism even after 4 months without water. A few of the hardiest sedum species for Minnesota are listed below, but these are only a very small portion of the huge palette of Sedums available on the market. Longer lists of succulents available for green roofs, are available, for example, in

- Getter, K.L.; Rowe, D.B. 2008. *Selecting Plants for Extensive Green Roofs in the United States*. Michigan State University Extension Bulletin E-3047. (View a slideshow [1] of this document)
- Snodgrass, E.C. and L.L. Snodgrass. 2006. *Green Roof Plants: A Resource and Planting Guide*. Timber Press.

Photo of sedums on the Target Center Arena green roof in Minneapolis, MN. Image Courtesy of The Kestrel Design Group, Inc.

Dvorak and Volder (2010) summarized North American green roof vegetation studies, including studies on growth of succulent plants on Midwestern green roofs. Other studies of succulents on Midwestern extensive green roofs that are not included in the Dvorak and Volder (2010) review include

- Butler, C., and C.M. Orians. 2011. *Sedum cools soil and can improve neighboring plant performance during water deficit on a green roof*. Ecological Engineering. 37(11). 1796–1803.
- Rowe, D. Bradley, Kristin L. Getter, and Angela K. Durhman. 2012. *Effect of green roof media depth on Crassulacean plant succession over seven years*. Landscape and Urban Planning (Elsevier) 104:310-319.
- Whittinghill, L.J. and D.B. Rowe. 2011. *Salt tolerance of common green roof and green wall plants*. Urban Ecosystems. 14(4):783-794.

Non-native succulent species appropriate for extensive green roofs in Minnesota. Note: Many species of sedums grow well on green roofs in Minnesota. The list below shows some of the most common species. Many other Sedum species can also perform well.

Link to this table

Scientific name	Common name	Plant height (inches)	Approximate bloom time	Flower color	Sun exposure	Winter interest
Allium schoenoprasum	Chives	10	Spring	White	Full sun to partial shade	Dormant
Sedum album	Stonecrop	6	Summer	White	Full sun	Red
Sedum hybridum 'Immergrünchen'	Stonecrop	6	Summer	Yellow	Full sun	Orange/bronze
Sedum kamtschaticum var. floriferum'Weihenstephaner Gold'	Russian Stonecrop	5	Summer	Yellow	Full sun	Red
Sedum kamtschaticum	Russian Stonecrop	6	Summer	Yellow	Full sun	Red
Sedum reflexum 'Blue Spruce'	Stonecrop	8	Summer	Yellow	Full sun	Blue-green
Sedum rupestre 'Angelina'	Golden Stonecrop	5	Summer	Yellow	Full sun	Coral/orange-red
Sedum sexangulare	Stonecrop	4	Summer	Yellow	Full sun to shade	Red
Sedum spurium 'Dragon's Blood'	Two Row Stonecrop	4	Summer	Red	Sun	Red

Growing native species on green roofs

Similarities between bedrock bluff prairies and green roof habitats. Image courtesy of The Kestrel Design Group, Inc.

Many species found in Minnesota's bedrock bluff prairies have also been found to grow well on Minnesota's green roofs. Bedrock bluff prairies have thin soil layers over bedrock and are often found along river bluffs. Plants growing in bedrock bluff prairies are adapted to growing conditions very similar to those found on many green roofs, including thin growing medium and high exposure to wind, sun and drought. Use of native prairie species on green roofs is controversial because most prairie species survive droughts by sending roots very deep into the soil to access water. The shallow growing medium of green roofs does not allow for such deep root growth. However, anecdotal observations in Minnesota, Michigan, Chicago IL and Lincoln NE, suggest that deep rooted native prairie species grow their roots horizontally on green roofs (Kestrel Design Group (2013), Sutton (2011), Grese (2008)).

Some studies have found that many native species do not survive on green roofs without irrigation (Monterusso et. al. (2005)). However, in some projects, certain native species thrive on green roofs without irrigation or with minimal irrigation. Since irrigation is needed during the plant establishment period anyway, many green roofs include an automatic irrigation system to provide water in times of drought.

Native species have been planted on at least five extensive green roofs in the Twin Cities area built between 2005 and 2009. The following table lists some of the native species that have performed well on green roofs in Minnesota (Kestrel Design Group observations). Because all of these except for one are irrigated regularly, the ability of most of these species to survive without irrigation on extensive green roofs in Minnesota is not known. Species that have been found to survive with little or no irrigation in Minnesota or elsewhere in the Midwest are noted.

Native species that have been grown successfully on extensive green roofs in Minnesota

Link to this table

Native plants on Minneapolis City Hall green roof, Minneapolis, MN. Image Courtesy of The Kestrel Design Group, Inc

Native Plants on Target Center Arena Green Roof, Minneapolis, MN. Image Courtesy of The Kestrel Design Group, Inc.

Native Plants on Phillips Eco-Enterprise Green Roof. Image Courtesy of The Kestrel Design Group, Inc.

References

[1] http://www.slideshare.net/Farrah85p/r2e367zzz

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