**GREEN ROOF DESIGN**

Note: The information in this section is not intended to be a comprehensive green roof design manual. The main goals of this section are to provide examples of issues to consider when designing a green roof, as well as factors that will affect stormwater treatment performance.

References that address green roof design include:

* ANSI/SPRI RP-14 Wind Design Standard for Vegetated Roofing Systems, available at [www.spri.org](http://www.spri.org)
* ANSI/SPRI VF-1 External Fire Design Standard for Vegetative Roofs, available at [www.spri.org](http://www.spri.org)
* ANSI/GRHC/SPRI VR-1 Procedure for Investigating Resistance to Root Penetration on Vegetative Green Roofs, available at [www.spri.org](http://www.spri.org)
* Cantor, S. L. 2008. [Green Roofs in Sustainable Landscape Design](http://books.wwnorton.com/books/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
* Green Roofs Tree of Knowledge (TOK): database on research and policy related to green roof infrastructure at http://www.greenroofs.org/grtok/
* 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. Downloaded from http://livingarchitecturemonitor.com/
* Mandel, L., 2013, EAT UP; The Inside Scoop on Rooftop Agriculture
* National Institute of Building Sciences. Whole Building Design Guide available at http://www.wbdg.org on 12/10/2012
* 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.

A typical progression for design of a typical green roof is shown in the 12 steps below.

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

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.

1. **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, for example, are (1) how deep growing medium will be, (2) whether or not additional structural support is financially feasible if needed, and (3) whether or not 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.

1. **Assemble Design Team**

Table 5.1 shows roles of various players that can be involved in green roof design and construction. Assemble team to fit project budget and goals, and level of complexity. Depending on the project, additional roles not shown in Table 5.1 may also be needed. INSERT Table 5.1

1. **Establish Goals**

Project goals can include, for example:

* Specific stormwater management goals
* Aesthetic goals
* Research and monitoring goals
* Specific uses, such as, for example, food production, gathering spaces
* Minimize building energy usage for heating and cooling
* Wildlife habitat goals
* Marketing and branding as part of an overall green building strategy
* Green building certification, eg. LEED or B3

1. **Estimate design, installation, and maintenance costs (see task 10)**
2. **Conduct lifecycle cost analysis (see task 10)**
3. **Determine project timeline**

* 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 F degrees or so, generally has long term negative impacts on plant health and should be avoided.
* See construction sequencing section for other issues to consider

1. **Determine green roof financial incentives available for project site, such as, for example, stormwater utility fee credits or grants.**
2. **Site analysis:**

Evaluate factors that affect roofing design, such as, for example:

* 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 10 A 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, for example, nature of intakes and exhausts onto the roof surface and presence of condensate 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
* Criteria presented by LEED, Sustainable Sites Initiative, Passive House, Living Building Challenge, etc.

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

See Table 5.2 for 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.

INSERT Table 5.2

1. **Design Green Roof**
2. ***Determine Implications of Roof Slope***

Specialized reinforcement is needed to protect green roofs on slopes steeper than 2:12 from sliding.

INSERT Figure 5.1: 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.

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.

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).

(provide link to <http://www.zinco-greenroof.com/EN/greenroof_systems/extensive_green_roofs/pitched_35.php> if we want to include an image)

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 studies of impact of slope 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.)

Examples of the magnitude of difference found in the studies that did find a correlation between green roof slope and stormwater retention are given 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%) at the lowest slope (2%) studied, and least (76.4%) at the greatest slope studied (25%). Retention was also greatest for light rain events (94%) and least for heavy rain events (63%).

Van Woert et al 2005 observed greatest retention (87%) at the lowest slope studied (2% slope), and least retention (65.9%) at the greatest slope studied (6.5%).

1. ***Determine what areas of the roof can be vegetated and what areas need to remain vegetation free.***

Green roofs may include vegetation free zones (hyperlink to 10 D m) designed, for example, 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.

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

INSERT Figure 5.2: Vegetation free zones at Target Center Green Roof, Minneapolis, MN, Image courtesy of The Kestrel Design Group, Inc.

The ANSI/SPRI VF-1 External Fire Design Standard for Vegetative Roofs, Available at <http://www.greenroofs.org/resources/ANSI_SPRI_VF_1_Extrernal_Fire_Design_Standard_for_Vegetative_Roofs_Jan_2010.pdf> 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, available at <http://www.greenroofs.org/resources/ANSI_SPRI_RP_14_2010_Wind_Design_Standard_for_Vegetative_Roofing_Systems.pdf> 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.

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.

1. ***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 are the primary driver of roof size, use MIDS or other credits calculator to determine green roof size needed to meet stormwater goals.

1. ***Determine project components desired and requirements for components***

The following components are part of almost all green roofs (hyperlink to definition of each in the glossary):

1. Waterproofing assembly
2. Root barrier (thermoplastic and thermoset membranes frequently do not require a root-barrier)
3. Protection layer
4. Drainage components
5. Filter layer
6. Growing medium
7. Wind or surface runoff erosion protection
8. Vegetation

Examples of optional green roof components are listed below:

1. Leak detection system
2. Water retention layer
3. Irrigation system
4. Edging
5. Vegetation free zone
6. Railing
7. Worker safety anchor systems
8. Amenities: for example, walkways, gathering areas, site furniture, water features, lighting, interpretive materials, other structural elements such as trellises and arbors

INSERT Figure 5.3: Typical Green Roof Sections, Images from [www.greenroofservice.com](http://www.greenroofservice.com)

INSERT Figure 5.4: Typical native soil vs. Typical Green Roof Profile, Images from [ZinCo](http://www.greenroofservice.com)

1. **Waterproofing assembly**

Choosing a durable, quality waterproofing assembly is crucial especially 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.

It is highly recommended that the waterproofing membrane is tested for leaks (see l, 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.

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.

INSERT Figure 5.5: Roof Membrane Installation at Target Center Green Roof, Minneapolis, MN, Image courtesy of The Kestrel Design Group, Inc.

1. **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 al 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, available at [www.spri.org](http://www.spri.org).

INSERT Figure 5.6: Root Barrier Welding, Image courtesy of Roofscapes

1. **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.

1. **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.

Drainage components typically include:

1. **Drainage layer**

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 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).

INSERT Figure 5.7: Aggregate Drainage Layer, Image courtesy of Roofscapes

1. **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: 1) easy access, 2) provide an enhanced pathway for surface water flow to enter the drain, and 3) improve the transition of subsurface flow into the drain.

1. **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.

INSERT Figure 5.8: Drain Access Chambers at Phillips Eco-Enterprise Green Roof, Minneapolis, MN, Image courtesy of The Kestrel Design Group, Inc.

1. **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.

1. **Growing medium**

“A combination of organic and inorganic matter than anchors plant roots, drains water from the roof, and sustains plant growth.” (Green Roofs for Healthy Cities and the Cardinal Group, 2006)

Growing medium characteristics that affect stormwater performance include:

* 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

1. **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, for example, include erosion control blanket, mats, or soil tackifier. Care must be taken not to damage waterproofing membrane when securing erosion control fabric. Once roof is fully covered with vegetation, vegetation typically protects soil from erosion.

INSERT Figure 5.9: Erosion Control Blanket and Native Plant Plugs at Minneapolis City Hall Green Roof, Minneapolis, MN, Image courtesy of The Kestrel Design Group, Inc.

1. **Vegetation**

**Plant selection**

Plant selection should be informed by, for example:

* 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
* 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.

See Task 4 for a list of examples of plant species that have been successfully grown on green roofs in Minnesota.

**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.

INSERT Figure 5.10: Plugs during Installation and One Year Later at Phillips Eco-Enterprise Green Roof, Minneapolis, MN, Image courtesy of The Kestrel Design Group, Inc.

INSERT Figure 5.11: Sedum Cuttings, Image courtesy of Roofmeadow

INSERT Figure 5.12: Progression of Sedum Cuttings Installation over Three Years, Image courtesy of Roofmeadow

INSERT Figure 5.13: Installation of Pregrown Sedum Mat, Image Courtesy of The Kestrel Design Group, Inc.

INSERT Figure 5.14: Installation of Pregrown Mats at Target Center Green Roof, Minneapolis, MN, Images Courtesy of The Kestrel Design Group, Inc.

Choice of technique used to install green roof vegetation will depend on, for example:

* Project goals
* How soon full vegetation cover is desired
* Budget
* Species
* Maintenance labor, accessibility, and budget

Table 5.3 shows some of the pros and cons of some potential green roof vegetation installation techniques. INSERT Table 5.3

A combination of techniques can be used to combine benefits of several techniques as well as to maximize vegetation resilience. For example:

* 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

**OPTIONAL COMPONENTS**

1. **Leak detection System**

Leak detection systems allow for pinpointing the exact location of leaks, and can also detect even small imperfections in the waterproofing.

INSERT Figure 5.15: Electronic Leak Detection at Target Center Green Roof, Minneapolis, MN, Images Courtesy of The Kestrel Design Group, Inc.

Milestones when leak detection testing is especially valuable, include, for example:

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

1. **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

1. **Irrigation System**

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.

INSERT Figure 5.16: Irrigation Installation at Minneapolis Central Library Green Roof, Minneapolis, MN, Image Courtesy of The Kestrel Design Group, Inc.

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\*\*
* Water harvested from air conditioning effluent\*\*
* Grey water harvested from baths, showers, and sinks\*, \*\*
* Municipal water
* Well water

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

\*\*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
* If no bare spots develop during drought, there is less chance of weed invasion.

Advantages of not irrigating extensive green roofs include:

* 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.

1. **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).

1. **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 quality 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.

See 10B for where vegetation free zones are generally located.

1. **Railings**

Railings are often required by code.

1. **Worker safety anchor systems**

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

1. **Amenities: for example, walkways, gathering areas, site furniture,** **water features, lighting, other structural elements such as trellises and arbors**

Walkways, furniture, and other amenities may also be desired on accessible roofs.

1. ***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 (determined according to ASTM 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. 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 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.
* See Task 6 for example vegetation performance requirements.

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

1. List of required submittals and when the submittals are due, including submittals related to materials as well as contractor qualifications
2. List of green roof performance requirements
3. Materials specifications for all green roof related components
4. Installation specifications
5. Maintenance specifications
6. Warranty requirements
7. Mockup requirements
8. **Refine project design, installation and maintenance, and lifecycle costs, based on green roof plan, specifications, and details.**
9. **Adjust design to fit budget if estimated capital or maintenance costs exceed budget.**

**GREEN ROOF CONSTRUCTION**

**Recommended Construction Sequence**

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, for example, all of the following that are relevant to the green roof project, as well any others involved in the green roof project: roofing, green roof, irrigation, leak detection, lightning protection, electrical, glaziers, mechanical, and general contractor. Designers should include, for example, all of the following that are relevant to the green roof project, as well any others involved in the green roof project: roofing consultant, green roof designer, irrigation designer, electrical and mechanical engineers.

Key factors in determining construction sequencing include:

* 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.

**REFERENCES**

Berndtsson, J. C. 2010. Green roof performance towards management of runoff water quantity and quality: A review. Ecological Engineering, 36, 351-360.

Cantor, S. L. 2008. [Green Roofs in Sustainable Landscape Design](http://books.wwnorton.com/books/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, 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., 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 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.

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.

National Institute of Building Sciences. Whole Building Design Guide available at http://www.wbdg.org on 12/10/2012

Snodgrass, E.C., and L.L. Snodgrass. 2006. Green Roof Plants. Timber Press, Portland OR.

Taylor, B. L. and Gangnes, D. 2007. Technical Memorandum: Stormwater Control Potential for Seattle Green Roof Retrofits. Seattle Public Utilities Green Roof Retrofit Study.

Van Woert, 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.