Technical Guidance Document for Green Roofs

Green Tier Clear Waters Initiative Charter

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I. OVERVIEW

A. Application

1. Green roofs can be an effective stormwater management practice employed over a wide range of applications but are most commonly employed on mid- to large-sized commercial, industrial, or residential structures in an urban setting. Green roofs may be most suitable as a stormwater management practice in dense urban settings where the potential for at-grade stormwater management is limited due to tight or contaminated soils, shallow bedrock, high groundwater, or where there are space constraints. Green roofs have also been shown to provide significant social, economic, and environmental benefits, particularly in an urban setting (City of Milwaukee ECO, 2019). The selection of which type of green roof to use should consider stormwater management benefits, climate, building parameters, maintenance requirements, intended use as an amenity space, as well as the long-term economics of installation and maintenance versus associated benefits.

B. Types of Green Roofs

Green roofs are generally classified as extensive, intensive, or semi-intensive. The type of green roof can further be categorized based on the type of assembly and system components. The following represent the primary types and systems of green roofs:

1. **Extensive green roofs** are characterized by a shallow growing medium—usually less than six (6) inches thick—with a modest roof load, limited plant diversity (typically sedum), lower cost, and typically lower watering and maintenance requirements.
2. **Intensive green roofs** are characterized by a deep growing medium–usually at least twelve (12) inches thick (this number may vary by municipality and may be as low as 6 inches if enhanced layers are added) and upwards to several feet. This depth of growing medium can support a more diverse plant selection, including small trees. They can be fully customizable and used on sloped roofs.
3. **Semi-intensive green roofs** share characteristics of both extensive and intensive roofs. Green roofs with portions of both extensive and intensive systems may be characterized as semi-intensive.
4. **Modular systems** consist of pre-assembled modules, each containing the various layers of the system and typically housed within a plastic tray or

container. Modular (tray) systems come in extensive and intensive types and are installed side-by-side to create a continuous green roof. They often require less expertise for installation but can create challenges for plant survivability due to the modular nature limiting root spaces as well as excessive heat absorption by the plastic containers.

5. **Layered systems** are built in-place on the roof and are typically associated with intensive systems. They can be fully customizable and used on sloped roofs.
6. **Enhanced systems** are typically a layered system that has additional layers added to increase water retention, reuse, and/or detention.
    a) A **sponge roof** enhances retention and reuse by adding an absorptive layer, typically made of needled mineral wool or thick layers of synthetic fabrics.
    b) A **blue-green roof** includes a sponge layer and a storage layer to provide additional detention storage.
    c) A **purple roof** system includes a sponge layer, a storage layer and a friction layer to further increase retention, detention, and reuse.

II. DESIGN CRITERIA & CONSIDERATIONS

A. Drainage Area

1. A green roof generally manages precipitation that falls directly on it and from adjacent walkways, patios, etc. Green roofs are generally not designed to handle significant runoff from other surfaces and should not be designed to accept runoff from impervious surfaces greater than the area of the green roof surface.

B. Roof Slope

1. The slope of a green roof impacts the detention volume and flow of water through the drainage layer. Increased slope can cause the green roof system to drain faster and should be considered during design for runoff management and plant selection.
2. Slopes steeper than 2:12 pitch (9.5 degrees) may need specialized reinforcement to protect the green roof system from sliding (Minnesota, 2022); an engineered slope stability analysis is recommended for slopes this steep.

C. System Layer Requirements

There are several types of green roof systems with variations in their system components and characteristics, but in general, most green roofs have the following layers or components (see Appendix 1):

1. Waterproofing Membrane
    a) Protects the roof material from moisture and leaks under the green roof. Design should follow the manufacturers' specifications and guidelines.
2. Root Barrier
    a) Protects roof (i.e., waterproofing membrane) from damage from plant roots.
    b) May not be needed if the waterproofing membrane is root resistant.
    c) Can be incorporated into the drainage layer.
3. Drainage Layer
    a) Design determines how much water is stored within the green roof system and how quickly water leaves the system.
    b) This layer can serve as retention or detention depending on the design requirements and can be designed to hold water for later use by plants. For example, it may contain voids for water storage or a high-storage-capacity (sponge) layer.
4. Filter Fabric
    a) This layer is installed directly under the growing media to prevent fines from migrating into the lower layers of the green roof system.
    b) Any filter fabric used for this purpose must be strong enough to support the weight of the growing media and vegetation.
    c) Roots are permitted to penetrate this layer.
5. Growing Media
    a) Provides the structure and nutrients for plant growth, allows rainfall to permeate into lower layers of the green roof system, and holds some of the runoff for later evapotranspiration from the surface. Also provides additional heat and noise insulation for the building.
    b) A lightweight, engineered aggregate is usually chosen to reduce roof loading. Mixes are generally 80-90% lightweight aggregate and 10-20% organic matter.
    c) Growing media should be tested using ASTM 2399 to determine the available water retention capacity value (percent by volume) for determining storage volumes and permeability. Permeability shall be at least 1 inch per hour (New Jersey, 2021).
6. Vegetation
    a) Vegetation can be established using plant plugs, cuttings, seed, pre-grown mats, or pre-vegetated modules.
    b) Each green roof is unique in its project goals, growing conditions, climate and micro-climate considerations, and maintenance requirements. The designer shall take all these into account when designing a green roof system for successful vegetation establishment and maintenance.

c) Choose plant species that are adapted to the soil and moisture conditions. The depth and composition of the growing media may limit the plant species that can thrive. Sedums are often chosen for extensive systems because they have shallow root systems and are adapted to conserve water. Intensive systems with deeper media depths can accommodate a larger variety of plants.
d) Native species are preferred, but the designer should choose plants that have the greatest chance to successfully establish.
e) The nutrient needs of the plants shall match that available in the growing media; care shall be taken that excess nutrients are not leaching out of the system.
f) Select species based on the local climate and the building micro-climates. Wind, temperature, sunlight, and rainfall (climate) all impact plant growth on green roofs; and those factors can vary in different areas of the roof (micro-climate), especially around the edges. Be aware of extreme conditions caused by edge effects, prevailing wind patterns, variable sunlight conditions, exhaust fans, and reflections from adjacent windows or siding. Consider no-planting zones as appropriate.
g) Planting should be avoided during the peak summer months due to the additional irrigation required.
h) See Appendix 2 for plant species recommendations.

D. Drains
1. Allows unconsumed water to exit the roof.
2. Drains that direct excess water off the roof should be kept free of vegetation and other organic matter to improve flow and reduce the risk of clogging.
3. In order to avoid potential erosion that may result from the concentration of flow on the rooftop, drains should be located on the roof so that the maximum flow length is 100 feet.

E. Irrigation
1. Irrigation, or the ability to irrigate when needed, is strongly recommended for all green roof systems.
2. Irrigation is an important design parameter and considerations should be made during the early design phases to accommodate this component.
3. Irrigation is required during plant establishment and during long durations without rainfall.
4. Moisture meters can be installed and used to determine when irrigation is necessary.

F. Leak Detection System

1. A leak detection system is recommended and shall be configured to identify the location of leaks within the green roof system. Leak detection systems shall be installed and used in accordance with manufacturer's specifications.

G. Equipment & Storage

1. Green roofs require regular maintenance. Space should be allocated for the needed equipment storage.
2. The design should provide appropriate storage and access (e.g., garbage shoot) for collecting and disposing of plant and other debris for maintenance activities.

H. Erosion Control

1. An erosion control plan shall be implemented to prevent erosion from exposed soils due to wind and rain during vegetation establishment.

I. Safety

1. Incorporate long-term safety measures into the design for both the installers and the maintenance workers.
2. Provide easy roof access and protection systems including, but not limited to: safety ladders, walkways, internal hatches, fall restraint or fall arrest systems, tie-offs, anchor points, lifelines, guard rails, and knee walls.
3. Consider not planting vegetation near the edge of the roof.
4. Ensure workers doing maintenance in elevated environments have proper training and personal protective equipment.

III. MODELING/CREDITS

A. Volume Reduction

1. Volume reduction on a green roof is achieved primarily through the drainage layer and growing medium components, which absorb and retain a portion of the rainfall that lands on it making it available for plant uptake and evapotranspiration.
2. For the calculation of runoff retention in the growing medium, the maximum available water capacity for runoff reduction is the difference in the water content between the field capacity and the wilting point.
    a) Field capacity is the water content of the soil after free drainage has ceased.
    b) Wilting point is the minimum soil moisture required by a plant to not wilt.
3. The following calculation provided in the New Jersey Stormwater Best Management Practices Manual can be used to estimate the reduction in runoff volume by a green roof (New Jersey, 2021).

Step 1: Calculate the runoff retention of the green roof

$$S_v = \frac{SA\ x\ [(d\ x\ \eta_1)+(DL\ x\ \eta_2)]}{12\ in/ft}, \text{ where:}$$

S_v = storage volume (cf)
SA = green roof area (sf)
d = media depth (in)
η_1 = available water capacity for runoff retention
DL = drainage layer depth (in)
η_2 = drainage layer field capacity

4. The values for field capacity and the wilting point of the selected growing medium must be obtained either from a published research article or tested in accordance with either the ASTM D-6836 method or the Soil Survey Investigations Report No. 42, Kellogg Soil Survey Laboratory Methods Manual, published by NRCS. The field capacity is tested at -10 KPa, for sandy material, or -0.33 KPa, for other materials. The wilting point is tested at 1,500 KPa under the ASTM D-6836 method or Kellogg Soil Survey Laboratory Methods Manual by NRCS (New Jersey, 2021).

B. Peak Runoff Rate Control

1. The peak rate control provided by a green roof is dependent on the storage volume provided by the roof and can be estimated using an adjusted Curve Number (CN). The following procedure outlined in the New Jersey Stormwater Best Management Practices Manual can be used to estimate the peak runoff rate from a green roof.

   Step 1: Calculate the runoff retention of the green roof
   Step 2: Calculate the discharged runoff volume
   Step 3: Calculate the direct runoff depth
   Step 4: Determine the Adjusted Curve Number (CN)
   Step 5: Calculate peak flow rates by Adjusted Curve Number

2. The adjusted CN will vary and must be calculated separately for each storm event when assessing peak rate control performance.
3. The time of concentration is calculated based on the vegetation condition, roof slope, and drainage path.
4. See Appendix 3 for additional information on the New Jersey procedure for determining the Adjusted Curve Numbers of a green roof, which can then be used in hydrologic modeling software to determine peak flow rates coming from the green roof.

C. Total Suspended Solids (TSS) Reduction

1. No credit shall be granted for TSS reduction for water passing through or over a green roof system; however, TSS reduction on a site-wide basis can be realized through a reduction in the overall volume of stormwater due to retention in the green roof (USEPA, 2009).
2. Other Considerations:
    a) Filtering layer must be included below the growing media and above the drainage layer to reduce migration of solids into system effluent.
    b) During vegetation establishment, consider implementing additional downstream measures to reduce TSS loading from leaving the site.

D. Phosphorus

1. No credit shall be granted for Total Phosphorus (TP) reduction for water passing through or over a green roof system; however, TP reduction on a site-wide basis can be realized through a reduction in the overall volume of stormwater due to retention in the green roof (USEPA, 2009).
2. The designer and owner should minimize concentrations of phosphorus in system effluent by appropriate selection of system components, proper maintenance procedures, and use of plants which require minimal fertilizing and will be most efficient in uptake of applied nutrients (nutrient cycling).
3. If nutrient management (including phosphorus) is required on a site, green roofs should be used in conjunction with other downstream measures which are designed to control nutrients to form a “treatment train”.
4. Other Considerations:
    a) Prior to application of fertilizers, a soil analysis should be completed to determine available nutrients and nutrient deficiencies and to optimize plant vigor. Avoid application of unneeded nutrients as they can result in higher concentrations of nutrient runoff.
    b) Consider collection and re-use of stormwater effluent from the green roof system to further reduce runoff volume and nutrient discharge.
    c) Effluent phosphorus concentrations have been shown to positively correlate with seasonal patterns and temperature, with the highest concentrations occurring during the warm temperature growing season; although the overall mass discharge can remain low due to the retention of water (USEPA, 2009).
    d) Effluent phosphorus concentrations have been shown to be reduced with age of green roof and establishment of plant community, assuming proper vegetation and growing media management practices are being maintained (Minnesota, 2022).

IV. CONSTRUCTION

A. Overview

1. Construction of green roofs can be complex and involve many trades working in a coordinated fashion to ensure proper construction methods and sequencing are adhered to.
2. A pre-construction meeting with the designer and installer, along with other key personnel, shall be required to review the construction plans and schedule/sequencing.

B. Specifications

Detailed specifications should be prepared which cover the procurement and installation of the green roof. See Appendix 4 for example specifications. At a minimum, specifications should include these outlined sections (ZinCo, 2018):

1. Submittals
    a) Require documentation of the following:
        (1) Product data, including all products and materials used in the construction process
        (2) Samples of any products as requested by the design team
        (3) Manufacturer's Certificates which verify manufacturer's experience
        (4) Closeout submittals, which provide the documentation necessary for the owner to maintain and repair the products used
2. Quality Assurance
    a) Manufacturer's qualifications
    b) Installer's qualifications
    c) Pre-installation conference
    d) Test all completed work to verify that it meets plans and specifications.
3. Materials Delivery, Storage, and Handling
    a) Measures to protect all materials and the adjacent site from damage throughout construction
4. Coordination
    a) Coordinate work with adjacent work trades.
    b) Provide sufficient supervision to oversee all construction procedures and ensure that they are being completed accurately and safely.
5. Documentation
    a) Maintain photo/video documentation of the pre-existing conditions, installation process, and final product.
6. Sequencing
    a) Complete work in proper order to ensure the highest quality and safe construction.
7. Project Conditions

a) Maintain environmental conditions throughout construction to meet design specifications.

8. Warranty
    a) Provide a warranty for materials and workmanship.

C. Other Considerations

1. A leak detection test is recommended to be completed after initial installation of waterproofing membrane, and again after all work is substantially completed on the roof, by a qualified technician in accordance with applicable standards and regulations. Electronic leak detection and moisture monitoring systems are recommended, as a flood test is generally considered insufficient for detecting small leaks (NJDEP, 2021).
2. Where required by project plans, Contractor shall implement and maintain short-term and long-term erosion protection practices to prevent clogging of the drainage system.
3. Keep heavy equipment off the green roof system components to avoid damage and/or compaction of the growing medium.
4. Ensure current project plan and specifications, including planting list species and quantities, are distributed to the project team.
5. Inspection of the green roof should be conducted during construction to ensure conformance to project plans and specifications. A detailed inspection checklist, including signoffs by qualified individuals at critical stages of construction, is recommended to be developed for use to ensure proper interpretation and installation of green roof components (Minnesota, 2022).

V. MAINTENANCE

A. Inspection Frequency

1. During vegetation establishment, green roofs shall be inspected at least twice per week. Irrigate as needed based on site specific planting requirements.
2. After vegetation has been established, the green roof system must be inspected at least four times annually (at least once each season) and after every storm or melt event exceeding one (1) inch.
3. Additional inspections shall be completed after major weather events including, but not limited to, high winds and periods of drought.

B. General Inspection

1. Inspect pipes, outlets, and overflows.
2. Inspect structures for cracking, erosion, and deterioration at least once each year.

3. Remove sediment, trash and debris as needed. Any clogs or blockages shall be removed as needed. Dispose of waste materials in accordance with local regulations.
4. Inspect the green roof for potential issues which may include displaced soil, weeds, plant health, pest control issues and roof drain issues.
5. Repairs must restore the component to the specifications of the original plan.
6. Snow should not be moved or piled on the roof. De-icing materials should not be used on the green roof.

C. Vegetation Inspection
1. It is strongly recommended to work with a landscaping professional to develop a site-specific plan and determine the appropriate frequency and timing for vegetation maintenance. Different parts of the green roof may require different maintenance procedures due to micro-climate conditions.
2. Vegetative cover shall be maintained at 80%. Dead vegetation and bare soil areas shall be addressed as soon as practical and in accordance with the original specifications.
3. Pruning and trimming of vegetation shall be performed on a regular schedule based on site specific conditions. Trimming, if needed, should be done using a string trimmer. Mowing with other equipment can damage the roof.
4. Review and record plant health, density, and diversity with each inspection.
5. Periodically check soil depth and moisture levels across the planted area. Add growing media to the system as needed to maintain design depths.
6. Use integrated pest management practices to minimize use of pesticides. Only use products and methods acceptable to membrane roofing manufacturer.
7. To prevent the spread of weeds, it is recommended to do visual inspections every other week during the growing season and pull any weeds before they go to seed.
8. Look for and remove debris and dead vegetation. Minimize disruption to remaining vegetation when removing unwanted growth.
9. Restoration of plant material shall be by plugging, not seeding alone.

D. Access and Safety
1. In elevated environments, maintenance workers shall use appropriate fall protection and have proper training using these measures. Fall protection measures should be inspected annually.
2. Mitigate fire risk by removing dry/dead vegetation regularly. Keep fire breaks around the perimeter of the planting bed clear of rubbish. Increase inspection during long dry spells and irrigate as needed.

E. Drain Time
1. The green roof facilities shall be deemed to have failed if standing water is evident 72 hours after a rainfall event has ended. Ponding beyond 72 hours may

result in odor, water quality, and mosquito breeding issues, vegetation loss, drain clogging, and damage to the roof. If the system has failed, the soil and plantings in the affected area shall be replaced to ensure proper infiltration and seepage into the underlying drain tiles.

F. Irrigation

1. If an irrigation system is present, it should be turned on after the last frost in the spring and turned off before the first frost in the fall.
2. In the fall, the irrigation system should be properly winterized, typically by being blown out and drained.
3. Do not water the green roof between October 15 and April 1, unless growing conditions are present, including temperatures above 55 degrees Fahrenheit. If temperatures are unseasonably warm, manually water the green roof and take care to drain the system at the end of each watering.
4. Consult your green roof manufacturer or landscaping professional to determine your irrigation duration and timing, making adjustments depending on the climate and micro-climate of the building.
    a) A typical irrigation schedule for native vegetation roofs in the Midwest during the establishment phase may consist of watering 2-3 times daily, for 5-10 minutes each cycle, so that the soil remains damp.
    b) Once the roof is established, water no more than once daily for 5-10 minutes each cycle.
5. Use a water sensor to minimize water use and monitor soil moisture.

VI. CONSIDERATIONS

A. Fire Resistance

1. Green roof design should include considerations for fire barriers, firebreaks, and border zones at key locations (ANSI, 2017).
2. The designer must adhere to all applicable building codes and other requirements related to mechanicals, access and egress, and other requirements related to fire protection.
3. Consideration should be given to the type of vegetation planted, its anticipated stress response due to drought, residual matter from dead vegetation, and its associated susceptibility to fire. Emphasis should be given when designing an intensive green roof system due to its ability to sustain a larger variety of plant species, or one which contains additional elements which would contribute to a fire hazard.

B. Vegetation

1. Choosing vegetation to increase biodiversity and provide pollinator and other wildlife habitat may be a project goal, especially considering the overall decline

of biodiversity and habitat with development in urban areas. Choosing native plants is the best way to accomplish this. Straight native species, as opposed to "nativars" (native cultivars), should be chosen whenever possible, as they have more genetic diversity and thus are more resilient to varying growing conditions. While very popular for green roofs because of their shallow root systems and drought tolerance, very few sedum species are native to Wisconsin.

2. Aesthetics play a role in vegetation selection. Consider bloom color and timing for flowering species so there are colorful blooms throughout the growing season. In addition, aesthetics during dormant periods (winter) should be taken into consideration. Consider views of the green roof for building occupants as well as views from adjacent buildings.
3. When selecting plants, the designer should also consider installation, maintenance, and accessibility.
    a) In some extensive tray systems, plants are established in a greenhouse prior to installation. This can reduce follow-up maintenance requirements as there may be less weed establishment pressure since the plants are already filling the soil media and shading out weed seeds.
    b) If plants will be established on the roof, choosing plant plugs or potted plants can speed up establishment compared to starting from seed.
    c) Starting green roof vegetation only from seed is not recommended due to the added irrigation, weeding, and monitoring requirements.
    d) Vegetation selection can impact the amount and type of maintenance necessary. Vegetation with high maintenance needs should be easily accessible and have a water source for irrigation during drought periods.

VII. REFERENCES

1. City of Milwaukee Environmental Collaboration Office (ECO), Milwaukee Metropolitan Sewerage District (MMSD), et al, City of Milwaukee Green Infrastructure Plan (2019) (https://city.milwaukee.gov/ImageLibrary/WCC/Images/GreenLots/FINALGIPLAN--reduced_2.pdf)

2. Minnesota Pollution Control Agency, Green Roof Guide (no date) (https://stormwater.pca.state.mn.us/images/2/2e/Green_roofs.pdf)

3. Minnesota Pollution Control Agency, Minnesota Stormwater Manual (2022) (https://stormwater.pca.state.mn.us/index.php?title=Overview_for_green_roofs)

4. New Jersey Department of Environmental Protection (NJDEP), New Jersey Stormwater Best Management Practices Manual, Chapter 9 (2021)

(https://www.nj.gov/dep/stormwater/bmp_manual/NJ_SWBMP_9.4-gree-roofs.pdf)

5. Berghage, R., D. Beattie, A. Jarrett, C. Thurig, F. Razaei, and T. O'Connor - U.S. Environmental Protection Agency (USEPA), Green Roofs for Stormwater Runoff Control, EPA/600/R-09/026 (2009) (https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=205444&Lab=NRMRL)

6. Approved American National Standard (ANSI) & Single Ply Roofing Industry (SPRI), ANSI/SPRI VF-1: External Fire Design Standard for Vegetative Roofs (2017) (https://www.spri.org/download/ansi-spri_standards_2020_restructure/vf-1/ANSI_SPRI-VF-1_External-Fire-Design-Standard-for-Vegetative-Roofs_2017.pdf)

7. ZinCo Corp, Guide Specifications for Extensive Green Roof System (2016, Revised 2018) https://zinco-usa.com/sites/default/files/system_specs/SPS_Sloped%20Sedum_Georaster.pdf

VIII. ADDITIONAL RESOURCES

1. The Water Research Foundation, Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (2021) (https://www.waterrf.org/research/projects/economic-framework-and-tools-quantifying-and-monetizing-triple-bottom-line)

2. Seol, Sophia - Dane County Office of Energy & Climate Change, Green Infrastructure for Dane County: Benefits Add Up (2020) https://daneclimateaction.org/initiatives/Green-Infrastructure

3. ASTM International (ASTM), ASTM E2399/E2399M-19: Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems (2019) https://www.astm.org/e2399_e2399m-19.html

4. ASTM International (ASTM), ASTM D6836-16: Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, or Centrifuge https://www.astm.org/d6836-16.html

5. R. Burt, Soil Survey Staff, et al - USDA & NRCS, Soil Survey Investigations Report No. 42, Kellogg Soil Survey Laboratory Methods Manual (2014)

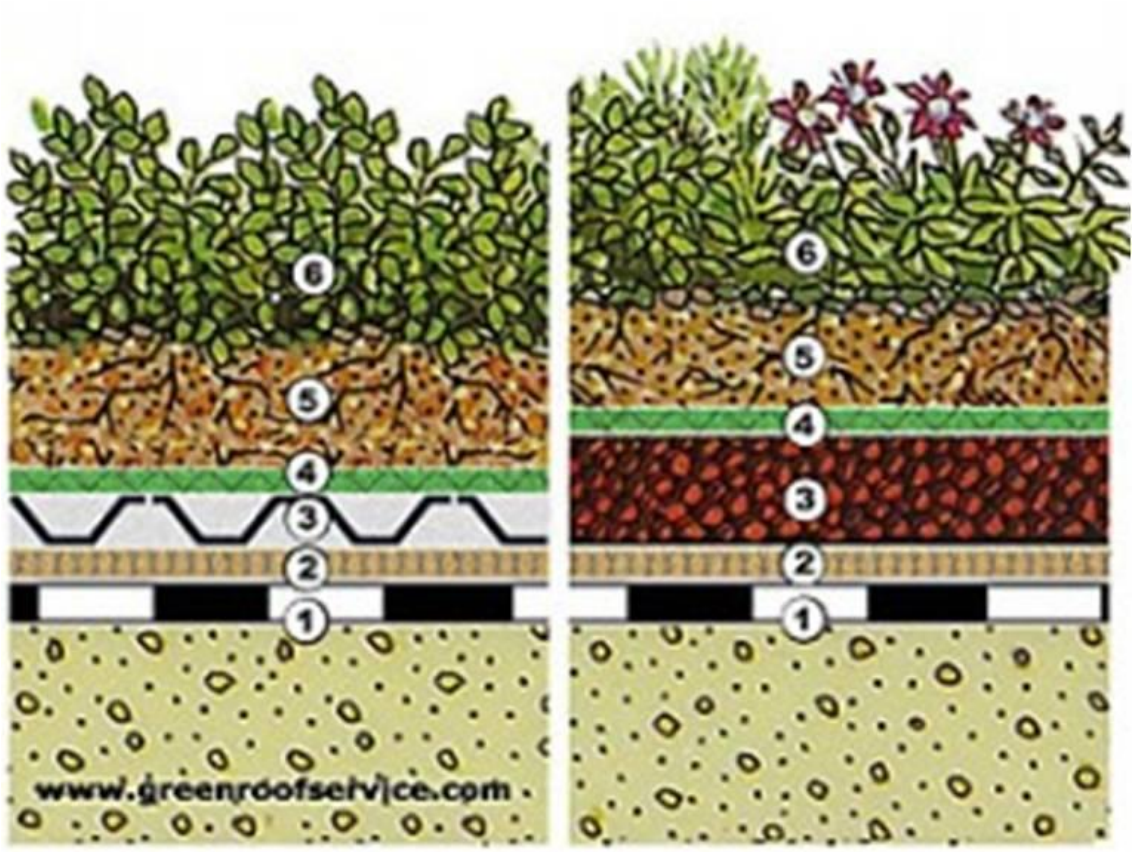
6. Green Roof Specialty Products, The Purple-Roof Concept (no date) https://www.purple-roof.com/

7. Approved American National Standard (ANSI) & Single Ply Roofing Industry (SPRI), ANSI/SPRI RP-14 2016: Wind Design Standard for Vegetative Roofing Systems (2016) https://www.spri.org/wpfb-file/ansi_spri-rp-14-2016-wind-design-standard-for-vegetative-roofing-systems-pdf-2/

8. Natural Resources Conservation Service (NRCS), National Engineering Handbook - Part 630 Hydrology, 1997 https://directives.sc.egov.usda.gov/viewerfs.aspx?hid=21422

Appendix 1

Typical Green Roof Components



1. The Roof Deck with insulation and waterproofing
2. Protection and moisture storage layer
3. Drainage Layer
4. Filter Layer
5. Growing Media
6. Green Roof Plants

https://stormwater.pca.state.mn.us/images/9/9b/Typical_green_roof_sections_2.jpg

Appendix 2

Plant Lists

This appendix provides a summary of performance results provided by Taylor Creek Restoration Nurseries. Results are based on green roof native plant nursery trials performed at their facility just south of Brodhead, WI over a period of 12 years (2006-2018) using 4” and 8” depth GreenGrid Vegetative Green Roof System trays.

4" Depth Modules	
Scientific name	**Common Name**
Best Performing Natives (> 75% survival)	
Allium cernuum*	Nodding Onion
Aster azureus	Sky Blue Aster
Aster ericoides	Heath Aster
Aster laevis	Smooth Blue Aster
Bouteloua curtipendula*	Side-Oats Grama
Carex bicknellii*	Copper-Shouldered Oval Sedge
Carex muhlenbergia	Muhlenberg's Sedge
Coreopsis lanceolata	Lance-leaf Coreopsis
Dalea candida	White Prairie Clover
Eryngium yuccifolium	Rattlesnake Master
Fragaria virginiana	Wild Strawberry*
Geum triflorum	Prairie Smoke
Heuchera richardsonii	Prairie Alumroot
Koeleria cristata	June Grass
Liatris cylindracea	Dwarf Blazing Star
Opuntia humifusa	Eastern Prickly Pear Cactus
Penstemon hirsutus	Hairy Beardtongue
Rudbeckia hirta	Black-eyed Susan
Solidago ptarmicoides	Upland White Goldenrod
Sporobolus heterolepis*	Prairie Dropseed
Tradescantia ohiensis	Ohio Spiderwort
Worst Performing Natives (< 50% survival)	
Anemone cylindrica	Thimbleweed
Anemone patens wolfgangia	Pasque Flower
Asclepias tuberosa	Butterfly Weed
Aster sericeus	Silky Aster
Camassia scilloides	Wild Hyacinth
Coreopsis palmata	Prairie Coreopsis
Dalea purpurea	Purple Prairie Clover
Echinacea pallida	Pale Purple Coneflower
Lespedeza capitata	Round-headed Bush Clover
Lupinus perennis occidentalis	Wild Lupine

Lycopus americanus	Water Horehound
Panicum leibergii	Prairie Panic Grass
Phlox pilosa	Prairie Phlox
Verbena stricta	Hoary Vervain
Zizia aptera	Heart-leaf Golden Alexanders

*Thrivers - populations doubled or more

8" Depth Modules	
Scientific name	**Common Name**
Best Performing Natives (> 75% survival)	
Allium cernuum*	Nodding Onion
Anemone cylindrica	Thimbleweed
Anemone patens wolfgangiana	Pasque Flower
Aster ericiodes	Heath Aster
Aster laevis	Smooth Blue Aster
Aster pilosus	Frost Aster
Aster sericeus	Silky Aster
Carex bicknellii*	Copper-Shouldered Oval Sedge
Coreopsis palmata*	Prairie Coreopsis
Dalea candida	White Prairie Clover
Dalea purpurea	Purple Prairie Clover
Echinacea pallida	Pale Purple Coneflower
Eragrostis spectabilis	Purple Love Grass
Heuchera richardsonii	Prairie Alumroot
Lespedeza capitata	Round-headed Bush Clover
Liatris aspera	Button Blazing Star
Liatris cylindracea	Dwarf Blazing Star
Opuntia humifusa	Eastern Prickly Pear Cactus
Panicum leibergii	Prairie Panic Grass
Penstemon digitalis	Foxglove Beardtongue
Penstemon hirsutus*	Hairy Beardtongue
Phlox pilosa	Prairie Phlox
Ratibida pinnata	Yellow Coneflower
Schizachyrium scoparium	Little Bluestem
Senecio pauperculus	Balsam Ragwort*
Solidago ptarmicoides	Upland White Goldenrod
Solidago rigida	Stiff Goldenrod
Sporobolus heterolepis*	Prairie Dropseed
Teucrium canadense	Germander*
Tradescantia ohiensis	Ohio Spiderwort
Verbena hastata	Blue Vervain
Worst Performing Natives (< 50% survival)	
Asclepias tuberosa	Butterfly Weed
Lupinus perennis occidentalis	Wild Lupine
Solidago speciosa	Showy Goldenrod

Verbena stricta	Hoary Vervain
Zizia aptera	Heart-leaf Golden Alexanders

*Thrivers - populations doubled or more

Additional plant resources for Upper Midwest locations:

- Selecting Plants for Extensive Green Roofs in the United States - Michigan State University https://archive.lib.msu.edu/DMC/extension_publications/e3047/E3047.pdf
- Plant Lists for Green Roofs - Minnesota Stormwater Manual https://stormwater.pca.state.mn.us/index.php/Plant_lists_for_green_roofs
- An Evaluation Study of Plants for Use on Green Roofs - Chicago Botanic Garden https://www.chicagobotanic.org/downloads/planteval_notes/no38_greenroofplants.pdf

Appendix 3

Adjusted Curve Number Calculations

This appendix provides an expanded overview of the procedure used to determine the adjusted Curve Number (CN) of a green roof, which can then be used in hydrologic modeling to determine peak flow rates coming from the green roof. This procedure is adapted from the New Jersey Stormwater Best Management Practices Manual, Chapter 9.4: Green Roofs (New Jersey, 2021).

Step 1: Calculate the runoff retention of the green roof

$$S_v = \frac{SA \times [(d \times \eta_1) + (DL \times \eta_2)]}{12\ in/ft}, \text{ where:}$$

S_v = storage volume (cf)
SA = green roof area (sf)
d = media depth (in)
η_1 = available water capacity for runoff retention
DL = drainage layer depth (in)
η_2 = drainage layer field capacity

Step 2: Calculate the discharged runoff volume

a. Calculate stormwater runoff volume produced by each of the design storms being analyzed using approved NRCS methodologies, assuming the green roof is a traditional impervious rooftop.

   Note: the Rational and Modified Rational Methods cannot be used for this calculation.

b. Subtract the storage volume, S_v, calculated in Step 1 from the stormwater runoff volume calculated in Step 2a for each of the storm events. The result is the runoff volume to be discharged from the green roof during each of the storm events being analyzed.

Step 3: Calculate the direct runoff depth

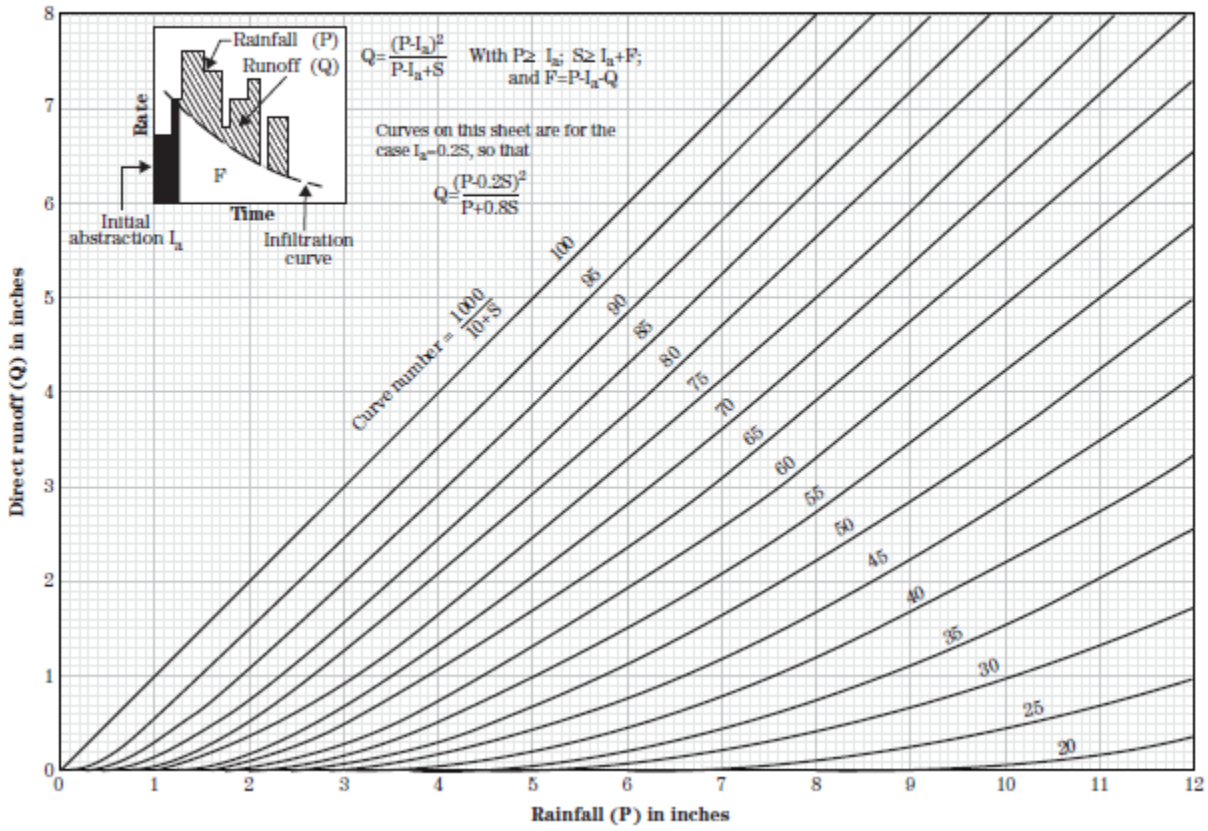
Divide the discharged runoff volume for each of the storm events calculated in Step 2 by the green roof area. The result is the direct runoff, *Q* (in), in the NRCS method or in Equation 10-11 of the *National Engineering Handbook (NEH), Part 630, Hydrology*.

$$Q = \frac{reduced\ runoff\ volume\ (cf) \times 12\ in/ft}{green\ roof\ area\ (sf)}$$

Step 4: Determine the Adjusted Curve Number

Use the direct runoff depth, *Q*, calculated in Step 3 and the rainfall precipitation (P) for each of the storm events being analyzed, to find the corresponding adjusted CN value in Figure 10-2 from the NEH, Part 630, Hydrology, reproduced below:

Figure 10–2 ES–1001 graphical solution of the equation $Q = \frac{(P - 0.2S)^2}{P + 0.8S}$



Step 5: Calculate Peak Flow Rates by Adjusted Curve Number

Calculate the time of concentration and use it along with the adjusted CN determined in Step 4 to calculate the peak flow rates of each of the storm events using NRCS methodology.

Note: The time of concentration of a green roof must be calculated based on the vegetation condition, roof slope and drainage path. A green roof with dense vegetation and a milder slope may provide a longer time of concentration, which will slow down the discharge of the roof runoff and lower the peak rate of the runoff. The time of concentration must be calculated in accordance with the velocity method described in the NEH, Chapter 15 - Time of Concentration.

Appendix 4

Example Construction Specifications

This appendix provides a sample of important components to include in construction specifications for the construction and installation of a green roof. This example specification is adapted from the *Guide Specifications for Extensive Green Roof System* (2016, Revised 2018), prepared by ZinCo USA Inc.

PART 1 GENERAL

SUBMITTALS

A. Product Data:
    1. Drainage Panels: Manufacturer's data sheets on each product to be used, including:
        a) Preparation instructions and recommendations.
        b) Storage and handling requirements and recommendations.
        c) Application procedures.
    2. Vegetation: Manufacturer's data sheets on each product to be used, including:
        d) Drainage panel root barrier.
        e) Vegetated roofing system, components, growing media type, and planting types with descriptive published data indicating characteristics and limitations.
        f) Include standard details, system components, and proposals for plant types and characteristics.
        g) Include manufacturer's installation instructions, special procedures, and conditions requiring special attention.
        h) Storage and handling requirements and recommendations.
B. Samples: Provide samples for each product specified.
C. Manufacturer's Certificates: Certify products meet or exceed specified requirements.
D. Closeout Submittals:
    1. Submit manufacturer warranty and ensure forms have been completed in Owner's name and registered with manufacturer.
    2. Manufacturer's instructions for Owner maintenance of planting media as needed for long term propagation and health of vegetation. Include special provisions as applicable for specific plant media and climatic zone.

QUALITY ASSURANCE

A. Manufacturer Qualifications: Company specializing in manufacture of green roof systems?
B. Installer Qualifications: Adequate experience for installing specified products?
C. Single-Source Responsibility: Obtain waterproofing and vegetative roof assembly components and materials from a single manufacturer regularly engaged in the manufacturing and supply of the specified products.
D. Pre-Installation Conference:
    1. Schedule a conference to be held on-site, or virtual, in advance of ordering materials and beginning application of roofing. Provide not less than 72 hours advance notification to attendees, Owner, and Architect.

2. Conference attendees shall include Owner, Architect, Contractor, roofing installer and representatives of other trades whose work may interface with or affect roof system application.
3. Topics to be discussed at conference shall include:
    a) A review of Contract Documents and accepted shop drawings shall be made. If conflicts exist between roofing system manufacturer's specifications and Contract Documents, these differences shall be defined and resolved.
    b) Establish trade-related work schedules and appropriate trade sequencing, including timely installation of equipment and penetrations to protect and limit traffic on membrane roofing.
    c) Review protection course, drainage layer, filter layer, water retention layer, growing, media and plant materials.
    d) Verify water source and connections for temp water and any future irrigation system. Verify placement of automated irrigation system and controls, if applicable.
    e) Construction schedules and work methods shall be reviewed to prevent damage to roofing, including provisions for installation of temporary traffic paths or walkways for protection of finished roofing system.
    f) Weather conditions and working temperature criteria shall be reviewed.
    g) Pre-construction conference and inspection shall serve to clarify Contract Documents, application requirements and what work shall be completed before application can begin.
    h) If a roofing applicator or representative of roof system manufacturer discovers problems during inspection of substrates, a second pre-application shall be held to verify that corrective measures have been taken.
    i) Following Waterproofing Membrane Testing and acceptance, if required, and prior to installation of vegetative roof system and plantings meet at site with installer and Owner's maintenance personnel to review procedures and Owner expectation.
4. Prepare and submit to parties in attendance, Architect, and Owner's a written report of each pre-installation conference. Reports shall be submitted within 3 days following the conference.

DELIVERY, STORAGE, AND HANDLING

A. Deliver pre-packaged materials in manufacturer's original unopened packaging with labels intact. Packaging or containers shall fully identify brand, type, grade, class, and other qualifying information used to describe contents.
B. Storage: Take measures to locate and spread loads in a manner to not exceed load bearing capacity of roof deck.
    1. Store all materials over plywood panels or protective sheeting and do not allow products, growing media, grit, debris, and pedestrian traffic on an unprotected roofing membrane.
        a) Maintain health of plant media as recommended by nursery guidelines prior to rooftop installation.
        b) Provide a water source for irrigation of and maintenance of plants until established.

COORDINATION

A. Coordinate Work of this section with associated roof mounted equipment, roof penetrations and related metal flashings as work of this section proceeds.
B. Supervision - Supervision during construction is recommended to ensure that the vegetated roof is built in accordance with these specifications. Inspection checklists should be used that include signoffs by qualified individuals as critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and manufacturer.
C. Safety
    1. Pre-Construction – discuss the prescribed safety plan in pre-construction planning.
    2. During Construction - establish a safe working environment for installation of the green roof. Provide fall protection through edge distance, handrails or anchor points for tie-off restraint.
    3. Post-Construction – provide permanent fall protection for maintenance activities for the green roof

DOCUMENTATION

A. Photos / Videos
    1. Pre-construction – document the existing conditions prior to starting the green roof construction.
    2. During Construction – document each step of the process
    3. Post – Construction – document the finished product prior to turn-over.

SEQUENCING

A. Apply roofing systems in a timely manner, including installation of protection layer(s), drainage panels, and insulation in conjunction with work of other trades. Coordinate with other trades to avoid traffic over completed membrane surfaces. Coordinate with installation of drains as shown on Drawings, including flashing, and associated waterproofing work.
B. Water tests of completed sections of waterproofing membrane shall be successfully completed before proceeding with protection layers and overburden. Schedule water tests promptly to allow timely installation of protection layers.

PROJECT CONDITIONS

A. Maintain environmental conditions (temperature, humidity, and ventilation) within limits recommended by the manufacturer for optimum results. Do not install products under environmental conditions outside manufacturer's absolute limits.
B. Ambient Air Temperature: Install plant materials preferably between April 1 and November 1 at temperatures between 40- and 95-degrees F, except as otherwise instructed by the supplier. Do not install if extended freezing temperatures are expected or if ambient growing media temperature is expected to remain below 50 degrees F.

WARRANTY

A. Contractor’s Warranty:
    1. Provide a workmanship warranty for not less than two-years commencing from Date of Substantial Completion.
B. Vegetation Warranty:

1. Provide a 2-year vegetation thrive coverage warranty of a minimum 50 percent thrive coverage at the end of the first year and minimum 80 percent thrive coverage at the end of the second year.

PART 2 PRODUCTS

DRAINAGE PANEL AND VEGETATED ROOF COMPONENT APPLICATION

A. General Requirements:
    1. Proceed with vegetated roof component application only after roof waterproofing and testing is complete. Obtain acceptance from the membrane manufacturer's field representative before proceeding with application.
    2. Install in accordance with membrane manufacturer's instructions and warranty restrictions, if any.
    3. Protect the waterproofing or roof membrane as necessary to prevent damage during application of vegetated roof system.
B. Prefabricated Drainage Panel: Place prefabricated soil drains under planters and all areas to be vegetated using the patterns indicated on the Drawings.
C. Place growing media to the depth required.
D. Pre-planted Vegetative Media:
    1. Install edging, if specified, along the perimeter border between vegetation-free zones and vegetated areas. Ensure modules fit tightly within the edging perimeter so that modules fit over flange feet.
    2. Place modules according to the landscape design and following the approved recommendations of the manufacturer.
    3. Modules shall be uniformly watered to sufficiently saturate the vegetation and soil media from top to bottom. Water shall be free of substances harmful to plant growth. The contractor shall furnish hoses or other methods of temporary irrigation.
E. Irrigation System:
    1. Install irrigation controller unit in location as per irrigation drawings.
    2. Install sprayers and supply lines as per irrigation drawings.
    3. Test system.
F. Pavers for Access:
    1. Fully support all edges.
    2. Shim and adjust pavers to provide level surface.

PROTECTION

A. Protect installed products until completion of project.
B. Waterproofing: Protect membranes after installation and testing.
    1. Eliminate construction traffic on newly tested membrane systems. Do not store construction materials on unprotected membrane surfaces.
    2. Membrane areas that are observed to be trafficked or used as a storage/working platform shall be retested and immediately repaired and covered with insulation and drainage composite.
C. Vegetated Roof Components:
    1. Protect installed vegetated roof system from construction traffic and subsequent construction operations.
    2. Maintain plants in a vegetated roof for a period of one year after Substantial Completion.