Page Content

Overview for green roofs

This page provides general information

Green Infrastructure: 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.

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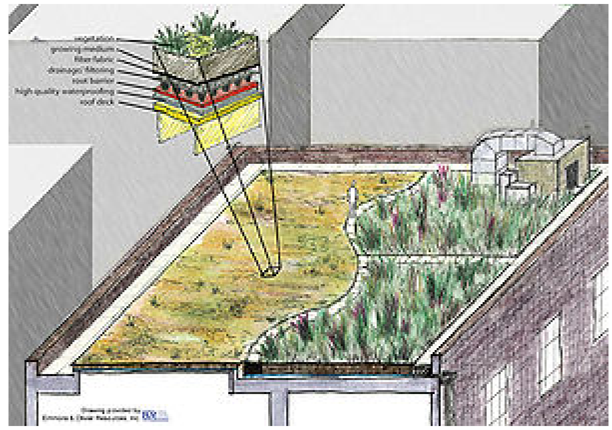
For a literature review of green roof benefits, see File:Green roof benefits.docx.

Contents

Function within stormwater treatment train

Green roofs (https://stormwater.pca.state.mn.us/index.php?title=Green_roofs) occur at the beginning of **treatment trains** (https://stormwater.pca.state.mn.us/index.php?title=Using_the_treatment_train_approach_to_BMP_selection). 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 (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program) (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.

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 (stormwater credit)** (https://stormwater.pca.state.mn.us/index.php?title=Overview_of_stormwater_credits) for combined stormwater treatment, as described in the Construction permit. Due to the statewide prevalence of the MPCA permit, design guidance (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_green_roofs) 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.

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

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 **highly urban and ultra-urban environments** settings.

Special receiving waters suitability

The following table provides guidance regarding the use of green roofs in areas upstream of **special receiving waters** (https://stormwater.pca.state.mn.us/index.php?title=Special_Waters_and_Impaired_Waters).

Infiltration and filtration bmp[1] design restrictions for special waters and watersheds. See also Special waters and other sensitive receiving waters.
Link to this table

BMP Group	receiving water A Lakes	B Trout Waters	C Drinking Water[2]	D Wetlands	E Impaired Waters
Infiltration	RECOMMENDED	RECOMMENDED	NOT RECOMMENDED if potential stormwater pollution sources evident	RECOMMENDED	RECOMMENDED unless target TMDL pollutant is a soluble nutrient or chloride
Filtration	Some variations NOT RECOMMENDED due to poor phosphorus removal, combined with other treatments	RECOMMENDED	RECOMMENDED	ACCEPTABLE	RECOMMENDED for non-nutrient impairments

[1]Filtration practices include green roofs, bmps with an underdrain, or other practices that do not infiltrate water and rely primarily on filtration for treatment.

[2] Applies to groundwater drinking water source areas only; use the lakes category to define BMP design restrictions for surface water drinking supplies

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** (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_bioretention#Materials_specifications_-_filter_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. (http://www.fll.de/)) guidelines for saturated **hydraulic conductivity (k)** 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 (http://www.sd-w.com/civil/mannings_formula.html), or similar. Green roofs do not have **curve numbers**, since nothing infiltrates.

Times of concentration in the context of TR-55 (https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf), 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 (http://www.astm.org/) 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 maximum media water retention (MMWR), the quantity of water held in a media at the maximum media density of the media using the ASTM E2399 (https://www.astm.org/standards/e2399) 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 (http://stormwater.pca.state.mn.us/index.php/File:Green_roof_pollutant_removal.docx)

Median pollutant removal percentages for several stormwater BMPs. Sources (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs#References). More detailed information and ranges of values can be found in other locations in this manual, as indicated in the table.
Link to this table

Practice	TSS	TP	PP	DP	TN	Metals[1]	Bacteria	Hydrocarbons
Infiltration (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices)[2]	3	3	3	3	3	3	3	3

Practice	TSS	TP	PP	DP	TN	Metals[1]	Bacteria	Hydrocarbons
Biofiltration and Tree trench/tree box with underdrain	80	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	50	35	95	80
Sand filter	85	50	85	0	35	50	80	80
Iron enhanced sand filter (http://stormwater.pca.state.mn.us/index.php/Iron_enhanced_sand_filter_%28Minnesota_Filter%29)	85	74	85	60[6]	35	50	80	80
Dry swale	68	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	35	0	80	80
Wet swale	35	0	0	0			0	
Constructed wet ponds[4, 5]	84	46	84	0	30	70	60	80
Constructed wetlands	73	38	69	0	30	70	60	80
Permeable pavement	74	41	82	0				
Green roofs	85	0	0	0				

TSS=Total suspended solids, TP=Total phosphorus, PP=Particulate phosphorus, DP=Dissolved phosphorus, TN=Total nitrogen

[1]Data for metals is based on the average of data for zinc and copper

[2]BMPs designed to infiltrate stormwater runoff, such as infiltration basin/trench, bioinfiltration, permeable pavement with no underdrain, tree trenches with no underdrain, and BMPs with raised underdrains.

[3]Pollutant removal is 100 percent for the volume infiltrated, 0 for water bypassing the BMP. For filtered water, see values for other BMPs in the table.

[4]Dry ponds do not receive credit for volume or pollutant removal

[5]Removal is for Design Level 2 (https://stormwater.pca.state.mn.us/index.php?title=Requirements,_recommendations_and_information_for_using_stormwater_pond_as_a_BMP_in_the_MIDS_calculator#Pollutant_Reduction)

[6]Removal is for Tier 2 iron enhanced sand filter. Tier 1 removal is 40 percent, resulting in a TP removal of 65%

Related pages

- Green roofs
- Overview for green roofs
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- Construction specifications for green roofs
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- Operation and maintenance of green roofs
- Cost-benefit considerations for green roofs
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- Green roof fact sheet
- Requirements, recommendations and information for using green roofs as a BMP in the MIDS calculator