PENNSTATE

College of Agricultural Sciences Cooperative Extension

Agricultural and Biological Engineering

F262

Green Roofs

Albert R. Jarrett, Professor of Biological Engineering
Robert D. Berghage, Associate Professor of Horticulture

The Pennsylvania Stormwater manual recommends vegetated roofs (green roofs) as a stormwater low impact development (LID) practice. Research at Penn State has shown that green roofs provide considerable reduction in the volume of stormwater leaving a developed site and they reduce the peak rates of runoff. Green roofs are unique in that they have the ability to capture and retain a volume (depth) of rain from each rainstorm. This captured water is then evapotranspired back to the atmosphere through the green roof vegetation. The purpose of this fact sheet is to provide guidance on how green roofs can be constructed and how they can be expected to contribute to solving stormwater problems.

Green roofs are typically characterized as intensive (having 6 to 24 inches of media and large vegetation) or extensive (having 3 to 6 inches of media and smaller vegetation). This fact sheet will focus on extensive green roofs.

Extensive green roofs are a surface treatment for rooftops, typically less than 6 inches in depth, involving the addition of growth media and plants to create a sustainable green space on a flat or nearly flat roof. Extensive green roof advocates have claimed numerous benefits including improved air quality, stormwater attenuation, reduction of the "heat island effect," extended roof life, and aesthetic value.

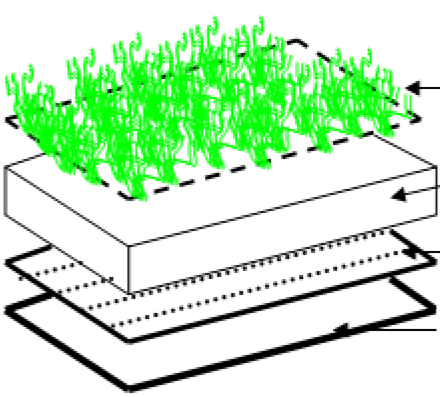

Figure 1. Green roof profile schematic including materials typically included in construction.

The general design of a green roof consists of four distinct layers: an impermeable roof membrane and root barrier, a drainage layer, lightweight growth media, and adapted vegetation, see Figure 1.

Stormwater Benefits

The stormwater benefits offered by green roofs include delaying the runoff peak and decreasing the peak rate of runoff from the building simulating runoff characteristics expected from a meadow. In Pennsylvania 50 to 60% of the rain falling on a green roof will be captured and evapotranspired back to the atmosphere, thus never entering the stormwater system. These benefits, in combination with the limited open space in cities, make green roofs a practical method for easing the pressure on storm drainage systems. Finally, green roofs intercept stormwater before it runs off a roof, which addresses the stormwater issue at the source rather than after the runoff has been collected.

Disadvantages

The two most frequent concerns expressed about using green roofs is the cost and the possible need to provide additional reinforcement to the structure. Commercially designed and installed green roofs often cost \$20 to \$30/ft^2. Careful selection of media and willingness to do some of the installation can greatly reduce this amount. Though the structural integrity of a roof should always be evaluated by a qualified engineer, we have found that if a building is designed and built to present-day codes, an extensive green roof can typically be placed on the roof without any additional reinforcement.

Green Roof Components

Roof Membrane. Before a green roof can be installed, the roof must be covered with an impermeable membrane that will not let roots penetrate.

Drainage Layer. The drainage layer is an open, highly drainable material that quickly channels gravitational water to the down-slope edge of the roof. The drainage layer is usually a thin layer (about 0.5 inches thick) of plastic netting or small chambers that receive the water flowing downward through the media and then channel this excess water to the edge or outflow location of the roof where a downspout takes the water to ground level. There are a number of products available and some folks are simply placing a 0.5-inch layer of pea-gravel between the roof membrane and green-roof media to serve as the drainage layer. We have used an ENKA[1] product with a layer of spunbonded geotextile on its top to keep the growth media from entering the drainage layer.

Growth Media. The growing media performs several functions. In addition to providing a suitable rooting zone for the selected vegetation, the medium should be of low density and have high water-holding capability. The lighter weight allows for retrofit installation on existing buildings, and also reduces the need for extra structural support in new buildings. This media layer also provides some insulation, depending on the thickness of the medium, properties of the medium, and its water content. The thickness of this layer also plays an important role in stormwater retention. Most of the commercially available media are produced by heating clay, shale, or slate to a high temperature. This heating process causes the base material to expand and develop more pores and a lighter density. This expanded material forms the base of the media. Usually peat, compost, or another light-weight organic material is mixed with the base to form the media used on a green roof. Most of these commercially available media have an average porosity of about 55% and a field capacity of about 30%. A 3.5-inch deep growing media provides an average of about 1.6 inches of water retention storage.

Plants. The environment on a green roof is harsh. Green roof plants are exposed to the hottest and driest conditions as well as the wettest and coldest conditions. The more successful plants have been succulents, especially the many varieties of sedums. Those who have tried green roofs have experimented with varying types of plants, some successfully and others not as much so. The plants provide shade to the surface below the foliage, intercept rainfall, and slow the movement of runoff from sloped roofs. We recommend that you consult a Horticulturist for more information about appropriate plant materials in your area.

1 Company names are included for clarity and do not imply endorsement of these products by the authors or Penn State University.

Green Roof Maintenance

Generally green roofs do not need much maintenance. Check the roof once or twice each year to make sure the plants are healthy and to pull a few weeds that may have made their way onto the roof. Extensive green roofs are not usually irrigated, except during the plant establishment period.

Green Roof as a Stormwater BMP

There are two important ways to look at a green roof's impact on stormwater runoff. The first is to answer the question, "how much of the total annual precipitation is expected to be captured and retained on the roof?" This question addresses the volume reduction provided by the green roof. The second question is to examine "how effective the green roof is in attenuating the peak runoff rate from varying sized (especially larger) storms."

Impact of Green Roof on Total Annual Runoff. To assess the volume of rainwater a green roof could be expected to capture and retain, the 28-year (1976-2003) daily rainfall record for State College, PA was applied to a green roof. This simple spreadsheet model accounted for daily evapotranspiration and adjusted the depth of storage available in the green roof media on a daily basis. Figure 2 shows the daily rain and associated daily green roof runoff for 1993 in State College, PA for a green roof having a maximum of 1.6 inches of water retention storage. Note that there was very little, if any, runoff during the May 1 to Sept 30 growing season. When these results were averaged over the 28-year simulation period, a 3.5-inch deep green roof was able to capture and retain 55% of the annual rainfall. This assessment has been repeated for eight weather stations across Pennsylvania and the results are similar. Extensive green roofs will capture and retain about 55% of the annual rainfall thereby reducing stormwater runoff to the storm drainage system in Pennsylvania. Keep in mind that this assessment only applies to the green roof footprint, which is typically less thasn 90% of the building footprint, not the whole parcel being developed.

When the depth of water stored in the green roof growing media was treated as a variable (roof storage was varied from 0.25 to 3.0 inches of storage) using the 28 years of State College's daily rainfall data, the results (see Figure 3) showed that the 3.5-inch green roof with 1.6 inches of water storage with a drainage layer and plants, was an excellent choice. Note that very little additional retention was experienced when the storage capacity was increased (simulating a green roof with a greater depth of media). Note also that when the roof's storage capacity was decreased (simulating a green roof with a lesser depth of media), considerable retention was experienced. The

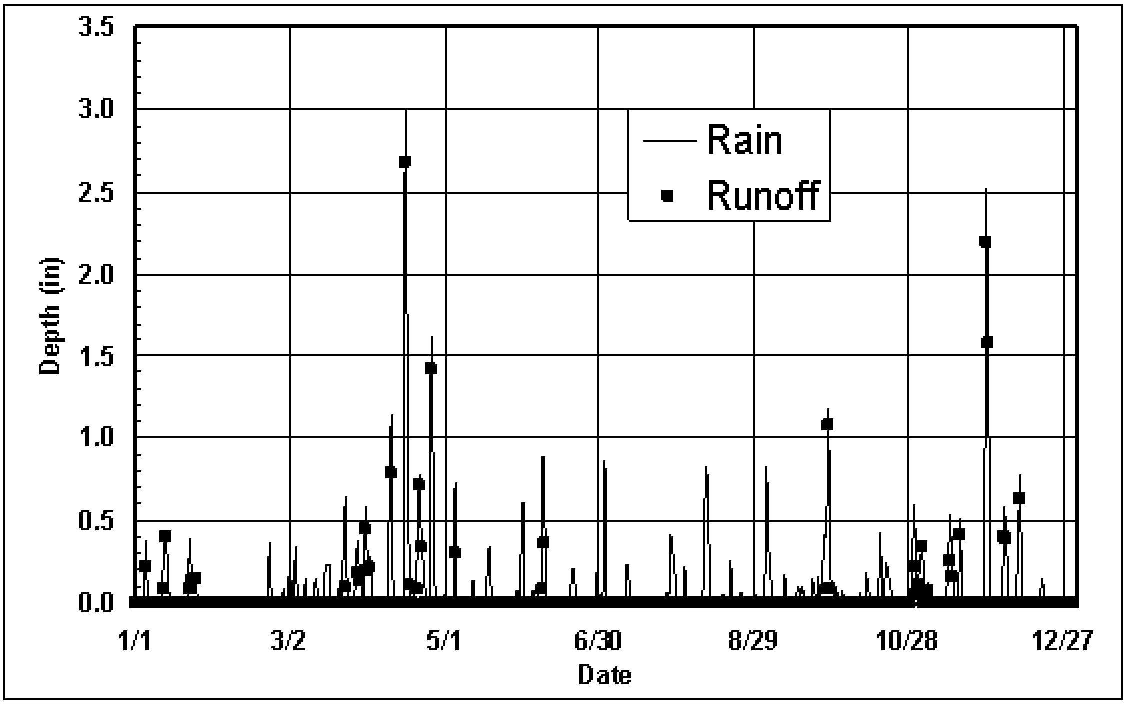

Figure 2. Daily rain and green roof runoff depth for 1993 in State College, PA for a green roof having 1.6 inches of storage.

extreme condition tested was a roof (probably no longer green or having media) with only 0.25-inches of storage. This is equivalent to spreading one or two layers of geotextile on the roof. The quarter-inch storage capacity was capable of capturing and retaining about 35% of the annual rainfall.

The Excel spreadsheet model used to simulate the annual capture and retention capacity of green roofs is available at the following website: http://www.abe.psu.edu/fac/jarrett/greenroofmodels/. The model named GR&BRAStateCollegeAssess.xls was used in this analysis. It is relatively easy to replace the State College rainfall data with daily rainfall data from your area and see the impact of a green roof in your area. The ET functions used in this model are for central Pennsylvania. To our knowledge, these green roof ET data have not been evaluated in other locations. You are welcome to download and use this model though we provide no technical support for the model.

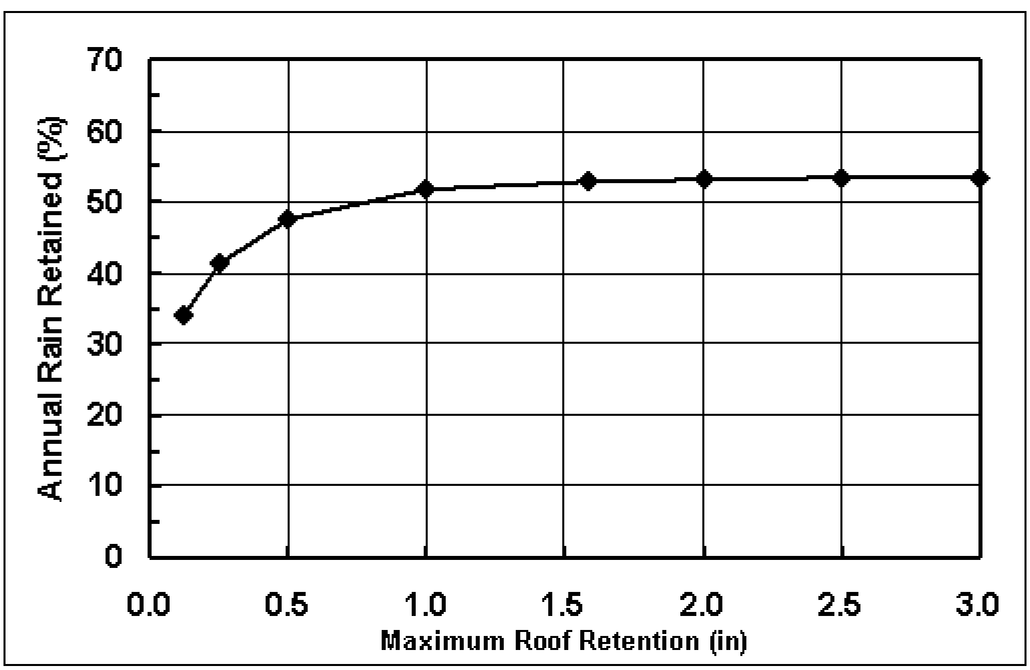

Figure 3. Annual rain retained by green roof as maximum roof retention (storage in the roof media) changes for State College, PA.

Impact of a Green Roof on Individual Rainfall Events. Just as a stormwater basin can be modeled to show what effect each basin is expected to have on a specific runoff hydrograph, a green roof can also be modeled. With a green roof, however, the setup for routing the event is more complex. First, you must consider that it is the rainfall hyetograph (rainfall intensity vs time), not a runoff hydrograph that must serve as the input to the green roof. Second, the green roof is a dynamic water flow system that has the ability to capture, retain, and release rainwater. The roof media also supports a plant growth system that transpires and evaporates water back to the atmosphere. All of these inputs and outflows must be quantified to create the stage-storage relationship needed for the routing model. The remaining input is a roof drainage relationship, which represents the stage-outflow relationship. This must be determined for each specific roof experimentally.

With the input and initial conditions data in place, some assumption must be made about the daily weather conditions when the "large" storm to be modeled occurred. Any of the 12 months can be chosen and the number of days since the last rainfall event can be set to any number between 0 and 21.

This spreadsheet model was applied to a wide range of actual and synthetic storms typical of central Pennsylvania. For any synthetic type-II storm evaluated it was assumed that the storm occurred following five non-rain days in July.

Based on these inputs and assumptions, the model accurately simulated all storms measured at our research site. It also showed that the 3.5-inch green roof, with 1.6 inches of storage was able to attenuate to the level of a pre-development (land use = meadow) synthetic rainfall events used in the design of stormwater facilities in the range of 2- to 100-year return period. This evaluation was repeated for similar storms in the dormant season and the results were similar.

The Excel spreadsheet model used to simulate the individual-storm responses is available at the following website: http://www.abe.psu.edu/fac/jarrett/greenroofmodels/. The model named GreenRoofRoute…xls is the model used in this analysis. Inputs must be made on all three sheets: First, choose a roof # (cell N10) and a roof size (cells E15 & E16). You can input your own roof outflow data in the chart if you have the data. Second, on the "Rain" sheet copy your synthetic rainfall hyetograph into columns D (time) and E (intensity). If you are using experimental rainfall data the rainfall hyetograph can be put into columns K and L. Third, on the "Setup" sheet, select the rain data (cell R4), the month being simulated (cell E40), and the number of days since the last rain (cell E39). With these cells adjusted to fit your situation, the routed response is shown on the "Setup" sheet below row 80. There are numerical answers as well as graphical charts. You are welcome to download and use this model though we provide no technical support for the model.

Summary

Green roofs are very effective stormwater BMPs. A typical extensive green roof of 3.5 inches depth will reduce the volume of runoff by about 55% in central Pennsylvania and attenuate the peak runoff rates to the level of the predevelopment land use. Their major drawback is the initial cost. More information about green roofs and the Center for Green Roof Research at Penn State can be accessed at http://horticulture.psu.edu/cms/greenroofcenter/

PSU
First Ed. 10/09