Green Roofs: Optimizing the Water Quality of Rooftop Runoff

Brett Long[1], Shirley E. Clark[1], Katherine H. Baker[1], Robert Berghage[2]

[1]Environmental Engineering, Penn State Harrisburg
[2] Department of Horticulture, Penn State University Park

Corresponding Author: Brett Long, bvl101@psu.edu

Abstract

While green roofing is an accepted stormwater control technology, little is known about the quality of the roof runoff. In Phase I of this research, several green roof media (formed from commonly-used expanded minerals, stormwater filter media, and organic matter) were evaluated for their abilities to retain the pollutants from a synthetic acid rain. The samples were analyzed for metals, nutrients, and pH. The hypothesis was that a mixed media that is "better" at pollutant removal and permanent retention could be created based on these laboratory testing results. A media composed of expanded shale, granular activated carbon, and sphagnum peat moss was the most effective. In Phase II, the optimized media is being field-tested on a green roof. The effluent quality is being compared to both its influent and to the runoff from a galvanized metal roof to determine whether the green roof provides significant water quality benefits.

Introduction

Green roofing is a best management practice for urban stormwater quantity management. However, more research is required to determine the impact green roofs can have on urban stormwater quality, especially the effect of optimum media selection on effluent quality. The two primary research objectives are the following: 1. To develop an effective media for green roofs that will improve roof runoff quality while maintaining the known water retention benefits, and 2. To determine if roofing will generate lesser pollutant loadings into urban runoff than traditional roofing materials.

Several studies have investigated the water quality of green roof runoff compared to the runoff of tradition roofing materials. A study at Penn State's Green Roof Research Center showed that green roof media has tremendous buffering capacity for acid rain (Berghage, 2005). A study conducted at North Carolina State University media utilizing filter columns showed that increasing the organic matter content of green roof media leads to an increase in nutrient leaching, which, in turn, led to an increase in nutrients in the runoff. Another study conducted in Estonia investigated the water quality of a lightweight aggregate and humus green roof runoff compared a bituminous membrane roof found that during light to moderate rainfall events the concentrations of COD, BOD, total nitrogen, and total phosphorus were greater in the bituminous roof. However during heavy rainfalls greater amounts of nitrogen and phosphorus washed from the green roof (Teemusk, 2007). A study conducted in Sweden found that conventional fertilizers substantially increased the concentration and total amount of nutrient runoff, while controlled release fertilizers contributed less.

Methodology

Phase I. The first task was to determine what medium will be the most effective in filtering atmospherically-deposited pollutants while not leaching pollutants itself. Researchers column tested several green roof media in three different phases (expanded mineral only, expanded mineral/stormwater filter additive, and expanded mineral/filter additive/organic matter). These materials were evaluated in the descending volumetric content. These media were evaluated for their abilities to retain the pollutants from a synthetic acid rain. We filled 4-in. diameter filter columns with different mineral media including two different gradations of expanded shale, two expanded clays (one with nutrient additives and one without), and an expanded slate, all on top of green roof drainage material and a filter fabric. The media depths were 4 inches.

The weight of media in each column was also recorded in order to normalize removals to unit weight. Replicates were run for each medium. Control columns containing green roof drainage material and filter fabric were also tested. Simulated rainwater at a pH of 4.5 and spiked with common stormwater pollutants was poured through each filter column using a device to spread and slow the flow. The filtered water samples were collected and analyzed for those pollutants using EPA, Standard, and HACH methods.

Pollutant loads applied into the columns from the simulated acid rain and the loads in the filtered samples were calculated for each "event" by multiplying the volume of rain applied or the amount of filtrate collected with the concentration of pollutant in the rain or sample. Since all columns were done in duplicate, the mean was calculated for each mineral type and applied to the load calculations. In addition, the cumulative normalized pollutant loading was calculated for each pollutant on each media by summing the individual storm loads and dividing by the weight of the media.

Next, a variety of storm water filter sorbents, cation exchange materials, and anion exchange materials (two zeolites, granular activated carbon, polymers) were tested in similar manner. These materials were added to the selected expanded mineral at recommended dosages.

Finally, different organic matter sources were added in low volumes to the mineral and additive combination and tested in the same manner as the two previous series of tests. The organic matters of interest were different gradients of leaf litter compost and peat.

Phase II. Following the laboratory optimization test pilot scale roofs were built outside on the Penn State Harrisburg campus. Three identical pilot scale green roofs were constructed using the selected medium. These roofs were made by placing one half inch of drainage material, a piece of geotextile, and three inches of the medium in a 23.5 by 29.5 inch HDPE box. The roofs were then planted in sedum spp. In addition, three traditional roofs were made by placing a sheet of galvanized aluminum in identical HDPE boxes. Three control roofs (only HDPE) were constructed also. All setups have a drain at the bottom to send all the runoff into a collecting cistern. At the end of each storm event, the quantity of water in these cisterns is measured. The quality of the runoff is being tested for at least two storms per month. These samples are being analyzed for pH, conductivity, metals, nutrients, and bacteria. These are the same analytes as listed in the media optimization section, with the addition of bacteria. Also, three rain gauges have been adapted to measure flow rate and volume from each roof type.

The loading of pollutants from both the traditional and the green roof will be compared. Since green roofs reduce the volume of runoff compared to traditional materials, it important to compare loads in addition to concentration. This is important for those pollutants, such as nutrients, for which loadings can affect water quality because of chronic exposure and chronic toxicity.

Results

The laboratory studies showed that the green roof media was able to buffer pH to near-neutral or above-neutral values. The fine-grade expanded shale had the highest buffering capacity. In addition to its buffering ability, the fine graded expanded shale consistently performed very well at removing pollutants from the simulated acid rain. Based on these results, the expanded shale was the "best" choice of the minerals we tested for the engineered mix. The medium grade expanded shale also performed well and was added to the mineral portion of our engineered mix to improve the hydraulic properties of our media in a 50:50 (v/v) ratio. The results from the additive portion of the study showed that some additional nutrient retention can be obtained using low volumes of additives. The zeolite and GAC additives both retained some nutrients. However, the GAC performed best on a per weight basis and was used in the final mix. Metals retention was not substantially improved over that seen with just the mineral media. The most noteworthy result from the organic matter was that the addition of high volumes of organic matter caused substantial nitrate leaching. Also, overall data trends for multiple parameters show that the peat we tested was "better" than the leaf litter compost.

The final media mix carried to the field study was 42.5% medium-grade expanded shale, 42.5% fine-grade expanded shale, 10% sphagnum peat moss, and 5% granular activated carbon by volume.

In the field study we found that the pH of the runoff from the green roofs was substantially raised. Ammonia and Nitrate loads were also reduced by the green roofs. Total phosphorus loads were only slightly greater for the green roofs. Zinc loads were much higher from the galvanized aluminum roofing compared to the green and control roof. The color of the runoff from the green roofs was greater. With respect to water quantity the green roof were found to reduce the volume of runoff substantially compared to the traditional and control roofs. Also, runoff peak intensities and peak delays were seen from the green roofs. Data collection and analysis is ongoing.

Conclusions

The laboratory testing has shown that engineering a green roof media for water quality improvement is possible. The mineral portion of the media should be considered first when the optimizing the media since it makes up the majority of the volume. Of the minerals tested, the expanded shale was selected because of its ability to retain the pollutants of interest. Granulated activated carbon was found to be the most effective low volume additive for additional pollutant removal. Sphagnum peat moss was the selected organic matter due to its minimal leaching of nitrogen and phosphorus. The field study showed that green roofs containing the optimized media substantially reduce nitrogen loads, although phosphate loads are slightly increased. Zinc loads from the galvanized aluminum roofs were much greater than the control and green roofs. Green roofs were also found to reduce runoff volume, peaks, and intensities. Plant development on these roofs was very slow, probably due to the lack of added fertilizers and minimal organic matter. However, the water quality, compared to traditional galvanized roofing, is improved, especially in relation to zinc, demonstrating that the media can play a substantial role in pollutant retention.

Acknowledgments

The authors would like to thank the Penn State Harrisburg Graduate Research Council and the Penn State Institutes of the environment for their funding of this project, and the Center for Green Roof Research for their donation of materials and expertise to the project development.

References

Berghage, R.D., D.J. Beattie, A.R. Jarrett, F. Rezaei, and A. Nagase. 2005. Quantifying evaporation and transpirational water losses from green roofs and green roof media capacity for neutralizing acid rain. Written for presentation at the World Green Roof Congress in Basel Switzerland. University Park, Pennsylvania: Pennsylvania State University.

Berghage, R., Beattie, D., Jarret, A., and O'Conner, T. 2007. Greenroof Runoff Water Quality. Greening Rooftops for Sustainable Communities 2007. Minneapolis, Minnesota.

DeNardo, J. C., A.R. Jarret, H.B. Manbeck, D.J. Beattie, and R.D. Berghage. 2003. Green Roof Mitigation of Stormwater and Energy Usage. ASAE Meeting Paper No. 032305. St. Joseph, Michigan: ASAE.

Dunnet, N. and N. Kingsbury. 2004. *Planting Green Roofs and Living Walls.* Portland, Oregon: Timber Press Inc.

Emilsson, T., Berndtsson, J.C., Mattson, J.E., and Rolf, K. 2007. Effect of Using Conventional and Controlled Release Fertiliser on Nutrient Runoff from Various Vegetated Roof Systems. Ecological Engineering, 29, 260-271.

Hafera, J., J. Elligson, S.Clark, J. Mikula, M. Lalor, S. Johnson. 2005. Presentation on

Wet-Weather Pollution from Commonly Used Building Materials. 2005 Pennsylvania Stormwater Management Symposium. Villanova University: Villanova, Pennsylvania. 12 October 2005.

Jarrett, A. 2005. Presentation on Storm Green Roof Stormwater Response Models. 2005 Pennsylvania Stormwater Management Symposium. Villanova University: Villanova, Pennsylvania. 12 October 2005.

Moran, A.C. 2004. A North Carolina Field Study to Evaluate Greenroof Runoff Quantity, Runoff Quality, and Plant Growth. Raleigh, North Carolina: North Carolina State University.

Teemusk, A. and Mander, Ü. 2007. Rainwater Runoff Quantity and Quality Performance from a Greenroof: the Effects of short-term events. Ecological Engineering, 30, 271-277.