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# Effect of a modular extensive green roof on stormwater runoff and water quality

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ABSTRACT

Runoff quantity and quality from a 248 $m^2$ extensive green roof and a control were compared in Connecticut using a paired watershed study. Weekly and individual rain storm samples of runoff and precipitation were analyzed for TKN, $NO_3 + NO_2$–N, $NH_3$–N, TP, $PO_4$–P, and total and dissolved Cu, Pb, Zn, Cd, Cr, and Hg. The green roof watershed retained 51.4% of precipitation during the study period based on area extrapolation. Overall, the green roof retained 34% more precipitation than predicted by the paired watershed calibration equation. TP and $PO_4$–P mean concentrations in green roof runoff were higher than in precipitation but lower than in runoff from the control. The green roof was a sink for $NH_3$–N, Zn, and Pb, but not for TP, $PO_4$–P, and total Cu. It also reduced the mass export of TN, TKN, $NO_3 + NO_2$–N, Hg, and dissolved Cu primarily through a reduction in stormwater runoff. Greater than 90% of the total Cu, Hg, and Zn concentrations in the green roof runoff were in the dissolved form. The growing media and slow release fertilizer were probable sources of P and Cu in green roof runoff. Overall, the green roof was effective in reducing stormwater runoff and overall pollutant loading for most water quality contaminants.



## 1. Introduction

Nonpoint sources are responsible for a significant amount of water quality impairments in the United States (USEPA, 2009). In urban areas, roof surfaces contribute excess nutrients and toxic metals to receiving waters (Bannerman et al., 1993; Egodawatta et al., 2009; Förster, 1996; Van Metre and Mahler, 2003). These surfaces can cover from 12% in residential areas to 21% in commercial areas (Bannerman et al., 1993; Boulanger and Nikolaidis, 2003).

Green roofs are becoming more common in North America as a means to control runoff and nonpoint source pollution from urban areas, and for their aesthetic value, insulation and noise reduction, and wildlife habitat (Getter and Rowe, 2006; Teemusk and Mander, 2006; USEPA, 2005b). Green roofs are classified as either extensive or intensive and are often added to an existing roof. The difference between the two types is based primarily on the thickness of the growing media and the vegetation present. Extensive green roofs typically have thin ($\leq$10 cm) media and drought tolerant vegetation, whereas intensive green roofs have thicker growing media and may include trees and shrubs (Berndtsson, 2010; Carter and Fowler, 2008; Getter and Rowe, 2006). All green roof construction typically consists of a root barrier, drainage material layer, filter fabric, growing media, and vegetation (Berndtsson, 2010; Clark et al., 2008; Getter and Rowe, 2006).

Research on the effectiveness of extensive green roofs to reduce stormwater runoff has shown that they intercept, retain, and evapotranspire between 34% and 69% of precipitation with an average retention of 56% (Fig. 1). The range in retention observed is partly due to time of year studied, sampling methods, climate, and the method used to calculate retention. The amount of precipitation retained by a green roof is improved by the number of increasing antecedent dry days preceding precipitation, lower rainfall amount, higher temperature and evapotranspiration, and a higher water holding capacity of growing media (Berndtsson, 2010; Bengtsson et al., 2005; Berghage et al., 2009; Carter and Rasmussen, 2005; DeNardo et al., 2005; Getter and Rowe, 2006; Hathaway et al., 2008; Simmons et al., 2008; Teemusk and Mander, 2007). While many green roof studies have utilized a control roof, to compare to stormwater runoff from a green roof, only VanWoert et al. (2005) reports the treatment effects statistically. Also, many green roof studies have been at the plot scale ($\approx$5 $m^2$), most of which are replicated, but results from these studies were not compared using standard statistical approaches.

Studies of nutrients in runoff from green roofs have had mixed findings. The majority of studies conclude that the green roof was a source of phosphorus in runoff (Berndtsson et al., 2006, 2009; Hathaway et al., 2008; Hutchinson et al., 2003; Köhler and Schmidt, 2003; Liptan and Strecker, 2003; MacMillan, 2004;

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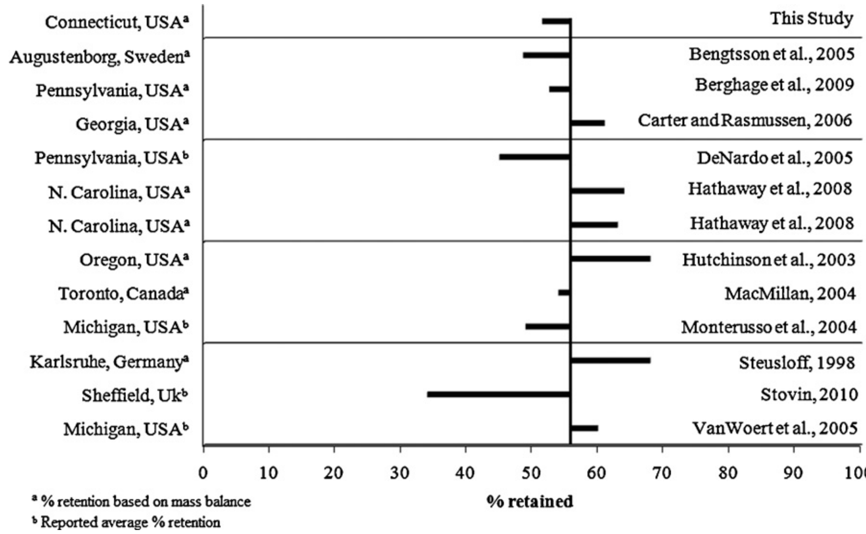


**Fig. 1.** Meta-analysis of green roof precipitation retention. The solid vertical line represents an average retention of 56%.

Monterusso et al., 2004; Teemusk and Mander, 2007). The percentage of compost in the soil media and the fertilizer used are the two key components apparently contributing to nutrients in runoff (Berndtsson et al., 2009; Emilsson et al., 2007; Hathaway et al., 2008; Teemusk and Mander, 2007).

Copper (Cu) and zinc (Zn) have been the two metals most commonly analyzed in green roof runoff (Alsup et al., 2010; Berghage et al., 2009; Berndtsson et al., 2006, 2009; Hutchinson et al., 2003; Köhler et al., 2002; Liptan and Strecker, 2003; MacMillan, 2004; Retzlaff et al., 2008; Steusloff, 1998). The majority of these studies have concentrated on total metals and ignored dissolved species, with copper (Cu) being the only metal analyzed in the dissolved form (Hutchinson et al., 2003; Liptan and Strecker, 2003). Dissolved metals can be more toxic to aquatic life (Makepeace et al., 1995). In addition, few studies have conducted water quality analysis on a broad list of constituents that included nitrogen (N), phosphorus (P), and heavy metals in green roof runoff (Berndtsson, 2010; Berndtsson et al., 2006, 2009).

While green roof studies have been conducted on roof surfaces or on green roof platforms, no studies have evaluated a modular extensive green roof system that is commonly utilized in the United States (Velazquez, 2003). Green roof platforms simulate roof surfaces. Unlike existing roof surfaces, the underside of the roof surface is open to the atmosphere (Monterusso et al., 2004; Stovin, 2010; VanWoert et al., 2005). A modular green roof system has removable trays, containing all the normal green roof components, that can be added to the roof surface (Velazquez, 2003). The objective of this study was to evaluate the effect of a modular green roof system in the northeastern United States on stormwater runoff and water quality for nutrients, and total and dissolved metals.

## 2. Materials and methods

### 2.1. Site description

The 248 $m^2$ green roof (Fig. 2) was installed September 2, 2009, on a public plaza at the University of Connecticut in Storrs. The plaza is located on a roof of a building that is set into a hillside and is accessible from street level. The green roof consisted of 334 extensive GreenGrid® modules (Weston Solutions Inc., West Chester, PA) each 1.2 m long, 0.6 m wide, and 10.2 cm thick, covering 81% of the 307 $m^2$ roof top watershed area. Each module had drainage holes and contained a root barrier/filter fabric that was overlain with 10.2 cm of growth media that consisted of 75% lightweight expanded shale, 15% composted biosolids, and 10% perlite (GreenGrid® Northeast Extensive Media). This material had a maximum water holding capacity of 31.8% and an organic matter content of 2.6% (PSU, 2008). Each module was planted with a mixture of 10 *Sedum* species, with 12 plugs in each module, on April 22, 2009. The *Sedum* varieties utilized were *S. album* 'Murale', *S. foresterianum* subsp. *elegans* 'Silver Stone', *S. kamtschaticum*, *S. kamtschaticum* var. *floriferum* 'Weihenstephaner Gold', *S. reflexum*, *S. selskianum*, *S. sexangulare*, *S. spurium* 'Dragons Blood', *S. spurium* 'Fuldaglut', and *S. spurium* 'John Creech'. After planting, the modules were fertilized with Espoma, Plant-tone® 5-3-3 slow release fertilizer at a rate of 586 $g/m^2$. A second fertilizer application in mid-May used Harrell's Live Roof Formula® 16-5-11 slow release fertilizer at a rate of 49 $g/m^2$. The modules received a total of 37 $g/m^2$ of N and 20 $g/m^2$ of P as fertilizer. Prior to installation on September 2, 2009, a 0.56 mm Easy Gardener, Inc. Pro WeedBlock® was placed over the existing roof surface.

The pre-existing roof, in order of increasing height from bottom to top, consisted of a concrete slab overlain with a 4-ply bituminous coal tar roof membrane system, a polyurethane film separator,

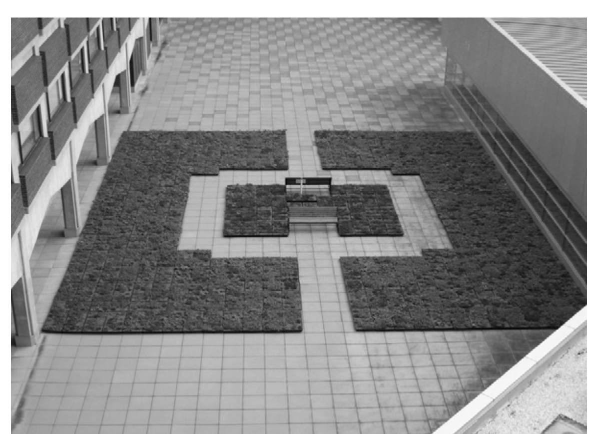

**Fig. 2.** Photograph of the plaza green roof. University of Connecticut, Storrs. For scale, each block is 0.61 m by 0.61 m.