Science of the Total Environment 625 (2018) 928–939

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Water quality function of an extensive vegetated roof

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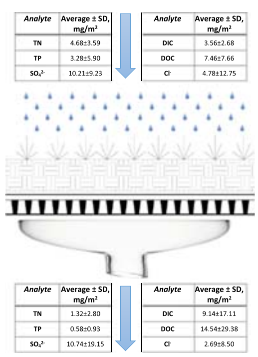
HIGHLIGHTS

- A four-year study of wet and bulk deposition and water quality in runoff from an extensive, urban, vegetated roof.
- Nutrient losses (TN, TP DOC) were low associated with the strong water retention.
- A marked seasonal variation was evident in the retention of nutrients.
- Water quality function of the roof did not change over the study period.
- The vegetated roofs met the USEPA freshwater standards, except for P.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 25 September 2017
Received in revised form 7 December 2017
Accepted 7 December 2017
Available online xxxx

Editor: Jay Gan

Keywords:
Green roof
Green infrastructure
Water quality
Stormwater management
Nutrients

ABSTRACT

In this paper we present the results of a four-year study of water quality in runoff from an extensive, sedum covered, vegetated roof on an urban commercial building. Monitoring commenced seven months after the roof was constructed, with the first growing season. Stormwater drainage quality function of the vegetated roof was compared to a conventional (impermeable, high-albedo) membrane roof in addition to paired measurements of wet and bulk depositions at the study site. We present concentrations and fluxes of nutrients and major solutes. We discuss seasonal and year-to-year variation in water quality of drainage from the vegetated roof and how it compares with atmospheric deposition and drainage from the impermeable roof. Drainage waters from the vegetated roof exhibited a high concentration of nutrients compared to atmospheric deposition, particularly during the warm temperature growing season. However, nutrient losses were generally low because of the strong retention of water by the vegetated roof. There was marked variation in the retention of nutrients by season due to variations in concentrations in drainage from the vegetated roof. The vegetated roof was a sink of nitrogen, total phosphorus and chloride, and a source of phosphate and dissolved inorganic and organic carbon. Chloride exhibited elevated inputs and leaching during the winter. The drainage from the vegetated and impermeable roofs met the United States Environmental Protection Agency freshwater standards for all parameters, except for total phosphorus.

1. Introduction

Vegetated roofs are an emerging technology for mitigating peak stormwater input to the combined sewer infrastructure in urban areas. Their application has gained interest in cities with combined sanitary systems that experience overflow events. Vegetated roofs are one of the best management practices (BMP) recommended by the USEPA for sustainable stormwater management (Carter and Jackson 2007), as they provide ecosystem services, including decreasing summer cooling demand, decreasing the heat-island effect and improving urban wildlife habitat (Oberndorfer et al., 2007). According to the Annual Green Roof

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https://doi.org/10.1016/j.scitotenv.2017.12.085

Industry Survey, there were 950 vegetated roof projects (totaling 596,580 m^2 (6,421,538 ft^2)) installed in 2013, a relative increase of ~540% compared to 2004 (GRHC, 2014). More than 371,612 m^2 (4,000,000 ft^2) of the installed roofs were an extensive design (substrate depth < 15 mm, GRHC, 2014). While the application of vegetated roofs is steadily increasing, the benefits and implications from their application are still being evaluated. There have been few long-term field studies of a vegetated (green) roof function.

Most of the studies that assessed water quality of the runoff from vegetated roofs found that roof drainage is enriched in nutrient concentrations. Phosphorus (P), commonly a management priority in urban watersheds, is almost always leached from roof media at elevated concentrations (Berndtsson et al., 2009, Teemusk and Mander, 2011, Vijayaraghavan et al., 2012, Seidl et al., 2013, Buffam and Mitchell, 2015, Mitchell et al., 2017). Observations of the net retention of nitrogen (N) species have been inconsistent. A majority of the studies have found that vegetated roofs are a sink for nitrate (NO_3^-) and ammonia (NH_4^+; Berndtsson et al., 2009, Speak et al., 2014), while others report net export or no change in N species (Mason et al., 1999; Seidl et al., 2013; Wang et al., 2017). Similarly, inconsistent results have been reported for the function of roofs with respect to sulfate (SO_4^{2-}), chloride (Cl^-), and dissolved organic carbon (DOC) (Mason et al., 1999; Berndtsson et al., 2009; Vijayaraghavan et al., 2012; Seidl et al., 2013; Speak et al., 2014). This varied behavior of the chemical species is likely driven by differences in climate, hydrology, substrate media, fertilizer application, and design and age of the roof (Rowe, 2011; Driscoll et al., 2015).

Previous studies of the concentrations and fluxes of solutes in runoff water from vegetated roofs have largely been conducted using experimental plots (Vijayaraghavan et al., 2012; Seidl et al., 2013) or tile roofs (Gregoire and Clausen, 2011). Some studies include only comparison between different vegetated roof types (Berndtsson et al., 2006; Berndtsson et al., 2009), while others consider a comparison of roof drainage with wet and/or bulk deposition (Speak et al., 2014) or comparison of light weight aggregate with sod roofs (Teemusk and Mander, 2011). There are limited data on the temporal performance of full-scale vegetated roofs under field conditions (Driscoll et al., 2015), and in particular in urban watersheds (Carson et al., 2013) with marked seasonal variability (Schroll et al., 2011).

When evaluating runoff quality, it is critical to compare runoff from vegetated roofs with conventional roofs-black or high-albedo roofs. This approach allows for direct comparison and characterization of the application of vegetated roofs as a sustainable alternative to the conventional roof systems as well as a comparison of roof runoff with inputs from atmospheric deposition. In recent years, the application of reflective roofing membranes (high-albedo roofs) has increased. While the high-albedo roofs outperform vegetated roofs in terms of reflectivity (Konopacki and Akbari, 2001), few studies have compared water quality function of vegetated roofs to high-albedo roofs.

In this paper we present the results of a four-year study of the water quality in the runoff of an extensive vegetated roof in an occupied commercial building in upstate New York. The monitoring started seven months following the installation of the roof. The function of the vegetated roof was compared to a conventional (impermeable, high-albedo) roof, in addition to paired measurements of wet and bulk deposition. We present concentrations and fluxes of nutrients and major solutes. We discuss seasonal and longer-term variation in water quality of drainage from the vegetated roof and how it compares with atmospheric deposition and drainage from the impermeable roof.

2. Methods

2.1. Study site and sample collection

The City of Syracuse is located in the center of New York State near the south/southwestern shore of Lake Ontario (Fig. 1). The area enjoys a humid continental climate with marked seasonal changes. The Syracuse Center of Excellence (SyracuseCoE) is an approximately 5100 m^2 (approximately 55,000 ft^2) facility, designed and constructed on a former brownfield site located at 727 East Washington Street in Syracuse, New York (43.049 N, 76.142 W). Certificate of occupancy was issued in 2010, while laboratory and space fit-out continued in 2011. The building achieved a LEED Platinum Certification from the U.S. Green Building Council. Among the sustainable strategies employed on the building is a vegetated roof with a study area of 1190 m^2 (12,809 ft^2). The vegetated roof is completely covered with sedum and includes sloped and flat areas (Fig. 1). Six different types of sedum were planted on the vegetated roof for complete coverage, including *Sedum refluxum*, *Sedum sexangulare*, *Sedum acre*, *Sedum kamschaticum*, *Sedum spurium "Fuldaglut"*, and *Sedum album*. The sedum layer is located over an average of 95 mm (3.75″) of FLL 2002 (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau) and DIN 18917 (Vegetation Technology in Landscaping - Grass and Seeding) compliant growth media. The growth media is blend of light weight mineral aggregates, organic components, and compost (http://www.rooflitesoil.com/specifications) installed over a stormwater retention layer (MiraDRAIN G4 by Carlisle). The growth media is manufactured by Rooflite for installation on extensive vegetated roofs in the mid-Atlantic region of the U.S. The air-filled porosity at the time of growth media installation was 41%. A complete description of physical and chemical properties of the growth media is available at http://www.rooflitesoil.com/specifications. The vegetated roof of the SyracuseCoE is comprised of eight layers (from top to bottom, (1) sedums, (2) growth media, (3) stormwater retention layer, (4) thermoplastic polyolefin (TPO) sheet, (5) gypsum board, (6) tapered roof insulation, (7) a vapor barrier, and (8) a concrete deck). Continuous monitoring commenced in April 2010 and continued for 44 months, until November 2013 (Todorov et al., 2018). Composite drainage samples were collected after precipitation events with intensity sufficient to generate runoff form the vegetated roof. Samples were collected from the six roof drains (Fig. 1). Two of the drains are located on the upper deck of the vegetated roof, where the slope to the landing is 15%. The other four roof drains are located on the vegetated roof landing, where the slope to drains is 1%; two drains each on the upstream and downstream of the landing. Each roof drain body is equipped with a custom-built sample collection assembly, which consists of a Teflon bottle and a glass funnel attached to the top of the bottle. The bottle is positioned directly in the drain pipe and is supported with a galvanized steel ring. This assembly allows stormwater runoff to be captured directly from the roof membrane and the glass funnel prevents contact of the stormwater with the cast iron roof drain body and stormwater piping. The Teflon bottle and glass funnel were washed with de-ionized distilled water on-site after each sample collection. Paired reference samples were collected from the flat portion of the impermeable high-albedo roof of the SyracuseCoE building using the same custom-built water collector. The reference roof (impermeable, high albedo, ethylene propylene diene monomer (EPDM)) is two-stories above the vegetated roof, positioned away from the influence of any vegetation (Fig. 1). Samples collected from this roof segment serve as reference. Collections from the reference roof commenced in 2011.

Precipitation quantity was determined using a Climatronics 6-inch tipping bucket precipitation gauge located on the vegetated roof. Precipitation data are recorded in real time and stored on a data logger type HOBO U30. Bulk and wet deposition collectors were installed on the high-albedo roof. The collectors were positioned toward the prevailing wind path and away from the influence of the existing building exhaust and vent systems on the SyracuseCoE roof. The bulk deposition collector consists of a funnel with a 200 mm diameter, connected to a 0.5 l HDPE capped container with a hose. The funnel was rinsed with distilled water after each sample collection. Precipitation samples were also collected using an automatic wet only collector, which consists of a collection bucket, a lid that can be opened and closed, a precipitation sensor, and a sample container (nadp.sws.uiuc.edu, The National