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## ► To cite this version:

Giulana Frizzi, Jennifer Drake. Impacts hydrologiques des couches de rétention dans les vastes toits végétalisés. Novatech 2023 11e Conférence internationale sur l'eau dans la ville, Jul 2023, Lyon, France. hal-04167829

**HAL Id: hal-04167829**

**<https://hal.science/hal-04167829v1>**

Submitted on 21 Jul 2023

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## Hydrologic Impacts of Retention Layers within Extensive Vegetated Roof Assemblies

### Impacts hydrologiques des couches de rétention dans les vastes toits végétalisés

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#### RÉSUMÉ

De vastes toits verts sont construits avec une strate végétalisée pour soutenir la croissance des plantes et assurer la rétention d'eau (FLL, 2018). Il s'agit notamment des matériaux en vrac et du substrat et des couches de stockage d'eau (FLL, 2018). De nombreux systèmes de toitures vertes extensifs qui réussissent commercialement reposent sur des produits de stockage d'eau manufacturés légers pour augmenter la rétention et la rétention des eaux pluviales tout en réduisant le poids total d'un système de toit vert et les coûts des matériaux associés. Cette étude évalue la performance hydrologique de quatre ensembles de toiture végétalisés génériques (VRA) qui utilisent des matériaux ultralégers – polaire, laine minérale et système combiné réservoir-rétention – au cours d'une saison de croissance complète dans les conditions naturelles de précipitations à Toronto, en Ontario, et compare leur performance à un toit vert étendu conventionnel avec substrat FLL et un toit gris conventionnel avec ballast en pierre. Étonnamment, le toit gris, recouvert de 50 mm de pierre claire, a retenu et évaporé la moitié des précipitations reçues au cours de la saison. Les toits verts, quel que soit leur assemblage, ont amélioré la rétention, retenant 92 à 96% des précipitations reçues. En moyenne, les VRA ont réduit les débits de pointe des précipitations de 94 à 98% et retardé le débit de 6 à 9 heures. Ces travaux démontrent que les couches de rétention et de rétention améliorent la performance hydrologique des systèmes de toits verts à des degrés divers.

#### ABSTRACT

Extensive green roofs are constructed with a vegetated stratum to support plant growth and provide water retention (FLL, 2018). These include bulk and substrate materials and water storage layers (FLL, 2018). Many commercially successful extensive green roof systems rely on lightweight manufactured water storage products to increase stormwater retention and detention while decreasing the overall weight of a green roof system and the associated material costs. This study evaluates the hydrologic performance of four generic vegetated roof assemblies (VRA) that use ultra-lightweight materials – fleece, mineral wool and a combined reservoir-detention system – over the course of a complete growing season under the natural rainfall conditions in Toronto, Ontario, and compares their performance to a conventional extensive green roof with FLL substrate and a conventional grey roof with stone ballast. Surprisingly the grey roof, covered with 50 mm of clear stone retained and evaporated half of the received rainfall over the season. The green roofs, regardless of their assembly, improved retention, retaining 92 - 96% of the received rainfall. On average, the VRAs reduced rainfall peak flows by 94 - 98% and delayed discharge by 6 - 9 hours. This work demonstrates that retention and detention layers improve the hydrologic performance of green roof systems to varying degrees.

#### KEYWORDS

Toits verts, Détention, Eaux pluviales, Matériaux ultra-légers, Contrôle de la quantité  
Green Roofs, Detention, Stormwater, Ultra-Lightweight Materials, Quantity Control

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## 1 INTRODUCTION

Urbanization has led to substantial depletion of natural environments that aid in the cycling of water, and without the infiltration of precipitation, cities have been subjected to excessive flooding (Montalto, et. al., 2007). To regain control of the stormwater, city planners and designers are looking vertically to implement green infrastructure (GI) practices. In high density urban environments, green roofs (GR) mimic predevelopment hydrology by allowing for evapotranspiration and infiltration. Extensive green roofs consist of shallow growing media, typically less than 6 inches deep, and vegetation and are lighter weighted compared to deeper intensive GR (Credit Valley Conservation and Toronto and Region Conservation Authority, 2010). Traditional extensive system designs only include vegetation, substrate-based planting media and drainage layers (Hill, et al., 2017; Carson et. al., 2013, Hakimdavar et. al., 2014). The vegetation helps reduce the urban heat island effect by means of evapotranspiration and increases the urban biodiversity by providing a habitat for pollinators and various bird species (Berndtsson, 2010; Vacek, Struhala & Matejka, 2017). By capturing the stormwater in its pores, the planting media mitigates urban flooding by retaining the rain, therefore delaying its entry into the sewer systems, and promoting vegetation uptake and evapotranspiration, therefore reducing the volume of water passing into the grey infrastructure (Carson, et al., 2013; Montalto, et. al., 2007; Hakimdavar, et. al., 2014). Despite the simple design of traditional GR systems, the planting media layer can be too heavy for roofs that were not originally designed for GI and may not provide enough stormwater detention to meet the desired flooding mitigation targets. In response, vegetated roof assemblies (VRA) are replacing the planting media layer with manufactured light-weight soilless materials that aim to increase the water holding capacity, retention, and detention of green roof systems. Other studies have included fleece (Carson, et. al., 2013; Hakimdavar, et. al., 2014; Abualfaraj, 2018) and mineral wool (Vacek, Struhala & Matejka, 2017; Kostadinovic, et. al., 2022) retention layers in the green roof design but fail to report on their specific hydrological impact compared to conventional roof systems. Therefore, the purpose of this study is to fill this research gap by evaluating the hydrological performance of generic ultra-lightweight and soilless materials for extensive green roof systems specifically under the natural rainfall conditions in Toronto, Ontario.

## 2 METHODS

### 2.1 Site Description and Testbed Composition

The study is being conducted in the Green Roof Innovation Testing Laboratory #1 (GRITLab1), located at the University of Toronto, Toronto, Ontario, Canada. A total of ten testbeds were utilized for the treatments including a stone grey roof control, a traditional green roof control (GRC), and duplicates of vegetated roof assemblies with fleece, mineral wool without growing media (MWwoGM), mineral wool with growing media (MWwGM), and a combined reservoir-detention system (CRD) (Figure 1). Sedum is used for vegetation, and the growing media is an extensive mix. The fleece consists of needle punched nonwoven fabric made of high-quality recycled mixed fibers. The mineral wool is composed of long rock mineral wool fibers specially needled to form a compact and dimensionally stable felt. The honeycomb reservoir is made up of fused 10mm-diameter polypropylene tubes oriented vertically. The polyester fabric consists of vertically orientated polyester thread between two knit layers of tightly woven polyester fabric.

### 2.2 Automated Data Collection

Each testbed is equipped with a tipping bucket rain gauge device (Model TB6 obtained by Hyquest Solutions) that tracks the amount of water draining from each bed. For these devices, an average of 6.28mL of water causes the device to tip. Tipping bucket data is recorded and stored via Onset HOBOWare data loggers, which is then accessed via the HOBOWare software program and converted into a volume quantity. The weather station located at GRITLab1 is used to collect temperature (°C) and rainfall (mm) data to gauge the relative climatic conditions and determine how much total stormwater is experienced by the testbeds. Following the United States Environmental Protection Agency's Stormwater Best Management Practices Monitoring Manual, quality assurance and quality control (QA/QC) techniques were implemented to validate the rainfall data by collecting measurements from two other rain gauges (US EPA, 2002). Another weather station is located at University of Toronto GRITLab2, roughly 260 meters northwest of GRITLab1. For an additional check, the Environment and Climate Change Canada (ECCC) daily climate data was consulted. The selected station is 'Toronto City,' Climate ID: 6158355, located roughly 950m north of GL1 (Government of Canada, 2022).

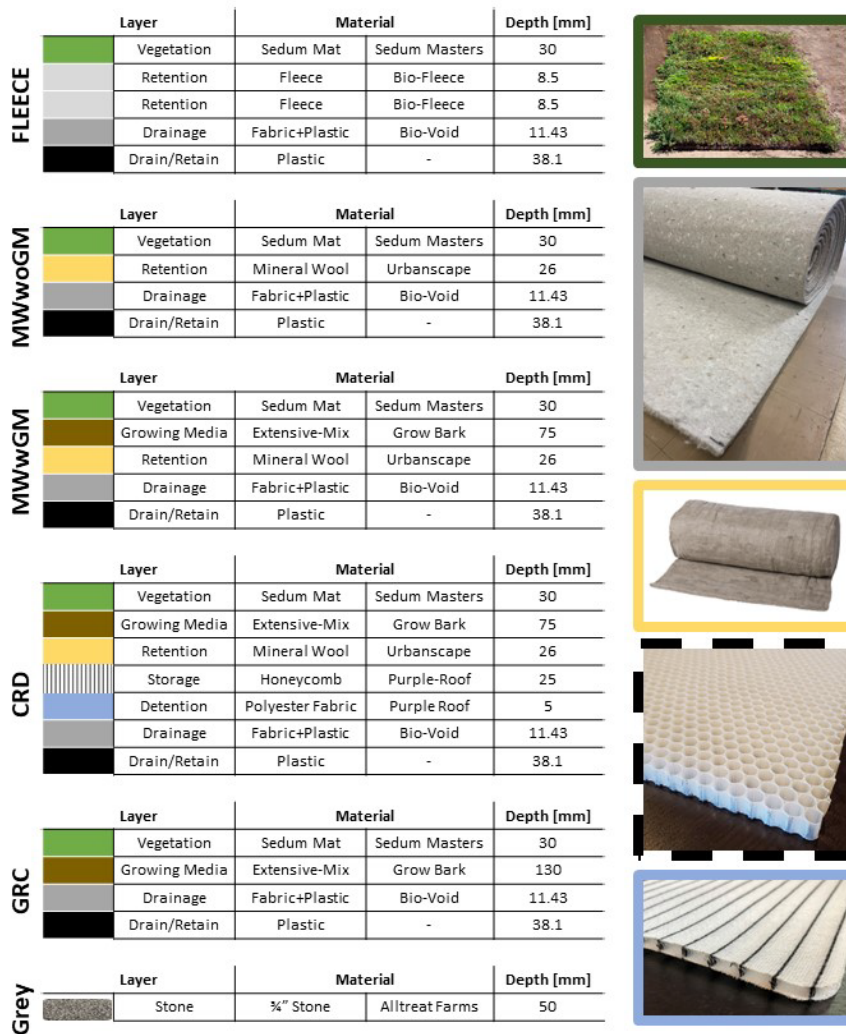


Figure 1: Testbed Layering Breakdown and Materials

### 2.3 Data Analysis

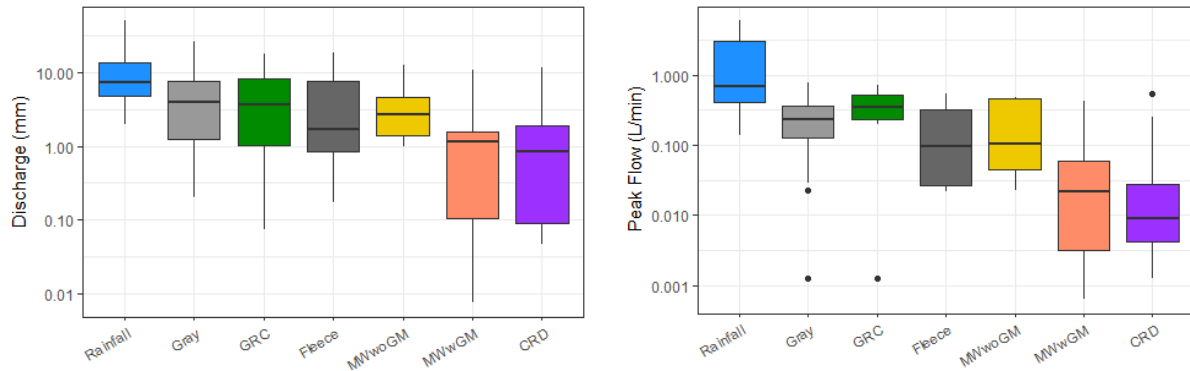
Rain events were defined when more than one tip (>0.2 mm) was recorded and discharge from the grey roof was also observed. Rain events lasted until there was >1 hr between tips. Resulting testbed discharge events started from the first tip following the rain event and ended when >1 hr was seen between tips. Compiled event-based data include rainfall depth (mm), peak rainfall (mm/min), total discharge (L), peak discharge flow rate (L/min), and time-to-discharge (min). Additional hydrological parameters calculated for the VRAs include reduction of rain peak flow rate (%), reduction of grey roof peak flow rate (%), retention (%) calculated by comparing the total discharge of the testbed to the amount of rain the testbed experienced, and detention (%) calculated by comparing the total discharge of the testbed to the discharge of the grey control roof.

## 3 RESULTS

Over the course of the monitoring period (July to November 2022) a total of 17 events resulted in a cumulative rainfall amount of 220 mm. Of these events, five were classified as small (0.2-4.8mm) with an average size of 3.2 mm, nine medium (5-20mm) averaged at 10.5mm, and three large (>20mm) averaged at 37mm. All recorded rainfall events fell under the 2-year storm line on local Toronto IDF curve.

The stone ballast roof was found to be a surprisingly effective system for stormwater control and retained 113 mm, or 53%, of the received rainfall. The VRAs improved retention, retaining an additional 66 mm, 69 mm, 85 mm, 88 mm, and 89 mm for the fleece, GRC, MWwoGM, MWwGM, and CRD, respectively (Figure 2a). The grey roof and VRAs had similar peak discharge flows, but the VRAs did provide additional flow reduction. On average, grey control peak flows were reduced by the VRAs by 64 – 92 % (Figure 2b). The VRAs also delayed

discharge by an average of 5.3 – 9.3 hours. All the large rain events caused discharge from all treatment bed types, and only two medium-sized rain events generated discharge from all roof assemblies. These were not the largest storms in these size category but both had short antecedent dry periods resulting in discharge from previously saturated roofs. The fleece VRA produced discharge most frequently (44% of the time), followed by MWwGM (41%), GRC (35%), CRD (35%) beds and MWwoGM (27%).



**Figure 2:** Distribution of rainfall and testbed (a) discharge (mm) and (b) peak flow (L/min)

After the first year of this study, we observed that systems with light-weight retention layers (fleece and MWwoGM) mitigated less stormwater, while the presence of growing media improved hydrologic performance. To date, the addition of a reservoir detention layer yielded the best results. As this is an ongoing study, data collection will continue over the winter and for one more growing season. Additional data analysis parameters that will be evaluated are rainfall and testbed discharge durations and antecedent dry periods.

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