First results of hydrological performances of three different green roofs

Premiers résultats de performances hydrologiques de trois différentes toitures végétalisées

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RÉSUMÉ

Les toitures végétalisées peuvent avoir plusieurs domaines d’application, notamment l’aménagement paysager, le développement des écosystèmes urbains, la réduction des îlots de chaleur en milieu urbain et la réduction des volumes et pics de ruissellement par temps de pluie. Les toitures végétalisées traditionnelles présentent de bonnes performances hydrologiques. Cependant des toitures végétalisées innovantes ont été développées avec pour objectif d’améliorer la rétention des eaux de pluie, de réduire les pics de ruissellement, de réguler le débit de vidange et d’accroitre l’évapotranspiration. Les performances hydrologiques de trois toitures végétalisées différentes installées sur un même site expérimental sont présentées : 1) une toiture végétalisée traditionnelle avec des cavités stockantes placées sous la couche de substrat, appelée GR1, 2) une toiture GR1 complétée par un réservoir stockant sous-jacent, équipé d’un régulateur de débit de sortie et de mèches de sub-irrigation, appelée GR2, et 3) une toiture GR2 sans mèches de sub-irrigation, appelée GR3. Le site expérimental est décrit et les résultats pour des événements pluvieux variés sont présentés. Les premiers résultats montrent des performances significativement plus élevées pour GR2 et GR3 en comparaison avec GR1. GR2 et GR3 montrent une réduction des pics de ruissellement d’environ 88 % et une rétention plus élevée des pluies faibles pouvant atteindre 85 %.

ABSTRACT

Green roofs may have several application domains including landscaping, ecosystems development, urban heat island reduction and also capacities to reduce runoff volumes and peaks for rainfall events. If traditional green roofs show satisfactory hydrological performances, innovative green roofs have been developed with the aim to improve rainfall retention, peak reduction, outflow regulation and evapotranspiration. Hydrological performances of three different green roofs located in the same experimental site are presented: 1) a traditional green roof with an additional storage layer under the substrate layer, named GR1, 2) a GR1 green roof completed with an extra underlying storage reservoir equipped with an outflow controller and sub-irrigation components, named GR2, and 3) a GR2 green roof without sub-irrigation components, named GR3. The experimental site is described and results for various rainfall events are presented. The first results show significantly higher performances for GR2 and GR3 green roofs compared to GR1. GR2 and GR3 showed runoff peak reduction of about 88 % and higher rainfall retention for lower rainfall intensities, reaching up to 85 %.

KEYWORDS

Rainwater management, rainwater retention, runoff peak attenuation, vegetated roofs

1. INTRODUCTION

Urbanisation process in cities leads to more impervious surfaces, leading to numerous threats during rainfall events, including flooding, erosion, transfer of pollutants to receiving water bodies and wastewater treatment plants, sewer overflows, etc. (Marsalek, 1998). In most developed cities, roofs constitute approximately 40-50 % of the impervious surfaces (Stovin, 2010). Therefore, in order to reduce runoff volumes and peaks to sewer systems during rainfall events, a source control approach is required.

Traditional green roofs have demonstrated satisfactory hydrological performances (Mentens *et al*., 2006; Czemiel Berndtsson, 2010), in addition to other achievements like landscaping, ecosystems development and urban heat island reduction (Oberndorfer *et al*., 2007). However, rainfall volume retention and runoff peak reduction need to be further improved when green roofs are designed specifically for stormwater control. New green roof technologies are thus developed, aiming to maximize rainfall retention and peak attenuation, to increase evapotranspiration and to regulate green roof outflow. This study presents the first results (August to October 2015) of the hydrological performances of three different green roofs located in the same experimental site.

2. MATERIALS AND METHODS

2.1. Experimental site

The experimental site is located in Mions, France (Figure 1, left) and is operated since August 2015. It includes four 4.8 m^2 experimental roofs: 1) an impervious roof named IR, used as a reference for comparison, 2) a green roof with a combination of sedum vegetation (principally Sedum lydium, Sedum hispanicum and Sedum oreganum), named GR1, composed of 20 prefabricated green roof elements (Figure 1, right): each element includes a 60 mm thick mineral substrate layer above a storage layer made of i) small cavities (alveolus) for water storage filled with clay pellets allowing plant water uptake by capillarity, 3) a GR1 green roof completed with an extra underlying plastic storage reservoir equipped with an outflow controller and two sub-irrigation wicks, named GR2; the outflow controller is designed for regulating the green roof outflow up to 0.1 L/s, and 4) a GR2 green roof without sub-irrigation wicks, named GR3.

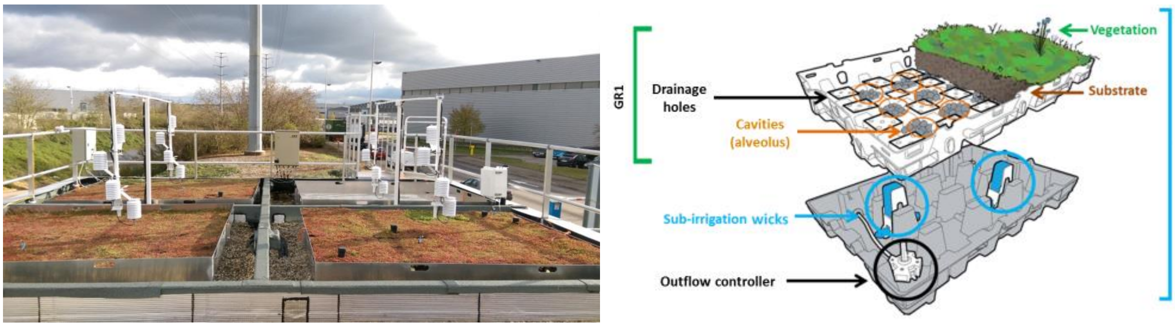

Figure 1: Experimental site in Mions, France (left) and GR1 and GR2/GR3 structures (right).

2.2. Monitoring

IR, GR1 and GR3 outflow rates are measured by means of double tipping bucket devices (10 mL and 1 L capacity). GR2 outflow is measured with a double tipping bucket device completed by an electromagnetic flowmeter. Water levels in storage cavities (alveolus) and in plastic reservoirs are measured by air bubbling level meters (Hydro L1000, Hydrologic®). Water content in substrate layers is measured with soil moisture sensors (EC-5, Decagon Devices®), with two sensors for each green roof. Meteorological data (temperature, humidity, wind speed, rainfall and net radiometry) are measured *in situ* ((Précis Mécanique® and Campbell Scientific® instruments) to estimate evapotranspiration. Data are recorded in two data loggers (LOG M, KACO® and CR6, Campbell Scientific®) at one-minute time step. Flowmeters and meteorological sensors were installed in July 2015, all other sensors in October and November 2015. Calibration was carried out for double tipping bucket devices, air bubbling level meters, soil moisture sensors and rain gauge according to laboratory procedures.

3. RESULTS AND DISCUSSION

The five most significant rainfall events since August 2015 are analysed. Their characteristics are presented in Table 1.

Table 1: Characteristics of 5 most significant events from August to October 2015.

Date (dd/mm/yyyy)	Total rainfall depth (mm)	Rainfall duration (h)	Mean intensity (mm/h)	Maximum intensity (mm/h)	Rainfall depth in 2 hours (mm)
09/08/2015	31.6	5.42	5.83	60	29.2
12/09/2015	39.4	15.52	2.54	36	14.2
13/09/2015	24	6.78	3.54	48	13.2
17/09/2015	51.4	8.58	5.99	48	22.6
27/10/2015	43.2	22.43	1.93	36	13

Rainfall depths range from 24 to 51.4 mm, mean intensities from 1.93 to 5.99 mm/h. The most intense rainfall event was recorded on 09/08/2015 (31.6 mm in 5.52 hours), where 92 % of the rain fell in 2 hours with a maximum intensity of 60 mm/h. At the start of the event, GR1 and GR2 green roofs can store all the rainwater volume and outflow is delayed respectively by 1 hour and 1.25 hour (Figure 2). For this event, the GR3 green roof reduces the runoff peak to 86 % and retains 76 % of the rainfall depth (Table 2).

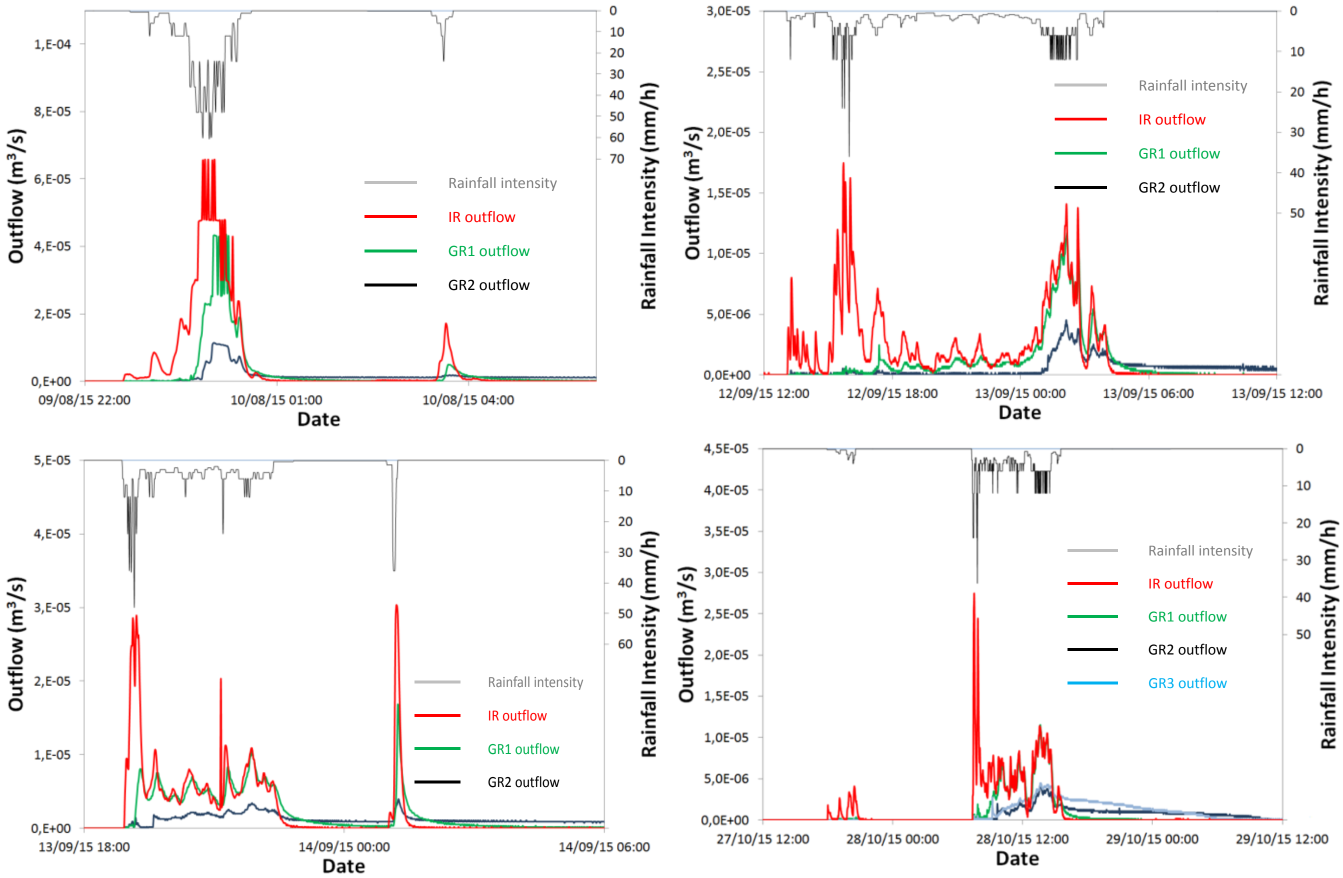

Figure 2: Outflow rates from all roofs for events dated 09/08/2015 (top left),
12/09/2015 event (top right), 13/09/2015 event (bottom left) and 27/10/2015 event (bottom right).

For lower intensity events as for the event dated 12/09/2015, the runoff peak is delayed by 3.83 h and

11.78 h for GR1 and GR2 respectively (Figure 2). For practical reasons, the effect of sub-irrigation process on hydrological performance can be investigated only from October 2015. The event dated 27/10/2015 shows a lower outflow rate for GR2 than for GR3: sub-irrigation wicks facilitates water uptake by vegetation and thus subsequently allow a higher evapotranspiration after the rainfall event. The water uptake decreases the water level in the plastic storage reservoir and afterward the outflow, due to the water level-flow correlation of the floating outflow controller. This hypothesis needs to be confirmed by future analysis of more events and will include soil moisture measurements for a complete water mass balance.

Table 2: Rainfall retention and peak runoff reduction for events from August to October 2015.

Date (dd/mm/yyyy)	Rainfall retention (%)				Runoff peak reduction (%)			
	IR	GR1	GR2	GR3	IR	GR1	GR2	GR3
09/08/2015	2	48	76	-	18	45	86	
12/09/2015	6	51	85	-	64	76	91	
13/09/2015	4	27	69	-	53	74	94	
17/09/2015	-8	26	50	65	24	35	77	85
24/10/2015	8	39	78	70	43	76	91	91
Mean	2	38	72	67	40	61	88	88

According to the first most significant events (Table 2), rainfall retention efficiency is around 38% for GR1 green roof, and almost twice for GR2 and GR3 green roofs with respectively 67 % and 72 % retention efficiency. In addition, GR2 and GR3 green roofs showed a high runoff peak reduction of 88 %, higher than GR1 and IR roofs with peak reduction of 61 % and 40 % respectively.

4. CONCLUSIONS

The first results obtained in the Mions experimental site for significant rainfall events with three different structures of green roofs show higher hydrological performances for GR2 and GR3 green roofs with extra storage compared to a more traditional GR1 green roof with less storage capacity and to the impervious roof IR. GR2 and GR3 green roofs show peak reduction of 88 % and rainfall retentions up to 85 %. Experiments in Mions will continue until summer 2016 in order to cover a full year and to analyse in detail all water transfers within the three green roofs.

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