Incidence of extensive green roof structures on the quantity and the quality of runoff waters – first results from an experimental test bench in Paris area

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Incidence de la végétalisation extensive des toitures sur la quantité et la qualité des eaux de ruissellement – premiers résultats d'un banc d'essais en région parisienne

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RÉSUMÉ

L'article présente les premiers résultats obtenus dans le cadre du projet TVGEP, sur les flux d'eau de polluants issus de toitures végétalisées extensives. Ces données ont été obtenues sur un banc d'essai extérieur situé en région parisienne et permettent d'évaluer l'incidence respective de l'épaisseur et la nature du substrat, du type de drainage et du type de végétation. La capacité des toitures végétalisées à réduire les volumes de ruissellement est confirmée à l'échelle annuelle, avec un coefficient de ruissellement annuel inférieur à 50%. A l'échelle de l'événement ce coefficient de ruissellement est cependant très variable en fonction de la hauteur de précipitation et de l'état d'humidité du substrat. Des conductivités élevées et de fortes concentrations en carbone organique et en phosphore ont été mesurées dans les eaux de ruissellement des toits végétalisés, ce qui doit être pris en compte dans cas d'une gestion à la source de ces ruissellements. Les flux polluants émis sont très dépendants du fonctionnement hydrologique du toit et une évaluation plus précise à l'échelle annuelle est nécessaire compte tenu de la forte variabilité des coefficients de ruissellement.

ABSTRACT

First results concerning the incidence of different types of extensive green roof structures on the quantity and quality of runoff are presented. The effect on substrate thickness, type of drainage layer and vegetation on these emissions is discussed. The data have been acquired within the field of the TVGEP project, on an experimental test bench in Paris area. Runoff measurements confirm the ability of green roof to decrease runoff volume, with annual runoff coefficients inferior to 0.5. At the event scale, this retention capacity is however strongly variable and depends on rainfall depth and soil moisture condition. Important levels of conductivity, organic carbon and phosphorus concentrations have been measured in the green roof runoff, which should be taken into consideration if the runoff waters are collected into small detention ponds or small creeks. Pollutant loads emitted are strongly dependent on hydrologic behavior of the green roofs. Further data is needed for an accurate evaluation of annual pollutant loads.

MOTS CLES

Green roofs, hydraulic retention, nutrients, pollutants, runoff

1 INTRODUCTION

Green roofs have known a rapid development in many countries over the last few years. In Germany - the leading country for green roofing - green roofs represent today 12% of the flat roof market. In France, the green roof market is still limited and represents about 4% of flat roof market but with a constant progression over the last 10 years (Adivet 2012).

Most part of these newly developed green roofs are extensive green roof structures (Lasalle 2008), i.e. light weighted structures consisting in a small layer (3 to 15 cm) of an engineered substrate, overlaying a drainage layer, and planted with plants of limited development like sedums. Extensive green roofing can be implemented when retrofitting existing flat roofs and need only limited maintenance once established.

Green roofs are expected to induce many benefits both at the building scale (protection of the water proofing layer, thermal and acoustical comfort of the building) and at the city scale (reduction of urban heat island, improvement of air quality, increase of urban biodiversity, aesthetic landscape). They are also being considered as a mean for urban runoff mitigation at its source (Carter et Rasmussen 2006; Mentens et al. 2006; Gendreau et al. 2007) and thus they generate a growing interest among stormwater managers. Green roof allow the interception and storage of a fraction of the precipitations by the plants and the substrate and its subsequent evapotranspiration. This phenomena could reduce annual runoff volumes by over 50%. Runoff reductions measured on time scales from 10 to 18 month vary in the literature from 46 to 86% (Berndtsson 2010; Voyde et al. 2010; Gregoire et Clausen 2011; Stovin et al. 2012) depending on the characteristics of the green roof and on the climatic conditions. However, the retention capacity varies in a wide range from one rain event to another, depending of the initial moisture of the roof and on the importance of the rain events.

Limited attention has been given up to now to the quality of green roof runoff, and the potential effect of these structures on stormwater contaminant loads (Berndtsson 2010; Rowe 2011). Green roofs are likely to act as a sink for some airborne contaminants, through adsorption and filtration in the substrate. But the materials used in the different layers of a vegetated roof (sealing layer, drainage material, geotextile, substrate and vegetation layer) could also be a source of contaminants into the waters percolating. Previous research mainly focused on nutrients and heavy metals (Emilsson et al. 2007; Hathaway et al. 2008; Berndtsson et al. 2009; Alsup et al. 2011; Gregoire et Clausen 2011). Most studies indicate an increased concentration for phosphorus and organic matter at the outlet of the vegetated roofs. Results are more contrasted for nitrogen and for heavy metal concentrations. When mass loads are considered however, green roof usually act as a sink for these contaminants in function of their water retention capacity (Van Seters et al. 2009).

Both the quantity and the quality of green roof runoff depends however of a number of parameters, among which nature of the construction materials, nature and thickness of the substrate layer (Mentens et al. 2006; Buccola et Spolek 2011), fertilisation practices (Emilsson et al. 2007), type of vegetation, but also age of the roof (Berndtsson et al. 2006; Getter et al. 2007) and hydrological conditions (Teemusk et Mander 2007; Carpenter et Kaluvakolanu 2011). The incidence of these parameters is far from being mastered today.

In order to better understand the contribution of each layer of a green roof on the quantity and quality of downstream runoff, an experimental test bench has been developed in France within the 3-years project TVGEP. Funded by the C2D2 program of the French Ministry of Environment and launched in early 2010, this project led by the CSTB aims to assess the interest of extensive green roofs for the quantitative and qualitative management of stormwater, identifying their strengths and limitations at the building's scale and at urban scale. The experimental test bench has been implemented on existing roof of a CETE-IF building, which has been segmented in 6 parts, each one consisting of a specific combination of the 3 main layers of a green roof: drainage, substrate and vegetation. The chosen combinations have been defined through discussions involving all the partners of the project: the research teams (LEESU, CETE-IF and CSTB), the French professional association dedicated to Green Roofs (ADIVET) and the Water Authority of the Hauts de Seine Department. This paper presents the first results of hydrological and qualitative results from data acquired on this test bench.

2 METHODS

2.1 Experimental green roof test bench

The experimental roofs are situated in Trappes, a small city of Paris suburb, 30 km South-West from central Paris. An existing 300 m² flat roof was transformed into 6 green roofs (35 m², 7x5 m) and 2 reference roofs (21m², 7x3 m) (Figure 1). In order to test effects of the green roof composition on the quantity and the quality of runoff water, 2 types of plants, 2 types of substrates, 2 different substrate depths and 2 types of drainage layers were tested, with each of the 6 green roof structures differing from an other by only one of these parameters (Table 1and Figure 1).

- **Thickness and nature of the substrate**: 3 or 15 cm with either extensive substrate (natural pumice, lava, bark compost and green compost, 3.4 % in mass of organic matter) or intensive substrate (natural pumice, lava, bark compost and green compost, 5.8 % in mass of organic matter) ;
- **Vegetation**: mix of *sedums* (*S.album, S. sexagularer, S. reflexum, S. kamchatikum, S. spurim, S. Acre*) or mix of grasses, perennial plants and sedums (*Festuca ovina, Festuca rubra, Dianthus carthusianorum, Poa pratensis, Koeleria glauca*) ;
- **Drainage layer:** expanded polystyrene or lava stone.

The two reference roofs are representative of standard flat roofs. The first one (code: BI) is covered with a self-protected (slate chippings) SBS elastomeric bitumen waterproofing membrane. On the second one (code: GR), the same waterproofing membrane is protected by a gravel layer.

Table 1 : composition of the 6 implemented green roofs

Code	SE3Y	SE3Z	NE3Y	SE15Y	GE15Y	GI15Y
Plant type	Sedum (S)		None (N)	Sedum (S)	Grasses + sedum (G)	
Substrate type	Extensive (E)					Intensive (I)
Substrate thickness	3 cm			15 cm		
Drainage layer	Expanded polystyrene (Y)	Pouzzo-lane (Z)	Expanded polystyrene (Y)			

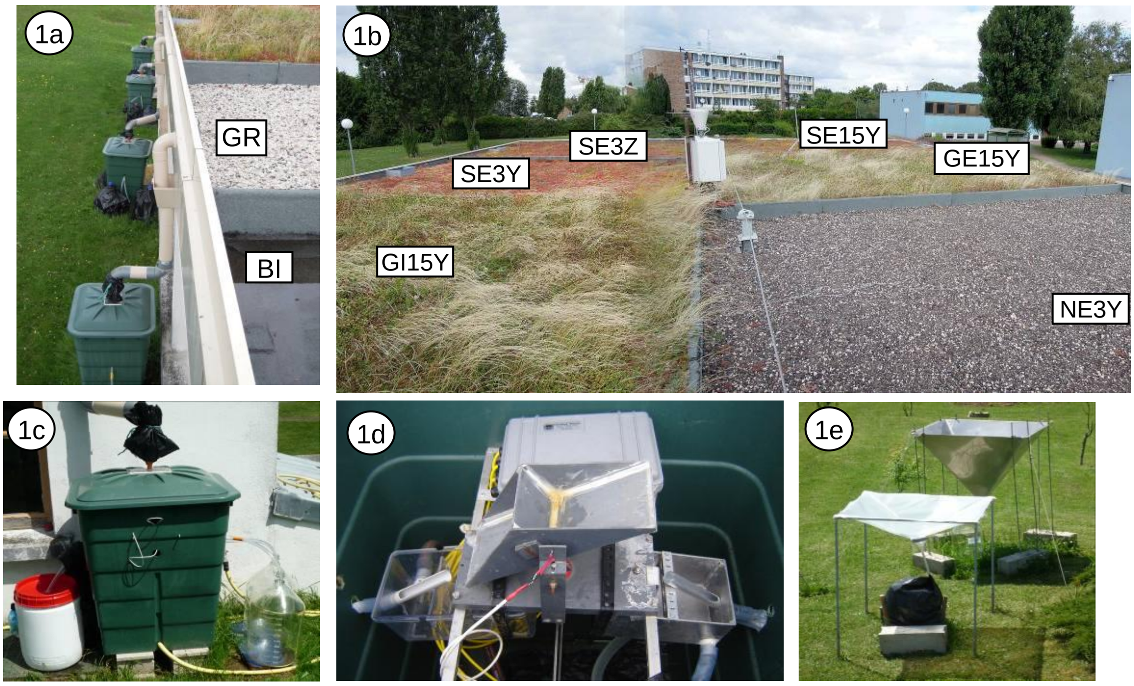

Figure 1 : (1a and 1b) An overview of the 8 experimental surfaces and runoff collection systems - (1c) Sampling devices. The green boxes contain equipment for flow and quality measurement detailed on photo (1d). (1e) Atmospheric fallout collectors

Rainfall is measured with a tipping buckets pluviometer located on the roof, with a resolution of 0.1 mm. Runoff flow from each roof compartment is measured in continuous at the outlet of the downspouts with tipping buckets (Figure 1), with a resolution of 0.01 mm. The water spilling from each side of the tipping buckets is then diverted into a 10% fraction and a 90% fraction, which can be collected separately in order to constitute event mean samples of different volumes. The 90% fraction allows the collection of event mean samples of sufficient volume (minimum of 4 l needed) in dry periods, when the runoff coefficient is very low. The 10% fraction is used in wet periods, when the runoff coefficients of the green roofs are more important. On one side of the tipping bucket the sampling line is entirely made of plastic components (PVC, PE, PTFE) ending with a 30 L plastic recipient for the analysis of heavy metals and global parameters. On the other side, the sampling line is entirely made of aluminium and PTFE ending with two 20 L glass recipients, for the analysis of organic contaminants.

The water quality sampling set-up was completed by two 1 m² rectangular funnels (Figure 1, one made of inox and the other one of polyethylene) for collection and analysis of total atmospheric fall out. In addition to this instrumentation, a meteorological station situated on the roof allows to monitored air temperature, relative air humidity, Wind speed and direction and net radiation. From these data, a local potential evapo-transpiration is assessed by the Penman-Monteith formula (Allen et al. 1998).

2.2 Studied rain events

2.2.1 Study period

Data are currently available since 15th of June 2011 for rain and runoff, and since august 2011 for meteorological data. Since the beginning of the measurements the maximum air temperature and maximum relative air humidity recorded were 33°C and 97%, respectively whereas the minimum were -10°C and 15 %, respectively. From the beginning of November 2011, the temperature decreases significantly whereas relative humidity rises. During the winter period, meteorological conditions are quite similar, daily average air temperature is around 9°c and relative humidity above 70 %. It should be noticed that the cooler period is February with daily average temperature around -5°C (minimum temperature occurs during this period). During the summer, the daily average air temperature varies from 15°C to 25°C and the daily average relative humidity is always higher than 50%.

Potential evapotranspiration, assessed from our meteorological station, shows a marked seasonal pattern with a maximum of 3.8 mm in June, 2012 and a minimum close to zero during the winter. This feature can be explained by low net radiation during winter period (lower than 100 $W.m^{-2}$ in diurnal average in winter instead of maximum diurnal average close to 350 $W.m^{-2}$ for the summer).

The cumulated rain for the whole period is 1020 mm. December 2011 was the wettest month with 136 mm, largely higher than the 30-years average for this month (65 mm). Other very wet months are: August 2011, June and October 2012. On the contrary, we also monitored very dry period (largely below the 30-years average) in October 2011, February, March and August 2012.

This hydrological period presents an interesting pattern with succession of very wet and very dry period. Unfortunately, no exceptional rain events were recorded. The maximum return period for rain event is below two years.

2.2.2 Rain events studied for water quality analysis

Five rain events were sampled for water quality analysis over the period 20/05/2012 to 09/10/2012. For these rain events, event mean samples of total atmospheric fallout and of runoff from the 8 experimental roof compartments were collected in parallel.

Table 2 : characteristics of the rain events collected for water quality analysis

Reference date	Rain depth (mm)	Max. intensity over 3 min (mm/h)	Previous dry weather period (days)	Antecedent * substrate moisture	Runoff rate**
21.05.2012	20.5	6	0.3	0.18 – 0.3	0.88 – 0.47
12.06.2012	6.8	12	1.7	0.15 – 0.28	0.49 – 0.00
14.06.2012	17.2	52	0.9	0.19 – 0.29	0.71 – 0.27
24.06.2012	10.2	22	2.9	0.15 – 0.29	0.60 – 0.19
09.10.2012	18.2	46	1.3	0.19 – 0.32	0.84 – 0.71

* range of substrate moistures measured immediately before the beginning of the rain event on the 6 green roof compartments
** range of runoff rates on the 8 compartments, with the highest value measured on the BI roof and the lowest on the 15 cm green roofs

Samples were collected within 24 hours after the end of each rain event and transported to the laboratory where they were analysed for pH, conductivity, turbidity, SS, organic matter (DOC, POC), nutrients, ions, metals. PAH, alkyphenols and Bisphenol-A concentrations were analysed for 3 out of the 5 events. However, data for ions, metals and organic micropollutants are still under process and therefore are not presented in this paper.

These 5 rain events were all collected during relatively wet periods, as can be seen from the low antecedent dry weather periods and the relatively high initial substrate moisture of the vegetated roofs (Table 2). These events are relatively similar as for the antecedent soil moisture conditions but differ for their rain depth and maximum intensities.

3 RESULTS AND DISCUSSION

3.1 Green roof runoff rates

Runoff coefficients were analyzed at the studied period scale and at the event scale. In order to have the same base for inter-comparison of the 8 roofs, we defined a rain event by the beginning of the rain and the end of the last runoff. Runoff is considered as ended when no flow was recorded during 1-hour. This method allows having accurate period of comparison but due to the delay of runoff by green roof we may observe long events, containing several rains.

To avoid accuracy problem, we only considered events with a cumulated rain depth higher than 1 mm. During our study period, 106 events were recorded, representing 931 mm of rain (e.g. 91% of the total rain amount for the same period). Due to technical problems among these 106 events, only 34 were simultaneously recorded on the 8 roofs. The cumulated rain amount for these events is 183 mm. Characteristics of runoff coefficient are summed up in Table 3. Runoff coefficients for the 34 common events are computed as the ratio of the sum of runoff for these 34 events and the sum of rain for these same events. Period scale runoff coefficient are compute as the ratio of the sum of runoff for all the recorded events by roof (number of these events is indicated by the left number in the bracket) and the sum of rain for these same events. Mean runoff coefficient at the event scale is the mean of the runoff coefficients calculated for each event.

Table 3: Runoff coefficient characteristics for the 8 roofs at the period and event scale

	Period scale		Event scale			
	34 common events	All events [(1)]	Mean	Median	Max	Min
BI	0.72	0.76 (90/90)	0.68	0.71	1	0.02
GR	0.44	0.56 (91/66)	0.36	0.33	0.84	0
SE3Y	0.21	0.49 (91/54)	0.19	0	0.96	0
SE3Z	0.15	0.37 (91/40)	0.13	0	0.82	0
NE3Y	0.19	0.31 (89/43)	0.13	0	0.90	0
SE15Y	0.11	0.36 (94/43)	0.13	0	0.82	0
GE15Y	0.07	0.29 (99/43)	0.11	0	0.81	0
GI15Y	0.06	0.26 (76/49)	0.09	0	0.90	0

[(1)] The first number in the bracket is the number of events recorded for the roof, the second number is the number of events where runoff was observed. Difference between number of events recorded for a roof and the total number of events (107) is due to technical problems)

The 34 common events presents rain amount comprise between 1 and 28.5 mm for duration from 81 min up to 64 hours (this duration is obtained for the event of 28.5 mm). Observations of runoff coefficient for the 34 common events reveal the effect of the different composition of the 6 green roofs. Green roofs with lower substrate show higher runoff coefficient. Comparison between same depth substrate pointed out the effect of the other constituents. Green roof with the lava stone (SE3Z) drainage layer has a lower runoff coefficient than those with the expended polystyrene (SE3Y). More surprising is the higher runoff coefficient for the vegetated 3-cm substrate (SE3Y) by comparison with the non-vegetated one (NE3Y). For the green roofs with 15-cm substrate, type of vegetation seems to play a role in the retention capacities. Green roof with sedum (SE15Y) has a higher runoff coefficient than those with more developed vegetation (GE15Y, GI15Y). However, substrate composition has no effect on retention. GE15Y and GI15Y have similar runoff coefficient. Obviously, reference surfaces presented higher runoff coefficients. However, it should be noticed that gravel may decrease significantly the runoff coefficient.

The studied period scale is more representative of the annual behavior and retention capacities of green roof as a higher number of events with more various characteristics are recorded. The maximum rain water amount recorded is 87 mm for one event. Observations of runoff coefficients reveal that up to 50% of the annual rain can be retained with a 3 cm substrate high (SE3Y, Table 3) whereas at least 64% can be retained with 15 cm (SE15Y, Table 2).

Differences between results at the period scale and for 34 common events are due to the differences between the studied events. At the period scale, studied events present higher water amount and more events occurs during the winter time. As a consequence, higher runoff is produced and that explain higher runoff coefficient at the period scale.

Numerous events didn’t produce any runoff, up to more than 50% of the events for several green roofs (SE3Z, NE3Y, SE15Y, GE15Y), and observation of runoff coefficients at the event scale underlined the great variability of the runoff coefficient. For the green roof, they vary from zero up to values higher than 0.90. The numerous events without runoff cause low values of mean runoff coefficient. These mean values are thus lower than those observed at the period scale.

These results confirm that green roofs are able to retain a great part of rain water, up to 70% at an annual scale, depending on the structure of the green roof. Observed runoff coefficients are consistent with previous work. (Mentens et al. 2006) presented average runoff coefficients around 0,5 for extensive green roof and close to 0.25 for intensive green roof, at a annual scale. But the ability of green roof to retain rain water is highly variable. As pointed out by (Baraglioli et al. 2008; Uhl et Schiedt 2008; Stovin 2009), rain water depth and initial moisture condition play an important role in this variability. Successive, long and large rain events in winter period, where the potential evapotranspiration is small, would seriously decrease retention capacities of green roof even with a high substrate.

Comparison between the different green roofs, on same events, shows that a thicker substrate retains more water. These results appear also in many other works (Baraglioli et al. 2008; Uhl et Schiedt 2008). For a same substrate thickness, the drainage layer with lava stones permit to decrease the runoff coefficient. This can be explained by the retention abilities of the lava stone. However, on the contrary of observations made by (VanWoert et al. 2005), the green roof without vegetation (NE3Y) has a runoff coefficient slightly lower than for the one with vegetation (SE3Y). Further observations are needed to confirm these observations. Comparison of runoff coefficients for green roof with different vegetation shows that more developed vegetation (GE15Y, GI15Y) seems to increase the retention capacities. This result was explained by (Berghage et al. 2007) as the effect of the rise of evapotranspiration by denser vegetation.

3.2 Runoff concentrations and pollutant loads

3.2.1 Concentrations

Figure 2 and Figure 3 summarize the range of concentrations observed in the runoff from the different roof compartments. An increase of turbidity, conductivity, SS, DOC and nutrient concentrations is noticed for the green roofs compared to the conventional flat roofs.

Though the samples showed a distinct coloration - probably attributable to humic substances eluted from the substrate - for the 3 cm depth substrates (SE3Y, SE3Z, NE3Y), the turbidity and SS remain moderated and in the same range as the gravel roof (medians: 12 to 21 NTU, 11 to 17 mg/l SS). SS and turbidity increase almost proportionally to the substrate depth for 15 cm depth roofs (medians: 60 to 138 NTU, 42 to 106 mg/l SS). Lower turbidity is noticed for roofs with a mixture of grasses and sedum (GE15Y and GI15Y), compared to the sedum coverage (SE15Y). Denser vegetation covert and more developed root network of grasses may offer a better protection against soil erosion.

The high conductivity of green roof runoff (medians: 198 to 446 µS/cm) clearly indicates the elution of dissolved components from the substrate and vegetation layer. The conductivity is superior, by a factor 1.5 to 2 for 15-cm-depth roofs compared to 3-cm-depth roofs. It does not seem to depend on the presence or not of vegetation, nor on the type of drainage layer.

An increase by a factor 5 to 10 in total phosphorus and dissolved organic carbon (DOC) concentrations is observed for green roofs with vegetation coverage compared to conventional flat roofs. DOC and Ptot concentrations are clearly lower in the case of the green roofs without any vegetation cover (NE3Y), which underlines the role of the vegetation layer in the emission of carbon and phosphorus. This is in contradiction with the results cited by (Rowe 2011) were runoff from an unplanted green roof had higher concentrations of P and N than that from planted roofs. However, in our case the vegetation was installed on the roof under the form of precultivated mats, which consist of a coco fiber and PE weft holding a small quantity of substrate and supporting the vegetation. These mats might have been subject to fertilisation previous to their implementation on the roof.

Substrate depth, type of drainage layer and type of vegetation do not affect much DOC and Ptot concentrations, which is consistent for Ptot with the observations of Monterusso 2004, cited by (Rowe 2011). (Teemusk et Mander 2011) noted higher Ptot and organic matter (BOD7) concentrations for heavy rain events – this result could not be confirmed here. One notes however high DOC concentrations for the last rain in October on the grass covered roofs, that may be linked to the decay of grasses after the summer flowering.

Though superior to conventional flat roof, total dissolved nitrogen concentrations in the runoff from our green roofs remain low, in the range of 0.7 to 1.8 mgN/l. It has to be noticed that these green roofs have not been subject to any fertilisation, thus the only source of nitrogen is atmospheric fallout and the compost that makes part of the substrate. However, constructers recommend the application of a slow release fertilizer on the surface of the green roof at the time of planting, this to ensure a good development of plants. These fertilisation practices may lead to much higher N and P concentrations in the runoff then those reported here. Concentrations up to 5 mgN/l were measured on an other test bench 20 month after fertilisation (Seidl et al., submitted). Total nitrogen concentrations up to 6.8 mgN/l have also been also reported by (Teemusk et Mander 2011) and (Berndtsson 2010).

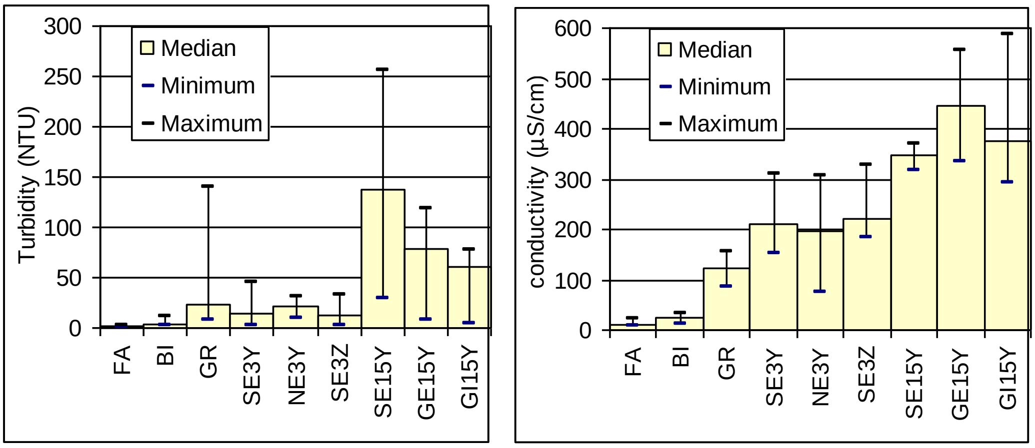

Figure 2 : range of turbidity and conductivity measured for the total atmospheric fallout (FA), runoff samples from the conventional flat roofs (BI: bituminous roof, GR: gravel roof) and from the 6 different vegetated roofs (SE3Y to GI15Y)

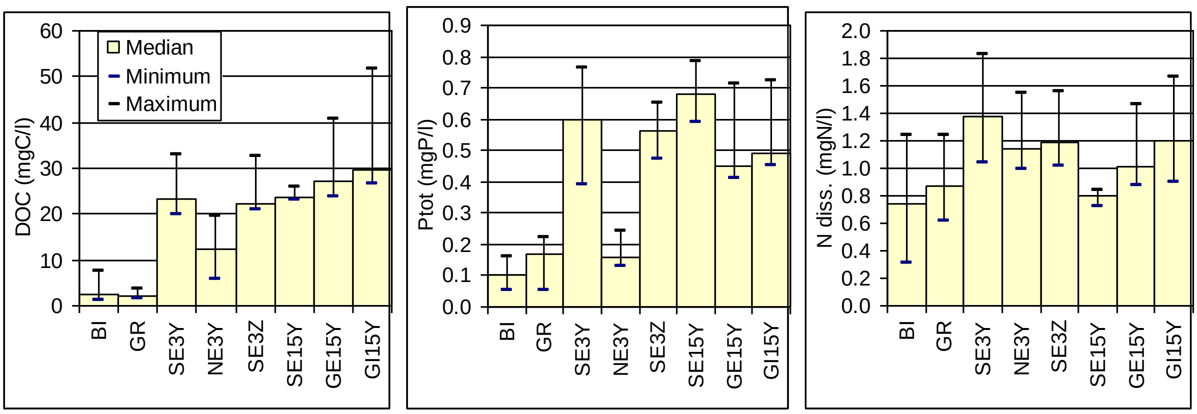

Figure 3 : range of dissolved organic carbon, total phosphorus and total dissolved nitrogen concentrations measured for runoff samples from the conventional flat roofs (BI: bituminous roof, GR: gravel roof) and from the 6 different vegetated roofs (SE3Y to GI15Y)

Organic matter and nutrient concentrations measured on our test bench are consistent with the values reported in the literature for different green roofs (Table 4). Compared to other types of roofs, green roof runoff shows high concentrations in organic carbon and phosphorus and an important coloration. This makes green roof runoff potentially interesting for plant watering, but relatively unsuitable for other uses of harvested waters as it might lead to algal development inside the storage tanks if it is not opaque enough and generate disinfection by products if the water is chlorinated (Mendez et al. 2011). Moreover, at a local scale, green runoff discharge into small urban ponds or ornamental basins could have detrimental effects on these small closed water bodies.

If we compare green roof runoff to other types of runoff waters like road runoff and mixed stormwaters we notice that nitrogen remains in the range of values usually observed, were as COP and Ptot are in the very upper range of concentrations reported for stormwaters.

Table 4 : comparison of organic carbon, phosphorus and nitrogen concentrations in green roof runoff and in the runoff from other urban surfaces

		TOC	DOC	Ptot	Ntot
Green roof runoff (EMC range)	this study * without vegetation layer	23–51 * 9–22	20–51 * 6-19	0.39–0.78 * 0.13–0.24	*0.8 – 1.8*
	(Hathaway et al. 2008; Berndtsson et al. 2009; Teemusk et Mander 2011)			0.16–1.50	0.4 – 6.9
Other roofs (EMC range)	this study	3–12	1–7	<0.05–0.22	*0.3 – 1.2*
	(Duncan 1999; Boller 2004; Gobel et al. 2007; Hathaway et al. 2008)	5–15	2-14	0.03–0.50	0.7-7.2
Road runoff (EMC range)	(Driscoll et al. 1990; Duncan 1999; Boller 2004; Gobel et al. 2007)	8–26	5-10	0.10– 0.80	0.9–9.0
Stormwaters (site medians)	(Williamson 1991; Duncan 1999; Smullen et Cave 1999; Pitt et al. 2004; Bressy et al. 2011)	8– 40		0.20–0.34	2.0–3.2

3.2.2 Pollutant loads emitted

An evaluation of the incidence of green roof on stormwater quality can not be based only on the consideration of runoff concentrations but needs to consider also the pollutant loads emitted, which are function of the runoff coefficient. As shown on Figure 4, the runoff coefficient varied in a wide range for the 5 sampled rain events (CR= 0 to 0.72 for the 15cm roofs, CR= 0.15 to for the 3cm roofs), which explains the important fluctuations in the exported pollutant loads per mm of rain event on a given roof.

Average DOC loads are about 7 times higher on the vegetated roofs compared to the bituminous reference roof (BI). The highest average Ptot loads are measured on the sedum roofs (6 times higher than BI roof), with lower loads for the grass roofs (2.5 time higher than BI roof). However, it has to be noticed that the average runoff rate for these 5 events is relatively important compared to the annual runoff values presented previously, thus the average pollutant loads calculated here might be overestimated compared to an annual average.

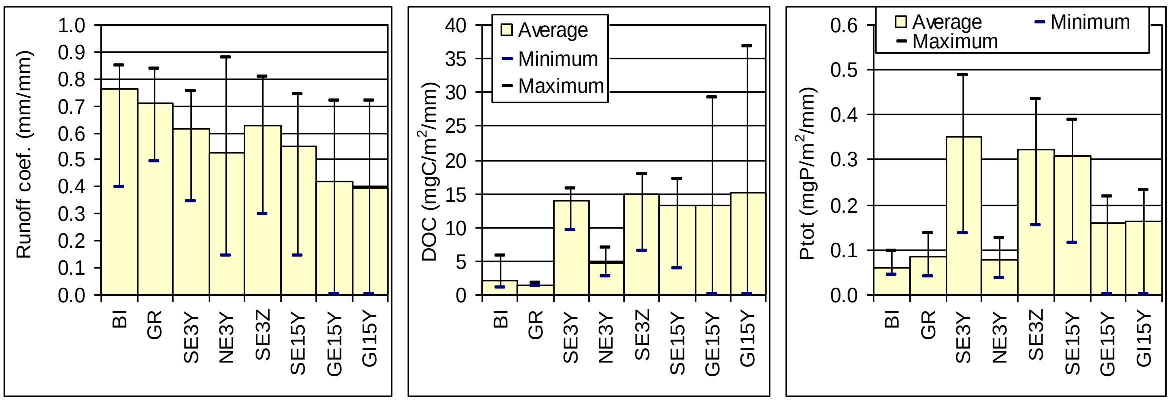

Figure 4 : runoff, DOC and Ptot load per mm of rainfall (average value is calculated over the sum of the 5 studied rain events)

4 CONCLUSION

An experimental green roof test bench was implemented in Paris suburb, within the field of the TVGEP project, in order to analyse the incidence of extensive green roof structures on runoff quantity and quality. This test bench allows a better analysis of the impact of different green roof parameters: type of drainage layer, type and thickness of substrate, type of vegetation.

Runoff monitoring over a one year period confirms the abilities of green roof to decrease the runoff coefficient by comparison with other roofs. At an annual scale, at least 50% of the rain can be retained and evaporated / evapotranspirated. However, the retention capacity is strongly variable and depends on rainfall depth and soil moisture condition. An increase in water retention can be obtained by a drainage layer with water retention capacities (as lava stone), higher substrate or denser vegetation.

First results concerning the quality of green roof runoff confirm the important level of coloration of green roof runoff, its high conductivity and high concentrations in dissolved organic matter and phosphorous. These specifications should be taken into consideration if the runoff waters are collected into small detention ponds or small creeks. Important SS concentrations were observed for the thick substrate (15 cm) with low development vegetation (sedums). Conductivity and turbidity increases with the substrate thickness, whereas substrate thickness, type of drainage layer and type of vegetation do not affect much DOC and Ptot concentrations. The emitted contaminant loads are very dependant of the hydrologic behaviour of the roof and thus on soil moisture condition and raindepth.

Further data acquisition is going on to confirm and extend these first results on both quantity and quality aspects. The hydrological measurements will be used to calibrate and validate a predictive runoff model under development. As for runoff quality, analysis are underway to determine the emission or retention of some metals and organic micropollutants (PAH, alkylphenols, BisphenolA) by green roof structures. Longer data sets are also needed for a better quantification of annual loads.

REFERENCES

Allen R. G., Pereira L. S., Raes D., Smith M. (1998). *Crop evapotranspiration: guidelines for computing crop water requirements.* FAO irrigation and drainage paper 56.

Alsup S. E., Ebbs S. D., Battaglia L. L., Retzlaff W. A. (2011). *Heavy metals in leachate from simulated green roof systems*. Ecological Engineering 37(11): 1709-1717.

Baraglioli A., Guillon A., Kovacs Y., Sénéchal C. (2008). *Studies on the quantity impacts of green roofs*. 11th International Conference on Urban Drainage, Edinburg, Scotland.

Berghage R., Jarrett A., Beattie D., Kelley K., Husain S., Rezai F., Long B., Negassi A., Cameron R., Hunt W. (2007). *Quantifying evaporation and transpirational water losses from green roofs and green roof media capacity for neutralizing acid rain.***:** 94 p.

Berndtsson J. C. (2010). *Green roof performance towards management of runoff water quantity and quality: A review*. Ecological Engineering 36(4): 351-360.

Berndtsson J. C., Bengtsson L., Jinno K. (2009). *Runoff water quality from intensive and extensive vegetated roofs*. Ecological Engineering 35(3): 369-380.

Berndtsson J. C., Emilsson T., Bengtsson L. (2006). *The influence of extensive vegetated roofs on runoff water quality*. Science of the Total Environment 355(1-3): 48-63.

Boller M. (2004). *Towards sustainable urban stormwater management*. Water Science and Technology: Water Supply 4(1): 55-65.

Bressy A., Gromaire M. C., Lorgeoux C., Chebbo G. (2011). *Alkylphenols in atmospheric depositions and urban runoff*. Water Science and Technology 63(4): 671-679.

Buccola N., Spolek G. (2011). *A Pilot-Scale Evaluation of Greenroof Runoff Retention, Detention, and Quality*. Water Air and Soil Pollution 216(1-4): 83-92.

Carpenter D. D., Kaluvakolanu P. (2011). *Effect of Roof Surface Type on Storm-Water Runoff from Full-Scale Roofs in a Temperate Climate*. Journal of Irrigation and Drainage Engineering-Asce 137(3): 161-169.

Carter T. L., Rasmussen T. C. (2006). *Hydrologic behavior of vegetated roofs*. Journal of the American Water Resources Association 42(5): 1261-1274.

Driscoll E., Shelley P., Strecker E. (1990). *Pollutant loadings and impacts from highway stormwater runoff*, Federal Highway Administration. vol. 1.

Duncan C. (1999). *Urban stormwater quality: a statistical overview*, Cooperative Research Centre for Catchment Hydrology, University of Canberra, Australia. Report 99 / 3.

Emilsson T., Berndtsson J. C., Mattsson J. E., Rolf K. (2007). *Effect of using conventional and controlled release fertiliser on nutrient runoff from various vegetated roof systems*. Ecological Engineering 29(3): 260-271.

Gendreau N., Rochefeuille P., Kovacs Y., Senechal C., Lassale F. (2007). *Les toitures végétalisées, une technique de gestion de l'eau devenue incontournable lors des nouvelles constructions respectant les critères de la Haute Qualité Environnementale.* Conférence internationale NOVATECH'07, Lyon, France.

Getter K. L., Rowe D. B., Andresen J. A. (2007). *Quantifying the effect of slope on extensive green roof stormwater retention*. Ecological Engineering 31(4): 225-231.

Gobel P., Dierkes C., Coldewey W. C. (2007). *Storm water runoff concentration matrix for urban areas*. Journal of Contaminant Hydrology 91(1-2): 26-42.

Gregoire B. G., Clausen J. C. (2011). *Effect of a modular extensive green roof on stormwater runoff and water quality*. Ecological Engineering 37(6): 963-969.

Hathaway A. M., Hunt W. F., Jennings G. D. (2008). *Afield study of green roof hydrologic and water quality performance*. Transactions of the Asabe 51(1): 37-44.

Mendez C. B., Klenzendorf J. B., Afshar B. R., Simmons M. T., Barrett M. E., Kinney K. A., Kirisits M. J. (2011). *The effect of roofing material on the quality of harvested rainwater*. Water Research 45(5): 2049-2059.

Mentens J., Raes D., Hermy M. (2006). *Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century?* Landscape and Urban Planning 77(3): 217-226.

Pitt R., Maestre A., Morquecho R. (2004). *The national Stormwater Quality Database (NSQD, version 1.1).* US Environmental Protection Agency.

Rowe D. B. (2011). *Green roofs as a means of pollution abatement*. Environmental Pollution 159(8-9): 2100-2110.

Smullen J. T., Cave K. A. (1999). *Updating the US NURP quality database*. Water Science and Technology 39: 9-16.

Stovin V. (2009). *The potential of green roofs to manage stormwater.* Water and Environment Journal 24: 192-199.

Stovin V., Vesuviano G., Kasmin H. (2012). *The hydrological performance of a green roof test bed under UK climatic conditions*. Journal of Hydrology 414: 148-161.

Teemusk A., Mander U. (2007). *Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events*. Ecological Engineering 30(3): 271-277.

Teemusk A., Mander U. (2011). *The Influence of Green Roofs on Runoff Water Quality: A Case Study from Estonia*. Water Resources Management 25(14): 3699-3713.

Uhl M., Schiedt L. (2008). *Green roof water retention - monitoring results.* 11th International Conference on Urban Drainage, Edinburg, Scotland.

Van Seters T., Rocha L., Smith D., Macmillan G. (2009). *Evaluation of Green Roofs for Runoff Retention, Runoff Quality, and Leachability*. Water Quality Research Journal of Canada 44(1): 33-47.

Vanwoert N. D., Rowe D. B., Andresen J. A., Rugh C. L., Fernandez R. T., Xiao L. (2005). *Green roof stormwater retention: Effects of roof surface, slope, and media depth*. Journal of Environmental Quality 34(3): 1036-1044.

Voyde E., Fassman E., Simcock R. (2010). *Hydrology of an extensive living roof under sub-tropical climate conditions in Auckland, New Zealand*. Journal of Hydrology 394(3-4): 384-395.

Williamson R. B. (1991). *Urban runoff data book.*, Water Quality Centre, National Institute of Water and Atmospheric Research, Auckland, New Zealand. Pubication 20.