

The fate of particulate pollutants in a horizontal sand filter for urban runoff treatment

Le devenir des polluants particulaires dans un filtre à sables horizontal pour le traitement du ruissellement urbain

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RÉSUMÉ

Cet article présente un focus sur le suivi des polluants particulaires dans un filtre à sable horizontal pour le traitement décentralisé des eaux de ruissellement à Rosny-sous-Bois en Seine-Saint-Denis. Le filtre, équipé en amont et en aval pour un suivi du fonctionnement hydrologique et épuratoire, montre une efficacité satisfaisante pour la plupart des paramètres suivis. D'une part, il réduit et retarde les extrêmes hydrauliques et d'autre part il montre des abattements des concentrations de l'ordre de 60% pour les MES et les polluants associés. Les traitements statistiques des données ont montré l'accumulation d'éléments plus conservateurs dans le filtre comme le plomb et les HAP. La nature des MES ne change que partiellement pendant la traversée du filtre et traduit un léger apport de sable. Une évaluation du stock de particules et de micropolluants piégés dans le filtre depuis la mise en service des filtres en service, c'est-à-dire il y a 10 ans, montre une masse interceptée très limitée. Sur cette base, la réduction des concentrations induit par le filtre serait environ 6 mg/l pour les MES et 1,5 µg/l pour le zinc. Le bilan montre également que le filtre dépollue plus par la sédimentation créée dans l'ouvrage d'alimentation, que par le piégeage au sein du substrat filtrant.

ABSTRACT

Sustainable drainage systems are more and more implemented in the urban space, though their operational efficiencies are not always well known. This article presents a focus on the fate of particulate pollutants in a horizontal sand filter for decentralised runoff treatment in a Paris suburb. The filter, equipped up- and downstream for hydrologic monitoring and for pollutant monitoring, shows a satisfactory efficiency for most of the monitored parameters. On one hand it reduces and delays the hydraulic extremes and on the other hand it shows concentration reductions in the order of 60% for TSS and associated pollutants. Statistic treatments of the data showed the accumulation of more conservative elements in the filter like lead and HAP. The nature TSS changes only partially during the filter trajectory and receives slight sand footprint. An evaluation of the stock of particles and micropollutants trapped in the filter since the filters were put into operation, i.e. 10 years ago, shows a very limited intercepted mass. Based on the latter, the average concentration reduction induced by the filter would only be about 6 mg/l for TSS and 1.5 µg/l for zinc. The mass balance shows that the filter depollutes more by sedimentation in the upstream collector, than by trapping elements in its filter medium.

KEYWORDS

horizontal filter, micro-pollutant retention, particle composition, road run-off, sustainable urban drainage system,

1 INTRODUCTION

Road runoff consists of a complex matrix of pollutants, mainly originating from automobile traffic, but also from leaching of urban infrastructures. In order to preserve the quality of receiving water bodies, source control and runoff depollution are needed. Various technical solutions have been developed for sustainable management of runoff over the past decades (Barbosa et al. 2012; Hilliges et al. 2013; Li et al. 2014; Revitt et al. 2014). In the framework of the French research project Roulépur (Ramier et al. 2016; Seidl et al. 2019) the hydraulic efficiency and the pollutant load reduction was evaluated in a horizontal sand filter. The present presentation focusses on the retention of particulate micro-pollutants and aims to show how the retention and composition of particles evolve from the inlet to the outlet.

2 MATERIAL AND METHODS

The studied filter catchment (0.76 ha) is situated in the east suburbs of Paris, in the municipality of Rosny-sous-bois with mainly residential land use (coordinates 48.8629308,2.4958384). It's composed of a road section of 150 meter (3410 m², contributing surface 2900 m²) and an adjacent school complex equipped with sustainable drainage (4200 m², contributing surface 2540 m²). The catchment is drained by a main collector connected to a landscape filter system for flow regulation and pollution treatment. The system, operated since 2008, is installed in a public square and freely accessible to the public. It's composed of 3 treatment filters in parallel connected in series with 3 other storage filters. Each filter has a rectangular surface of 16 m² and is filled with 1-meter substrate. The filtering substrate layer is covered with 40 cm soil and grassland. A threefold layer of geotextile separates the vegetated soil from the sand layer, allowing infiltration of exceeding irrigation water, but no capillary uptake by the vegetation. The filters are operated horizontally with a flow limiter at the outlet of the whole system. The municipality maintains the vegetal filter cover, while the hydraulic system is operated by the waste water section of Saint-Denis county. Figure 1 shows the details of one of the treatment filters and the principal of hydraulic functioning of the system.

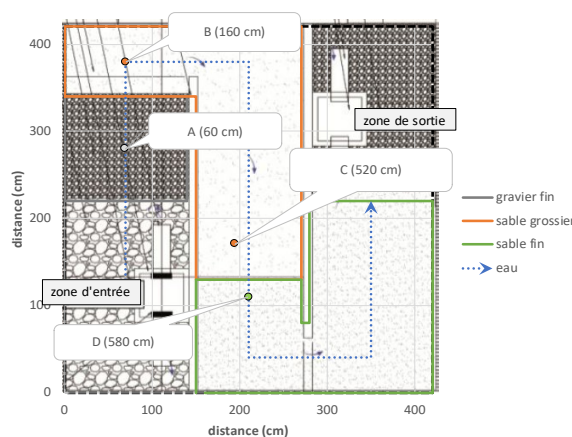


Figure 1: Top view of the structure of a horizontal filter. The substrate particle diameter is decreasing from the inlet to the outlet in the sense of the blue arrow: gravel, fine gravel, coarse sand and fine sand. The sampling points are indicated with letter and distance from the inlet.

The flow was continuously monitored by an electromagnetic flow sensor (Krohne, Tidalflex 4300 F) upstream and by a triangular weir system (Hydreka / Sigma) downstream. A separated level probe at the filter entrance measured the bypass frequency. The vortex flow limiter was equipped with a second level probe for verification. To evaluate the treatment efficiency both flow-meters were connected with automatic, refrigerated water samplers to sample proportionally to time (inflow, Bühlher 1029) or proportionally to flow (outflow, Sigma-AS950) to obtain event mean samples, either in polyethylene recipient for global and trace metal analysis, or in glass recipient for organic pollutant analysis. About 10 events were sampled by between 2017 and 2018. To evaluate the pollutant fate inside the filter, the deposit formed in the manhole at the filter entrance and in the filter substrate were sampled. The filter substrate was afterwards 3 times consecutively extracted with water (ratio of 100 g /l) to extract and study the <100 µm solid fraction. The selected contaminants include global parameters (TSS, DOC, POC), nutrients, 12 metals and 3 families of organic micropollutants (PAH, alkylphenols and bisphenolA). After collection, the samples were transferred to the partner university laboratories and analysed according to the French standards AFNOR (AFNOR 2005) or the APHA Standard methods for water quality analysis (APHA et al. 2012). The particulate fractions and the dissolved fractions were treated separately, whereby the particulate fraction for metal analysis was analysed after complete acid digestion. The different particulate concentrations served to calculate the pollutant flux generated by the

watershed, its reduction by the filter, the pollutant enrichment and origin and to estimate the balance across the filter.

3 RESULTS AND DISCUSSION

A comparison of the pollutant concentrations at the inlet and outlet shows the capacity of the filter to (partially) retain the runoff pollution. The median reduction in total suspended solids concentration (EC50) is about 60%. The retention is even less effective for the dissolved phase than for the particulate one (Seidl et al. 2019).

Data in Table 1 confirms the runoff character of the collected solids: relatively low carbon content, and elevated metal contents. The contamination is lower than observed in road deposits and runoff SS in Paris (Gromaire et al. 1999; Flanagan 2018), but close to those measured in sediments from sustainable drainage in Paris suburbs (Bressy et al. 2014). The values are slightly above the regional river Seine sediments (Le Gall et al. 2018), what could be seen as an (anthropogenic) background. The level of organic micropollutants contamination such as PAHs and NPs, is similarly of the same order of magnitude as that reported previously by (Bressy et al. 2014).

Table 1: Average values of micro-pollutants in the solids sampled (deposits at the filter inlet, SS: suspended solids of run off (IN) and water discharged (OUT), solids of less than 100µm retained in the filter substrate)

	Cu	Pb	Zn	Fe	POC	C10-C40	Σ 13 PAH	BPA	ΣNP
	mg/kg	mg/kg	mg/kg	g/kg	g/kg	mg/kg	µg/kg	µg/kg	µg/kg
Deposit (3)	172	110	623	24,4	52	2535	4905	79	703
SS IN (8)	310	311	1423	30,2	12,7	4218	6544	339	3289
SS OUT(3)	259	128	1063	28,1	10,4	4520	7233	160	355
Retained (20)	25	105	408	6,49	7,86	378	290	961	12

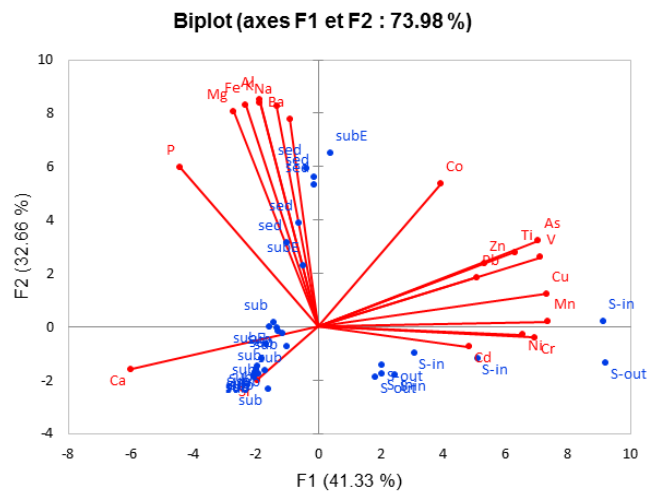
The retention of particles in the substrate tends to increase with depth (not shown) due to most frequent charge of the lower filter zone. The retained particle content is also lower in the first gravel zone (A) than in the sand (B and C) zones as consequence of the difference in the filtering pore diameter. If the composition of the trapped particles is compared with that of the sediments collected at the inlet, the solids retained in the substrate appears enriched with lead and zinc, elements present in equal or greater quantities than in the incoming solids. The contamination is mainly retained at the gravel-sand and fine sand interfaces. The last part of the filter, the fine sand zone, contributes only slightly to the pollutant retention. The organic micropollutants show a behavior comparable to that of metals, with the same tendency for the concentrations to decrease from upstream to downstream. However, the vertical profiles of alkylphenol contents are distinguished by higher values in the surface layers of all 4 sampling points, probably as consequence of alkylphenol emission from the geotextile separating the filter substrate from the topsoil.

The organic micropollutant contents of the particles retained by the substrate remain for all the organic micropollutants studied below the level of the sediments formed at the filter inlet and much lower than the TSS content of the incoming runoff water. Though the sediment is an integration over time, while in- and outflow measures are just a snapshot of the reality.

To evaluate the relative importance of micropollutants contamination and identify their possible origin it's useful to estimate the enrichment ratio or normalized pollutant content. It's calculated as the content of the considered micropollutant divided by the content of a reference element. The reference element is iron for metals and organic carbon for organic micropollutants. This number thus indicates how close the filter particles are to the sediment. Thus, 100% is equivalent to sediment and 0% approaches material with little or no runoff solids contamination as at the mid-depth of the last filter point sampled, D2 or D3. In figure 2-II we can see the enrichment of copper and lead, the first more mobile and not significantly retained in the filter, the second accumulated at the entrance, slightly more in the lower layers. For polycyclic hydrocarbons (PAH) and total hydrocarbons (HC) we obtain a similar image, with HC more retained in the upper layers. The HC are retained at the gravel and fine sand section and thus probably linked to two different granulometry classes.

Figure 2 : (I) Example of spatialized micro pollutant enrichment, A, B, C, D : sampling point and depth, ex A5 : 5th layer at 80-100 cm depth at point A. Red color intensity : enrichment degree compared to deposit. (II) PAC with 20 trace elements, "sed" : deposit (n=5), "sub": substrate (n=18), "s-in": incoming SS (n=5), "s-out": outgoing SS (n=3),

	Cu	Pb	ΣHAP (18)	HC
A1	43%	565%	53%	152%
A2	36%	259%	80%	202%
A3	49%	239%	65%	180%
A4	68%	407%	42%	123%
A5	76%	429%	41%	100%
B1	51%	460%	79%	126%
B2	51%	281%	31%	91%
B3	51%	417%	43%	136%
B4	65%	278%	34%	37%
B5	87%	384%	28%	22%
C1	51%	505%	39%	105%
C2	57%	298%	47%	47%
C3	57%	252%	15%	49%
C4	64%	546%	23%	71%
D1	37%	317%	79%	145%
D2	20%	331%	50%	211%
D3	39%	298%	43%	100%
D4	40%	257%	36%	71%
SED (3)	100%	100%	100%	100%



The application of principal component analysis (PCA) of the mineral components of the different particles allows to distinguish 3 groups of particles on the basis of their composition: sediment (sed), substrate (sub) and all particles entering (s-in) and leaving (s-out). The PCA shows us that the substrate is clearly marked Si as consequence of its sand component. The entering and leaving particles are better qualified by trace elements like Cr, Cu, Pb and Zn. They are distinct from the rest by their size, which allows them to be transported, and by their composition with higher contents of elements issued from runoff pollution. With multi-correlation tests, it can be observed that for the sediments and the substrate, the metals copper, chromium, nickel and zinc are correlated ($r^2 > 0.9$) with iron, whereas for the incoming and outgoing particles this is not the case, which indicate a less geological and more anthropogenic character of the latter.

4 CONCLUSION

Statistic treatments of the data showed the accumulation of more conservative elements in the filter like lead and HAP. The TSS change only partially during the filter trajectory and receive slight sand footprint. An evaluation of the stock of particles and micropollutants trapped in the filter since the filters were put into operation, i.e. 10 years ago, shows a very limited intercepted mass. Based on the latter, the average concentration reduction induced by the filter would about 6 mg/l for TSS and 1.5 µg/l for zinc. The balance shows that the filter depollutes more by sedimentation created at the entrance than by trapping element in its filter medium.

The presentation proposes to give more details for the micropollutant profile and spatial distribution as well to present a balance for the main elements.

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