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Soil water retention is the primary mechanism for contaminant trapping in source-control infiltration systems

La rétention de l'eau dans le sol est le principal contributeur de l'interception des flux polluants dans les ouvrages d'infiltration à la source

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ABSTRACT

This study investigates the effects of infiltration-based sustainable urban drainage systems (SUDS) on contaminant loads conveyed by surface runoff. For that purpose, an in-situ survey of three devices with contrasting designs was carried out, with a continuous monitoring of the outflow rate during more than one year, combined with water sampling in the underdrain followed by micropollutant analysis for several events. Comparison to a reference impervious surface enabled the computation of the devices' performances regarding volume, concentration, and mass load reduction between in- and outflow. The soil-based system (swale) showed a much greater volume reduction than the other two systems made of gravels (trench and porous pavement with reservoir structure – PPRS), as a result of which mass load removal was higher and more stable from one event to another (> 80%). Interestingly, this performance was achieved despite a poor retention of dissolved contaminants such as bisphenol A. Conversely, the PPRS acted more as a detention facility except for the smallest rain events, so that load reduction overall followed concentration reduction. Hence, water retention capability of source-control and soil-based SUDS appears to be the main contributor to micropollutants removal, which we think should be prioritized regarding wet weather run-off water management.

RÉSUMÉ

Cette étude se penche sur les capacités des systèmes de gestion des eaux pluviales à la source à décontaminer les eaux de ruissèlement par l'analyse *in-situ* de trois dispositifs infiltrant différents grâce à un dispositif de mesure des débits à l'exutoire des ouvrages couplé à un système d'échantillonnage pour l'analyse en laboratoires de 64 micropolluants. Les données ainsi récoltées ont été comparées avec celles obtenues sur un site imperméable de référence afin de déterminer leurs performances en terme de réduction des volumes d'eau, des concentrations et des flux massiques en micropolluants. L'ouvrage de filtration par substrat de sol végétal (la noue) a montré une propension à retenir les volumes d'eau beaucoup plus marquée que sur les deux autres sites avec un substrat de grave (une tranchée d'infiltration et une chaussée poreuse à structure réservoir - CSR), résultant en une réduction des flux de pollution plus importante et plus stable d'un évènement à un autre (>80%). Il est intéressant de noter que cette haute performance est atteinte malgré une faible rétention des substances en phase dissoute telles que le bisphénol A. Inversement, la CSR agissait plus comme un ouvrage de décantation, sa rétention de flux suivant de fait les diminutions de concentrations observées. De ce fait, la rétention d'eau par les ouvrages de gestion à la source (et plus spécifiquement dans un substrat de sol végétal) se présente comme le principal contributeur à l'interception des flux polluants.

KEYWORDS

Pollution retention, Stormwater management, Sustainable Urban Drainage Systems, Water retention

1 INTRODUCTION

As a consequence of urban sprawl and soil sealing, the hydrological balance is highly modified leading to higher flow rates and volumes to be managed during wet weather (McGrane, 2016). Additionally, human activities and land use change increase the amounts of diffuse pollutant sources, resulting in significant loads to the receiving environment and water quality impairment (Müller *et al.*, 2020; Wicke *et al.*, 2021). To cope with these problems, stormwater management in urban areas increasingly relies on *Sustainable Urban Drainage Systems* (SUDS), among which are infiltration-based facilities. In addition to alleviating the sewer network and shifting the water cycle towards a more “natural” state, such devices have been shown to offer interesting perspectives for pollution mitigation (Bressy *et al.*, 2014; Davis, 2005).




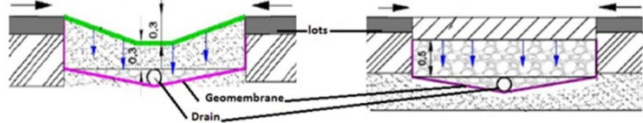
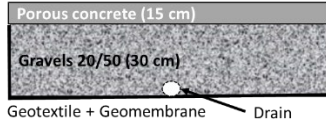
Optimizing SuDS design towards enhanced retention of contaminants requires a proper understanding of the main processes occurring in these systems. In this regard, significant research efforts have been dedicated to characterizing the physicochemical processes governing the fate of dissolved contaminants, as well as the trapping mechanisms affecting particle-bound substances (Flanagan *et al.*, 2019). Numerous studies addressing the water quality performance of SUDS have provided extensive data on concentration removal between stormwater runoff and seepage/outflow water, at the lab-, pilot- or field scale (LeFevre *et al.*, 2014). However, the purely physical retention of water by the soil also participates in the interception of contaminant fluxes, to an extent that remains poorly characterized. In this context, the present study aims at achieving a comprehensive view of the processes contributing to contaminant retention, in three source-control, infiltration-based systems: a swale, a trench, and a pervious parking lot.

2 MATERIAL & METHODS

2.1 Presentation of the study sites

This study is based on *in situ* monitoring and sampling of three different source control systems collecting stormwater runoff from small parking lots (Table 1): a vegetated infiltration swale, an infiltration trench made of gravels, and a porous pavement with a reservoir structure (PPRS). The catchment of the former two devices is composed of impervious classical asphalt and semi permeable materials.

Table 1. Source control storm water facilities used as study sites

	Vegetated Swale	Gravel Trench	Porous pavement with reservoir structure
System			
Catchment Surface	302 m ²	260 m ²	94 m ²
Cross section			

All these systems were sealed at the bottom (*i.e.*, below the substratum) with a geomembrane to allow outflow water to be monitored and sampled. Since inflow water could not be representatively sampled at the inlet of these devices, the characterization of runoff water was made through a comparison to a reference. For runoff quality, the latter consisted of a classical asphalted parking lot situated in their immediate vicinity. For runoff quantity, the reference was estimated from rainfall measurements and the catchment characteristics.

A specific monitoring and sampling installation was designed and implemented at the outlet (underdrain) of each system, as well as at the outlet of the reference catchment (*cf.* Garnier, 2020). Flow rate was continuously monitored during more than one year, and composite water samples were collected during specific rainfall

events. These samples were sent for analysis to different analytical laboratories, targeting 64 micropollutants in total (metals, PAHs, pesticides, alkylphenols, and flame-retardants).

2.2 Event-based performance of the devices

The study aims to present the micropollutant fluxes reduction achieved through these three systems. This is reflected by the reduction of the event-based mass load of contaminant:

$$\text{Removal}_M = \frac{M_{\text{in}} - M_{\text{out}}}{M_{\text{in}}} \quad (1)$$

where $M = C \times V$ (C being the event mean concentration of a given micropollutant and V the event volume, and the subscripts in and out referring to inflow (reference) and the collected outflow from each site)

Mass removal being a consequence of both concentration and volume removal (to a different extent), an additional focus will be dedicated to the removal of these two quantities of interest:

$$\text{Removal}_X = \frac{X_{\text{in}} - X_{\text{out}}}{X_{\text{in}}} \quad (2)$$

where $X = C$ or $X = V$.

3 RESULTS & DISCUSSION

In the present abstract, we chose to focus only on the comparison between the swale and the porous pavement, the behavior of which showed the greatest differences. Flow data represent a monitoring of 106 rain-events for the swale and 49 rain-events for the porous pavement over a 14-month period. Micropollutant data were acquired for 9 events over a 12-month period. Among the different analyzed substances, the focus will be on Copper (Cu) and Bisphenol A (BPA), due to their contrasting fractionations between the particulate and dissolved phases.

3.1 Volume reduction

The swale and the porous pavement both contributed to volume reduction, albeit with relatively dissimilar hydrologic behaviors (Figure 1a). The porous pavement showed a high variability in its performance, with a volume removal spanning the whole range 0% (detention only) – 100% (median value: ~55%). Conversely, for the swale, no outflow was observed for 64% of the monitored events (in other words, the median removal was 100%); the volume removal was $\geq 95\%$ for 90% of the events, and in any case $> 55\%$.

3.2 Concentration reduction

Copper – indeed found to be predominant in the particulate phase of stormwater runoff, with a high inter-event variability of concentrations (6 – 91 $\mu\text{g/L}$, Garnier, 2020) – was generally quantified in lower concentrations in the outflow water of both devices. However, the concentration removal appeared to be variable from one event to another (20-90% except for one event) and relatively comparable between the two systems (*cf.* Figure 1b).

Regarding BPA – mostly dissolved in runoff, with total concentrations ranging from 125 to 380 ng/L – removal performances were highly variable in both systems. Cases of pollution release (*i.e.*, “negative removal”) occurred for nearly half of the events. The data do not allow the demonstration of a retention in the dissolved phase, even in the soil-based system supposed to favor physico-chemical interactions.

3.3 Load reduction

From the perspective of preserving the quality of water bodies, the most important element to consider is the load reduction, as it directly reflects the systems’ ability to avoid micropollutant discharges into surface waters. As we can see in Figure 1, while the swale and porous pavement could not be really distinguished regarding concentration removal, both had very distinct performances regarding load removal.

For the porous pavement, the statistical distributions of concentration and load removals presented similar patterns whatever the contaminant considered (Figure 1c). In other words, its performance towards pollution reduction is mostly driven by the physical and/or physico-chemical retention mechanisms in the structure. Contrariwise, for the swale, the mass load removal of Cu, BPA, as well as almost all other substances under study, was systematically $\geq 75\%$, despite the previously noticed variability in concentration removal. The computed

values mostly followed the swale's behavior regarding water volume retention. Hence, its higher depollution capabilities are mainly driven by water retention in the soil.

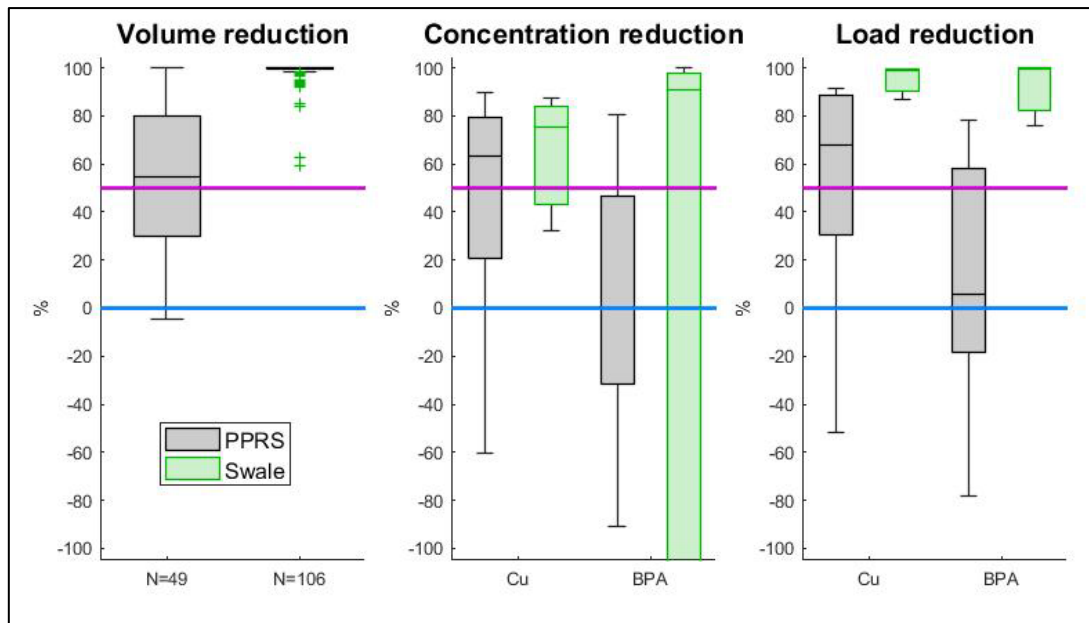


Figure 1. Event-based performances for the two devices: a) Outflow Volume reduction, b) Cu and BPA Concentration reduction, c) Cu and BPA Load reduction

4 CONCLUSION

It is of interest to try to analyze and deconvolute the different processes that occur during stormwater management in SUDS. Many systems – including, to some extent, those under study – tend to show promising propensity to remove and retain certain pollutants (particulate and sometimes dissolved) from runoff water, thus decreasing the micropollutant concentrations in SUDS outflow. It is however to be noted that the main gain from many source-control and soil-based SUDS is probably not their settling/filtration capability but their water retention capability. The swale showed load removal performances close to 100% thanks to its significant volume retention: we can note that 99% of the rain events with a total depth ≤ 15 mm (representing 93% of rain events between 1985 and 2013) did not generate any outflow. However high the concentration levels of micropollutants may be, in the end if limited amounts of water discharges at the outlet of the system, limited amounts of pollution discharges in the receiving bodies.

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