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Efficiency of source control systems for reducing runoff pollutant loads: Feedback on experimental catchments within Paris conurbation

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ABSTRACT

Three catchments, equipped with sustainable urban drainage systems (SUDS: vegetated roof, underground pipeline or tank, swale, grassed detention pond) for peak flow mitigation, have been compared to a reference catchment drained by a conventional separate sewer system in terms of hydraulic behaviour and discharged contaminant fluxes (organic matter, organic micropollutants, metals). A runoff and contaminant emission model has been developed in order to overcome land use differences. It has been demonstrated that the presence of peak flow control systems induces flow attenuation even for frequent rain events and reduces water discharges at a rate of about 50% depending on the site characteristics. This research has also demonstrated that this type of SUDS contributes to a significant reduction of runoff pollutant discharges, by 20%–80%. This level of reduction varies depending on the considered contaminant and on the design of the drainage system but is mostly correlated with the decrease in runoff volume. It could be improved if the design of these SUDS focused not only on the control of exceptional events but also targeted more explicitly the interception of frequent rain events.

1. Introduction

Stormwater management has become a critical issue in the field of sustainable urban development to protect civil society against flood and because runoff on urban surfaces has been recognised as a major cause of the degradation of receiving waters (Burton and Pitt, 2001). In the past, stormwater was collected by drainage networks, but with fast urbanization these networks have become inadequate, leading local authorities to develop strategies to prevent flooding.

The first strategy adopted was the large-scale management of urban drainage systems by building large reservoirs. It was not sufficient to remove the flooding risks and now a local stormwater management approach is preferred (Brombach et al., 2005; Ellis and Revitt, 2010; Jefferies et al., 2009; Roy et al., 2008). In recently urbanised areas, facilities are developed simultaneously to the urban growth promoting retention

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or infiltration at a small scale. These facilities are often called "Sustainable Urban Drainage Systems" (or SUDS). Two major types of SUDS design are used worldwide: flow rate regulation and volume regulation. Both in France and in the USA, the most widespread regulation is based on a limited flow rate value (Petrucci et al., 2013; Roy et al., 2008). For example in the French department Seine Saint-Denis, in the suburb of Paris, the local authorities have imposed a flow rate regulation at 10 l/s/ha since 1993 (DEA, 1992). Thus SUDS are typically intended to facilitate hydraulic management and have been designed for exceptional precipitation events; only on rare occasion are contamination mitigation objectives actually addressed (Martin et al., 2007).

Studies have revealed that such SUDS are capable of: reducing the discharged volumes, delaying catchment response, slowing flow velocities and increasing water residence time within the various facilities (Jefferies et al., 2004; Scholes et al., 2008). Thus they can have a substantial impact on the pollutant fluxes being conveyed by stormwater and discharged into receiving waters. Purifying effects have indeed been observed at the system scale for several types of SUDS (Jefferies et al., 2004; Pagotto et al., 2000; VanWoert et al., 2005). However, there are few studies highlighting the overall effect of SUDS on pollutant fluxes control, at a suburban catchment scale. The effect of SUDS that were designed for flow control and not pollutant control remains poorly documented. Moreover literature data is usually limited to metals and nutrients and few data is available on organic micropollutants (DiBlasi et al., 2009; Matamoros and Salvadó, 2012).

Therefore, the objective of this research is to assess the effect of peak flow control policies, on the water and contaminant flows discharged during frequent rain events at a small catchment scale. A special attention has been given to a selection of priority substances listed in the Water Framework Directive (2000/60/EC), whose presence is significant in runoff (Bressy et al., 2012), but whose fate in SUDS is not much documented to date. Three catchments containing SUDS were compared to a reference catchment featuring a conventional separate sewer network, in terms of hydraulic behaviour and discharged contaminant fluxes (i.e., suspended solids (SS), organic carbon (OC), trace metals (copper, lead, zinc) and organic micropollutants: polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and alkylphenols). Moreover, the deposits formed in storage zones were characterised so as to better understand the fate of micropollutants during their transfer and in order to devise the best strategy for recovering and treating these wastes.

2. Materials and methods

2.1. *Site characterisation*

A residential site, characterised by low-density traffic and no industrial activity within a 5-km radius, was studied in a suburban area near Paris (France). The site was drained by a separate sewer system. Land use on this site was quite homogenous, while the stormwater management system featured a wide diversity.

On this site, four small catchments ranging from 0.8 ha to 1.9 ha were studied. The "Reference" catchment was drained by a conventional separate sewer system, while the other three catchments ("North", "Park" and "South") temporarily stored stormwater in various SUDS to comply with the 10 l/s/ha flow limitation imposed by local authorities. Stormwater on the North catchment was stored in a vegetated roof and in an underground pipeline for common rain events (up to 1 year return period) with an overflow onto a swale or on parking for exceptional events. In the Park catchment, stormwater was stored in a grassed detention pond that is part of a public garden. Stormwater management on the South catchment had been incorporated into the land use plan and the practices associated various types of storage facilities: underground tank for private parcels, swales and a public square covered by grass. The outlets of the catchments with SUDS are fitted with flow rate regulators as usual in France (Table 1). According to Martin et al. (2007), these SUDS were representative of the kinds of solutions adopted in France.

The characteristics of the catchments are listed in Table 1. The four catchments displayed a homogeneous pattern of

Table 1 – Description of the studied catchments.

Name	Size (ha)	Land use (%)						Retention system	Flow regulation
		$R \neq Zn$[a]	$R = Zn$[a]	S[a]	P[a]	Gs[a]	G[a]		
Reference	0.82	36	7	28	3	25	0	Conventional stormwater system	–
North	1.5	47	2	24	4	18	6	Vegetated roof + retention in an oversized pipe (return period of up to 2 years), possible overflow into a swale and a parking lot	16 l/s vortex flow regulator
Park	2.0	12	4	0	19	26	39	2 grassed retention basins in a public park	23 l/s float valve flow regulator
South	0.92	28	10	8	19	17	17	Swales + grassed retention basin in a square + underground tank	2 × 1 l/s nozzles + 5.6 l/s vortex flow regulator + 3 l/s pump
Built parcel	0.13	22	43	0	4	31	0	Conventional stormwater system	–
Street	0.031			100				Conventional stormwater system	–

[a] $R \neq Zn$: Roof without zinc; $R = Zn$: roof made with zinc; S: street; P: walking paths; Gs: garden above underground parking; G: garden.