Biofiltration for the on-site management of micropollutants in urban runoff: lessons from a field study

Kelsey Flanagan, Philippe Branchu, Lila Boudahmane, Emilie Caupos, Dominique Demare, Steven Deshayes, Philippe Dubois, Laurent Meffray, Chandirane Partibane, Mohamed Saad, et al.

To cite this version:

Kelsey Flanagan, Philippe Branchu, Lila Boudahmane, Emilie Caupos, Dominique Demare, et al.. Biofiltration for the on-site management of micropollutants in urban runoff: lessons from a field study. International Sponge City Conference, Sep 2018, Xi'an, China. hal-02065497

HAL Id: hal-02065497
https://hal-enpc.archives-ouvertes.fr/hal-02065497
Submitted on 12 Mar 2019

Biofiltration for the on-site management of micropollutants in urban runoff: lessons from a field study

Kelsey Flanagan[1,*], Philippe Branchu[2], Lila Boudahmane[1], Emilie Caupos[1], Dominique Demare[3], Steven Deshayes[1], Philippe Dubois[1], Laurent Meffray[2], Chandirane Partibane[1], Mohamed Saad[1], Marie-Christine Gromaire[1]

[1]LEESU, UMR MA 102, École des Ponts, AgroParisTech, UPEC, UPE, Champs-sur-Marne, 6-8 avenue Blaise Pascal, Cité Descartes, 77455 Marne-la-Vallée Cedex 2, France. kelsey.flanagan@enpc.fr

[2]CEREMA, 12 Rue Léon Teisserenc de Bort, 78190 Trappes, France.

[3]IFSTTAR, Laboratoire Eau et Environnement- route de Bouaye CS4 – 44344 Bouguenais Cedex, France.

*Corresponding author

Keywords: Biofiltration, swale, vegetative filter strip, road runoff, micropollutant

Abstract

The present work focuses on lessons learned from the monitoring of total and dissolved concentrations of a wide range of micropollutants (TM, PAH, BPA, AP, PAE) in a biofiltration swale (BFS) treating runoff from a suburban highway during 15 rain events over a 14 month period. This study showed the ability of biofiltration to improve runoff quality with respect to micropollutants, especially those associated with the particulate phase. However, both smaller runoff particle sizes and the formation of cracks in the filter media were associated with degraded particle retention during some events. In addition, materials commonly used in biofilter construction (asphalt, geomembranes, drains and filter fabric), were shown to be sources of BPA, AP and PAE, which led to degraded performance for these pollutants, and should thus be avoided in biofilter design wherever possible. Finally, significant overflow from the studied system limited its annual load reductions significantly, underlining the importance of good hydrologic design in pollutant load removal.

Introduction

Urban runoff is contaminated by a number of micropollutants, including trace metals (TM), polycyclic aromatic hyrdocarbons (PAH) and various endocrine disruptors (bisphenol-A or BPA, alkylphenols or AP, phtalates or PAE) (Zgheib et al., 2012). Managing this pollution is important to protecting ecosystems and, when stormwater reuse is intended, human health.

Biofiltration (also referred to as bioretention), wherein runoff water is filtered through a planted filter medium and either drained or exfiltrated into the surrounding soil (Liu et al., 2014), may be useful for managing these pollutant loads close to the source in sponge cities. Numerous studies have demonstrated the potential of this technique for treating traditional pollutants such as total suspended solids (TSS), nutrients and TM. In addition, two previous studies have shown biofiltration to effectively retain PAH from urban stormwater (David et al., 2015; DiBlasi et al., 2009). However, relatively few studies have distinguished the dissolved phase of pollutants (LeFevre et al., 2014) and no previous studies have studied the treatment of BPA, AP and PAE *in situ*.

The present work focuses on lessons learned from the monitoring of a wide range of micropollutants (TM, PAH, BPA, AP, PAE) in a biofiltration swale (BFS) treating runoff from a suburban highway.

Materials and Methods

Study site

The study site includes a biofiltration swale (BFS), which drains water from the RD 212, a suburban highway with 11,000 vehicles/day/direction traffic located in Compans, France in the Paris region. The system is both drained and lined and was constructed in March 2016. Water is collected from a drain beneath the filter media (a sandy loam) of this device at a depth of 50 cm. Water quality is compared to that of untreated road runoff (RR) collected from a reference catchment on the same road and with identical traffic, located 68 m from the BFS catchment (Fig. 1). Flow is measured in the BFS drain and RR manhole using tipping bucket flow meters; overflow from the BFS is measured using a V-notch weir.

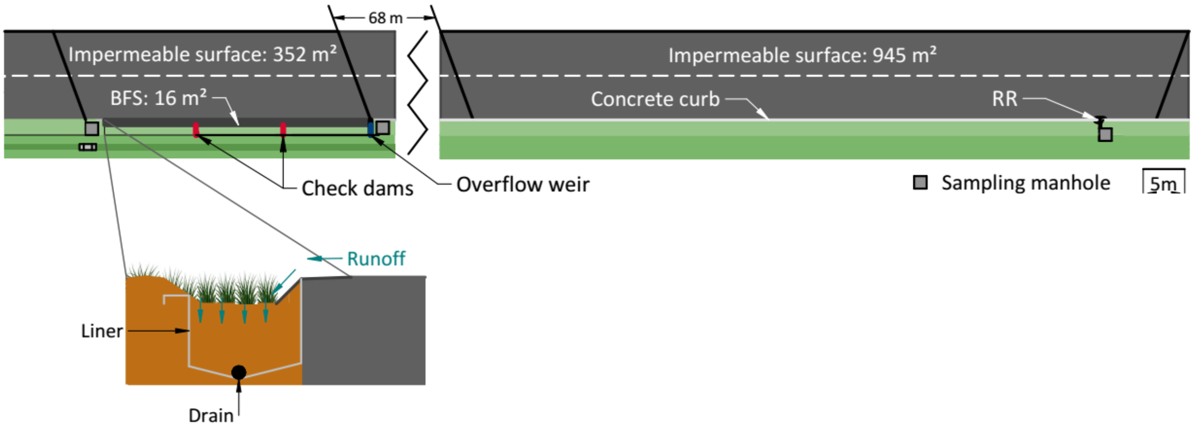

Figure 1: The Compans study site

Sampling and analysis

Water was collected at each point in proportion to water flow in order to achieve an event mean concentration (EMC). 15 rain events were sampled between May 2016 (two months after the construction of the BFS) and July 2017. While simultaneous sampling of all points was attempted, due to technical difficulties, not all data is paired. Samples were collected within 24h of each rain event and sent to partner laboratories within 24h of collection where they were immediately filtered to distinguish between dissolved and particulate phases. They were analyzed for pH, conductivity, turbidity, suspended solids (TSS), organic carbon, nutrients, 12 trace metals, 9 major elements, total hydrocarbons (TPH), 19 PAH, BPA, 7 AP and 5 PAE. Results for all pollutants have been discussed thoroughly elsewhere (Flanagan et al., submitted); results for a selection of pollutants are presented here.

In addition, seven composite filter media cores were sampled in the BFS from zones with homogeneous Cu, Pb and Zn surface contaminations, as determined from a cartography produced by soil contamination at 90 points using X-ray fluorescence spectrometry.

Computational methods

Treatment efficiency is considered in terms of concentration reduction (E_c) in BFS compared to RR for each sampled event. In addition, inlet and outlet loads were evaluated at the annual scale using a stochastic approach for a selection of pollutants, as was the evolution in the mass stored in the filter medium over the same period (Flanagan, 2018). This enabled evaluation of annual load reductions in the BFS (E_L) as well as a comparison of intercepted pollutant mass with the mass accumulated in the filter media.

Results

Road runoff quality

Road runoff from the Compans site was found to be quite polluted, with concentration levels (Table 1) situated in the upper range of those previously reported in the scientific literature (Kayhanian et al., 2012). Many pollutants, including TM and PAH, were very particulate, with over 90% found to be associated with the particulate phase.

Treatment efficiency

This study demonstrated the ability of biofiltration to improve runoff quality with respect to micropollutants. The BFS very effectively retained total suspended solids (TSS) for most events (median concentration reduction E_{C50}>90%, Table 1); as many micropollutants were mainly associated with TSS in RR, this resulted in excellent removals of Zn and PAHs (E_{C50}>90%) and good removals of Cu, and octylphenol (E_{C50}>70%). BPA and nonylphenol were moderately well removed (E_{C50} 56-57%), while performance for DEHP was poor (8%).

Parameter	RR Concentrations		Concentration reduction (E_c)		Load reduction (E_L)
	Total	Dissolved	Total (%)	Dissolved (%)	Total (%)
Water Volume	.	-	-	-	20 (15, 23)
TSS	291 (70, 933) mg/L	-	92 (11, 95)	-	60 (50, 66)
Cu	258 (98,546) µg/L	25 (14, 42) µg/L	76 (19, 93)	21 (-7, 46)	56 (47, 62)
Zn	693 (236, 1653) µg/L	32 (16, 66) µg/L	89 (25, 98)	57 (-74, 76)	58 (45, 66)
Pyrene	851 (205, 2298) ng/L	21 (15, 41) ng/L	94 (42, 95)	25 (-126, 55)	65 (54, 72)
Phenanthrene	356 (102, 594) ng/L	23 (11, 100) ng/L	92 (30, 96)	>44 (-11,>90)	63 (52, 70)
BPA	412 (234, 964) ng/L	280 (66, 697) ng/L	57 (-57, 79)	43 (-452, 75)	39 (32, 45)
Octylphenol	430 (235, 1527) ng/L	126 (33, 224) ng/L	76 (-109, 94)	59 (-81, 83)	46 (34, 54)
Nonylphenol	1647 (863, 5818) ng/L	386 (100, 752) ng/L	56 (-219, 72)	4 (-113, 40)	30 (8.5, 41)
DEHP	14 (4.6, 130) µg/L	3.4 (0.88, 12) µg/L	8 (-132, 36)	-202 (-754,62)	21 (-3.7, 38)

Table 1: Partial presentation of pollutant concentrations in RR and concentration and load reductions in the biofiltration swale (BFS), median (min, max) observed at the event scale for concentrations and concentration reduction, median and 95% confidence interval from stochastic calculations of annual load reduction.

During a winter period when deicing salt was frequently applied, high TSS concentrations were observed at the outlet of the BFS. Particle characterization demonstrated that poor filtration of RR particles rather than soil particle dispersion and erosion was responsible for this phenomenon. This was due to an exceptional abundance of fine (<10µm) TSS particles in RR during this period, combined with filter media cracking.

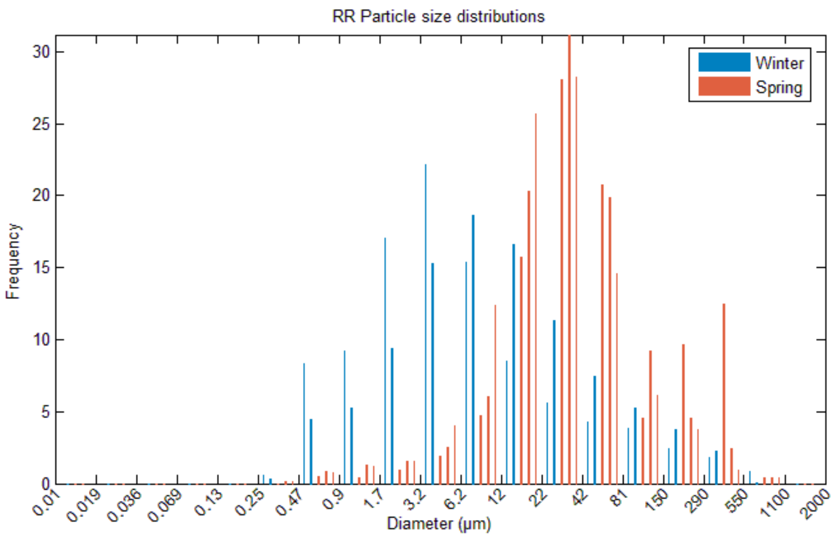

Figure 2: Total suspended solid particle size distribution by volume in road runoff. Events with degraded filtration (in Winter 2017) are shown in blue, while events with normal filtration (in Spring 2017) are shown in orange.

Performance in the dissolved phase tended to be lower, with the highest E_{c50} observed for octylphenol (59%); dissolved concentration increases were observed for some pollutants (for example, DEHP for which E_{c50}=-202%).

For Cu and Zn, observed dissolved concentrations frequently exceeded those expected at equilibrium with the filter media, indicating that performance may be limited by the chemical speciation of dissolved metals. For organic pollutants, observed dissolved concentrations were compatible with or sometimes below those expected at equilibrium with the filter media. In the cases of BPA, octylphenol, nonylphenol and DEHP, the mass accumulated in the filter media over the first year of operation significantly exceeded that intercepted from runoff (Figure 3). Batch leaching tests demonstrated that construction materials (asphalt, geomembrane, drain, drain filter fabric) were potential sources of all of these pollutants. These emissions are likely responsible for elevated outlet concentrations of these pollutants during the first months of operation and contamination of the filter media, limiting its ability to sorb dissolved fractions of these contaminants.

Finally, annual load reductions in this study were lower than the total E_{C50} for most pollutants. This was mainly due to frequent overflow, which accounted for about 38% (34-40%, 95% confidence interval) of water volume, while only about 20% of water volume was retained in the biofilter and lost to evapotranspiration. One exception to this was DEHP, which had very poor total concentration removal (E_{c50}=8%), most likely due to dissolved-phase emissions from construction materials. In this case, the annual load reduction was higher than E_{c50}, mainly due to water volume reduction.

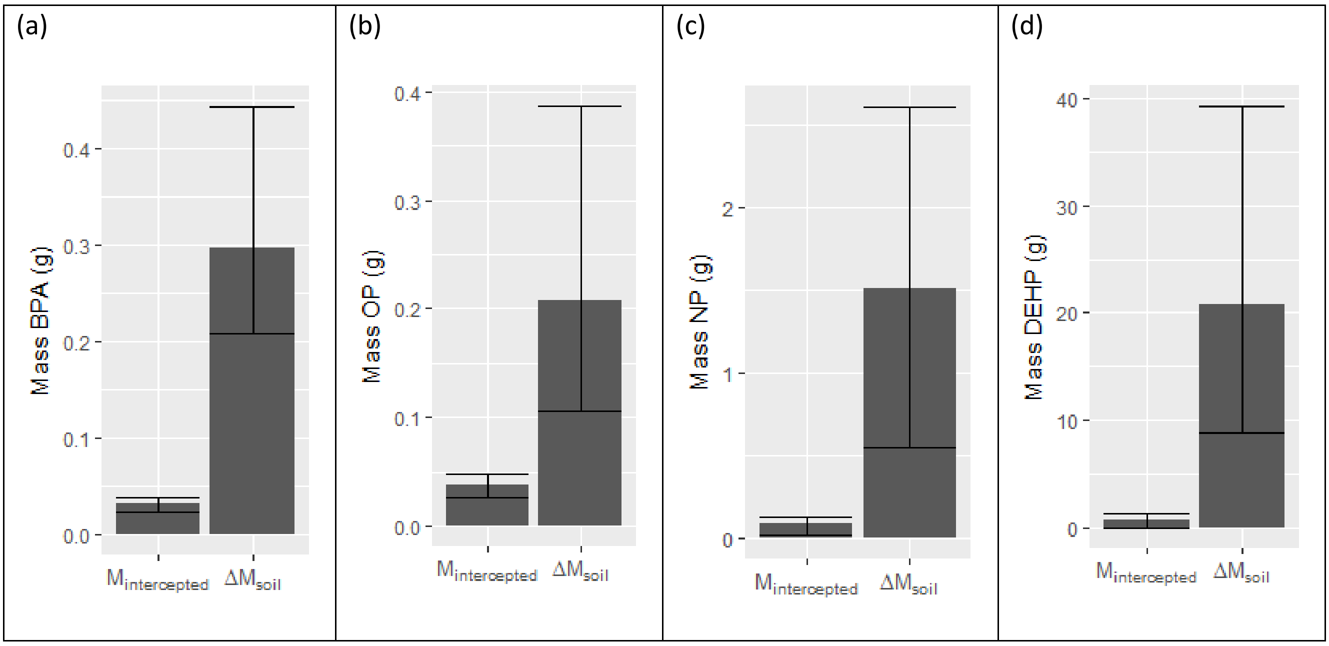

Figure 3 (a-d): Net mass balance terms associated with water fluxes (difference between mass entering and exiting the system – Mintercepted) and soil (difference between initial and final masses stored in soil - ΔMsoil) for (a) bisphenol-A, (b) octylphenol, (c) nonylphenol and (e) DEHP. Bars represent medians, while error bars represent the 95% confidence interval.

Discussion and practical implications

Several practical implications and operational lessons can be taken from these results.

First, as biofiltration is generally effective at particle capture, it is particularly well adapted for treating water from catchments producing high TSS concentrations and thus highly particulate micropollutants. This was the case for the road studied in the present study (median TSS in RR = 291 mg/L) and is likely to be the case for other roads with significant traffic. Concentration reductions in biofilters are likely to be lower in catchments producing less particulate matter (for example, rooftops).

Particle capture was shown to be reduced when particle sizes were smaller, a phenomenon observed in the present study only during winter. Smaller particle sizes in road runoff have also been observed in winter in previous studies (Hilliges et al., 2017; Monrabal-Martinez et al., 2016). Whether this is an effect of deicing salt application, temperature or another factor, it indicates that biofiltration performance may vary seasonally, although further research is required to prove this effect.

Filter media cracking was also seen to reduce filtration efficiency in the present study. Limiting clay content in filter media may reduce the formation of such cracks.

With respect to the dissolved phase of pollutants, the present study demonstrates two different cases where concentration reduction may be difficult to achieve. One such case occurs when chemical speciation (complexation or association with colloidal particles) limits pollutant reactivity, as appears to be the case for Cu and Zn in the present study. Another is when filter media contamination is on the order of that expected at equilibrium with dissolved concentrations in RR, demonstrating the importance of selecting a filter media which is relatively uncontaminated with respect to the pollutants to be treated. On the other hand, achieving dissolved concentrations below those expected at equilibrium with typical soil concentrations in a given region may not be a realistic objective; when dissolved concentrations in runoff are close to this level, concentration reductions are likely to be limited. In this case, loads of dissolved pollutants may be reduced most effectively by optimizing volume reduction in the system.

The study also demonstrated that biofiltration construction materials may be significant sources of organic micropollutants, leading to both degraded water quality improvement performance and filter media contamination. As such, when treatment of organic micropollutants which are ubiquitous in synthetic materials (such as AP and PAE) is an objective, the authors strongly recommend avoiding the use of synthetic materials in system design wherever possible. When these materials are absolutely necessary, the least polluting materials should be selected. Regulatory bodies could facilitate this selection by developing of standard protocols for considering pollutant emissions and by establishing archives of pollutant emission data from various types of materials.

Finally, the excessive overflow observed in the present study, leading to lower annual load reductions compared to concentration reductions highlights the importance of good hydraulic and hydrologic design. In the case of linear devices located beside even slightly sloped roadways, overflow may be minimized by separating the system into sections using check dams. System design may also be improved by using long-term, continuous simulations with a simple hydrologic model to select a configuration for which a desired proportion of water will be treated.

Conclusions

In order to consider the performance of biofiltration for treating road runoff as well as the processes responsible for this performance, a large range of micropollutants (TM, PAHs, BPA, AP, PAE) were monitored in water drained from a biofiltration swale treating road runoff and in untreated road runoff in both the total and dissolved phases. This work demonstrated excellent concentration reductions of particles and highly particulate pollutants. Performance was more limited for the dissolved phase of pollutants and for total concentrations of less particulate pollutants.

A number of operational lessons were drawn from this experience. In particular, biofiltration appears to be particularly well adapted to reducing concentrations from catchments producing large amounts of particles, though its efficiency may be subject to seasonal effects due to variable particle sizes. Filter media cracking was also seen to degrade filtration performance, underlining the importance of minimizing clay in filter media composition. Removal of the dissolved fraction of some pollutants may be their chemical speciation in road runoff or by background filter media concentrations; when this is the case runoff volume reduction may be the best strategy for reducing pollutant loads. Synthetic construction materials (asphalt, geomembrane, drain, drain filter fabric) were shown to be potential sources of organic micropollutants within the biofiltration swales, capable of contaminating the filter media and degrading water quality performance and should thus be avoided. Finally, high levels of overflow from the present system underlined the importance of good hydraulic and hydrologic design in limiting pollutant loads.

Acknowledgements

This work was supported by funding for the Roulépur research program (AFB and AESN), the Observatory of Urban Pollutants in Paris (OPUR, supported by AESN, SIAAP, CD92, CD93, CD94 and Ville de Paris), and a PhD scholarship from ENPC. We also acknowledge the Seine-et-Marne

Departmental Council, and especially Eric Thomas and Tina Ratovelomanana, for their partnership and technical support, as well as Tianran Dong, Delphine Truong, Thi Kim Phung Nguyen, Meriem Kajeiou and Maria Vitart de Abreu Lima for their help with sampling campaigns.

Bibliography

David, N., Leatherbarrow, J.E., Yee, D., McKee, L.J., 2015. Removal Efficiencies of a Bioretention System for Trace Metals, PCBs, PAHs, and Dioxins in a Semiarid Environment. Journal of Environmental Engineering 141, 04014092. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000921

DiBlasi, C.J., Li, H., Davis, A.P., Ghosh, U., 2009. Removal and Fate of Polycyclic Aromatic Hydrocarbon Pollutants in an Urban Stormwater Bioretention Facility. Environmental Science & Technology 43, 494–502. https://doi.org/10.1021/es802090g

Flanagan, K., 2018. Evaluation de la rétention et du devenir d'un panel diversifié de micropolluants dans un ouvrage de biofiltration des eaux de ruissellement de voirie. Université de Paris-Est.

Flanagan, K., Branchu, P., Deshayes, S., Saad, M., Caupos, E., Boudahmane, L., Partibane, C., Dubois, P., Meffray, L., Gromaire, M.-C., submitted. Field performance of two biofiltration systems treating micropollutants from road runoff. Water Research.

Hilliges, R., Endres, M., Tiffert, A., Brenner, E., Marks, T., 2017. Characterization of road runoff with regard to seasonal variations, particle size distribution and the correlation of fine particles and pollutants. Water Science and Technology 75, 1169–1176. https://doi.org/10.2166/wst.2016.576

Kayhanian, M., Fruchtman, B.D., Gulliver, J.S., Montanaro, C., Ranieri, E., Wuertz, S., 2012. Review of highway runoff characteristics: Comparative analysis and universal implications. Water Research 46, 6609–6624. https://doi.org/10.1016/j.watres.2012.07.026

LeFevre, G., Paus, K.H., Natarajan, P., Gulliver, J.S., Novak, P.J., Hozalski, R.M., 2014. Review of Dissolved Pollutants in Urban Storm Water and Their Removal and Fate in Bioretention Cells. Journal of Environmental Engineering 141.

Liu, J., Sample, D., Bell, C., Guan, Y., 2014. Review and Research Needs of Bioretention Used for the Treatment of Urban Stormwater. Water 6, 1069–1099. https://doi.org/10.3390/w6041069

Monrabal-Martinez, C., Muthanna, T.M., Meyn, T., 2016. Seasonal variation in pollutant concentrations and particle size distribution in urban stormwater - design implications for BMPs. 9th Novatech conference: Planning & technologies for sustainable urban water management, in: NOVATECH 2016. Presented at the Novatech.

Zgheib, S., Moilleron, R., Chebbo, G., 2012. Priority pollutants in urban stormwater: Part 1 – Case of separate storm sewers. Water Research 46, 6683–6692. https://doi.org/10.1016/j.watres.2011.12.012