Clogging of infiltration basins by stormwater sediments : influence of invertebrate bioturbation

Colmatage des bassins d'infiltration par des sédiments urbains : influence de la bioturbation par les invertébrés

Mermillod-Blondin Florian, Nogaro Géraldine, Gibert Janine

UMR-CNRS 5023 Ecologie des Hydrosystèmes Fluviaux,

Equipe HBES. Université Claude Bernard Lyon I,

Campus de la Doua, 6 rue Dubois, 69622 Villeurbanne cedex.

E-mail : mermillo@univ-lyon1.fr

RESUME

Les sédiments transportés par les eaux de pluies et déposés dans les bassins d'infiltration conduisent souvent en un colmatage des systèmes d'infiltration. L'objectif de cette étude est de quantifier l'influence de vers tubificidés sur ce processus de colmatage par utilisation de colonnes infiltrantes impactées par des sédiments provenants de deux bassins d'infiltration. Nos résultats indiquent que la réduction du colmatage par les vers dépend des caractéristiques des sédiments (granulométrie). Nous avons aussi montré que les vers tubificidés, en augmentant la conductivité hydraulique, stimulaient les processus aérobies et augmentaient les flux verticaux de polluants dans la matrice sédimentaire.

ABSTRACT

Stormwater sediments that accumulate at the surface of infiltration basins often reduce their infiltration efficiencies. The aim of this study was to quantify the influence of tubificid worms on clogging process using slow filtration columns impacted by stormwater sediments from two infiltration basins. Our results showed that reduction of clogging by worms depended on sediment characteristics (particle size distribution). We also highlighted that tubificid worms, by increasing hydraulic conductivity, stimulated aerobic processes and increased vertical fluxes of pollutants in the sediment layer.

KEYWORDS

Bioturbation, clogging, organic matter mineralization, pollutant fluxes, stormwater sediment characteristics.

1 INTRODUCTION

In urban area, most infiltration basins are clogged by fine sediments (stormwater sediments) transported by stormwater during its runoff on waterproofed surfaces (Datry *et al*. 2003a). It has also been shown that stormwater sediments could be colonized by dense populations of invertebrates such as tubificid worms (Datry et al. 2003a). A previous study indicated that structures produced by worms could have significant influences on the structure of stormwater sediments (Datry et al. 2003b, Figure 1). Due to these activities, we developed experimental studies to determine if invertebrates could reduce the clogging due to stormwater sediments (Nogaro et al. 2006). Thus, the aim of the present study was to quantify the impact of tubificid worms on the clogging process due to two types of stormwater sediments (originating from two infiltration basin of the East of Lyon). Hydraulic conductivities and physico-chemical analyses (dissolved oxygen, nitrate, heavy metals –Pb, Zn, Cu, Cd-, and polyaromatic hydrocarbons –PAH-) were measured to determine how a modification of infiltration process may affect biogeochemical processes and pollutant releases.

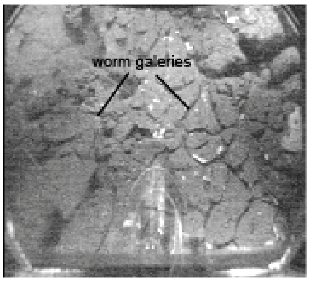

Figure 1 : Bioturbation activity of tubificid worms in stormwater sediments

2 MATERIAL AND METHODS

2.1 Experimental setup

Experiments took place in 12 slow filtration columns (height = 25 cm and inside diameter = 7 cm) which were filled with sand and gravel onto which stormwater sediment was deposited (Figure 2). Each column was filled with sand and gravel to a height of 18 cm to simulate the heterogeneous and porous granulometry of infiltration basins (before stormwater sediment deposit). The columns were supplied with synthetic water with a constant pressure head (ΔH = 2.5 cm). Five days after column filling, stormwater sediment was deposited at the sediment surface of the columns (Fig. 2): 6 columns were filled with the sediment (STORM-IUT) collected on the infiltration basin situated on the Campus of Lyon I University (Datry et al., 2003a) and 6 columns were filled with the sediment (STORM-DR) collected on the infiltration basin situated in the industrial zone of Chassieu (Barraud et al. 2002). Before deposition, these stormwater sediments were sieved through a 0.5-mm mesh aperture net to remove resident animals and coarse particles. The total height of sediment in each column was 20 cm (18 cm of heterogeneous sediment and 2 cm of stormwater sediment). Eight days after stormwater sediment addition (day 0), 50 tubificid worms were introduced in 3 columns of each stormwater treatment. The worm density used (around 20 000 individuals/m²) was typical for organic sediments. Experiments were performed at constant temperature (15 ± 0.5 °C) and light was controlled on a 12 h light, 12 h dark cycle in the overlying water.

2.2 Physical and chemical measurements

2.2.1 Characteristics of stormwater sediments

Stormwater sediments were analysed to determine their organic matter characteristics (total organic carbon –TOC-, total nitrogen –TN-, and total phosphorus –TP-), pollutant (Pb, Zn, Cu, Cd, and PAH) contents, and their particle size distributions. Sediment analyses for organic matter characteristics, metals, and PAH were performed by the Health and Environmental Laboratory of Lyon following standard methods (AFNOR, 1999). The particle size distributions of the two sediments were determined by laser diffraction granulometry.

2.2.2 Hydraulic conductivity

During the course of the experiments, water flow rates were measured for each column. We determined the hydraulic conductivity of the sediment (K) in the infiltration columns using the Darcy's formula:

$$q = K\,(\Delta H)/z$$

where q is the specific discharge (in cm/h), K is the hydraulic conductivity (in cm/h), ΔH is the hydraulic head (in cm) and z is the thickness of the sediment section (in cm). In our experiment, z was 20 cm (height of the porous medium) and ΔH was 2.5 cm.

2.2.3 Dissolved oxygen, nitrate, and pollutants (heavy metals and PAH)

Dissolved oxygen (DO) concentrations were obtained using micro-sensors (UNISENSE) fitted to the tubes at the inlet or the outlet of each column during the course of the experiment. On days J-10, J-7, J0, J2, J6 and J12, water samples were collected in the overlying water and at the outlet of each column. These samples were filtered through Whatman GF/F filters, and stored at 4°C until analyses for NO_3^-. The analyses of NO_3^- were performed using an EasyChem autoanalyzer (Systea, Roma, Italy) following standard colorimetric method (AFNOR, 1999). Pollutant (Pb, Zn, Cu, Cd, and PAH) concentrations were measured at the outlet of each column on samples collected from day 0 to day 3 of the experiments. Water analyses of metals and PAH were performed by the Health and Environmental Laboratory of Lyon following standard methods (AFNOR, 1999).

Using water flow rates measured in each column, we calculated the fluxes of dissolved oxygen, nitrate, and pollutants in the system using changes in the concentration of each species between the inlet and the outlet of the columns reported to the time of transfer (quantity per day and m^2 of infiltrating surface).

2.3 Statistical analyses

We tested sediment treatments (STORM-IUT versus STORM-DR) and animal treatments (control versus tubificid worms) by analyses of variance (ANOVA) using Statistica 5 TM (Statsoft, Tulsa) for each variable and each date of the experiment. When homoscedasticity was not observed, data were ln or square-root transformed to homogenize variances.

3 RESULTS

3.1 Characteristics of stormwater sediments

The two stormwater deposits presented high pollutant and organic matter contents (Table 1). Pollutant and organic matter contents were higher (2 fold higher for most compounds presented in Table 1) in STORM-DR than in STORM-IUT. STORM-DR was also characterized by a higher proportion of very fine sediment particles (< 10 μm) than STORM-IUT (1-way ANOVA, p<0.01).

	STORM-DR	STORM-IUT
Cd (mg/Kg of dry sed)	19.1 ± 0.35	3.15 ± 0.16
Cu (mg/Kg of dry sed)	257.1 ± 3.93	152.3 ± 1.79
Pb (mg/Kg of dry sed)	532.5 ± 12.2	216.8 ± 6.54
Zn (mg/Kg of dry sed)	1069 ± 14	489.6 ± 6.42
Total hydrocarbons (mg/Kg of dry sed)	39920 ± 1467	590 ± 82
HAP (mg/Kg of dry sed)	8.89 ± 0.49	9.92 ± 0.73
TOC (g/Kg of dry sediment)	162.7 ± 3.32	58.43 ± 1.84
TN (g/Kg of dry sediment)	6.33 ± 0.25	3.42 ± 1.10
TP (g/Kg of dry sediment)	4.60 ± 0.45	2.74 ± 0.86
Sediment grain sizes (% of volume):		
0-10 µm	59.9 ± 3.0	12.9 ± 0.6
10-100 µm	34.6 ± 1.7	31.77 ± 1.6
100-200 µm	3.6 ± 0.2	14.3 ± 0.7
200-500 µm	2.0 ± 0.1	31.2 ± 1.6
500-1000 µm	0.0 ± 0.0	9.8 ± 0.5

Table 1 : Characteristics of the two stormwater deposits

3.2 Bioturbation

During the experiment, visual observations showed that tubificid worms only dug galeries in the top centimetre of the STORM-DR (Figure 2). In contrast, tubificid worms burrowed deeper in the STORM-IUT and modified the structure of the whole stormwater sediment layer. Image analyses showed that gallery network occupied 18 ± 3 % of the layer with stormwater sediments (comparable to values reported in the field by Datry et al. 2003b).

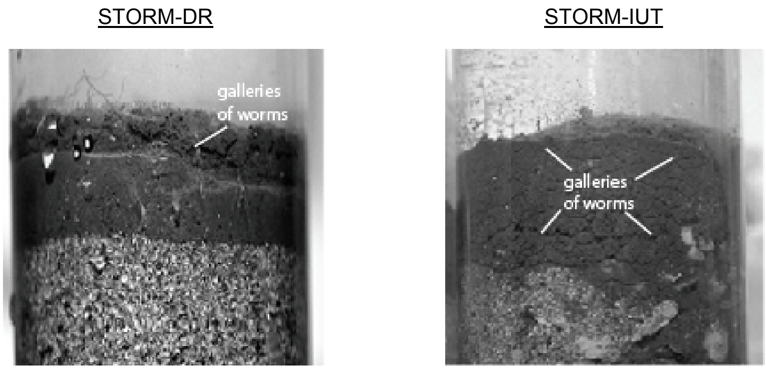

Figure 2 : Photographs of sides of experimental columns with the two stormwater sediments showing the *Tubifex tubifex* gallery-building activities

3.3 Hydraulic conductivity

Addition of the sediments from infiltration basins reduced strongly the hydraulic conductivity of the system (Figure 3). However, the hydraulic conductivity was more reduced with STORM-DR (values < 0.5 cm/h) than with STORM-IUT (values > 1 cm/h) (2-way ANOVAs, $p < 0.01$).

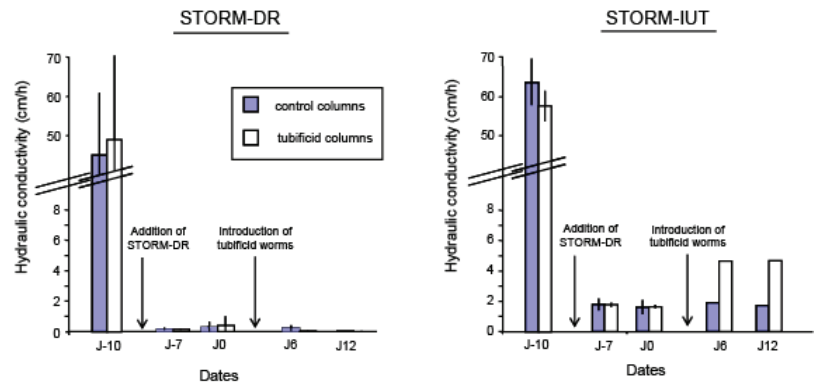

Figure 3 : Evolution of the hydraulic conductivity in systems impacted by STORM-DR and STORM-IUT before and after introduction of tubificid worms

Introduction of tubificid worms did not influence the system impacted with STORM-DR. In contrast, tubificid worms increased by around 3 fold the hydraulic conductivity in the system impacted with STORM-IUT (2-way ANOVAs, $p < 0.01$).

3.4 Biogeochemical processes and pollutants

Addition of STORM-DR produced a rapid decrease of dissolved oxygen at the outlet of the columns (Figure 4). This decrease of DO was associated with a decrease of nitrate certainly due to denitrification processes occurring under anaerobic conditions. As observed for hydraulic conductivities, tubificid worms did not affect these processes with STORM-DR. With STORM-IUT, decreases of DO and nitrate were less marked (certainly due to differences in hydraulic conductivity between the two sediments). Moreover presence of tubificid worms led to significant increases of DO and nitrate concentrations at the outlet of the columns in comparison with the control (Figure 4, 1-way ANOVAs, $p < 0.01$).

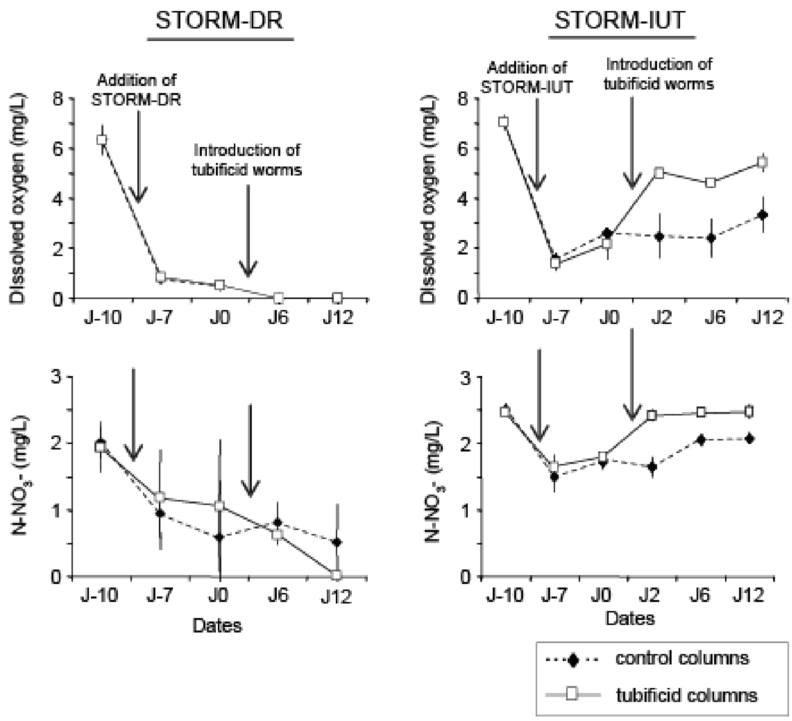

Figure 4 : Evolution of the concentrations of DO and nitrate at the outlet of the columns during the experiment. DO concentrations were around 7.8 mg/L and N-NO_3^- concentrations were between 2.5 and 2.8 mg/L at the inlet of the columns.

Reported to the vertical flux rates ([concentration at the outlet – concentration at the inlet] x water flow rate), measures of the DO fluxes (respiration) and nitrate fluxes (mainly anaerobic reduction of nitrate) showed that consumptions of O_2 and NO_3^- were higher in the system impacted with STORM-IUT than in the system impacted with STORM-DR: 13.5 versus 3.17 mM of O_2 respiration per day and m^2, and 0.64 versus 0.32 mM of NO_3^- reduction per day and m^2. Moreover, the increase of hydraulic conductivity by worms in STORM-IUT stimulated the O_2 fluxes in the system: 20.3 versus 13.5 mM of O_2 respiration per day and m^2 in tubificid and control treatments, respectively.

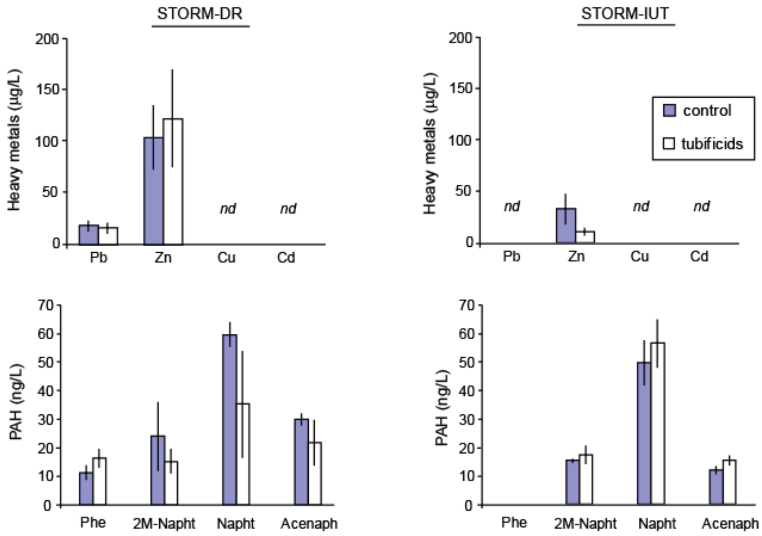

Figure 5 : Concentrations of pollutants (heavy metals and PAH) at the outlet of the columns during the experiment. No pollutant was detected at the inlet of the columns.

Concerning the pollutants, Zn and 3 PAH (2-Methyl-Naphtalene, Naphtalene, and Acenaphtene) were detected the outlet of all columns (Figure 5). Phenanthrene and Pb were also detected but only in system impacted with STORM-DR. No differences in pollutant concentrations were measured between control and tubificid treatments. Despite higher Zn concentration at the outlet of control columns with STORM-DR than with STORM-IUT (1-way ANOVA $p< 0.01$), higher vertical fluxes of Zn were measured with STORM-IUT than with STORM-DR: 1.71 versus 0.81 mg of Zn released per day and m^2 for STORM-IUT and STORM-DR, respectively. It is also interesting to note that increase of hydraulic conductivity by worms in system with STORM-IUT enhanced the flux of PAH in the porous media: 2.59 versus 5.86 mg of naphthalene released per day and m^2 in control and tubificid treatments, respectively.

4 DISCUSSION-CONCLUSION

We can conclude that the influence of tubificid worms on permeability in infiltration basins impacted by stormwater sediments depends on the physical characteristics of the stormwater (particle size distribution of the deposits). When sediments are not very fine (as STORM-IUT), tubificid worms produced dense galleries that act as water pathways through the clogging layer and increase the hydraulic permeability of the system (see more details in Nogaro et al. 2006). This reduction of the clogging favoured aerobic conditions in the sediment matrix, stimulating aerobic degradation of organic matter. Increase of hydraulic conductivity also enhanced the vertical fluxes of several PAH released from the sediments (such as naphthalene). Thus, our results highlighted that the effect of worms on hydraulic conductivity (in STORM-IUT) influenced the whole functioning of the sedimentary system (equilibrium between aerobic and anaerobic processes, interactions between water flow rate and pollutant releases from sediments). Moreover, comparisons between systems impacted with STORM-DR and STORM-IUT showed that vertical fluxes of pollutants (to groundwater) were strongly determined by the hydraulic conductivity of the stormwater sediments (which controls the vertical flow of water). Therefore, physical characteristics of stormwater sediments are essential to assess pollutant fluxes but also the potential role of tubificid worms in infiltration systems.

ACKNOWLEDGMENT

This work was a part of the OTHU project (Experimental Observatory for Urban Hydrology) and was funded by the urban community of Lyon (COURLY), the Rhône-Alpes Region, and the program ECOPLUIES (ANR PRECODD).

5 CITED LITERATURE

AFNOR (1999). *La qualité de l'eau*. Association Française de la normalisation, Paris.

Barraud, S., Gibert, J., Winiarski, T. and Bertrand-Krajewski, J.-L. (2002). Implementation of a monitoring system to measure impact of stormwater runoff infiltration. *Wat. Sci. & Technol.,* 45, 203-210.

Datry, T., Hervant, F., Malard, F., Vitry, L. and Gibert, J. (2003a). Dynamics and adaptative responses of invertebrates to suboxia in contaminated sediments of a stormwater infiltration basin. Arch. Hydrobiol., 156, 339-359.

Datry, T., Malard, F., Niederreiter, R. and Gibert, J. (2003b). Video-logging for examining biogenic structures in deep heterogeneous subsurface sediments. *C. R. Biol.,* 273, 217-233.

Nogaro, G., Mermillod-Blondin, F., François-Carcaillet, F., Gaudet, J.P, Lafont, M. and Gibert, J. (2006). Invertebrate bioturbation can reduce the clogging of sediment: an experimental study using infiltration sediment columns. Freshwat. Biol., 51, 1458-1473.