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Constructed wetlands to treat micropollutants of urban runoff from three residential watersheds

Les massifs filtrants plantés pour traiter les micropolluants issus des eaux de ruissellement urbain de trois bassins versants résidentiels

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RÉSUMÉ

Les eaux de ruissellement urbain sont reconnues comme étant polluées par différentes substances telles que les hydrocarbures, les produits phytosanitaires ou les micropolluants métalliques. L'importante variabilité des effluents (concentrations et débits) de réseaux pluviaux séparatifs stricts est un verrou technique pour une conception optimale des systèmes de traitement. L'objectif principal de ce travail est d'évaluer différents dimensionnement et conceptions d'installations extensives de traitement pour traiter les polluants contenus dans les effluents de réseaux pluviaux séparatifs stricts. Chaque système est composé d'une mare artificielle et d'un massif filtrant planté de roseaux. L'évaluation des différents systèmes mis en œuvre nécessite une méthodologie adaptée afin de préciser les mécanismes à l'origine de la dépollution des différents polluants. Un important dispositif d'instrumentation assure le suivi hydraulique et qualitatif des trois filières de traitement. Cet article résume la description des installations de traitement et la méthodologie employée pour atteindre les objectifs fixés.

ABSTRACT

Urban stormwaters are recognized as being polluted by different substances like hydrocarbons, pesticides or metallic pollutants. Moreover, the importance of the variability of the effluents (concentrations and flows) coming from the separated sewer network is a problem for an optimal design of the stormwater treatment systems. The main objective of this work is to set up several constructed wetland treatment systems to treat the different pollutants present in the effluents coming from separated sewer networks. Each system is composed of an artificial pond followed by a subsurface constructed wetland. Different configurations and sizing are compared. Data concerning the mechanisms governing the fate of the studied pollutants are also collected. Several measuring devices are installed to carry out the hydraulic and the qualitative monitoring of the three treatment systems. This article summarizes the on-site treatment facilities and the methodology employed to reach the objectives.

KEYWORDS

Hybrid constructed wetlands systems, Micropollutants, Urban runoffs

1 INTRODUCTION

In France, at the time of the construction of most sewer networks, it was believed that urban runoffs were not polluted. By the way, they were directly discharged into the environment, without any prior treatment. It is now recognized that urban runoffs are highly polluted with different substances, among which suspended solids, metals, hydrocarbons or pesticides. Pollution load in urban runoffs globally increases with the distance from paved area to discharge from the moment when rainwater reaches the soil and the moment when runoff arrives at the watershed outlet [Gromaire, 1998; Lee & Bang, 2000; Tassin & Chebbo, 2000; Chocat et al., 2007; Zgheib et al., 2012].

Being discharged into the environment without any prior treatment, urban runoffs can have a considerable impact on aquatic fauna and flora. Because of the Water Framework Directive [CE, 2000], the European Union countries have to reduce or even remove the different sources of pollution that have an impact on the aquatic environment. This is the reason why treating urban runoffs becomes more requested by local authorities. But conventional treatment systems can be very expensive. Consequently, extensive systems appear to be of interest when space is available.

Extensive techniques, and more specifically constructed wetlands, are recognized as being a good way to treat different types of effluents. The efficiency of constructed wetlands has already been demonstrated to reduce many pollutants contained in domestic wastewater [Molle et al., 2005; Vymazal, 2007; García et al., 2010] as well as for combine sewer overflow [Uhl & Dittmer, 2005].

Even if the efficiency of constructed wetlands for the treatment of urban runoffs has been partially demonstrated, no consensus is found concerning the optimal design and conception. Indeed, a major difficulty in treating strict urban runoffs comes from the stochastic characteristics of event in term of frequency, duration, intensity and pollutant concentrations. Moreover, with subsurface flow constructed wetlands, reeds can suffer from water stress during long dry periods. As well, biomass dynamics and stock vary a lot according to the event frequency. These changes might affect treatment performances of constructed wetlands, decreasing the quality of the outlet effluent for the next coming raining events.

The goal of this study is to optimise the performance of subsurface flow constructed wetlands for the treatment of urban runoffs. To do so, different mechanisms that contribute to the treatment of pollutants will be investigated. To reach this aim, three different treatment systems are built to treat urban runoffs. Each of these systems is composed of an artificial pond followed by subsurface flow (SSF) constructed wetland.

This article will present the methodology that is set up in the aim to evaluate potential reduction of global parameter as well as hydrocarbons (PAH, THC), pesticides (glyphosate, AMPA, diuron, isoproturon) and metals (Cd, Ni, Pb, Co, Cu, Ti and Zn).

2 METHODS

2.1 The treatment facilities

The urban runoffs of three urban watersheds were previously discharged directly into the aquatic environment. In order to treat these effluents, three treatment facilities have been installed. Each treatment system is made up of an artificial pond and a SSF constructed wetland. The artificial pond aims in providing a primary treatment (decantation of the heaviest particles, separation of floatables, eventually photodegradation due to sunlight exposure and partial biodegradation). Then, the subsurface flow constructed wetland (SSFCW) reduces the pollution load thanks to different mechanisms, like physical filtration of particles, adsorption of pollutants and biodegradation by microorganisms present in the porous media (Figure 1).

All systems are designed to accept until a two year rain return period (peak flow of 200 L/s). Above that, an overflow implemented into the artificial pond goes directly to the river (Figure 1). The three artificial ponds have the same design.

The three SSFCWs are planted with *Phragmites Australis*. Three different configurations have been set up, one horizontal flow constructed wetland (configuration 2) and two vertical flow constructed

wetlands (configurations 1 and 3). The different characteristics of the three constructed wetlands are described in Table 1.

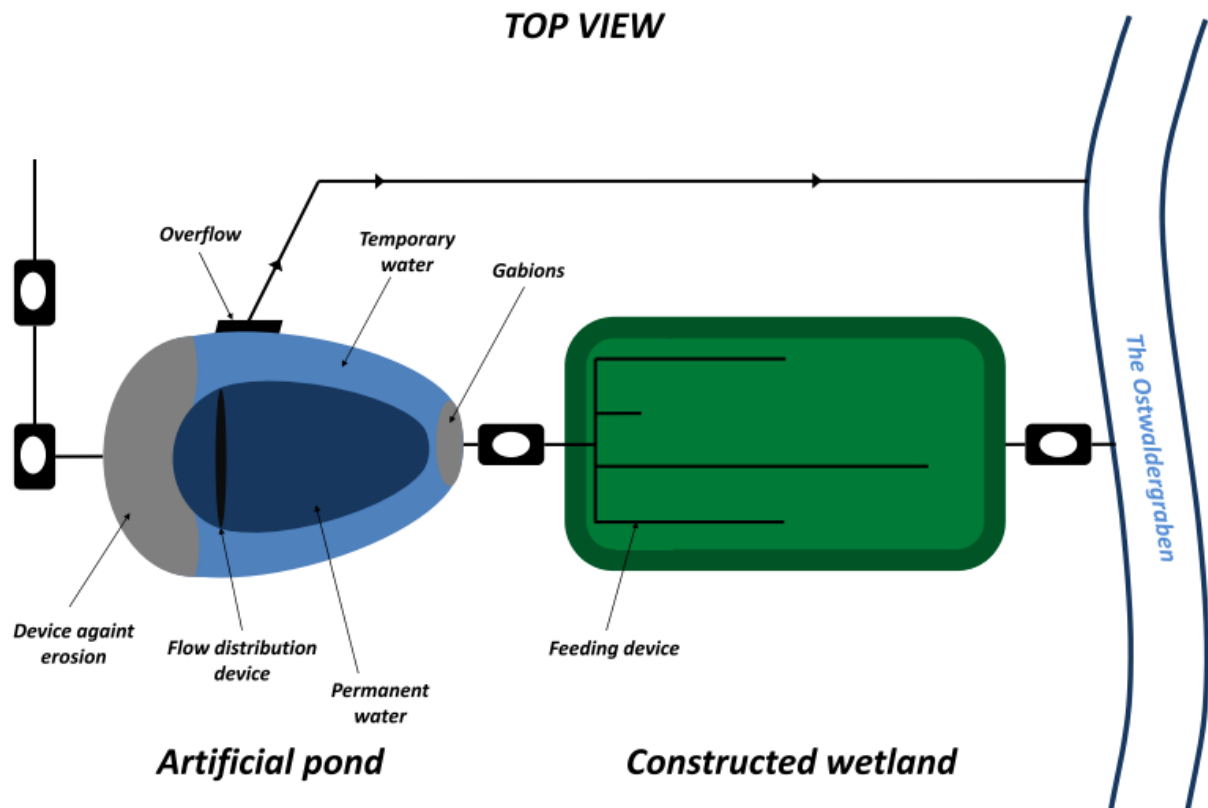


Figure 1. Treatment system of effluents coming from urban watershed

Table 1. Summary of characteristics of the three treatment systems

		Configuration n°1	Configuration n°2	Configuration n°3
Watershed	Total area (m²)	27 000	12 200	18 000
	Active area (m²)	9 000	3 800	5 200
	Type	Urban	Urban	Urban
Artificial pond	Area (m²)	31	22	18
	Sizing (m)	9 x 7	7 x 5	5,5 x 5
Constructed wetland	Area (m²)	90	480	100
	Sizing (m)	15 x 7,5	42 x 7	25 x 5
	Flow type	Vertical	Horizontal	Vertical
	Saturated hydraulic conductivity (m/s)	$5 \cdot 10^{-4}$	$5 \cdot 10^{-3}$	$5 \cdot 10^{-5}$
	Hydraulic load (m³/m²/an)	60	-	30
	% of active area (m²)	1%	-	2%

Configurations 1 and 3 were designed in order to evaluate the impact of contact time between the porous media and the effluent on the treatment efficiency.

Configuration 1 (Figure 2) corresponds to the recommendations made by the different constructed wetlands companies. This is the reason why this configuration is known as the “standard” one. This configuration aims at favouring the hydrodynamic behaviour of the constructed wetland by accepting a hydraulic load equal to 60 m³/m²/year. This enables to treat an important volume of effluent but it implies to have a relatively short residence time between the porous media and the effluent. This is the reason why the saturated hydraulic conductivity is about $5 \cdot 10^{-4}$ m/s. Moreover, the constructed wetland area is equal to 1% of the active area of the drained watershed.

Configuration 3 is assumed the optima one. In fact the contact time between the porous media and the effluent is longer than for configuration 1. The saturated hydraulic conductivity of the filter layer is about $5 \cdot 10^{-5}$ m/s. The hydraulic load accepted by this constructed wetland is equal to $30 \text{ m}^3/\text{m}^2/\text{year}$. To compensate the low saturated hydraulic conductivity and the low hydraulic load, the constructed wetland area is equal to 2% of the active area of the drained watershed.

These two constructed wetlands are both filled with three different layers:

- Top layer (20 cm depth for configuration 1 and 30 cm depth for configuration 3): filter layer composed of sand with a grain size distribution varying between 0 and 4 mm ($d_{10} = 0.16\text{mm}$ and $d_{60} = 0.45\text{mm}$ for configuration 1 and $d_{10} = 0.16\text{mm}$ and $d_{60} = 1.38\text{mm}$ for configuration 3)
- Transition layer (25 cm depth for both configurations): it is composed of fine gravel with a grain size distribution varying between 4 and 8 mm
- Drainage layer (20 to 30 cm for both configurations): it is composed of pea gravel with a grain size distribution varying between 16 and 22.4 mm.

Aerobic conditions are favoured by the implementation of two aeration pipes installed between the top and the transition layers on the one hand and at the bottom of the constructed wetland on the other hand.

As said previously, extended dry periods can potentially have an impact on macrophytes or on microorganisms. To prevent plant from water stress, a saturated zone is implemented at the bottom of the filters for configurations 1 and 3. In order to optimize the treatment efficiency, the height of this saturated zone is adjustable (from 23 to 70 cm).



Figure 2. Treatment system of watershed n°1 (picture taken on the 7th September 2012)



Figure 3. Treatment system of watershed n°3 (picture taken on the 7th September 2012)

About configuration 2 (Figure 4), the constructed wetland is a horizontal flow constructed wetland. This constructed wetland has four different zones:

- Inlet gabion (50 cm thick): supply zone composed of river stones with a size distribution varying between 80 and 150 mm
- Second zone (6 m thick): filter zone composed of coarse gravel with a grain size distribution varying between 4 and 8 mm
- Transition zone (10 cm thick): it is composed of medium gravel with a grain size distribution varying between 8 and 16 mm
- Outlet gabion (50 cm thick): drainage zone composed of small river stones with a size distribution varying between 22 and 63 mm

The four zones are 60 cm depth.

Contrary to configurations 1 and 3, this type of constructed wetland has a permanent depth of water equal to 55 cm (surface height minus 5 cm). This may favour the development of anoxic conditions. This constructed wetland is also planted with *Phragmites Australis*. The saturated hydraulic conductivity of the main zone (second zone) is equal to $5 \cdot 10^{-3}$ m/s.



Figure 4. Treatment system of watershed n°2 (picture taken on the 7th September 2012)

2.2 Monitoring

In order to evaluate precisely the treatment performances as well as the fluxes entering and leaving the system, a specific monitoring was set up. The aim is to monitor both hydraulic and quality characteristics of the effluents throughout the treatment system. This instrumentation has to deal with the extreme variability of the influent.

The different probes and devices are described in Figure 5.

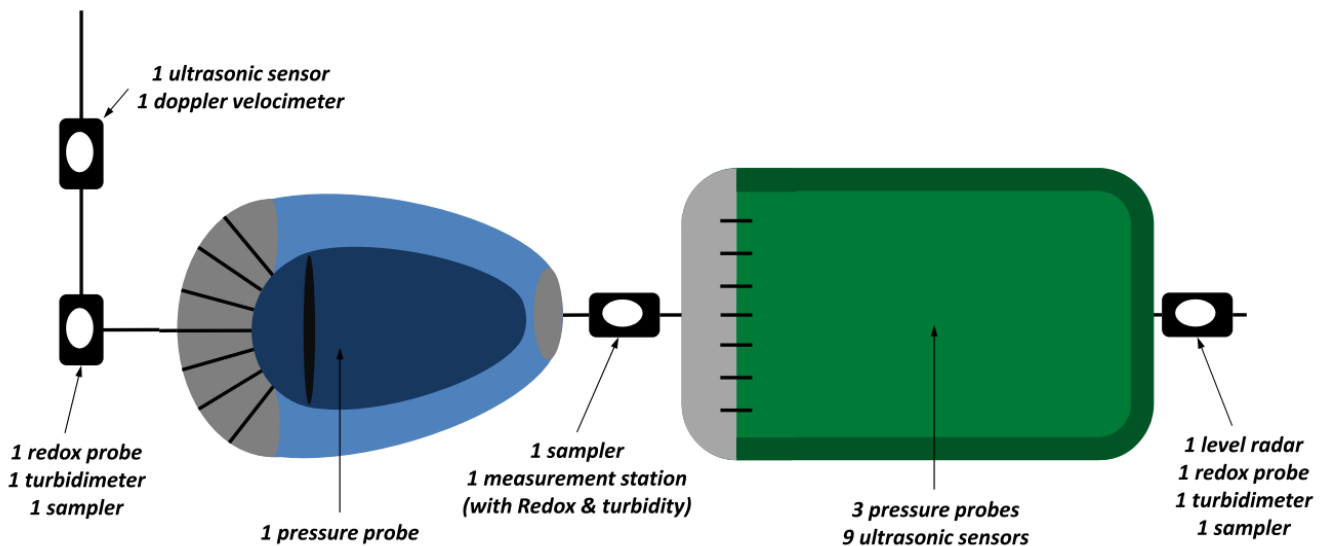


Figure 5. Probes and devices installed for one treatment system

To understand the hydraulic operation of the different treatment systems, several probes were installed:

- Ultrasonic sensor in the first upstream manhole to determine the flow rate coming from the sewer network (Siemens ultrasonic sensor – The Probe – measuring range: 0.25 to 5 m). It will allow to measure high flows.
- Ultrasonic Doppler flowmeter in the first upstream manhole to measure the higher flows (Nivus ultrasonic Doppler flowmeter – measuring range: water height from 0 to 3.5m and fluid velocity from -6m to +6m).
- Water pressure probe in the artificial pond to determine its volume variations (Endress Hauser pressure probe– Waterpilot FMX 21 – measuring range: 0 to 20 bar)
- 9 ultrasonic sensors to determine the distribution of the effluents at the surface of the constructed wetland, as well as infiltration rates once ponding occur (Ijinus ultrasonic sensors – M0111 – measuring range: 0 to 3 m)
- 3 water pressure probes inside the constructed wetland to determine the outflow rate in different zones of the constructed wetland and to determine evapotranspiration during dry periods (Endress Hauser pressure probe – Waterpilot FMX 21 – measuring range: 0 to 20 bar)
- 1 radar sensor in the downstream manhole to determine the outflow rate (Endress Hauser level radar – Micropilot M FMR 240 – measuring range: 0 to 40 m)

To monitor the quality of the effluents throughout the treatment system, several devices and probes were installed:

- Measuring station between the artificial pond and the constructed wetland to divert the flow in order to realise the Redox and turbidity analyses *in situ* continuously (Endress Hauser Redox probe – Turbimax CUS 51D – measuring range: 0 to 4000 FNU or 0 to 4 g/L)
- Redox probe to monitor the redox potential throughout the treatment system (Endress Hauser Redox probe – Orbipac CPF 82D – measuring range: -1500 to +1500 mV)
- Turbidity probes to monitor the suspended solids quantity throughout the treatment system (Endress Hauser turbidity probe – Turbimax CUS 51D – measuring range: 0 to 4000 FNU or 0 to 4 g/L)
- Automatic samplers to determine the treatment efficiency of each treatment stages (Endress Hauser sampler – Liquistation CSF 48)

The samplings have to occur only during raining events. They have to begin at the beginning of the raining event, to sample the whole raining event and stop at the end of the raining event. To do so, it is necessary to automatize the samplings. This is possible by coupling of the “hydraulic” instrumentation to the different samplers.

Three sampling strategies have been set up for the different sampling points. The three strategies are based on the combination of an event control sampling and a time proportional sampling: the water level sensor placed at the measurement point detects the increase of the water level and sets off the sampling campaign. This strategy has been set up thanks to a statistical study of the hydrological data available between 1999 and 2012. These data were collected on a rain gauge 800 m apart from the studied watersheds. The advantage of this strategy is that it does not depend on a flowmeter that could diverge and distort the sampling. The main drawback of this strategy is that it is necessary to recreate manually a mean event sample, with the uncertainties linked to this method.

The calibration of the different probes and their synchronisation with the measuring station and the automatic samplers has been realised in laboratory prior to the installation on the treatment systems.

2.3 The different analyses

In order to determine the treatment efficiency of the different parts of the treatment systems (artificial pond, constructed wetland or both of them), different parameters were monitored during the study. The different parameters are: organic matter (COD, BOD₅), nutrients (N, P), suspended matter (TSS, VSS), hydrocarbons (PAH, THC), pesticides (glyphosate, AMPA, diuron, isoproturon) and metals (Cd, Ni, Pb, Co, Cu, Ti and Zn).

Inlet/outlet balances are made for the artificial pond, for the constructed wetland and for the whole treatment system.

Several other analyses are planned at the end of the study in order to get further insight on the mechanisms at the origin of the observed pollutants removal:

- Sorbed pollutant by organic matter attached to the sand media and sedimentation at the surface of the constructed wetlands: soil analyses will be performed in order to monitor the amount of pollutants retained in the soil matrix;
- Pollutants uptake by plants: grinding and analyses of the different callus of macrophytes will allow the analyse of pollutants either in roots, stems or leaves;
- Microbial degradation: bacteriological investigations will allow to evaluate microbiological functions responsible for biodegradation of some pollutants

Previously to the beginning of the monitoring of the different treatment systems, tracer experiments have been performed. They allowed the determination of residence time distribution in both the artificial pond and the constructed wetland [Laurent *et al.*, 2012].

The monitoring of the first treatment system (configuration 3) will start at spring 2013. On a long run, the different treatment efficiencies of the three treatment systems will be compared. This will enable to recommend design criteria for the treatment systems that treat urban runoffs.

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