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Constructed wetlands treating stormwater from separate sewer networks in a residential Strasbourg urban catchment area: Micropollutant removal and fate

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ABSTRACT

A full-scale treatment system made of a sedimentation pond followed by a subsurface flow constructed wetland has been set up to collect stormwater from an urban residential watershed. Despite the high variability of hydraulic and pollutants loads, high removal efficiencies for TSS (>90%), COD (70–98%) and nutrients (TN > 79%; TP > 77%) have been observed. The pond contributes to particulate pollution mitigation in large quantities (55–92% of TSS): particle-bound micro-pollutants (metals, PAHs) are then mainly removed there; the vertical subsurface flow constructed wetland allows removal of the remaining particulate fraction through filtration. Experimental data show that metals are retained in the pond and the filter whereas PAHs are retained in the pond only. Biochemical transformations seem to occur, decreasing soluble COD and nutrient concentrations. Finally, micropollutants concentrations in sediments, sand and plants allow estimating storage in constructed wetland compartments.

1. Introduction

The European Water Framework Directive [17,18] introduced quality objectives to improve the global quality of water bodies across Europe. This requires the reduction of all pollution sources. Among them, contaminants from stormwater runoffs are of great concern, since they could negatively alter the habitat for aquatic fauna if there is no treatment. Depending on the type of catchment – urban, rural or industrial – the impact of stormwater runoffs on the receiving water body might change due to the large variety of pollutants involved. This study deals with contaminants from urban stormwater runoffs. Urban catchments are significant sources of metals and hydrocarbons [13,15,50,27] associated with particulate matter [31,1,50,7]. It has been shown that stormwater quality and quantity is directly related to impervious areas (roads, sealed areas, roofs) in an urban catchment [33]. These authors highlighted a relation between the receiving wetlands' condition and the catchment degree of urbanization.

To prevent the pollution of hydrosystems by these substances, effluent treatment before discharge in the environment is necessary. Several intensive treatment systems exist [1]; other techniques, namely sediment traps and settling tanks, rely on the fact that most urban runoff pollutants are bound to particles [2,12]. The main drawback of traps is the cost, while tanks do not efficiently remove dissolved pollution. Thus local authorities in developing and developed countries increasingly consider natural and rustic treatment processes, i.e. constructed wetlands (CWs).

Constructed wetlands are engineered systems that are designed and built to use natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating various types of contaminated waters [45]. Various types of CWs for stormwater treatment have been considered through scientific literature [5,6,40,24,8,48,7,46,27,35,36,47]. When considering an upstream stormwater management, the options are: ditches, valleys, blind drains, retention and infiltration basins, etc. Whereas downstream stormwater CW treatment ("end-of-pipe" approach) – the subject of this study – encompasses: sand or gravel filters, sedimentation ponds, retention and infiltration basins and floating treatment wetlands (FTW), etc.

CWs efficiency for this kind of treatment has already been proved. Depending on the type of effluent, CW treatment performances were reported on: (i) domestic wastewater [44], (ii) industrial effluents [23], (iii) agricultural effluents [34,36], (iv)

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Nomenclature

AFNOR	Association Française de Normalisation
BOD_5	Biochemical oxygen demand in 5 days
COD	Chemical oxygen demand
CWs	Constructed wetlands
FTW	Floating treatment wetland
$N\text{-}NH_4$, $N\text{-}NO_2$, $N\text{-}NO_3$	Ammonia, nitrite and nitrate ions, respectively
NF	French norm
$P\text{-}PO_4$	Phosphate ion
PAHs	Polycyclic aromatic hydrocarbons
TSS	Total suspended solids
TN	Total nitrogen
TP	Total phosphorus
VSSF	Vertical sub-surface flow

combined sewer overflows [43] and (v) stormwater from highway runoffs, residential and road areas [19,24,46,27,47,28]. When dealing with stormwater-only, subsurface flow constructed wetlands are often referred to as biofilters [9]. They are used to remove heavy metals and polycyclic aromatic hydrocarbons (PAHs). Ladislas et al. [27] successfully investigated the feasibility of using a FTW associated with a pond for the removal of dissolved metals from urban runoff under full-scale conditions. They particularly highlighted the important function of roots in heavy metal accumulation. By partitioning the inflow runoff hydrography and then investigating the treatment performance in each partition, Mangangka et al. [35] found that the treatment of small rainfall events (<15 mm) is better at the beginning of the runoff events while the trends in pollutant reductions for large rainfall are generally lower at the beginning. They also pointed out the necessity of low turbulence in order for the inflow to achieve consistent performance for both small and large rainfall events. Borne et al. [8] compared two parallel stormwater ponds in terms of suspended solids and heavy metal removal. Their findings showed that the pond containing the floating treatment wetland significantly improved the runoff water quality and thus reduced the impact on the receiving environment. Conversely, Birch et al. [4] obtained mixed results: removal rates varied between −294% for Mn and 65% for Cu and Pb.

Indeed, CWs treating urban runoffs face a large variability of separate sewer network effluents such as raining events characterized by a random distribution of frequency, duration, intensity and pollutants concentrations.

Several issues must be accounted for:

- Water stress of macrophytes and microorganisms due to extended dry periods, leading to potential treatment efficiency decrease;
- Risk of biological/physical clogging due to particle matter accumulation; and
- Inadequate CWs sizing depending on the type of raining event collected.

Solutions to prevent these can be set up: for instance, a saturated zone can be maintained in the wetland during extended dry periods [52].

The aim of this study is to evaluate the performance and operation of a treatment system made of a sedimentation pond and a vertical subsurface flow constructed wetland (VSSF CW) treating urban stormwater runoffs from a small residential watershed. The catchment area is located in Strasbourg (Alsace, France).

Comprehensive instrumentation was set up, including flow monitoring (hydraulic measures), continuous monitoring of physico-chemical parameters, water sampling and pollutant analysis in sediments, soil and plants. This allowed the evaluation of water quality throughout the pond and the VSSF CW as well as the estimation of pollutant storage in constructed wetland compartments. Special attention has therefore been paid to the link between pollutant dynamics and the characteristics of raining events.

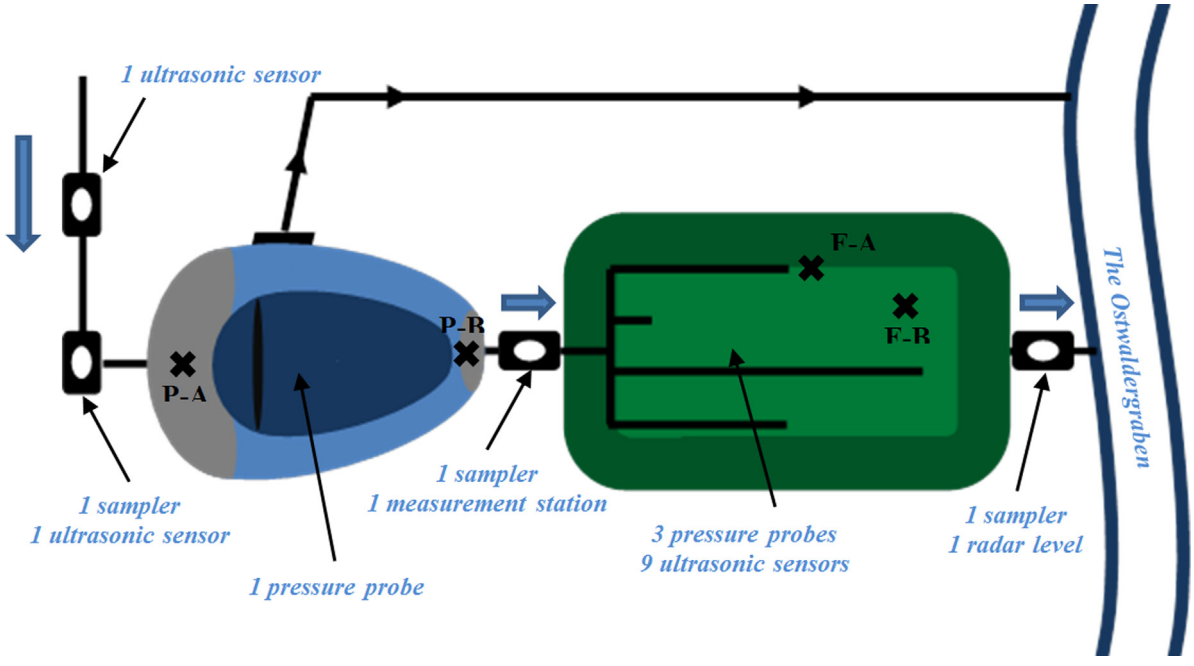

Fig. 1. Instrumentation installed on one treatment facility (P–A, P–B, F–A, F–B: sediment and sand sampling locations).