Science of the Total Environment 566–567 (2016) 113–121

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Performance of vegetated swales for improving road runoff quality in a moderate traffic urban area

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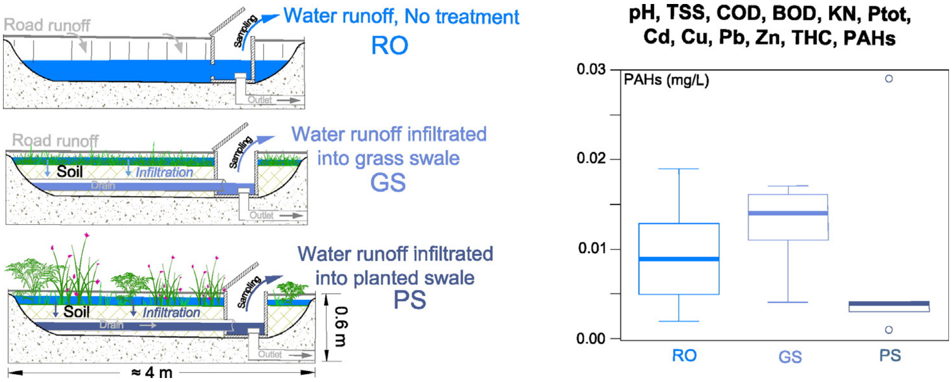
HIGHLIGHTS

- Two grass and macrophyte covered swales collecting road runoff were evaluated.
- Runoff pollution was low and justifies the use of swales for water management.
- Macrophytes cover reduced Zn, Cu, Pb and PAHs concentrations in infiltrated waters.
- A dense root system provides better performance for mitigating pollutions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 October 2015
Received in revised form 4 May 2016
Accepted 4 May 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Water quality
Runoff
Swales
Green water infrastructure
Trace elements
Polycyclic aromatic hydrocarbons
Macrophytes

ABSTRACT

In recent years, due to their economic and ecological advantages, green infrastructures for stormwater management have been widely implemented. The present study focused on vegetated swales and compared two vegetated covers, grassed or planted with macrophytes in order to evaluate their performance in terms of water quality improvement. These swales collected runoff of a moderately busy road (<2500 veh day^{-1}) in a commercial area. Twelve storm events were analyzed over a two year period with measurement of total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total hydrocarbons (THC), total phosphorous (TP), total Kjeldahl nitrogen (TKN), trace elements and 16 polycyclic aromatic hydrocarbons (PAHs). The grass cover led to poor results due to lower retention of soil particles on which trace elements and PAHs are bounded. The swales planted with macrophytes, with a deeper root system more capable of retaining soil particles, led to reductions of concentrations from 17 to 45% for trace elements such as lead, zinc and copper and 30% for the 16 PAHs in infiltrated waters. In addition, the macrophyte cover showed lower variability of pollutant concentrations in infiltrated waters compared to incoming waters. This buffering capacity is interesting to mitigate the impact of moderate peak pollution on surface water or ground water quality.

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http://dx.doi.org/10.1016/j.scitotenv.2016.05.027
0048-9697/

1. Introduction

Population growth is accompanied by the expansion of impervious surfaces that cause an increase in the stormwater volumes and the flow of pollutants accumulated by these water volumes (Gnecco et al., 2005; Pataki et al., 2011). In urban areas, the stormwater management strategy has long been to evacuate the water as fast and as far as possible in branched networks. Faced with the densification of the population and the expansion of cities, this strategy has reached its limits due to the excessive amount of water to be treated especially during large rain events. To address this issue, alternative techniques of water management are being developed. A more and more common technique is to manage water closer to the source, on a smaller scale, for example by storing and/or infiltrating water into green areas called green infrastructures such as biofilters, wetlands, green roofs, vegetated swales or permeable pavement. In addition to the landscape and cultural interest that introducing green spaces in urban areas brings, green infrastructures have the advantage of restoring water to the receiving environment closest to the place of precipitation which may recharge groundwater. This strategy limits the impact of cities on the water cycle (Stovin et al., 2012). However, one of the obstacles to the creation of these infiltration spaces is the risk of contaminating groundwater with pollutants found in runoff. It is therefore important to know the performance of these systems for improving water quality.

To collect, store and infiltrate the road water runoff, drainage devices such as swales can be implemented. These consists of flat-bottomed linear channels of several centimeters deep that receive roadway flows laterally through grassed or vegetated side slopes. Total runoff volume is reduced through infiltration (Davis et al., 2012). An overflow connected to a piped network guaranties the management of excess water when infiltration is not sufficient to manage considerable storm events. Vegetated swales are designed to slow water flow and to ensure the decantation and filtration of suspended particles and thereby to improve water quality (Stagge et al., 2012).

A few studies have examined the performance of vegetated swales (mainly grassed) on water quality (Barrett et al., 1998; Barrett, 2005; Bäckström, 2003; Stagge et al., 2012; Schueler, 1994; Yu et al., 2001). They have however been more focused on outgoing water through the outlet of the swale than on infiltration waters that can potentially contaminate groundwater. Grassed swales showed a good ability to reduce the Total Suspended Solids (TSS) from outgoing waters, with removals between 44% and 98%. The results were also very satisfactory on trace elements such as Cu, Zn, Pb and Cd with reductions in concentrations in outgoing waters from 17% to 99% and most of the time over 85% (Kabir et al., 2014). The impact of road vegetated swales on nutrients such as nitrogen or phosphorus gave contrasted results, sometimes decreasing concentrations (Yu et al., 2001) and sometimes increasing them (Barrett, 2005; Stagge et al., 2012). These results are not surprising since the organic matter present in swales is itself a source of nutrients that could migrate in outgoing water.

Regarding organic pollutants such as hydrocarbons or polycyclic aromatic hydrocarbons (PAHs), their reduction by swales has been little studied, and not to our knowledge on infiltration waters and on field experiments. Nonetheless, Hong et al. (2006) observed approximately 80 to 95% removal of naphthalene, toluene, and dissolved motor oil hydrocarbons from synthetic runoff via sorption and filtration at bench scale. At a bioretention field site, PAH event mean concentration reduction ranged from 31 to 99%, and a mass load reduction of 87% was observed to the discharging watershed (DiBlasi et al., 2009). Moreover, we reported that on artificially contaminated mesocosms, very low levels of PAHs were measured in infiltrated water with a significant reduction of PAHs of over 99% (Leroy et al., 2015). Thus, based on the available evidence, swales seem to be successful in removing hydrocarbons from infiltrated stormwater.

In fact, the vegetated swale is a complex ecosystem composed of water, soil, air and plants also comprising living organisms. Retention and/or degradation of inorganic and organic pollutants therefore involve various processes: sedimentation, filtration (Bäckström, 2002), adsorption (Cox et al., 1997), complexation (Shuman, 1988), degradation by microorganisms for PAHs and hydrocarbons (Cébron et al., 2008; Martin, 2006; Lefevre et al., 2012) or phyto-retention/phyto-extraction for trace elements (Krämer, 2005). These complex physicochemical and biological processes need to be elucidated, particularly to understand the fate of a mixed organic and inorganic pollution in infiltration waters.

The objective of this study on vegetated swales located in a commercial area with a moderate traffic (<2500 veh day^{-1}) is to provide data on water quality after and before infiltration through the swales soil. To meet this objective, three experimental swales were built along a moderately busy road. Two of these swales were planted with macrophytes and grass, the third one being allowed to collect runoff from the road without infiltration. Incoming and infiltrated water were analyzed for two years with a total of 12 storm events. The collected data could provide information to professionals in water management on: 1) the ability of swales to mitigate pollutant concentrations 2) the effect of the vegetated cover on water quality.

2. Materials and methods

2.1. Experimental setup

The experimental swale was installed in a commercial area (49°52′ N, 0°97′ E) in Barentin (France) along a road with an average traffic of about 2269 cars and 27 trucks per day in one traffic direction. The experimental swale was divided into three sections: runoff (RO), grass swale (GS) and macrophyte planted swale (PS) (see Fig. S1).·The road catchment area of the sections RO, GS and PS were respectively equal to 10.0 m^2, 14.7 m^2 and 13.8 m^2. The incoming water corresponded only to the northern half of the road, and to one traffic direction. In order to collect the water, the bottom of each section was waterproofed with a polypropylene geomembrane and a manhole (Nicoll, France) was installed at the lowest point (Fig. 1). At the bottom of the manhole (i.e. at the lowest point), a PVC pipe was connected that could drain water outside the swale. This pipeline was permanently open to ensure drainage and prevent anoxia of the system except during precipitation events targeted for sampling. The section RO was 3 × 3 m with a maximum depth of 0.4 m for a water storage capacity of about 1 m^3 whereas the sections GS and PS were larger, 4.9 × 3 m with a maximum depth of 0.53 m and 4.6 × 3 m with a maximum depth of 0.51 m, respectively. A 30 cm-thick layer of soil was added in the sections GS (1419 kg of soil dry weight (DW)) and PS (1462 kg of soil DW). Soil characteristics are given in Section 2.4. RO section contained no soil. To collect infiltrated waters in sections GS and PS, a drain (i.d. = 100 mm) was placed at the bottom of each section and was connected to the manholes. It was surrounded by a geotextile with a porosity of 12 μm to avoid clogging. A grass cover composed of fescue (*Festuca arundinacea*, *Festuca rubra*) and ryegrass (*Lolium perenne*) was sown in the GS section. Yellow flag (*Iris pseudacorus*) and meadowsweet (*Filipendula ulmaria*), grown on site over 6 years, were planted in the PS section 4 months prior to the first sampling to recover initial density of 6 plants m^{-2}. During the first year of the study, a fourth section (RF) was studied. It consisted of a section identical to RO but not connected to the road. It received only rainfall and atmospheric dry deposit. The maintenance of the experimental swales was close to the conventional maintenance instructions: the grass and plants were mowed once a year (winter) and plant waste was evacuated to a green waste collection center.

2.2. Analytical methodology

To assess the water quality, various indicators were selected and compared to values from the French environmental quality standards for surface water (EQS-SW) by application of the European community