Journal of Environmental Management 128 (2013) 306–312

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

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

A three-stage treatment system for highly polluted urban road runoff

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ARTICLE INFO

Article history:
Received 15 October 2012
Received in revised form
1 March 2013
Accepted 8 May 2013
Available online 14 June 2013

Keywords:
Road runoff
Treatment system
Heavy metals
Best management practice

ABSTRACT

A three-stage treatment device for polluted urban road runoff was installed and tested at a highly trafficked urban road over a period of one year. In the first stage coarse material and particles from the runoff are removed by a special gutter system. The second stage eliminates particles using a hydrodynamic separator. In the third stage dissolved pollutants are adsorbed in a filter unit with lignite as filter material. Twenty-four rain events were sampled over the one year period and analyzed for dissolved and particulate copper (Cu), zinc (Zn), lead (Pb), suspended solids (SS), total organic carbon (TOC), sodium (Na), and pH value. The treatment system was able to safely retain all relevant pollutants during the investigated period, except Na. In the effluent of the treatment device Pb could never be detected, values measured for Zn were in the range of the detection limit. Cu, the element most frequently detected in the effluent, never exceeded the critical value of 50 μg/L set by the German Federal Soil Protection Act and Ordinance. The median Cu concentration in the effluent of the treatment system was 8.13 μg/L. The treatment system proved to be very effective. Highly polluted road runoff can be purified by the system to an extent that no contamination risk for soil and groundwater remains when infiltrated into the soil.

1. Introduction

Stormwater runoff from urban catchments is considered a major source of pollution in the environment (Brenzonik and Stadelmann, 2002; Rice et al., 2002; Siriwardene et al., 2007; Davis and Birch, 2010; Yu and Zhao, 2012). The quality of road runoff is dependent on the types of surfaces the storm water encounters, the ambient air quality as well as the anthropogenic activities within each specific catchment such as for example the traffic density (Davis and Shokouhian, 2001; Färm, 2002; Eriksson et al., 2007; Helmreich et al., 2010; Wei et al., 2010; Davis and Birch, 2010; Budai and Clement, 2011). During rain events the pollutants including nutrients, heavy metals and organic substances like hydrocarbons are washed off the road surfaces. Without treatment they can be discharged directly into receiving waters or infiltrated into the soil along-side the roads (Perdikaki and Mason, 1998). Some of the heavy metals, e.g. copper (Cu) and zinc (Zn) are elements that are to a varying degree essential for plants and animals, but can become toxic when bioavailable at certain elevated concentrations (Karlen et al., 2001; Rice et al., 2002). Additionally, some heavy metals like lead (Pb), and organic pollutants like polycyclic aromatic hydrocarbons (PAH) found in road runoff are classified as priority pollutants (EU EQS, 2007; Eriksson et al., 2007). On account of the potential malign effects to biota and human health, the presence of these compounds in terrestrial and aquatic environments is of concern. In particular heavy metals has become one of the most serious environmental problems (Fu and Wang, 2011).

In industrialized countries urban runoff is often drained by traditional combined sewer systems and treated in municipal wastewater treatment plants. In the case of a separate sewer systems it is merely treated by sedimentation. These traditional urban drainage concepts result in the following negative ecological effects: increase of runoff volume and runoff peak in receiving surface waters, possible drawdown of the groundwater table underneath the sealed urban area, pollution of receiving water bodies by discharge or sewer overflow and accumulation of pollutants in the activated sludge of the wastewater facility. Additionally, most wastewater treatment facilities are not designed for the removal of heavy metals and persistent organic pollutants and therefore retention of these pollutants is often limited.

Structural best management practices (BMPs) are widely used to reduce the amount of runoff based pollutants entering the receiving water environment. Structural BMPs can be categorized in four main groups: (a) filter strips and swales, (b) infiltration systems (e.g. soakaways, infiltration trenches and infiltration basins), (c) storage facilities (e.g. retention ponds, lagoons,

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0301-4797/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jenvman.2013.05.024

constructed wetlands), and (d) alternative road structures (e.g. porous paving, porous asphalt surfaces) (Eriksson et al., 2007). Some of these BMPs retain pollutants only insufficiently. Their main purpose is the reduction of the urban runoff peak.

Soil infiltration can be considered as a promising way of managing road runoff in urban areas, provided the hydrological and geological conditions allow infiltration, and provided the pollutants contained in the road runoff are effectively removed before the runoff enters the soil and the groundwater. Otherwise, the pollutants may accumulate in the soil or can become mobile and can eventually lead to highly contaminated sites and groundwater (Hashim et al., 2011). Additionally, soil infiltration systems have a high space requirement, which is a general problem in densely populated urban areas. Additionally, seasonal changes are considered to reduce the effectiveness of some BMPs, for example, detention ponds during winter periods (Westerlund et al., 2003; Starzec et al., 2005).

Therefore the development of new decentralized treatment facilities with low space requirements and effective retention of pollutants are necessary (Matsui et al., 2003; Boller and Steiner, 2002; Athanasiadis et al., 2007; Siriwardene et al., 2007).

This study presents a one year field experiment where a new developed decentralized three-stage treatment device has been installed at a highly trafficked urban road. The treatment device has been evaluated regarding its treatment efficiency. The treatment mechanisms involved are sedimentation and up-flow filtration for the removal of dissolved or colloidal pollutants. Focus lay on the behavior of the treatment device during the winter months, under de-icing salt influence. The following parameters were measured: Cu, Zn, Pb, sodium (Na), suspended solids (SS) and total organic carbon (TOC).

2. Material and methods

2.1. Description of the treatment system

A treatment device for urban road runoff was installed for one year at a highly trafficked road in Munich with an average annual daily traffic load (AADT) of 57,000 vehicles/day (Munich, 2008). The major land use at the sampling site comprised residential housing, office buildings and a park. The connected catchment area on the sampling site was 300 m^2 and consisted of two lanes with asphalt paving, one acceleration lane and one emergency lane. The speed limit was 60 km/h.

The treatment system consists of three-stages (Fig. 1). First stage was a special gutter system, which was installed along-side the road and in which the road runoff was drained (Fig. 2). The gutter consisted of a conventional concrete gutter with integrated barriers (one barrier per meter gutter length) to enhance sedimentation of mainly mineral particles in the gutter. A stainless steel perforated plate (hole diameter 2 mm) was installed on top of the gutter in order to prevent coarse material like branches, leaves and cigarettes from entering the gutter and the system. The perforated plate was located at the level of the road surface. Coarse materials retained on the perforated plate were removed by street sweeping. After passing the gutter, the pre-treated runoff was channeled tangentially through a pipe (diameter: 100 mm) into the filtration pit (diameter: 1000 mm) (Fig. 1), which consisted of a hydrodynamic separator with a grit chamber (stage 2), and stage three, a filter unit equipped with a pre-filter. Particles settle on the hydrodynamic separator and glide into the grit chamber, where they are retained until removed during maintenance. After passing the hydrodynamic separator the runoff flows through a stainless steel pre-filter (mesh 0.7 mm) and a filter unit in up-flow mode. The filter unit consisted of lignite coke (HOK® from Rheinbraun Brennstoff GmbH) with a particle size 1.25–3 mm, which was packed between two sieve plates (mesh 0.7 mm). The main chemical composition of the activated lignite was: 87.2% TOC, 2.11% oxygen, 2.9% hydrogen. The loss in ignition was 92.5%. Before application, the lignite coke was washed with tap water in order to remove fine dust.

The pre-filter retains particles still present in the runoff in order to prevent blocking of the filter unit. An emergency overflow was installed in the filter unit to allow runoff to by-pass the filter unit in case it should fail hydraulically in extreme weather conditions or when blocked somehow. The construction of a pipe through the filter unit permits the cleaning and maintenance of the pre-filter from street level without having to dismantle the filter unit or filter material. It also allows easy emptying of the grit chamber of the hydrodynamic separator. After passing the filter material the

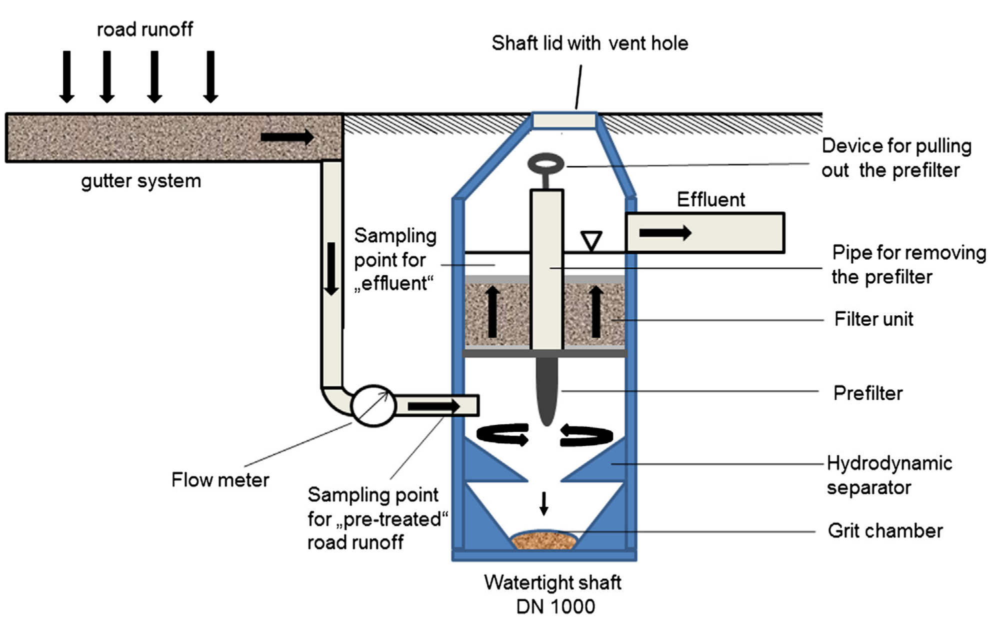

Fig. 1. Layout of the three stage treatment facility.