Treatment Of CSO In Retention Soil Filters - Lessons Learned From 25 Years Of Research And Practice

Traitement des surverses de réseaux unitaires par temps de pluie par filtres plantés de roseaux – Leçons tirées de 25 années de recherche et d'expérience

Ulrich Dittmer[1], Daniel Meyer[2], Katharina Tondera[3], Benedikt Lambert[4] Stephan Fuchs[5]

[1] ISWA, University of Stuttgart, Bandtaele 2, 70569 Stuttgart (ulrich.dittmer@iswa.uni-stuttgart.de)
[2] IRSTEA, Freshwater Systems, Ecology and Pollution Research Unit, 5 rue de la Doua, CS70077, F-69626 Villeurbanne cedex, France
[3] Institute of Environmental Engineering, RWTH Aachen, Mies-van-der-Rohe-Straße 1, 52074 Aachen
[4] BIOPLAN Landeskulturgesellschaft, Pfohlhofstraße 20, 74889 Sinsheim-Steinsfurt
[5] Institute for Water and River Basin Management, Department of Aquatic Environmental Engineering, Adenauerring 20b, 76128 Karlsruhe, Germany

RÉSUMÉ

Les émissions de polluants par les surverses de réseaux unitaires constituent une problématique d'un intérêt grandissant dans beaucoup de pays. Il a été prouvé que les zones humides artificielles constituent une mesure efficace afin de réduire les impacts environnementaux des surverses de réseaux unitaires. En Allemagne, un procédé particulier combinant filtration biologique et rétention hydraulique fut développé et le premier filtre de ce type fut mis en service en 1988. Depuis, plusieurs centaines de filtres plantés de roseaux à écoulement vertical (FPRV) ont été construits. S'appuyant sur l'expérience opérationnelle accompagnée de travaux de recherche intensifs, le dimensionnement et l'exploitation des FPRV ont été optimisés et standardisés pour l'Allemagne.
Cet article résume l'expérience acquise en 25 ans au fil de nombreux projets de recherche et d'études sur le terrain. Malgré la faible activité biologique des FPRV, leur efficacité d'élimination est comparable à celle des stations d'épuration conventionnelles. L'alternance de périodes sèches et humides est primordiale pour atteindre cette haute performance. De plus, le matériau filtrant doit être homogène et chimiquement inerte afin d'assurer la stabilité du processus de traitement à long terme.

ABSTRACT

Pollutant emissions via combined sewer overflow (CSO) are an issue of growing concern in many countries. Reed beds have proven to be an effective measure to mitigate environmental impacts of CSO discharges. In Germany a particular design was developed that combines biofiltration and hydraulic retention. The first plant of this type started operation in 1988 and several hundred of these retention soil filters (RSF) have been constructed since then. Design and operation of RSF have been optimized and standardized based on operational experience accompanied by intensive research. This paper summarizes the experience gained over the last 25 years in various research projects and by field surveys. Despite low biological activity the removal efficiency of RSF is comparable to state-of-the-art WWTPs. It is shown that the succession of wet and dry periods is essential for this high performance. The filter material should be homogeneous and chemically inert to ensure process stability in the long run.

KEYWORDS

Combined sewer overflow, retention soil filter, constructed wetland, biofilter

1 INTRODUCTION

Pollutant emissions via combined sewer overflow (CSO) are an issue of growing concern in many countries. Various studies show that for many substances the pollutant loads emitted by CSO are of a similar magnitude as the emissions from wastewater treatment plants or even higher (e.g. Gasperi et al., 2012; Launay et al., 2013; Scherer et al., 2003). Furthermore, CSOs can cause serious damage to the aquatic ecosystem especially when the receiving water body is small and particularly sensitive. Considering the impact on freshwater eco-systems the most relevant effects of CSO discharges are high peak flows, oxygen depletion due to excessive organic loads from single events, ecotoxic concentrations of unionized ammonia and silting of the watercourse by fine sediments (Borchardt and Sperling, 1996; David et al., 2013; Miskewitz and Uchrin, 2013). As European legislation calls for a good chemical and ecological status of all water bodies these effects have to be limited. In many cases this requires treatment of CSO discharge.

Filtration has proven to be an effective measure to mitigate environmental impacts of CSO discharges. In Germany Retention Soil Filters (RSF) were developed for this purpose. It combines biofiltration and hydraulic retention. The first plant of this type started operation in 1988, and several hundred of these have been constructed since then. Design and operation of RSF have been optimized and standardized based on operational experience accompanied by intensive research.

This paper summarizes research results and findings from practical experience gained over the last 25 years. Reviewed studies cover all scales from lab-experiments to detailed monitoring of full-scale plants. The review is complemented by a recent survey of more than 100 plants after at least 5 years of operation. The survey included sampling and analysis of filter material and sediments and an assessment of vegetation.

2 GENERAL LAYOUT AND LOADING REGIME

A RSF combines a vertical flow sand filter with a detention basin on top of the filter layer. The filter is planted with reed to prevent clogging. The filtrate is collected by perforated drain pipes. The filtration rate is controlled by a throttle device in the outlet structure. The filter is sealed from the ground by a HDPE liner to prevent interaction with groundwater. To achieve optimal aeration, the filter is drained completely after each loading event. Figure 1 shows a cross-section and a schematic plan of an exemplary RSF with standard dimensions. Basics of layout and operation are described in Uhl and Dittmer (2005).

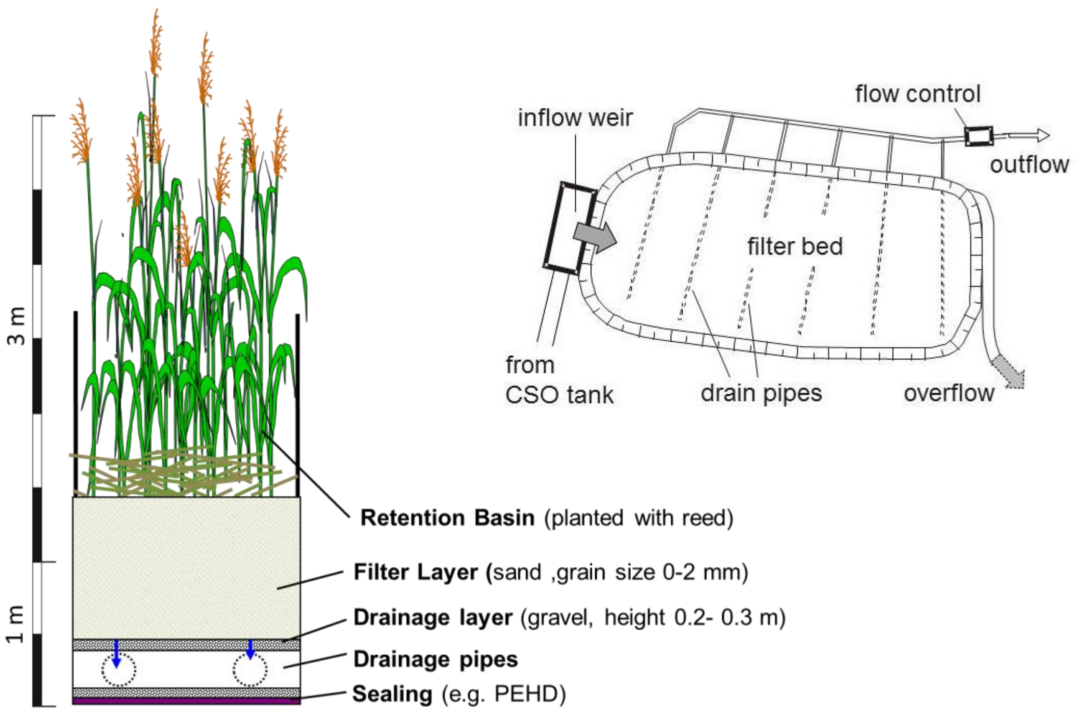

Figure 1: Cross-section (bottom, left) and schematic plan (top, right) of an exemplary RSF

3 PURIFICATION PROCESSES

The main goals of CSO treatment in RSF are the retention of SS and pollutants associated to particles, the reduction of COD loads and the reduction of peak concentrations of ammonia nitrogen. The processes relevant for these goals had been analyzed in various research projects including small-scale lab experiments, filter columns, pilot plant scale and detailed monitoring of full scale plants (Dittmer, 2006; Dittmer and Schmitt, 2011; Frechen et al., 2006; Henrichs et al., 2007; Henrichs et al., 2009; Meyer et al., 2008; Meyer, 2011; Tondera et al., 2013; Turkovic, 2009; Waldhoff, 2008; Welker, 2007; Woźniak et al., 2007; Woźniak, 2008). From the results of these studies a consistent description of the basic processes in RSF can be derived despite differences in the loading regime and in environmental conditions.

Particles and associated pollutants (e.g. heavy metals and PAH) are retained on the filter surface. Concentrations of suspended solids (SS) and particulate COD (COD_X) are reduced to a constant background concentration. Particulate organic matter is mineralized mainly during dry periods when unlimited availability of oxygen and long residence times provide ideal conditions for biological degradation. The sediments accumulate on top of the original sand filter where they form an additional filter layer. This layer improves the performance of the filter as it has a higher adsorption capacity and shows a much higher biological activity than the sand layer.

Concentration of active biomass in RSF is low in comparison to filter systems for sewage treatment. Schwarz et al. (2006) found maximum concentrations of 60 $\mu g_{DNA}/g_{sand}$ in the upper 2 cm of the sand layer. Due to the low microbiological activity the capacity of RSF for immediate degradation of solute COD compounds (COD_S) is limited. To some extent COD_S is retained by adsorption in the filter layer. The elimination can be described by a constant removal rate. In case of extremely low inflow concentrations a minimum background concentration remains in the effluent. Like for particulate compounds degradation mainly takes place in the following dry period.

The elimination of ammonium is based on a two-step process: During the filter passage ammonium is adsorbed almost completely by biofilms within the filter layer. Effluent concentrations of NH_4-N are reduced to less than 0.2 mg/l. During the following dry period the retained ammonium is nitrified and the sorption capacity regenerated. The nitrate is washed out at the beginning of the next loading event. The activity of nitrifying bacteria is highest immediately after the draining and re-aeration of the filter layer (Dittmer, 2006). Sorption capacity is reestablished almost completely within a few days. In cases of prolonged loading events the input of ammonium can exceed the adsorption capacity which leads to a breakthrough of the infiltrating concentration.

Table 1 summarizes the most important performance parameters of RSF and gives values derived from monitoring of full scale plants under real operational conditions. The resulting removal rate is calculated by long term simulation.

Table 1: Performance parameters of full scale RSF and resulting long term removal rate (load reduction)

Substance		**Performance Parameter**		**Value**	**Long term removal**
SS		background concentration	$C_{0,SS}$	5 mg/l	90 %
COD	COD_X	backgrund concentration	C_{0,COD_X}	3 mg O_2/l	80 %
	COD_S	removal rate	η_{CSB}	45 %	
		background concentration	C_{0,COD_S}	3 mg O_2/l	
NH_4-N		maximum sorption capacity	$b_{sorb,max}$	5 gN/m²	95 %

4 MODE OF OPERATION

Bio-chemical transformation processes mainly take place during dry periods. Therefore, the hydraulic retention time has only limited influence on the elimination process. Still filtration rate of a RSF should be limited to avoid preferential flow through macro pores. High filtration rates promote unsaturated flow during events of lower intensity. This reduces the contact surface between solid and liquid phase which results in a decrease of the sorption capacity for ammonium (Woźniak, 2008). On the other hand low filtration rates reduce the treatment capacity. Filtration rates of up to 3×10^{-5} m/s have no negative effect on the sorption capacity of uniform middle sand. Coarser or less uniform sand requires lower filtration rates to reach its maximum performance (Uhl and Jübner, 2004).

The filter layer of a RSF is kept aerobic, which inhibits the elimination of nitrogen. The possibility to achieve denitrification by maintaining a permanently submerged zone is investigated and discussed in various studies on stormwater management (e.g. (Collins et al., 2010; Hatt et al., 2007, 2009; Kim et al., 2003). Denitrification can also be achieved in RSF. Yet the process cannot be controlled without advanced instrumentation. The duration of dry periods is highly random and anoxic conditions are not stable. During the survey several plants were operated with a submerged zone in order to provide water for the reed. This causes anoxic conditions in the stagnant water. However, in the long run it leads to a degradation of the filter material. A clear evidence for the negative impact of keeping the filter material submerged are iron precipitates in the filter outlet structure.

5 FILTER MATERIAL AND RISK OF CLOGGING

First RSF plants were equipped with cohesive soils because of their higher cation-exchange capacity needed for NH_4-Elimination. Another advantage over sand is their higher field capacity which provides water for the reed in case of long dry periods. On the other hand cohesive soils are prone to preferential flow which significantly lowers efficiency. Excavations of combined filters (top: cohesive, bottom: sand) after several years of operation revealed that organic material passes the cohesive layer through macro pores and accumulates on top of the sand layer. Limited oxygen availability in this zone reduces degradation (MUNLV, 2003). Based on these findings and on several lab-scale experiments (Uhl and Jübner, 2004; Woźniak et al., 2007) newer design guidelines recommend uniform middle sand as filter materia (DWA, 2005; MUNLV, 2003). After a few loading events sand filters develop biofilms that provide a sorption capacity for NH_4 comparable to the capacity of cohesive soils. The sediment layer that develops over time on top of the sand filter has a high field capacity and serves as water storage for the plants.

Dimensioning of the filter area and the retention depth has been dominated by the fear of clogging for a long time. First guidelines aimed at limiting the load of SS to 4 kg/(m² · a). Assuming an average concentration of 100 mg/l in CSO discharge this leads to a limit value of 40 m/a for the hydraulic loading calculated by long-term rainfall runoff simulation. In the course of a survey the accumulation rate of sediments was determined at 25 plants after 5 to 15 years of operation. Infiltration tests were carried out in 8 cases. Observed accumulation rates of SS ranged from below 0.1 to 11.4 kg/(m² · a). The results showed no correlation between sediment loading on one hand and infiltration capacity on the other. This can be mainly attributed to the reed on the filter surface. As the plants are not harvested the straw mixes with the sediments which results in a thick (up to 40 cm) but highly permeable layer. As a consequence of these findings a limit value of 8 kg/(m² · a) is discussed in the current revision process of the actual design guidelines.

Yet clogging can still occur if RSF are loaded constantly with high loads of solute organic compounds. This happens in some areas of Germany when the seasonal variation of infiltration water flow reaches its maximum between January and April which results in dry weather overflows with a high content of raw sewage. This can lead to clogging due to the growths of biomass within the filter. Schwarz et al. (2006) found maximum concentrations of 170 $\mu g_{DNA}/g_{sand}$ in the upper 2 cm of a RSF that was clogged under these conditions. Another cause for clogging are excessive loads of mineral fines from agricultural land. The risk of both dry weather loading and excessive mineral fines should be evaluated in a feasibility study previous to the planning of the filter.

6 CONCLUCIONS AND OUTLOOK

RSF are a standard technology for CSO treatment in Germany by now. Designed and operated according to the fundamental requirements of an aerobic filtration process they show an extraordinary purification efficiency. Aerobic conditions are the result of the fact that the filters are fed only during wet weather and therefore show an alternation between submerged and dry conditions.

The efficient filtration process is guaranteed by using sand as filter media. Under regular loading conditions the accumulation of sediments on the filter surface does not lead to clogging. The development of an additional sediment layer improves the removal efficiency and should therefore be considered as maturation more than aging of the filter.

A limitation for a wider application of RSF in the urban environment is the required space. Around 1 %of the connected impervious area is needed to construct a RSF. Recent research is therefore aiming at increasing surface load to limit the required space and at integrating RSF in the design of urban landscape. A future challenge is to increase the robustness against extreme wet and dry seasons and, if needed, the modification to other climatic conditions.

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