Development and investigation of a pollution control pit for treatment of stormwater from metal roofs and traffic areas

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ABSTRACT

Source control by on-site retention and infiltration of stormwater is a sustainable and proven alternative to classical drainage methods. Unfortunately sedimentary particles and pollutants from drained surfaces cause clogging and endanger soil and groundwater during long-term operation of infiltration devices. German water authorities recommend the use of infiltration devices such as swales or swale-trench-systems. Direct infiltration by underground facilities such as pipes, trenches or sinks without pre-treatment of runoff is generally not permitted. Problems occur with runoff from metal roofs, traffic areas and industrial sites. However, due to site limitations, underground systems are often the only feasible option. To overcome this situation, a pollution control pit was developed with a hydrodynamic separator and a multi-stage filter made of coated porous concrete. The system treats runoff at source and protects soil, groundwater and receiving waterways. Typically, more than 90 % of the pollutants such as sedimentary particles, hydrocarbons and heavy metals can be removed. Filters have been developed to treat even higher polluted stormwater loads from metal roofs and industrial sites. The treatment process is based on sedimentation, filtration, adsorption and chemical precipitation. Sediments are trapped in a special chamber within the pit and can be removed easily. Other pollutants are captured in the concrete filter upstream of the sediment separator chamber. Filters can be easily replaced.

KEYWORDS

Stormwater treatment; stormwater infiltration, heavy metals, metal roofs

INTRODUCTION

Source control by on-site retention and infiltration of stormwater is used in many countries as a sustainable alternative to classical drainage methods. Infiltration reduces the impact of sewer systems on receiving waters, allows installation of storm-sewers with smaller diameters and helps return the urban water cycle to its pre-urbanized state. In recent years, however, it has become apparent that sediments and pollutants from drained surfaces cause clogging and endanger soil and groundwater during long-term operation of devices. German water authorities recommend the use of infiltration devices such as swales or swale-trench systems. Infiltration by underground facilities such as pipes, trenches or sinks without pre-treatment of runoff is generally not admitted, especially for runoff from metal roofs, traffic areas and industrial sites. The decreasing size of private allotments and restrictions on land use often prevent the use of space-consuming swale infiltrations. Small decentralised stormwater treatment facilities can solve the problem, if they have the capacity to remove all important pollutants.

PROBLEM IDENTIFICATION

Four types of drained surfaces in urban areas must be differentiated for a treatment system. These are: semi permeable surfaces (grass areas in gardens, parks and public space, paved areas), roofs, traffic areas and industrial / commercial sites. The first type of surface is not of major concern, because the water normally infiltrates directly into the ground and pollutant loads are usually small. Roofs and traffic areas show higher loads of pollutants and the concentration of specific substances varies. Industrial sites show highest concentrations in runoff, but these are not easy to predict and tend to require individual measurement.

The German ATV-DVWG-worksheet A 138 (2002) classifies runoff as harmless, tolerable or intolerable. Harmless runoff can be discharged in any kind of infiltration facility; tolerable runoff needs at least a soil passage; and intolerable runoff can only be infiltrated in exceptional cases and only with soil passage. Harmless runoff comes from green areas, and certain types of residential roofs and terraces. Tolerable runoff is stormwater from exposed metal roofs, pedestrian walkways, yards, parking areas and streets with more than 15.000 vehicles per day. Intolerable runoff is stormwater from yards and roads in commercial and industrial areas with significant air pollution and special surfaces used for truck parking and loading, and aircraft operation. A pollution control facility is necessary to infiltrate tolerable and intolerable runoff.

POLLUTANTS IN RUNOFF

Stormwater contains pollutants that can endanger soil and groundwater in the long term (Remmler & Hütter 2001). Infiltration facilities must therefore ensure that pollutant concentrations are below specified levels before water is infiltrated. Pollutant concentrations and loads have been measured in many investigation projects over recent years. The atmosphere contains a wide spectrum of substances that are emitted by natural processes (volcanoes, forest fires, wind) and anthropogenic processes (heating, industry, traffic). Some substances cause problems in infiltration systems, notably:

- dissolved metals from metal roofs (Odnevall-Wallinder et al. 2001);
- mineral oils and polycyclic aromatic hydrocarbons from traffic areas; and
- hydrocarbons from other sources such as asphalts and bituminous roof coverings.

Concentrations of these substances vary with location, land use and material of the drained surface. While concentrations in rain are usually low, levels increase when runoff flows off roofs and traffic areas. Copper (Cu) or zinc roofs (Zn) and metal drainage components, eg gutters and drainpipes, emit very high concentrations of these metals. Very high concentrations of cadmium (Cd), lead (Pb), PAH (polycyclic aromatic hydrocarbons (PAH) and mineral oil type hydrocarbons (MOTH) have been found in traffic areas (Drapper et al. 2000). Concentrations progressively increase in line with traffic intensities. In Coldewey and Geiger (2004) concentrations were evaluated from over 300 studies with more than 1300 event mean concentrations. The literature data was tested for plausibility (value levels, quality of documentation). Median concentrations of selected heavy metals and hydrocarbons cited in the literature are shown in Table 1. The development of filters in the current study was based on these concentrations.

Table 1. Median concentrations in runoff of heavy metals and hydrocarbons from different drained surfaces

Drained surface		Unsealed surfaces, garden, grassland	Roof, green roof	Roof, without metal elements	Roof, with zinc drains	Roof, zinc	Roof, copper	Traffic, pedestrian lane, yard	Traffic, car park	Traffic, residential street
Heavy metals										
Cd	µg/l	0.7	0.1	0.8	0.8	1.0	0.8	0.8	1.2	1.6
Zn	µg/l	80	468	370	1851	6000	370	585	400	400
Cu	µg/l	11	58	153	153	153	2600	23	80	86
Pb	µg/l	9	6	69	69	69	69	107	137	137
Hydrocarbons										
PAH	µg/l	0.39	-	0.44	0.44	0.44	0.44	1.00	3.50	4.50
MOTH	mg/l	0.38	-	0.70	0.70	0.70	0.70	0.16	0.16	0.16

PAH: polycyclic aromatic hydrocarbons
MOTH: mineral oil type hydrocarbons

POLLUTION RETENTION IN INFILTRATION SYSTEMS

During the natural infiltration process, the soil removes most substances from the water. The pollution retention capacity for particulate matter is based on filtration and biological degradation. The processes important in the case of dissolved substances are physicochemical filtration, biological degradation and uptake by roots of plants. Physicochemical processes include adsorption, ion exchange, complex building and chemical precipitation.

German environmental authorities have recently sponsored a research project entitled “Evaluation and reduction of the emission of heavy metals - copper, zinc and lead - from roof surfaces, gutters and down pipes“. The results of this research, which are shown in Table 2, highlight the need for stormwater treatment prior to infiltration (Athanasiadis et al. 2004).

Table 2. Total emission and distribution of heavy metals from roofs and coverings in Germany in watercourses and soil

Total emissions	copper kg/s	lead kg/s	zinc kg/s
Roofs and coverings	0.0027	0.0008	0.022
Watercourses	0.0019	0.0005	0.015
Soil	0.0005	0.0002	0.004

STUDY OBJECTIVES

The main objective of this study was to develop a compact, decentralised stormwater treatment system, consisting of a treatment pit with a specially coated porous concrete filter and a variable length of porous concrete infiltration pipe. The facility needed to be optimized to achieve both high pollution retention capacity and a satisfactory flow-rate. Solid and dissolved pollutants needed to be removed from runoff by sedimentation, filtration, adsorption and chemical precipitation. The mobility of heavy metals and hydrocarbons and the impact on soil and groundwater was investigated.

The project involved three stages. In the first stage, a treatment pit was designed and tested using a laboratory scale model, with a view to observing in particular hydraulic behaviour and retention of sediments. Secondly, filters made of porous concrete were assessed in laboratory rigs. The filters were charged with artificial runoff containing pollutants. Dissolved heavy metals and mineral oils were added. Concentrations in influent and effluent were measured and the structure and composition of the pollution control pit and concrete filters were optimized. In the third stage, a 1:1 scaled model of the device was built in a test-facility so that the behaviour of the system could be assessed under near natural conditions.

FILTER PIT AND TRENCH

Stormwater treatment measures can be classified as primary, secondary or tertiary. In primary level treatment, physical screening or trapping and rapid settling of pollutants are the main processes. In secondary treatment, sedimentation of fine particles and filtration dominate; and at tertiary level, enhanced sedimentation and filtration, biological uptake and adsorption onto sediments are the main processes.

The new stormwater treatment system, which is the subject of this study, provides all three levels of treatment at source. The system is located underground and consists of specially designed concrete pits (Figure 1) and porous concrete pipes. Primary and some secondary treatment of stormwater occurs in the pit by means of sedimentation, filtration, adsorption and chemical precipitation. The initial cleaning process is undertaken using a hydrodynamic separator and a vertically charged multistage porous concrete filter. Comprehensive pre-filtering of sediments and debris greatly increases the life of the filter and enables regular maintenance of the system at a single, easily accessible location.

After initial treatment in the concrete pit, stormwater flows into horizontally positioned porous concrete piping. Diameter of the pipes and total length will have been sized on the basis of the quantity of stormwater generated by specified rainfall events. The base of the piping is sealed to allow particles to settle on the bottom of the pipes. The concrete buffers the pH level of the stormwater, which otherwise is typically acidic. Further mechanical removal of pollutants occurs as stormwater is infiltrated through the sides of the pipes and into the surrounding sand or gravel media. Heavy metals are removed by chemical precipitation as stormwater flows through the porous walls of the pipes. Removal of metals is improved if certain hydroxides are added to concrete at the time the pipes are manufactured. Sediments and associated pollutants, such as heavy metals, can be removed by back flushing and extracted from the special concrete pits. Tertiary treatment of stormwater is undertaken both within the porous concrete pipe system and the surrounding media as biofilms develop and digest organics and nutrients.

The combined effect of this treatment train ensures very high retention of pollutants and high water quality for infiltration into the ground, discharge into waterways or storage for reuse.

METHODS

The stormwater treatment system was tested with different kinds of runoff both in the laboratory and under near natural conditions in the field.

Development of filters

Filters were developed using different recipes in order to identify the best materials for removing pollutants in different types of runoff. On the one hand, filter media must have small pore sizes and a large inner surface so as to filter and adsorb as much as pollutant as possible. On the other hand, the flow rate must be sufficient to treat the most severe storm events. Generally, treatment systems are designed with a maximum of 500 m^2 connected area to one DN1000 filter pit. In Germany, filters must have a permanent flow rate of about 4 l/s to treat more than 98 % of annual runoff. Systems are equipped with an overflow, so that when a severe storm occurs, stormwater is able to bypass the filter and flow directly into the infiltration pipes.

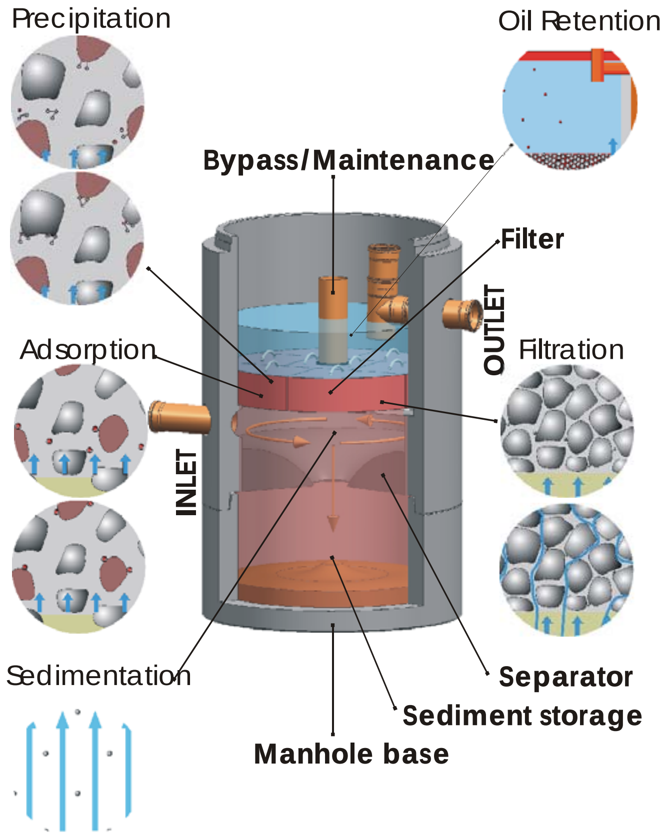

Figure 1. The stormwater pollution control pit

Laboratory tests

Laboratory tests using rigs and an artificial runoff were undertaken at the University of Münster. Five filters were investigated in parallel during one test. The test rigs had dimensions of 0,4 m x 0,4 m. Tests for different kinds of runoff were carried out. Presented are the results of runoff from a copper roof. Only dissolved copper was simulated, since particulate metals will be removed in the pre-filtering chamber. The flow rate in the tests was about 0.59 l/s, which corresponds to a rain intensity of 56 l/(sxha). The filters were subjected to concentrated runoff at 5 times the expected normal level. Heavy metals concentrations were analyzed in the inflow and in the outflow of the rigs.

Test under near natural conditions

A real scale concrete filter pit followed by a trench with infiltration pipe was built. The trench was installed in a stainless-steel basin of 2.80 m x 1,50 m x 0,80 m with an infiltration pipe DN 300. Artificial runoff was mixed in two stainless steel tanks with a volume of 2 m^3 that were equipped with stirrers. Therefore rainwater was collected on a roof and was spiked with additional heavy metals. The water was pumped by a peristaltic pump through the filter pit into the infiltration pipe. Simulated rain intensity was controlled by flowmeters. For testing runoff from traffic areas oil was added directly into the inlet of the pit. Samples were taken from the inlet, the outlet of the filter pit and at the seepage of the trench. Diferent kinds of runoff were used. Tests were carried out, simulating a period of 2 years.

RESULTS

Table 3 shows the composition of 9 different filters tested during this study. Four filters (nos. 1-4) were made of porous concrete using aggregates of different grain size (Figure 2). To increase adsorption capacity, micro dispersed iron-oxides and iron-hydroxides were added to the concrete mix. All four filters had a height of 16 cm and were charged in an upward flow direction. Such filters are designed to treat mainly different types of suspended solids.

In order to treat severely polluted runoff from metal roofs, high density traffic areas and especially industrial sites, filters with higher adsorption capacities (nos. 5 ,7 & 8) were made, consisting of two layers of porous concrete (Conc.) separated by a filling of adsorbents (Figure 2). Fillings consisted of iron-hydroxides (IH) (no. 7), a blend of IH and recycled concrete (IH/c)(no. 5) and dried iron sludge (FE) (no. 8). To assess the influence of the concrete and the fill, one chemically inert filter (no. 6) was made with special epoxy resin cement without $CaCO_3$. A filter without fill (no. 9) was tested for comparison. All filters were charged in an upward flow direction.

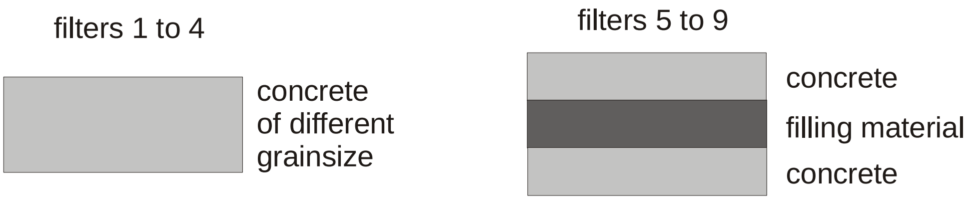

Figure 2. The stormwater pollution control pit

Table 3. Composition of tested filters

Filter no.		1	2	3	4	5	6	7	8	9
Material		Concr. 1	Concr. 2	Concr. 3	Concr 4	Concr. 4	Epoxide 4	Concr. 4	Concr. 4	Concr. 4
Fill		no fill	no fill	no fill	no fill	IH/c	IH	IH	Fe	blank
Height	cm	16	16	16	16	36	36	36	36	36
Area of operation	Surfaces with high SS (turbidity) roofs and traffic areas					Metal roofs, industrial areas, roads with high traffic density				-
Pollutant removal	Heavy metals, hydrocarbons, suspended solids					Heavy metals, hydrocarbons, suspended solids				-

IH: Iron-hydroxide
IH/c: Iron-hydroxide with recycled concrete
Fe: Dried iron sludge

All filters were initially tested for hydraulic pressure. Since the normal water head in the system should be up to 50 cm, the flow rate was measured for heights between 0 cm to 75 cm. The results are shown in Figure 3 and, as expected, indicate that the flow rate of the concrete filters increases significantly with hydraulic pressure with low head loss. In the case of filter no. 4, which seems to be the most suitable filter for most areas of application, the flow rate increased from 6 l/s without head loss to 27 l/s for 75 cm water pressure.

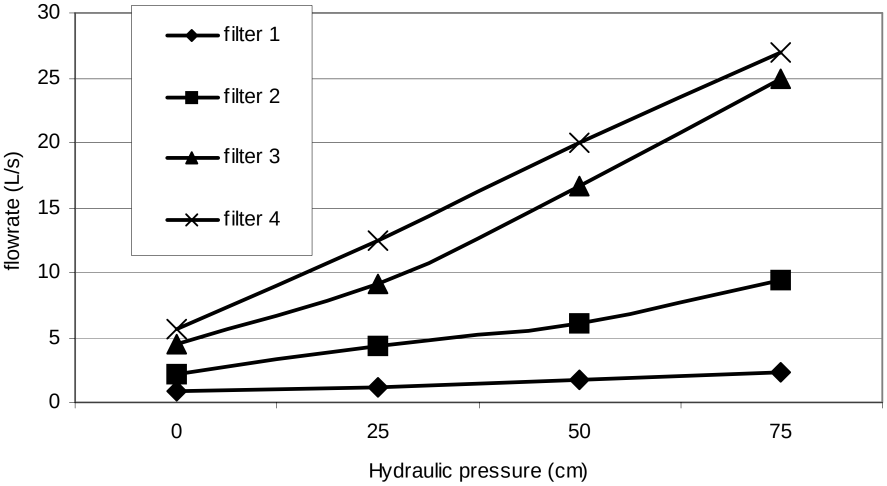

Figure 3. Flowrate through filters 1 to 4 at various hydraulic pressures

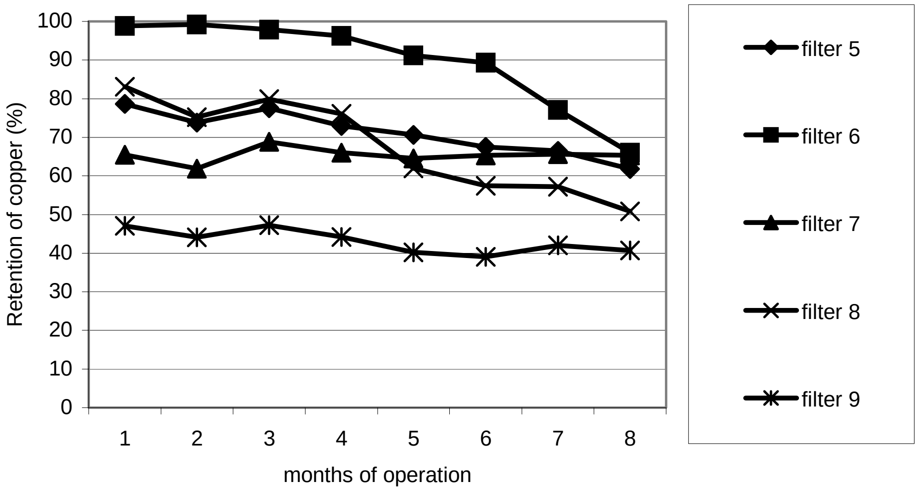

Figure 4. Removal efficiency for copper

Figure 4 shows the amount of copper removed over 8 experiments during a simulated 8 month period in the laboratory tests. Best results were achieved by the filter containing iron hydroxide fill and epoxy resin cement (no. 6), which over the period of the tests decreased from 100 % at the beginning to 87 % at the end. This decline is due to the behaviour of copper, since the dissolved metal is adsorbed by the iron hydroxide material. After several months of operation, the adsorption capacity decreases and higher amounts of copper are able to pass the filter. Concrete-based filters allow chemical precipitation as well as adsorption processes to take place. Such filters showed lower removal efficiencies in the beginning, but efficiency did not decrease as in the case of the GEH filter over the tested period. Thus, concrete-based filters can be assumed to have a longer operational life. Since the amount of dissolved copper in the effluent from these filters is less than 1 %, the remaining copper particles can be removed easily in the trench of washed sand surrounding the system, as indicated in the following section.

Following laboratory tests, the system was investigated in a real scaled facility. Performance of the system in infiltrating road runoff is presented in Table 4. Two years of operation were simulated in the facility with artificial runoff being used over a period of several weeks. Removal efficiency was found to be more than 96 % for lead (Pb) and copper (Cu) and 84 % for zinc (Zn). Over 99 % of mineral oils (MOTH) were trapped with no concentrations able to be detected in effluent. The retention of total suspended solids (TSS) was greater than 99 %.

Table 4. Removal efficiency under near natural conditions

Parameter	Pb	Cu	Zn	MOTH	TSS
Removal Efficiency	96 %	99 %	84 %	99 %	99 %

CONCLUSIONS

The investigation results from the decentralised filter system show that pollution retention greater than 90 % can be achieved for most constituents. In particular, heavy metals and hydrocarbons can be removed from runoff even when runoff is generated from metal roofs, traffic areas or industrial sites. As pollution retention works by means of sedimentation, filtration, adsorption (ion exchange) and chemical precipitation, even dissolved pollutants can be removed by the pit. The use of different kinds of filters allows the system to treat runoff from a large range of drained surfaces. Pollutants will be trapped within the pit by the sedimentation chamber and filters and can be removed easily. In some cases, maintenance will only be required every 5 to 10 years. Long term studies on treating runoff from metal roofs and industrial areas have started, with initial results of performance expected to be available over the next few years.

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