Treatment of Phosphorus and Bacteria in Filters used for On-Site Sanitation in Cold Climate

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Abstract
Swedish rural on-site wastewater facilities need to reduce the phosphorus (P) concentrations in the wastewater to prevent eutrophication of the Baltic Sea, as well as the bacteria concentrations to comply with EU standards for bathing water quality. The aim of this study was to investigate two different on-site filter systems at full-scale, sand filters and (often subsequently used) alkaline P filters towards their performance to treat P and bacteria from domestic wastewater. Flow-proportional composite samples were taken from five sand filter beds and two P filters. Four of the five investigated sand filters considerably reduced the concentration of total P in the wastewater. However, infiltrating soil / ground water may have diluted the effluents. The investigated P filters varied in performance. While one of them treated P effectively, the other one performed poorly, probably due to old age and clogging. Low inlet P concentrations impeded the general assessment of the P filters' efficiency. Concentrations of four indicator bacteria, intestinal enterococci, E. coli, total coliforms and C. perfringens, were considerably reduced in four of the five investigated sand filter beds. Bacteria removal in the two investigated P filters was difficult to assess because of low bacteria concentrations in the influents.

Keywords
Soil filter; sand filter; constructed wetland; bathing water quality; phosphorus reduction; small scale wastewater treatment

INTRODUCTION

Rural on-site wastewater treatment facilities in Sweden do not always meet the Swedish EPA's treatment performance standards (Swedish EPA, 2006), especially with regard to the treatment and recycling of phosphorus (P). Due to the discharge from on-site wastewater facilities Sweden's contribution to P emissions to the Baltic Sea is considerable (HELCOM, 2005). Another potential problem is the discharge of bacteria from these facilities. As many of them are located at lakes and watercourses used for recreational purposes, bacteria discharge is an important issue because it represents a risk for a good bathing water quality as stipulated in the EU bathing water directive (EU, 2006).

To improve wastewater treatment at rural private facilities, the responsible authorities have worked and are still working on an inventory of the existing facilities and started to upgrade or replace facilities of old age and/or with insufficient treatment capacity. Private rural on-site wastewater treatment facilities in Sweden typically have a primary treatment in a septic tank and a subsequent secondary treatment in a biological filter (sand filter bed). To prevent eutrophication of the receiving waters, many rural on-site facilities have recently been upgraded with a tertiary treatment unit in form of an alkaline filter bed that traps P (P filter). P filter media and P filters have been extensively studied in laboratory- and pilot-scale (Johansson Westholm, 2006; Vohla, Kõiv et al., 2011). P filters increase the wastewater's pH and might therefore also help to decrease the bacteria content of the effluent.

The aim of this study was to investigate full-scale on-site sand filter beds and alkaline P filters in Sweden towards their performance to treat P and bacteria from domestic wastewater.

MATERIAL AND METHODS

Identification of suitable on-site facilities

In co-operation with three Swedish municipalities in the province of Västerbotten, Sweden, on-site facilities featuring sand filters and P filters were identified in the municipal databases. The operators of these facilities (private property owners in all but one case) were contacted by telephone to obtain their approval of taking part in the study. Only after receiving the owner's approval, a facility was inspected. 19 sand filter facilities and 10 P filters were visited for an inspection to decide if they were suitable for the sampling intended to be carried out within the project. During inspection, it was checked if the sand filters' outlet was designed in a way that would enable flow-proportional sampling. For P filters, it was checked if both inflow and outflow were accessible for sampling and if at least one of them was suitable for flow measurements.

Investigated on-site facilities

A description of the filters is shown in Table 1. The sand filter beds were constructed according to the Swedish norm, featuring a 80 cm thick layer of filter media (sand/gravel with particle sizes between 0 to 8 mm). The wastewater was spread over the filter through slotted pipes and collected in drainage pipes at the bottom of the filter. Both spreading and drainage pipes were embedded in a 30 cm thick gravel layer.

Two P filters were investigated (Table 1). P filter 1 was a bag filled with the filter material Polonite® (supplier: Ecofiltration AB, Sweden) which was placed in a well and operated in up-flow mode. P filter 2 was a tank with two chambers, filled with the filter material Filtra P (supplier: Wavin-Labko Ltd), where the water percolated downwards through the filter media in the first chamber and upwards in the second chamber.

Table 1 Properties of the investigated sand filter beds and P filters

	Location	Design	No. of users	Start of use
Sand filter 1	Sävar	biomodules	2	2014
Sand filter 2	Håkmark	Swedish norm	5	2009
Sand filter 3	Brån	Swedish norm	3	2009
Sand filter 4	Skellefteå	biomodules	2	2013
Sand filter 5	Skellefteå	biomodules	5	2015
P filter 1	Sävar	Polonite-bag	2	2014
P filter 2	Håkmark	Wavin-Labko tank	5	2009

Sampling

To assess the P treatment performance and the discharge of bacteria, two sampling campaigns (autumn 2015 and spring 2016) were carried out at five sand filter beds (sand filter 1 to 5; sand filters 4 and 5 were only sampled in spring 2016) and two P filters (P filter 1 and 2). At the sand filters, influent samples were taken from the third chamber of the septic tank or from the distribution/pumping tank from where the wastewater is transferred to the sand filter. Samples were taken flow-proportionally during several hours in the morning, evening and during day time, depending on when the owners were at home, i.e. water flow could be expected. In this way, the morning and evening flow peaks of the facilities were covered. Within each sampling campaign, samples were taken at three different occasions from each treatment facility. Flow was measured at the outlet of the sand filters, and either the outlet or the inlet of the P filters by capturing the flow in a measuring container and taking time. At each sampling occasion, two composite samples were taken and analysed on total and dissolved P, total and dissolved organic carbon, total suspended solids (not at all occasions), pH, biological oxygen demand (BOD_7, one sample at each facility), and the indicator bacteria *E. coli*, total coliforms, *C. perfringens* and enterococci. Standards for *E. coli* and enterococci are included in the EU bathing water directive for the assessment of bathing water quality (EU, 2006).

Analyses

TOC and DOC were analysed using IR detection (based on CSN EN 1484, CSN EN 16192, SM 5310). P analyses were performed using a Quattro spectrometer and the device-specific method number A-031-04, according to European standards (ammonium molybdate method) with digestion (persulfate oxidation, SS-EN 1189 performance 6.4) (Swedish Standards Institute, 2005a). Samples for analysis of DOC and dissolved P were filtered through 0.45 µm - filters prior to analysis. The pH was measured using a WTW pH330 pH meter with a WTW SenTix41 pH electrode. TSS was determined following the European standard EN 872:2005 (Swedish Standards Institute, 2005b). BOD_7 was analysed according to CSN EN 1899-1 (modified). Presumptive *C. perfringens*, *E. coli*, intestinal enterococci and total coliforms were analysed according to ISO/CD 14189, SS 028167-2, SS-EN ISO 7899-2 and SS 028167-2, respectively.

RESULTS AND DISCUSSION

Treatment of phosphorus

The five investigated sand filters considerably reduced the concentration of both dissolved and total P (Figure 1). However, it is uncertain if the P reduction was due to the correct functioning of the treatment. Sand filters 2 and 3, and at one sampling occasion also sand filter 5, 2 to 4 showed high flows of water in the outlet, possibly due to wet soil conditions, presence of holes in the pipes or bad sealing of the systems. Thus, infiltration of soil water into the system diluting the outlet water may have caused the low P concentrations in the outlet.

During several sampling events, the outlet flow of sand filters 4 and5 was very low although the owners were at home and consumed water. This was probably caused by dry soil conditions enabling exfiltration of the wastewater into the surrounding soil environment. In these cases, sampling was difficult and could not be carried out flow-proportional. Despite the low flow, the P concentrations were high in the outlet of facility 4 (Figure 1).

Despite the fact that the concentrations of total P in the different septic tanks differed greatly across the facilities, ranging from 6.05 to 19.83 mg L^{-1}, the concentrations in the outlet of the sand filters were rather similar and generally low, ranging from 0.72 to 3.45 mg L^{-1} of total P (Figure 1). Only sand filter 4 treated P ineffectively (2 ± 1 mg L^{-1} reduction of total P). In the effluent of this sand filter, concentrations of organics were also high (data not shown) indicating malfunctioning. This could be due to clogging and lack of air circulation in the filter bed, as well as the ageing and saturation of the filter media which might not have capacity to retain P any longer hence it is discharged in the outlet.

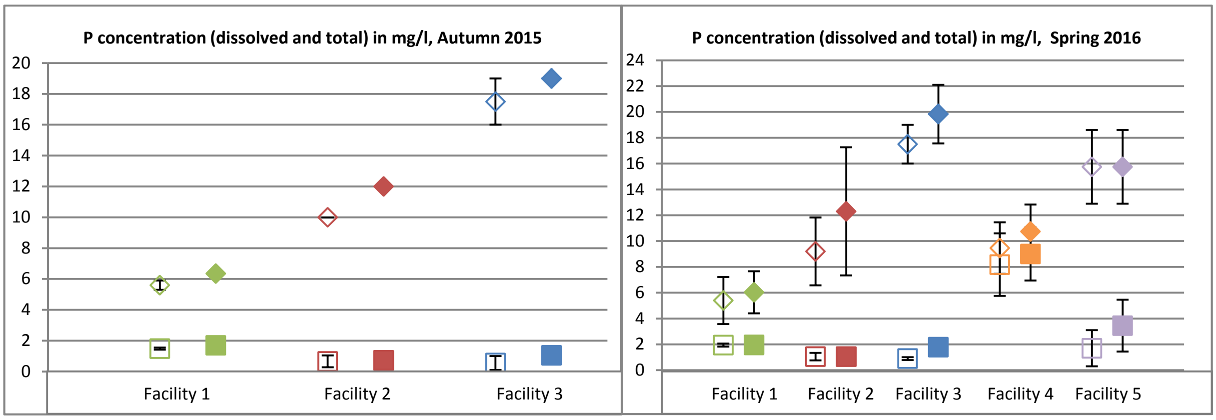

Figure 1. Average concentrations of dissolved P (empty markers) and total P (filled markers) for each facility in both the septic tank (diamond shapes) and the outlet of the sand filters (square shapes) during the two main sampling campaigns carried out in autumn 2015 (left) and spring 2016 (right). Standard deviations are shown as error bars.

Two facilities with P filters, 1 and 2 (Table 1), were sampled and evaluated with respect to P reduction. The sand filters substantially reduced the P concentration in both facilities, compensating for the difference in P concentration in the septic tanks (Figure 2), which ranged from 8.4 - 3.6 mg L^{-1} in facility 1 to 23-17 mg L^{-1} in facility 2. P filter 1 effectively removed between 1.44 and 1.72 mg L^{-1} of total P from the influent (Figure 2). However, the P reduction in P filter 2 was smaller; only 0.06-0.24 mg L^{-1} of total P was removed. This could have several possible reasons. Firstly, in this filter, a by-passing of a part of the influent water from the upper level of the filter to the lower level (without percolating through the filter material) was observed during the sampling. Secondly, the filter had been in use since 2008 without changing the filter media that probably was exhausted.

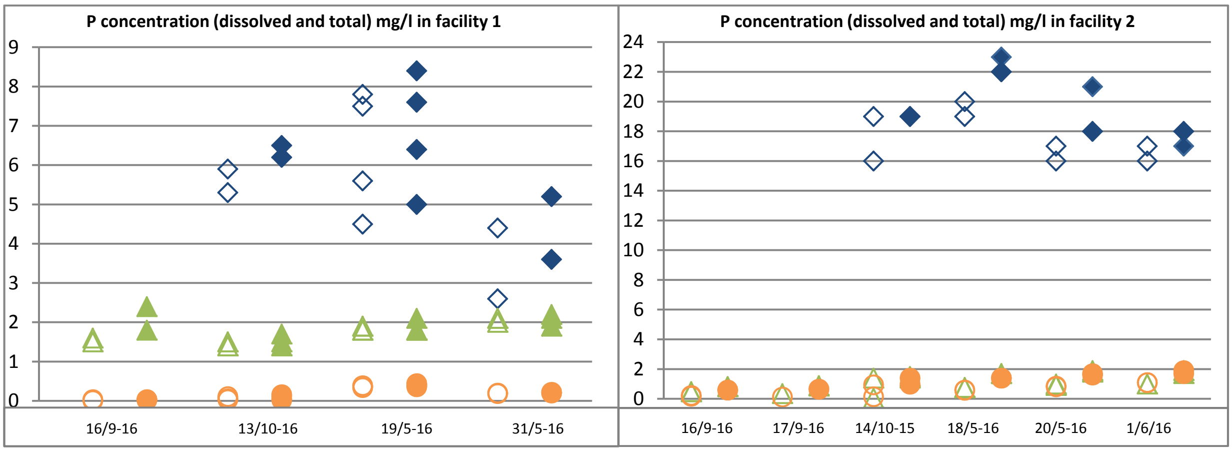

Figure 2. Concentrations of dissolved P (empty markers) and total P (filled markers) in the septic tank (diamond shape), after the sand filter (triangular shape) and after the P filter (circular shape) of facility 1 (featuring sand filter 1 and P filter 1) and 2 (featuring sand filter 2 and P filter 2).

Only in the effluent of P filter 1, concentrations of total P were consistently below the recommended limit of 1 mg L^{-1} (Swedish EPA, 2006). In the effluent of P filter 2, the concentration of total P exceeded the recommended limit in four of six samples (Figure 2).

Treatment of bacteria

The five investigated sand filters reduced the bacteria concentration of the wastewater to various extents (Figure 3). Concentrations of intestinal enterococci and *E. coli* in the effluents of the sand filters were generally lower during the sampling campaign in autumn 2015 compared to the one in spring 2016. *E. coli* concentrations measured in the samples taken during the autumn were generally low, in most cases under the detection limit. This was probably due to the low air temperatures during sampling (-5 to 10°C) and the low temperatures of the samples (2.1 to 10.9°C) making survival difficult for *E. coli* bacteria. Intestinal enterococci were detected in a number of samples. Enterococci concentrations in the effluent of the sand filters ranged from under detection limit (<10 cfu/100mL) to 50 cfu/100 mL (Figure 3).

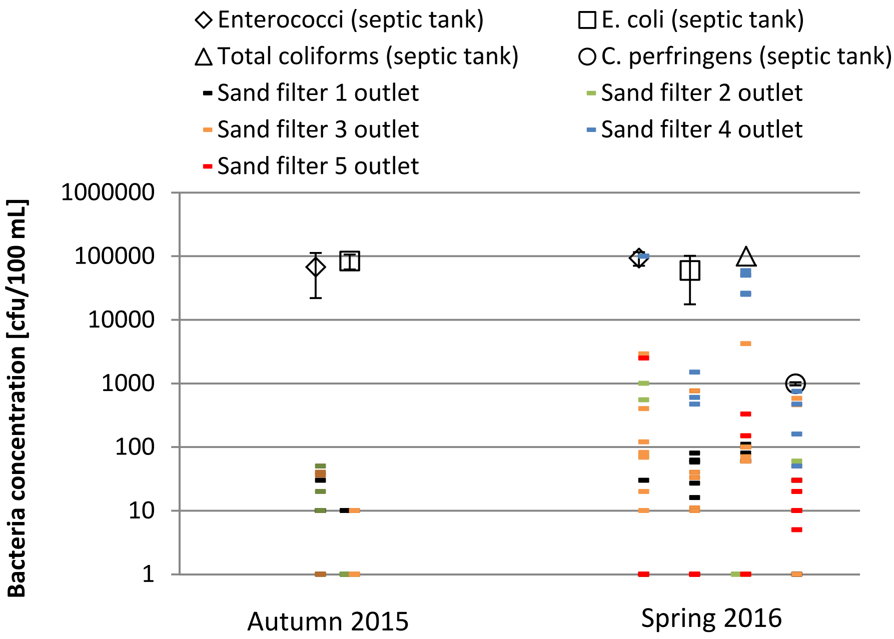

Figure 3. Concentrations of intestinal enterococci (diamond markers), *E. coli* (square markers), total coliforms (triangle markers) and *C. perfringens* (circle markers) in the effluent of the septic tanks (non-filled markers; averages of all samples taken at the different facilities with standard deviations shown as error bars); and in the effluent of the sand filters (shown as dashes in different colours for sand filter 1-5) with concentrations of intestinal enterococci below the diamond marker, *E. coli* below the square marker, total coliforms below the triangle marker and *C. perfringens* below the circle marker; during the sampling campaign in autumn 2015 (left) and spring 2016 (right).

The sampling campaign in spring 2016 was carried out in May and June with air temperatures between 2 and 25°C, with an average of 15°C. The weather was warmer compared to the autumn which may have caused higher concentrations of bacteria in the effluents of the sand filters (Figure 3), sand filter 4 exhibiting the highest concentrations of all four indicator bacteria; concentrations of intestinal enterococci being as high as in the septic tank effluent. Sand filter 4 treated the wastewater insufficiently also with regard to P (Figure 1, discussed above) and BOD (data not shown) indicating that the filter bed did not function properly. However, also in the effluent of sand filters 2, 3 and 5 bacteria concentrations were high at some sampling occasions during spring 2016 (Figure 3), exceeding the concentrations for good quality for coastal waters as stipulated in the EU bathing water directive (EU, 2006).

Bacteria removal in the two investigated P filters (Figure 4) was difficult to assess because the bacteria concentrations in the inlets to the P filters were low, in many samples below detection limit, and did not exceed 100 cfu/100 mL (with exception for intestinal enterococci concentrations in P filter 2 at some sampling occasions during spring 2016). These concentrations were also low compared to the concentrations stipulated as excellent quality of coastal waters in the EU bathing water directive (EU, 2006) which are 100 cfu/100 mL for intestinal enterococci and 500 cfu/100 mL for *E. coli*. The low inlet concentrations can be attributed to an effective treatment in the preceding sand filters, in P filter 2 together with a certain dilution of the wastewater by infiltrating ground or soil water.

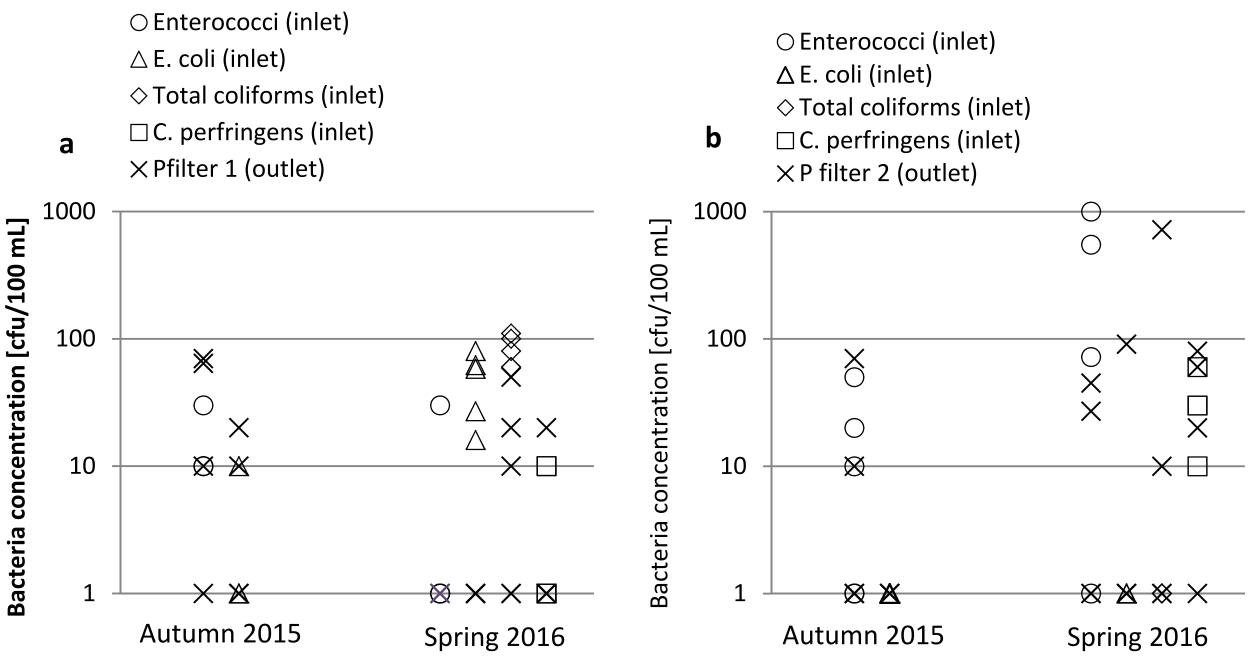

Figure 4. Concentrations of the four indicator bacteria in (a) the inlet (empty markers) and outlet (cross markers) of P filter 1, and (b) the inlet (empty markers) and outlet (cross markers) of P filter 2. All measurements are shown but not in all cases visible in the figure because of overlaps.

Despite low inlet concentrations, data collected during spring 2016 indicate a certain reduction of bacteria in the P filters. P filter 1 reduced the content of E. coli to concentration below detection limit (Figure 4), which is also reflected in reduced concentrations of total coliforms. In P filter 2, the inlet concentrations of *E. coli* were high in some of the collected samples, ranging from 72 to 1000 cfu/100 mL (Figure 4), while the outlet concentrations were considerably lower during these sampling events (ranging from below detection limit to 45 cfu/100 mL).

CONCLUSIONS

Four of the five investigated sand filters considerably reduced the concentration of total P in the wastewater. However, there are some uncertainties about their effectiveness because processes such as infiltration of soil / ground water and hence dilution of the effluent might have affected the observed effluent concentrations. Sand filters should be sealed to avoid infiltration of soil water into the sand filter and exfiltration of wastewater into the ground which is especially important in cases where the sand filter precedes a P filter.

The investigated P filters varied in performance; P filter 1 functioned well, while P filter 2 did not perform properly, probably due to the age of the filter media which had not been changed since it was installed in 2008. Probably, the filter was clogged causing some of the influent water to by-pass. The low P concentrations measured in the influent to the P filters make it difficult to generally assess P filters' efficiency.

Concentrations of four indicator bacteria, intestinal enterococci, *E. coli*, total coliforms and *C. perfringens*, were considerably reduced in four of the five investigated sand filters. *E. coli* are sensitive to cold temperatures and were therefore less suitable as indicator bacteria for assessing bacteria discharge during the sampling campaign in autumn when temperatures were low. Bacteria removal in the two investigated P filters was difficult to assess because of low bacteria concentrations in the influents.

REFERENCES

EU 2006 Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC. Official Journal of the European Union L64, 37-51.

HELCOM 2005 Nutrient Pollution to the Baltic Sea in 2000. Baltic Sea Environmental Proceedings BSEP 100

Johansson Westholm, L. 2006 Substrates for phosphorus removal - Potential benefits for on-site wastewater treatment? *Water Research* **40**(1), 23-36.

Swedish EPA 2006 Statute book of the Swedish EPA. General advice about small-scale household wastewater treatment facilities. (Naturvårdsverkets författningssamling. Naturvårdsverkets allmänna råd om små avloppsanordningar för hushållsspillvatten.) NFS 2006:7. In Swedish.

Swedish Standards Institute 2005a Water quality - Determination of phosphorus - Ammonium molybdate spectrometric method. SS-EN 6878:2005, chapter 7.

Swedish Standards Institute 2005b Water quality - Determination of suspended solids - Method by filtration through glass fibre filters. EN 872:2005.

Vohla, C., Kõiv, M., Bavor, H. J., Chazarenc, F., Mander, Ü. 2011 Filter materials for phosphorus removal from wastewater in treatment wetlands - A review. *Ecological Engineering* **37**(1), 70-89.