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Published in:
Proceedings of the 13th Nordic Wastewater Conference

Publication date:
2013

Citation (APA):
Sørud, M., Nielsen, K., Skau Damskier, S., Torpenholt Jørgensen, A., Fjendbo Petersen, M., Kofoed Rasmussen, L., Mikkelsen, P. S., & Eriksson, E. (2013). DEMFIL - treatment of stormwater for recreational use. In *Proceedings of the 13th Nordic Wastewater Conference* Svenskt Vatten.

DEMFIL - treatment of stormwater for recreational use

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ABSTRACT

Decoupling of stormwater (road runoff) in a residential area has been implemented in order to reduce flooding and to increase the hydraulic capacity of a lake with a high recreational value. The object here was to evaluate a disc filter technology in combination with a green polymer for flocculation for its feasibility of particle removal. Secondary, the particulate pollution in the separate road runoff should be assessed.

The road runoff was found not to be highly contaminated with particle pollution, here measured as turbidity and total suspended solids (TSS). The particles were generally small (< 10 µm) and negatively charged. The disc filtration was hampered during the winter season and by the large fraction of small particles, but supplementing it with flocculation increased the removal efficiencies. The inlet particle concentrations (mg/L) affected the removal efficiencies, and events with inlet concentrations < 10 mg TSS/L or FNU had no statistically significant removal of the particle pollution whereas the events with the highest concentrations yielded among the highest removal efficiencies. The green polymer is as efficient as previously tested commercial coagulant/ flocculent and the disc technology is promising but need to be further tested with higher hydraulic loadings.

RESUME

Et mindre boligområde er blevet separeret således at oversvømmelsesproblemer minimeres og samtidig kan regnvandet (vejvand) biddrage med rekreativ værdi i forbindelse med en nærliggende sø. Vejvandets sammensætning samt mulig rensning skal undersøges inden vandet kan blive udledt til søen. Formålet med undersøgelserne er, at vurdere og evaluerer effekten på partikelfjernelse ved anvendelse af skivefilter teknologi i kombination med ”grøn” polymer baseret på kartofler. Samtidig kortlægges partikelforureningen i det konkrete vejvand fra området.

Forureningsgraden af vejvandet er meget begrænset i forhold til partikulært materiale, som i projektet er undersøgt via turbiditet og totalt suspenderet stof (TSS). Partiklerne er generelt små (<10 µm) og med negativ overfladeladning. Effekten ved et filter med 10 µm filterdug er således begrænset, men suppleret med flokkulant blev effekten væsentligt forbedret. Fjernelses graden påvirkes kraftigt af indløbskoncentrationen af suspenderet stof (mg/L) og ved regnhændelser med en indløbskoncentration på under 10 mg TSS/L var der ingen signifikant rensning i filteret, mens den største fjernelse blev opnået ved de hændelser, hvor koncentrationen i indløbsvandet var højest. Tilførsel af grøn polymer øgede effektiviteten af filteret markant og resultaterne er på samme niveau som tidligere resultater opnået med konventionel anionisk polymer og koagulant. Kombinationen af skivefilter teknologien og grøn polymer er lovende inden for rensning af regnvand, og bør også testes ved højere hydraulisk belastning.

Keywords: Best available technologies; disc filtration; flocculation; particle pollution; stormwater

Introduction

In Denmark, the management of stormwater runoff is receiving much attention due to the growing paved surfaces caused by increasing societal wealth and increased frequency of heavy rainfalls, which has been experienced potentially as a result of the climate changes (Arnbjerg-Nielsen, 2006). The larger rainfall events challenge the combined drainage systems, as they will not be able to comply with the design criteria resulting in surcharge and flooding problems in urban areas (Paludan et al, 2011). Expansion of the capacity of the combined drainage systems by replacement by larger pipes is extremely costly, thus municipalities and utility companies are seeking alternative solutions.

In parallel, stormwater runoff is increasingly considered as a resource that can be exploited locally for recreational and environmental purposes rather than hidden away in pipes (Jensen and Fryd, 2009). Separating stormwater from sewage water is frequently applied in Denmark as it is often seen as a cost-effective solution to the hydraulic capacity problems. In this manner the stormwater runoff can be discharged to recipients without passing the central wastewater treatment plant (WWTP); however, pollution is a large barrier as the stormwater washes off pollutants accumulated on surfaces. The discharge of polluted stormwater can not only have detrimental effects on the flora and fauna (Grant et al., 2003), it can also pose human health risks for those using the water bodies for recreational purposes (Clauson-Kaas et al., 2011). Consequently, the utility companies are struggling to get discharge permits and they are therefore keen to apply stormwater treatment measures by applying best available technologies (BAT).

The discharge of untreated stormwater to receiving water bodies like streams and lakes can be a major obstacle on the way to achieve good water quality by 2015 as set by the European Water Framework Directive (European Commission, 2000). In Denmark, stormwater treatment often consists of wet detention basins prior to discharge, but this paradigm requires large surface areas which are difficult to come by in urban areas. Therefore, an increasing number of studies have investigated different small footprint technologies for stormwater treatment. The technologies apply and combine physical filtration, settling, precipitation, adsorption, plant uptake and degradation (Vezzaro et al., 2009). However, filter bed technologies often experience problems with clogging leading to unforeseen operational costs (Clark and Pitt, 2009).

A large part of the pollutant loading and toxic effects in stormwater is associated with particulate material and it is therefore important to assess how the treatment technologies function with respect to settleable, suspended, colloidal and dissolved matter (e.g. Grant et al., 2003). Though much is known about the fate and removal of larger particles, colloids are still sparsely documented (e.g. Grout et al., 1999; Tuccillio, 2001; Vollertsen et al., 2007).

The technology applied in the Hydrotech® filter is a mechanical disc filter that uses automatic flushing to prevent clogging. Few have investigated its use for stormwater treatment as disc filters are generally considered less suited for capturing dissolved compounds and colloids (Pedersen, 2010). The addition of coagulant and flocculent however enhances the aggregation of particles into larger particles thus improving the treatment efficiency. Typically used flocculants contain acrylamide that is believed to be carcinogenic (Rice, 2005); hence, the Danish municipalities have been reluctant to permit its use for stormwater treatment, bearing in mind the subsequent discharge into receiving waters and potentially within recreational areas. Green polymers created from non-eatable potatoes are emerging as they do not contain anthropogenic acrylamide.

In this study we investigated treatment of stormwater runoff from residential streets in the suburb Bagsværd, Gladsaxe Municipality, Denmark, using a 10 µm Veolia Hydrotech® disc filter. The overall aim was to evaluate the applicability of the disc filter technology in combination with flocculation using green polymer for treatment of particulate pollution in stormwater including very small particles in the colloidal and nanosized scale. A secondary aim was to assess the particulate pollutant loads in a separate road runoff sewer in a residential area.

Materials and methods

Catchment

The catchment used for testing the disc filter and addition of polymer is called the Aldershvilevej Catchment and is located in the northern part of the greater Copenhagen area, Denmark (latitude:55.764792°; longitude:12.457049°). Figure 1 shows an overview of the catchment area.

The Aldershvilevej Catchment has a size of approximately 24 hectares. The impermeable area of the catchment is approximately 3 hectares and about 79 % of this area consists of roads, which corresponds to 2.4 hectares. The catchment was originally fitted with a combined sewer system, but in 2009-2010 the road runoff was separated from the combined sewer system. This means that the road runoff is now drained in its own sewer system from Aldershvilevej. However, further downstream the separate stormwater is mixed with a combined system again and transported to the WWTP. Figure 2 shows an aerial photo of the area

The lake visible in the northern part of the catchment (Figure 1 and Figure 2) is Bagsværd Lake, which has a high recreational value, both in a local and national context. It hosts a rowing club, with national rowing competitions, and frequent hosts recreational anglers for ice fishing and angling for pikeperch, pike and carp, as well as paths for jogging, dog walking, etc. at the brinks of the lake. As only two small watercourse stations (influent and effluent) exist for Bagsværd Lake, it is in need of further dilution and mixing.

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Figure 1: Overlook of the Aldershvilevej Catchment, where the disc filter is situated in the north-western corner (DEMFIL)

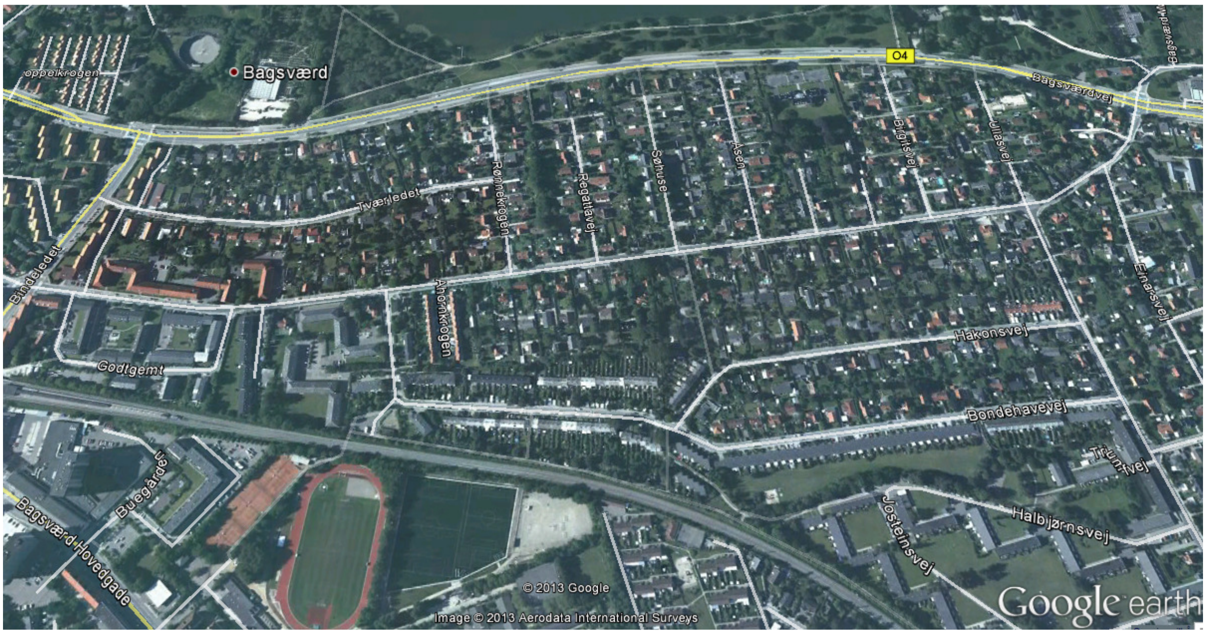
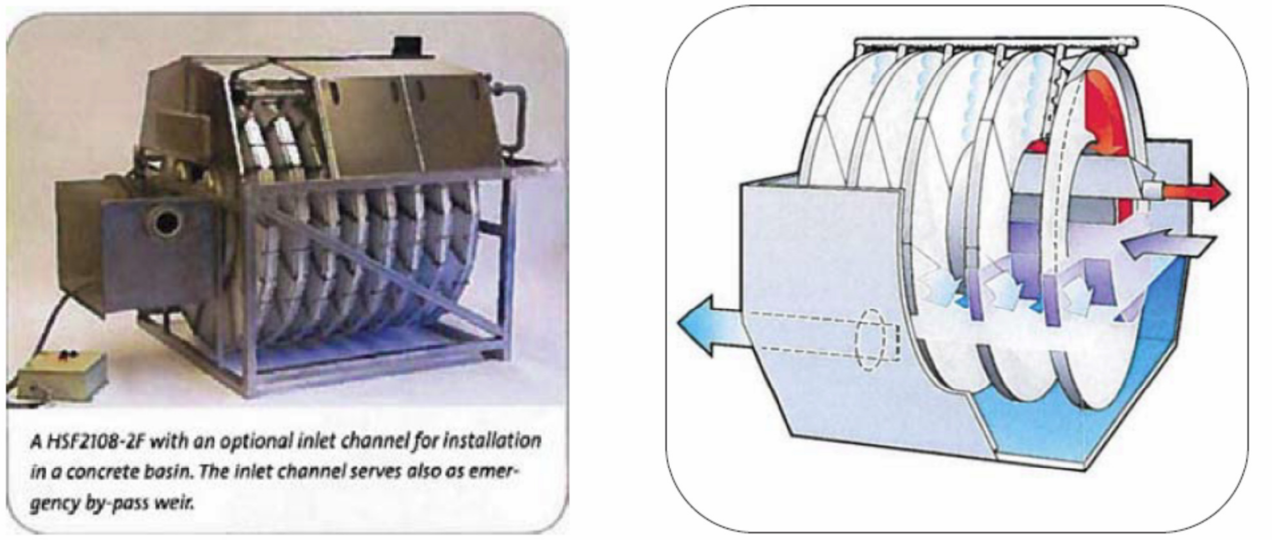


Figure 2: Aerial photo of the Aldershvilevej Catchment.

Disc filter technology

The separate road runoff from the Aldershvilevej Catchment is led through a disc filter from Hydrotech in order to reduce the amount of total suspended solids (TSS) and other compounds associated with TSS. Hydrotech disc filters are typically used in WWTPs for effluent polishing and it is well suited for stormwater treatment in urban areas because of the potentially large filter area and small spatial footprint. Figure 3 shows a typical layout of a disc filter. Water enters the filter through the central cylinder and the water flows out through the disc filters. When the filter is clogged the discs rotate and the filter is flushed with high pressure nozzles. The reject water is transported away from the disc filter in a separate piping system. In normal operation the disc filter is approximately 60% submerged and the head loss across the filter media varies between 50 and 200 mm. The maximum allowable head loss with the filter in operation is 300 mm. Backwash and rotation can be continuous or controlled by an automatic level control system. The modular filter panels consist of woven polyester filter media which is held within a stainless steel frame. The structure of the disc filter is as standard manufactured of stainless steel.

The setup used here contains only one filter disc with a filter mesh of 10 µm. The capacity of the filter is approximately 20 m³/h but could be increased by adding more discs, however, during the project period ca. 3 m^3/h were pumped though the system.



A HSF2108-2F with an optional inlet channel for installation in a concrete basin. The inlet channel serves also as emergency by-pass weir.

Figure 3: Typical disc Hydrotech filter.

The stormwater is pumped from the separate sewer when the water level in the sewer increases due to runoff, and is subjected to online measurement of flow and water quality (turbidity and electrical conductivity) by installed measuring devices. There is also a possibility to sample for laboratory analysis. Once the water has passed the measurement devices it flows into two tanks, where there is a possibility to add polymer. Mixers are installed in the tanks, which ensure that the water is always completely mixed. After the tanks the water enters the filter, where it is filtrated through the disc filter mesh. The treated water is then discharged into the receiving water Bagsværd Lake whereas the reject water is discharged back to the sewer system where it is led towards the WWTP. Figure 4 shows how the road runoff from the Aldershvilevej Catchment is transported to the filter with a pump.

Green polymers

Hydrex^{TM} 6864 from Veolia Water is a modified (cationized) industrial non-genetically modified organism (GMO) potato-based product with enhanced flocculation properties. The product has according to the producer a friendly environmental profile with effect or inhibitory concentrations (EC/IC50) for 50% of the aquatic population (fish, crustacean, and algae) above 100 mg/L. According to the material safety data sheet it is biodegradable and without impurities of heavy metals. It has been tested in several Hydrotech pilots such as tertiary treatment of moving bed biofilm reactor (MBBR) and municipal effluents from WWTPs. It will be predominantly be present in the rejected water from the Hydrotech disc filter. Within this project the green polymer is mixed with potable water and dosed as 20-40 mg/L.

Sampling

Inlet and outlet samples were collected using flow activated, event based, sampling (100 mL/sub-sample) with two Hach Lange Bühler 1029 autosamplers fitted each with 24 400-mL plastic bottles (acid washed). For nine events all sample-filled bottle were analysed individually, whereas for three events all bottles were pooled. Samples were collected and analysed within 24 hours, and afterwards refrigerated at 4 ºC if needed.

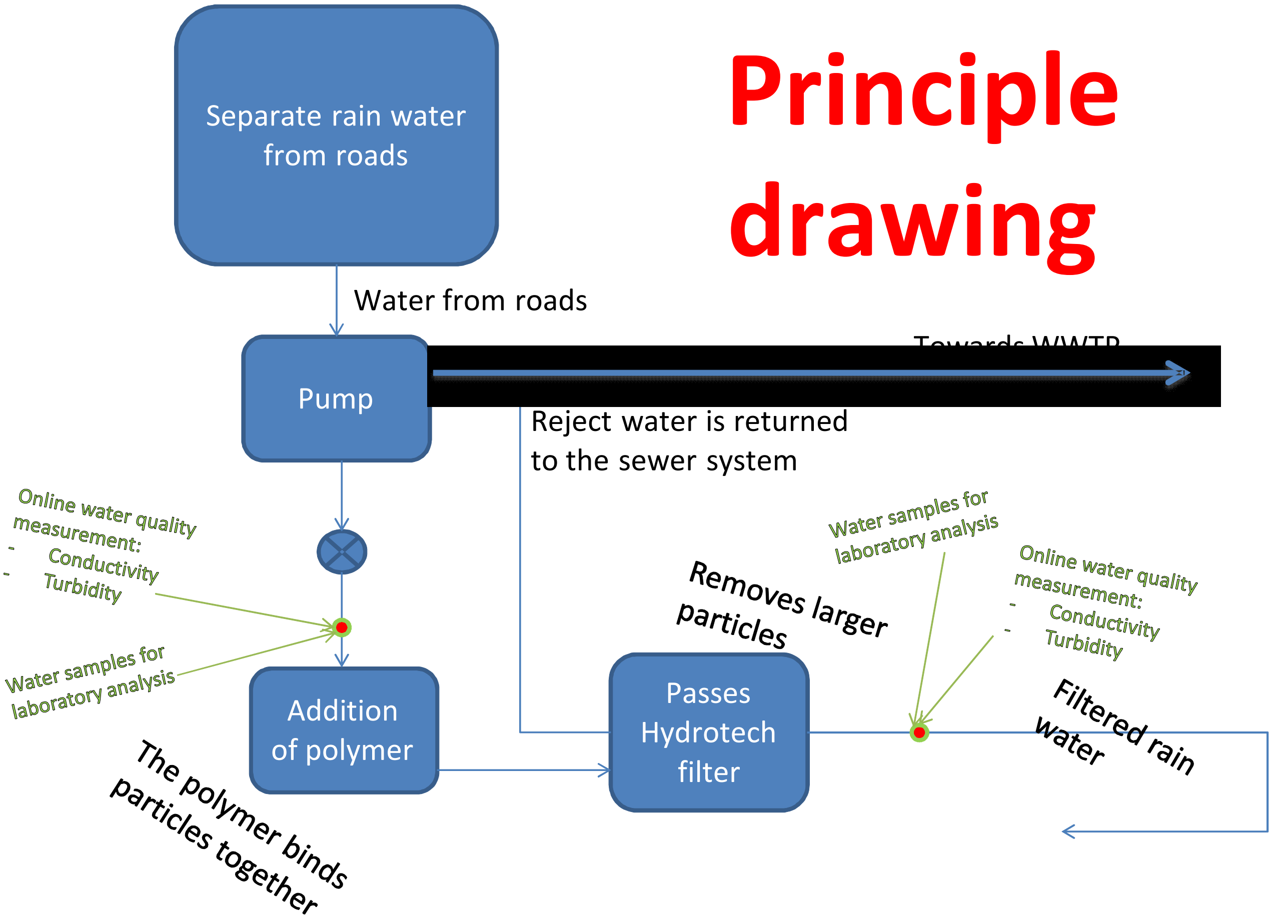


Figure 4: Principle drawing of the system setup.

Particle analyses

TSS were analysed in duplicates though a gravimetric analysis using a glass fibre filter (0.7 µm) according to Danish Standard DS/EN 872:2005, and reported in mg/L. The turbidity was measured in triplicates using a handheld turbidimeter (WTW Turb 430 IR) with an infrared LED light source with a wavelength of 860 nm, and reported in Formazin Nephelometric Units (FNU). A Coulter Counter, Multisizer II, was used for the particle size distribution in the micrometer range (2-43 µm) using the "Coulter principle" (changes in electrical resistance), and reports no. of particles/L. A Malvern Zetasizer Nano ZS operating at 633 nm was used for particle size distribution of the nano particles (< 1.2 µm). Both counts were done in triplicates. The Zetasizer was also used to determine the zeta potential, i.e., the charge attraction or repulsion between particles.

Results and discussion

The sampling was conducted from October 2012 to august 2013, during an unusually cold winter and a notably dry spring.

Particulate pollutants

Particle pollution measured both as TSS and turbidity in seven events from October (10th) 2012 until May (8th) 2013 showed a linear relationship which also has been observed previously in other studies (e.g. Pfannkuche and Schmidt, 2003; Métadier and Bertrand-Krajewski, 2012).

Variation between events were two orders of magnitude where the rain events during the autumn where low in both TSS and turbidity, but the beginning of the de-icing season (31st Oct, 2012) yielded high event mean concentrations (EMCs) for TSS in both in- and outlet, Table 1, caused by the use of salt (NaCl) observed on the road and bike paths in the 31st of October 2012, as well as the seasonal first flush in April of 2013. The intra-event variability was also often observed to range from 10-200 mg/L or FNU in the inlet, and 5-100 mg/L or FNU in the outlet. Site to site and event to event variability is though known and TSS ranging from 1-36,200 mg/L has been documented (Makepeace et al., 1995), whereas Danish data are recorded for TSS between 0.5 and 5,700 mg/L (Ledin et al., 2004).

Table 1 Particle pollution in the inlet (untreated) stormwater

	TSS (mg/L)	Turbidity (FNU)
	Inlet	Inlet
Min	5	7
Max	659* (231)	226
Average	97* (89)	61
Median	87* (86)	20

* Including the high ECM for the first seasonal road de-icing (31st Oct 2012)

The average TSS concentration and turbidity measurement were 97 mg/L (89 if excluding the de-icing event) and 61 FNU, and stormwater runoff from this catchment is therefore not heavily polluted compared to other studies of road/highway stormwater quality (compare with e.g. Makepeace et al., 1997).

Particle size distributions and characteristics

Two events with low TSS and turbidity, and the de-icing event, all had a vast majority (95%) of their particle pollution present as < 10 µm based on the particle size distribution (2-43 µm). Hence, even if the salt yielded an increase of the particle fraction larger than 0.7 µm, the average size was still small. It has also been found in another study highway runoff that 90% of the particles (2-1000 µm) were below 10 µm in size, and that the medians were in the range 2.7-7.1 µm (Li et al., 2006). Based on these findings the used filtration technology with a 10 µm mesh is insufficient for events with a large fraction of small particles, unless a coagulant and/or flocculent is added.

The colloids had a size range around 100 nm (Nielsen et al., 2013), and the measured zeta potential showed they were negatively charged on the (e.g. consisting of humic acids, and clay minerals) and, thus, ideal to be destabilised (agglomerated) with a cationic coagulant and/or flocculent.

Removal efficiencies

The disc filter technology on its own removes on average 48% of the TSS and 20% of the turbidity, based on comparing inlet and outlet values, Table 2. Especially the cold season events were low in the removal which may be explained by that fact that de-icing salts may contain anti-coagulants (Zhao et al., 2010), which may have destabilized the particle pollution. In another Danish study the same filter technology located at another site with a separate storm sewer (Pedersen, 2010) found a removal efficiently of 50-60%, but a direct comparison is hampered by the large difference of samples analysed in the two studies, as Pedersen (2010) only reported one inlet concentrations, and two outlet values.

For the combination of pre-flocculation followed by disc filtration it was found that both the TSS and turbidity removal increased which can be compared with the study by Petersen (2010) where commercially available coagulant (PAX-XL60, 3 mg Al/L) and flocculent (NOVUS CE2688E, 1 mg/L) were used in order to yield an 80-90% removal of TSS.

Hence, the addition of flocculation prior to the disc filter substantially increased the TSS removal on average from 48 to 79% and the turbidity removal from 20 to 73%, but it should also be pointed out that the flocculation was conducted during the warm season, where the removal efficiency is normally higher than in the cold season.

Table 2 Removal efficiencies for TSS and turbidity from this study and Pedersen (2010)

Removal percentages (%)		TSS	No. of samples (inlet + outlet)	Turbidity	No. of samples (inlet + outlet)
Disc filter	1)	48	66+106	20	111+151
Disc filter and green flocculent	1)	79	3+3	73	49+73
Disc filter	2)	50-60	1+2	-	-
Disc filter and commercial coagulant + flocculent	2)	80-90	1+2	-	-

1) This study; 2) Pedersen, 2010; Not analyzed: - ; no. of inlet samples + no. of outlet samples

Although the average TSS removal efficiently for the disc filter was 48%, Table 2, the efficiencies for the six individual events with both inlet and outlet samples ranged from no removal to 59%. Figure 5 show that the disc filter technology improves with increased concentrations. Higher pollutant concentrations yield higher removal efficiencies and events with low EMCs, i.e. < 10 mg/L or FNU, showed no statistical difference ($p < 0.05$; Graphpad prism) between the inlet and outlet concentration, and for one event even a somewhat higher concentration in the outlet than in the inlet due to previous accumulation. In two of the three events with the lowest removal efficiencies it had been found that the particle pollution mainly was < 10 µm, see above, hence, merely physical filtration with 10 µm were inadequate. For further evaluation of the treatment efficiencies, loads (concentration × flow) should be calculated.

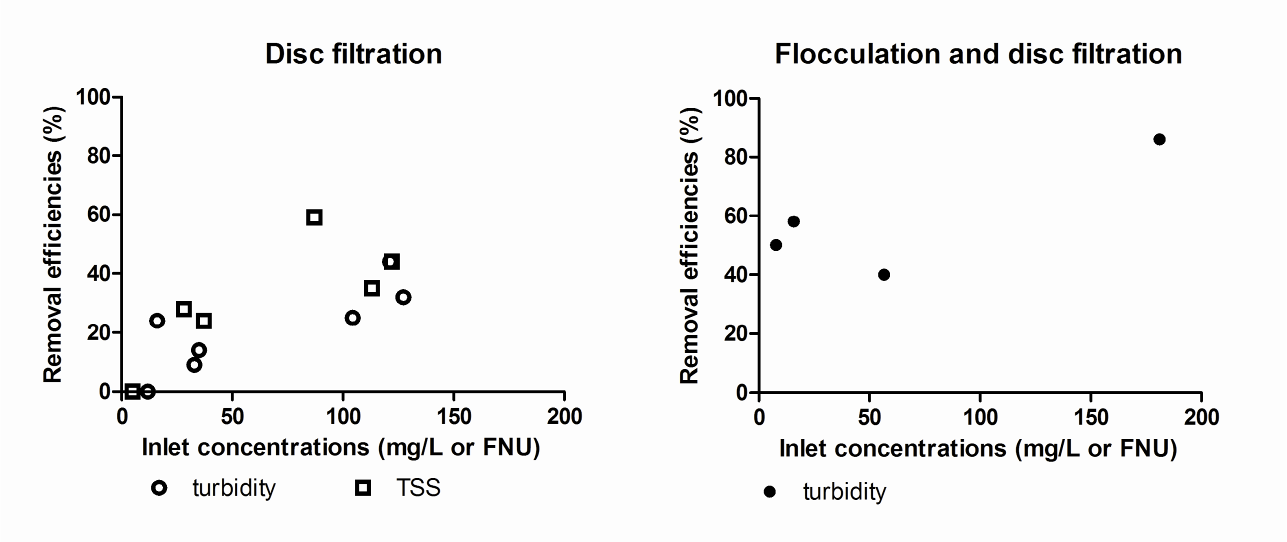


Figure 5 Removal efficiency relative to the inlet (untreated stormwater) concentrations for disc filtration (left) and flocculation and disc filtration (right)

The average effluent concentrations (treated stormwater) for disc filtration during eight events were 44 mg TSS/L and 45 FNU turbidity, whereas for flocculation in combination with filtration (four events) 18 mg TSS/L and 17 FNU turbidity, respectively.

Perspectives

The disc filtration technology can be used for stormwater treatment but combining it with pre-flocculation increases the removal efficiencies for particle pollution. As no emission limit values exist for stormwater in Denmark, the emission limits for municipal WWTPs (20-35 mg TSS/L; pers. comm..) can be used in lieu of these, and here the disc filter on its own could did not meet these criteria whereas for flocculation and disc filtration the criteria were met in the sampled and analysed events.

Due to the low hydraulic loadings (ca. 3 m^3/h) it cannot here be forecast how the removal efficiencies would change if instead 20 m^3/h was pumped through the system. As the stormwater in the Alderhvilevej Catchment is not highly contaminated with particle pollution it would be relevant to subject the treatment system to runoff from a more trafficked road with a larger pollution loading.

Generally, it took 1 hour from the start of the rain until the stormwater in the sewer rose and the pump started, and the sampling were performed during the first two hours of pumping. Hence, rain events with long durations (>3 h) were not sampled throughout the whole event, so nothing can be concluded on the overall treatment efficiencies for these events. Therefore, online measurement with frequent data logging is an excellent supplement to assess the events with long durations.

Decoupling of road runoff from the combined sewer system as done in the Aldershvilevej Catchment and discharging it into Bagsværd Lake have been found to potentially reduce the number of release nodes (floodings) by 11%. If the roof runoff also were decoupled from the combined system as much as 58% of the release nodes would be mitigated (Moghadas, 2013). However, the pollutant combinations in road and roof runoff are different (Makepeace et al., 1995; Ledin et al., 2004) and other pre-treatments such as activated carbon, pH adjustment etc could be necessary.

Conclusions

The Alderhvilevej Catchment is not highly polluted with respect to particle pollution.

The small particle size distribution (95% < 10 μm) and colloid negative surface charge encourage the use of the cationic flocculent.

The filter technology removed about 50% of the TSS and 20% of the turbidity, but the removal efficiencies were subjected to influence of the ambient temperature, potentially de-icier and inlet pollutant concentrations.

Application of the green polymer significantly increased the particle pollution removal.

The green polymer were equally efficient as a set of commercial coagulant/flocculent for TSS removal.

Acknowledgements

The Foundation for Development of Technology in the Danish Water Sector (VTU-Fonden) is acknowledge for funding the DEMFIL project and the authors would like to thank the DTU MSc students Andreas L. Brock and Jörg Schullehner for their assistance with the sampling.

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