Removal of stormwater particulates by disc filter technology

Élimination des particules des eaux pluviales par une technologie de filtre à disques

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RÉSUMÉ

Au Danemark, la tendance est de déconnecter l'eau de ruissellement du réseau des eaux usées et d'installer si nécessaire un traitement local utilisant la meilleure technologie disponible. L'objectif de cet article est d'évaluer une technologie de filtration rapide pour le traitement des particules dans les eaux de ruissellement en portant particulièrement attention aux colloïdes et aux nanoparticules.

La durée du projet est caractérisée par 8.5% de pluie avec une moyenne de 2.9 mm/jour. Pour trois périodes de pluie, 95% des particules sont estimés avoir un diamètre de <10 µm. Les nanoparticules (0.01-1.2 µm) sont ionisées et ont un diamètre autour de 100 µm.

La filtration des particules à 10 µm est insuffisante pour éliminer les particules fines identifiées dans ce projet. La coagulation avec un coagulant cationique suivie d'une floculation sont suggérées pour l'amélioration du procédé de traitement des eaux de ruissellement

ABSTRACT

The trend in the Danish society is toward disconnection of stormwater from the combined sewers and, where needed, local treatment using the best available technologies (BAT). The aim here was to assess a fast filtration technology for removal of particulate matter in stormwater with an emphasis on colloidal and nanosized particles.

During the project period it rained 8.5 % of the time and the average daily rainfall was 2.9 mm/day. Based on three individual storm events it was found that 95 % of the particles were <10 µm. The nanosized particles (0.01-1.2 µm) were found to be anionically charged and in the size-range of 100 nm.

The physical treatment of particle filtration at 10 µm mesh was inadequate to remove the small particles identified in this project. Coagulation with a cationic coagulant and subsequently flocculation is suggested as process improvement technologies.

KEYWORDS

Colloids, Flocculation, Organic matter, Runoff, Suspended solids

1 INTRODUCTION

Combined sewers in Denmark have been flooding increasingly during the last couple of decades, due to growing impervious surfaces and an increased occurrence of heavy rain storms potentially caused by climate change (IPCC, 2007). Danish water utilities and municipalities are thus keen to disconnect stormwater from the combined sewers and, if needed, treat the stormwater runoff locally by using the best available technologies (BAT). Thereby it is expected that flooding problems and combined sewer overflows (CSOs) will be reduced, and that less diluted wastewater will be conveyed to the wastewater treatment plants (WWTPs). Stormwater is commonly retained in wet retention ponds, but the treatment processes of sedimentation and biodegradation are slow in the Danish climate-zone and may yield insufficient treatment for dissolved pollutants. Therefore faster, yet efficient, physical and chemical treatment processes are considered for treating source separated stormwater prior to discharges into urban receiving waters. Some of the priority pollution removed in the cleaning process of stomwater runoff is; particles > 0.45 µm (Hvitved-Jacobsen et. al. 2010; Buffle et. al. 1995; Gustafsson et. al. 1990) and organic compounds as hydrocarbons in the form of polycyclic aromatic hydrocarbons (PAH's) (Brown et. al. 2006; Eriksson et. al. 2007; Maliszewska-Kordybech 1999) and inorganic compounds in the form of zink (Zn), lead (Pb), cubber (Cu), chrome (Cr), nickel (Ni), sodium (Na), and chlorine (Cl) (Göbel et. al. 2007; Sörme et. al. 2002) adsorbed to the particles.

The pollutants in the stormwater are of physical, chemical and microbial type, ranging from dissolved salts (electric conductivity (EC)), organic summary parameters, dissolved and particulate metals, as well as xenobiotic organic compounds, yielding over 600 measured stormwater pollutants (Eriksson, 2002). Good ecological and chemical status in the receiving waters is one of the goals in the Europe Union (EU) Water Framework Directive (WFD) and the priority substance daughter Directives (EU, 2008, 2012). Some are of the substances are also stormwater pollutants (Eriksson, 2002; Eriksson et al., 2007; Makepeace et al., 1995).

Thus, discharge of stormwater after appropriate treatment should not put the good ecological and chemical status at risk or yield erosion or eutrophication in the receiving surface water. Many pollutants are adsorbed onto particulate matter, settleable solids, suspended solids and colloidal material, and heavy metals, oils, and grease are typically associated with smaller particles (<100 µm) (Walker et al., 1997). Knowing the particulate pollution one can foresee pollutant transport and treatment efficiency based on settling parameters.

The aim of this study was to assess a fast filtration technology for removal of stormwater particulate matter in the smaller size range (0.01 - 40 µm).

2 MATERIALS AND METHODS

The project work was carried out from September 27th to November 22nd 2012, and will serve as a baseline for future studies planned in 2013.

2.1 Catchment and site-specific data

2.1.1 Catchment and test-site

The studied catchment is located in the north-western sub-urban parts of Copenhagen (Denmark). The impervious area is approximately 3.03 km^2 and consists mainly of small roads, driveways and bike and footpaths. Parts of the existing combined sewer system was converted into a separate sewer system in 2009-2010; this was achieved by constructing new stormwater pipes in selected streets and connecting the traffic surfaces to these new pipes. De-icing is a common winter time practice in the area, but street-sweeping is sparse and de-weeding is limited to a few active substances.

The newly constructed stormwater pipes are still connected to the combined system at a downstream location, but this will change once the necessary treatment of the stormwater has been identified. A by-pass is presently led to the test-site yielding a flow of ca. 3 m^3/h. The long-term plan is to discharge the treated stormwater into Bagsvaerd lake, which is 1.22 km^2 (Naturstyrelsen, 2011). The lake has a high recreational value, and is being used as the Danish national rowing centre, by hobby anglers and, despite injunction (which is not recommended), by swimmers.

2.1.2 Sampling and sample handling

Stormwater in the by-pass was sampled by Hach-Lange online automatic sampler (Bühler 1029), based on time-proportional (event 1 and 2) or event-based sampling (event 3) with four 100 mL samples per bottle, flow related. The automatic samplers were placed on top of coolers fitted with cooling elements, which contained 24 acid washed plastic bottles of 400 mL. Samples were collected and placed in a refrigerator at +4°C within 24 h of the sampling.

Rainfall, sampled to determine total deposition, was sampled in a 25 L glass container fitted with a 15 cm funnel and a glass fiber screen to keep leaf litter, insects and other debris out. The rainfall sampling was carried out for 56 consecutive days including the days where stormwater sampling took place. The glass container was encased in a dark plastic container fitted with polystyrene-foam packaging peanuts, while the sampling took place.

Reject water from the filter was grab-sampled during rinsing cycles of the filter in connection with event 2. The rinsing cycle was carried out using treated stormwater for filter-flushing of clogging materials. The rinsing cycle is started automatically based on the head loss over the filter.

2.1.3 Treatment technology and principle of treatment

A disc filter from Veolia Hydrotech AB, model 1702-1 with one steel disc with a woven polyester filter mesh of 10 µm on both sides, was used for treatment of the stormwater. The tank contains about 2.5 m^3 of water, and the filter disc was partially (60 %) submerged (Hydrotech, 2012). Hence, the principle for the technology is physical filtration of particulate matter ≥ 10 µm.

2.2 Physical and particle analyses

All analyses followed in-house standard methods and Danish standard methods, and instrument were equipped with logbooks where measurement results of reference standards are recorded.

2.2.1 Gravimetric analyses

Total suspended solids (TSS) and volatile suspended solids (VSS) were analyzed following Dansk Standard (2005) using binder-free, borosilicate glass fiber filters with a pore size of 0.7 µm.

2.2.2 Particle counting

The turbidity was measured using a WTW turbidity meter (Turb® 430 IR/Turb® 430 T) as nephelometric measurements at 90° scattered light. A Coulter Counter, Multisizer II, was used to count the number of particles in predefined size ranges (2-43 µm) based on the principle of detectable changes in electrical impedance produced by non-conductive suspended particles in an isotonic solution. Triplicate 200 µL thoroughly mixed aliquot-samples were suspended into a 20 mL isotonic solution and counted three times each. A Malvern Zetasizer Nano ZS instrument with a He-Ne laser at 633 nm was used to assess the nano- and colloidal particle size distributions and zeta potential. Samples were filtered by binder-free borosilicate glass fiber filters with a pore size of 1.2 µm. The temperature was set to 25 ºC and water with a reflective index (RI) of 1.330 was used as dispersant.

2.2.3 Electrode analyses

Both pH and electric conductivity were measured using electrodes.

2.3 Calculation methods

Calculations of particle size distribution (PSD) = $\frac{total\ number\ of\ particles\ in\ a\ certain\ size\ range}{total\ number\ of\ particles\ (2-40\ \mu m)}$ were adapted from Li et al. (2006) whereas statistical tests (t-test, f-test and ANOVA) were conducted in Microsoft Excel.

3 RESULTS AND DISCUSSION

3.1 Rain events and run-off

During the project period in September to November it rained 8.5 % of the time. The average daily rainfall recorded at a nearby gauge (DMI, 2012) during the sampling period was 2.9 mm/day, ranging from dry weather (0 mm/day) to one event of 48 mm, Figure **1**. The three storm events were sampled on Oct 10th, Oct 13th and Oct 30th 2012 and included 3.6, 17, and 3.6 mm rainfall.

The total rainfall sampled corresponded to 2.2 mm/day, and hence ca. 0.7 mm/day were lost to evaporation, which fits with what has previously been observed in Denmark (0.6 mm/event according to LIFE-TREASURE, 2007). The calculations of the catchment size combined with evaporation losses suggests that the 2.7 mm rainfall per day is required to generate stormwater runoff, within the October's temperature range.

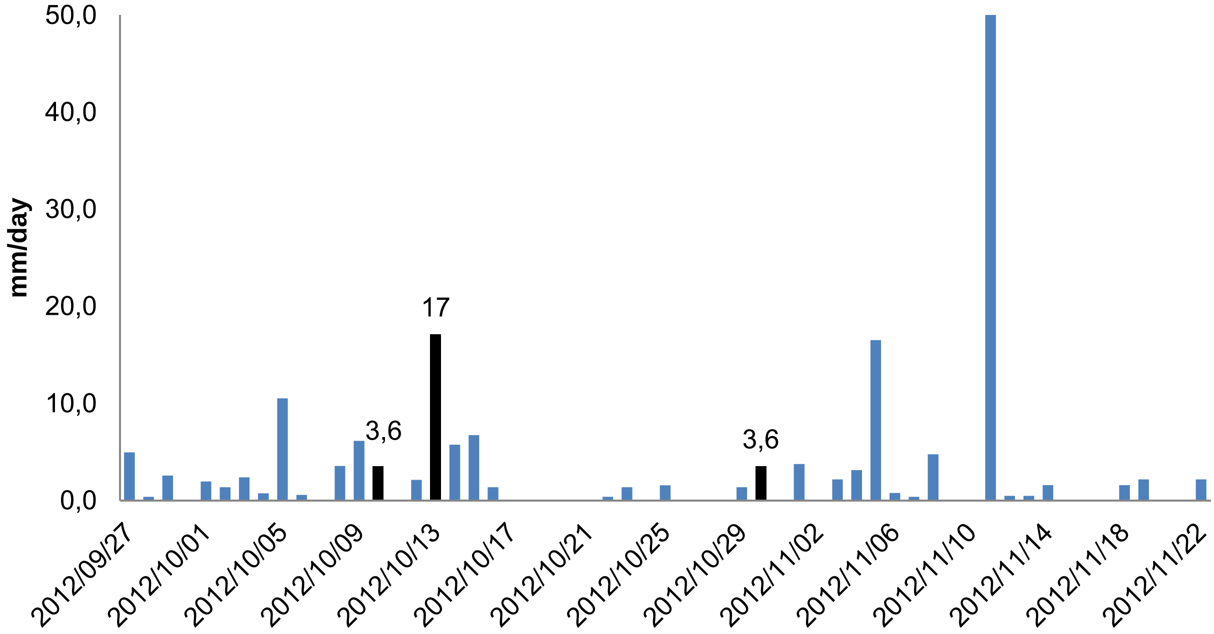

Figure 1: Average daily rainfall in mm/day over the sample collection period. The black events were collected and measured.

3.2 Turbidity and particulate matter

3.2.1 *Turbidity and suspended solids*

The first two stormwater events in early October had a low content of particulate matter, Table 1. The 3rd event occurred after the first frost has set in and thus also contains salts intended for de-icing, as indicated by a high EC, Table 2. The low pollution level is noteworthy as the littering in the surrounding gutters due to the falling leaves was substantial. But, the deposition collected during 1.5 months had a turbidity <1 NTU, thus the higher turbidity noted in the runoff is directly connected to the surfaces from which the rainfall generates stormwater runoff.

Table 1: Event mean concentrations (EMC) measured in three runoff events, deposition and reject water. Inlet = unclean stormwater before entering the disk filter, Outlet = cleaned water after cleaning in the disk filter. *Single sample representing the total deposition during 56 days; DL = detection level; ND = not detected.

	Turbidity (NTU)		TSS (mg/L)		VSS (mg/L)	
	Inlet	*Outlet*	*Inlet*	*Outlet*	*Inlet*	*Outlet*
Event 1	12	12	<DL	28	<DL	25
Event 2	16	12	<DL	37	<DL	26
Event 3	33	30	659	623	455	398
Deposition*	0.81		ND		ND	
Reject water event 2		195		352		272

Where the ratio could be calculated, VSS contributed with 74 % (63-89 %) of the TSS, suggesting that the majority of the particulate matter is of organic origin.

For event 1 and 2 no apparent treatment could be calculated as the inlet values were below the detection limit (DL), and the outlet concentrations were higher presumably as the hydraulic setting of the in- and outlet sampling were non-calibrated. Hence, a tracer test for determination of accurate hydraulic retention time (HRT) is a relevant and required activity. The reject water should only compose of a minor part of the flow (<3 % according to the manufacturer), and this concentration effect can be seen as the reject water in event 2 had a substantially higher pollution content than both the influent and the treated effluent. For event 3 the average removal efficiencies of the filter were 9 % for turbidity, 5 % for TSS and 12 % for VSS, hence, inadequate for being BAT, but relates to the stormwater particulate composition as described in the following sections.

3.2.2 pH and electrical conductivity

Stormwater normally has a pH in the range 3.9-9.8 (Makepeace et al., 1995; Eriksson, 2002) whereas rainwater pH normally is in the range 3.99-4.88 (Willey et al., 1988). Here, the collected rainfall is notably acidic, Table 2, whereas the stormwater runoff has near neutral pHs. The inlet pH and EC is not statistically different from the outlet pH and EC, which confirms that the filter technology is not expected to have any effect on these two parameters. As can be seen for EC, Table 2, event 3 has a higher salt content than events 1 and 2, which is to be expected with de-icing activities observed in the catchment.

Table 2: pH and electrical conductivity (EC) measured in three runoff events, the deposition and reject water from event 2. Inlet = unclean stormwater before entering the disk filter, Outlet = cleaned water after cleaning in the disk filter. ND = not detected.

	pH		EC (µS/cm)	
	Inlet	*Outlet*	*Inlet*	*Outlet*
Event 1	6.7	6.4	64	60
Event 2	7.0	7.1	61	52
Event 3	6.5	6.6	1166	1281
Deposition	3.5		91	
Reject water event 2		ND		40

3.2.3 Particulate matter

The total particle (2-40 µm) concentration ranged from 3.6×10^7 to 7.2×10^7 particles/L in the inlet samples and 6.1×10^7 to 20×10^7 particles/L in the outlet samples, whereas the reject water had 78×10^7 particles/L. Based on the total particle concentrations no statistical difference could be observed between the inlet and outlet samples, hence no apparent treatment of 2-40 µm particles was observed. The PSD for the inlet, outlet, reject and deposition water samples showed that the 100 %-mass was reached for inlet sample at 19 µm (10-20), outlet sample at 13 µm (12-14), reject water sample at 19 µm and deposition water sample at 5.8 µm. The 50 %-mass was reached for inlet at 2.5 µm (2.4-2.6), outlet at 2.7 µm (2.6-2.7), and reject water at 2.6 µm as well as deposition at 2.4 µm. Hence, the vast majority (95 %) of the particles were below 10 µm as seen in Figure 2. The average particles size in the inlet is larger than in the outlet, but the difference is not statistically significant. Hence, the used filter technology with a 10 µm mesh would only be suitable if the particle size range were increased, e.g. though coagulation and flocculation.

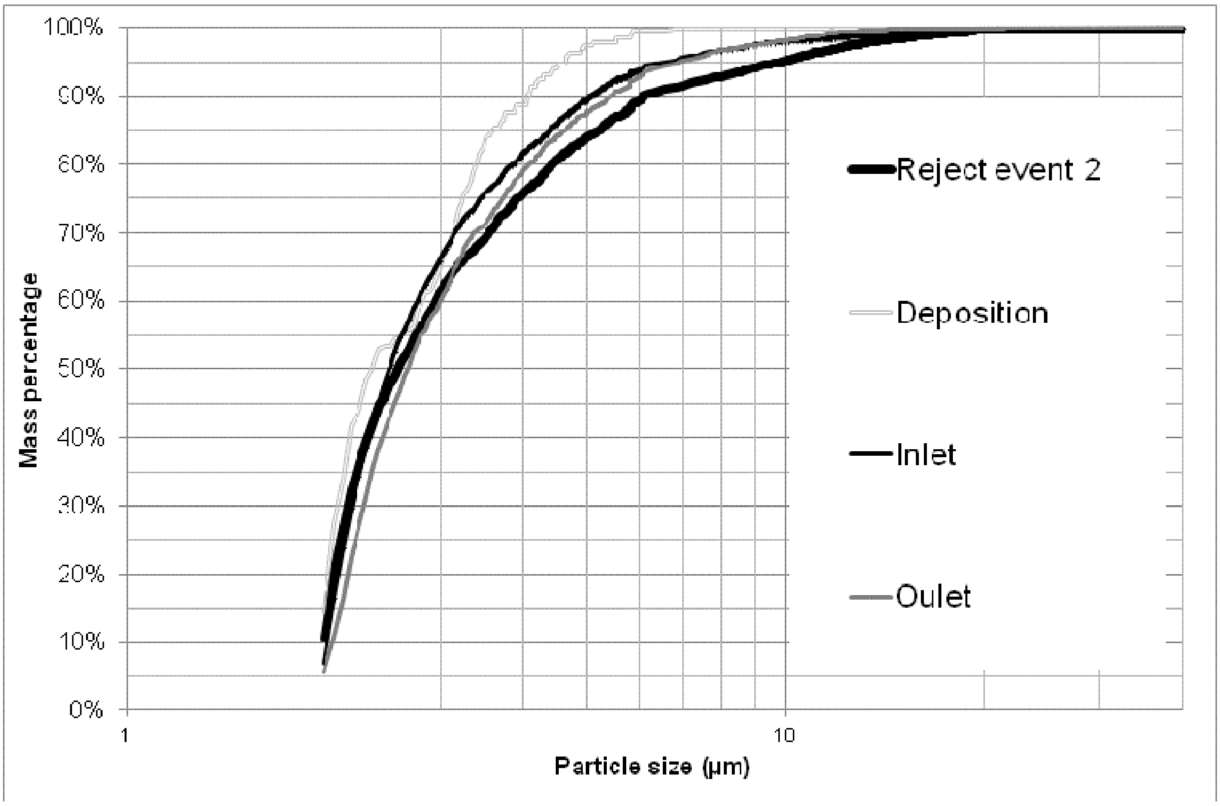

Figure 2: Particle size distribution (2-40 µm). Inlet = unclean stormwater before entering the disk filter, Outlet = cleaned water after cleaning in the disk filter.

Li et al. (2006) also reported that 90 % of the particles (2-1000 µm) were <10 µm in 172 highway runoff samples, and that median values were between 2.72-7.15 µm. Previously, 80 % were noted to be < 25 µm (Randall, 1982). Nanoparticles are per definition in the nanosized range, and hence, not included in the TSS measurement which target micrometer sized particles.

The above measurements show the particles in the range 2-40 µm which are also the particles which are represented in the TSS measurements (>0.7 µm) in Table 1. Here particles less than 1.6 µm are not considered as suspended solid and is therefore not measured.

The Coulter counter principle is a well-known methodology, but confined to laboratory measurement. In situ measurement of PSD using laser diffraction (Laser In Situ Scattering and Transmission, LISST) (Brown et al., 2012) is a new tool, which could with benefit be used in the field.

Measurements on the ZetaSizer showed nano-sized particles present in all the collected samples, Figure **3**. The particle sizes measured were from 86.3 to 112 nm in the inlet samples, and from 90.0 to 108 nm in the outlet samples. The reject water gave a size of 90.1 nm and the rainwater of 99.5 nm.

No statistical significant different is seen between the inlet and the outlet of the particle size range. The particles in the rainwater were having the same size as the particles in the inlet and outlet water. This indicates that the stormwater are not accumulating any smaller particles on its way through the catchment. It was expected to see larger particles in the reject water, but the size of 90.1 nm could indicate that the larger particles are broken into smaller particles during the high pressure cleaning cycle.

Out from the measurements on the ZetaSizer it cannot be concluded that smaller particles are not to be found in the collected samples. As the ZetaSizer works with dynamic light scattering techniques, larger particles could scatter smaller particles, which were not detected. Even that the scattering of the smaller particles could occur, the measurements shows that the minority of the particles found in the collected water samples were having a size around 100 nm.

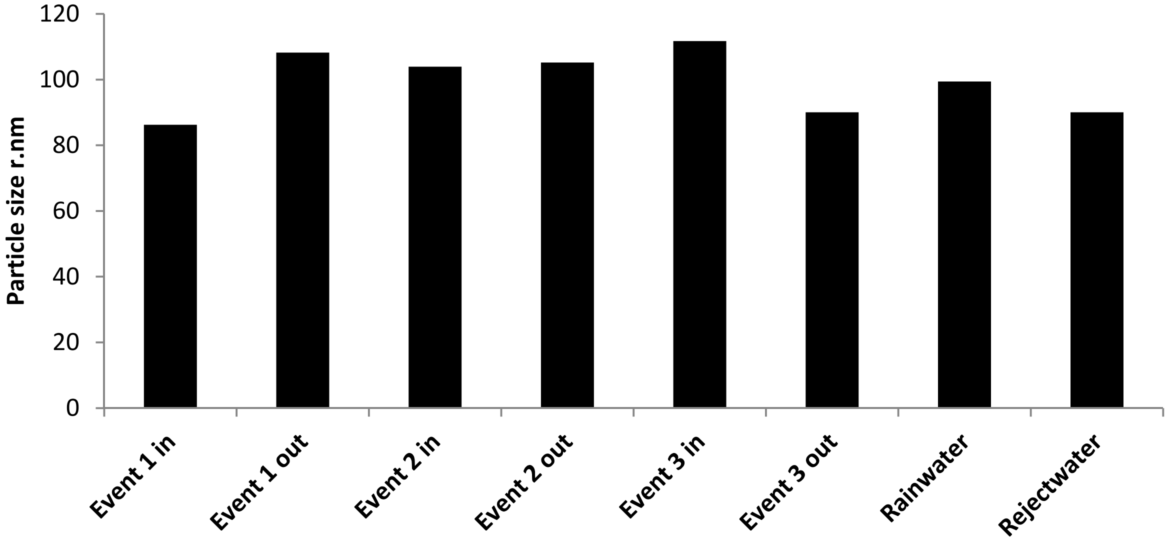

Figure 3: Size of nanoparticles found in the untreated stormwater, treated stormwater, the reject water and the collected rainwater. (nano-PSD) (1-1000 nm).

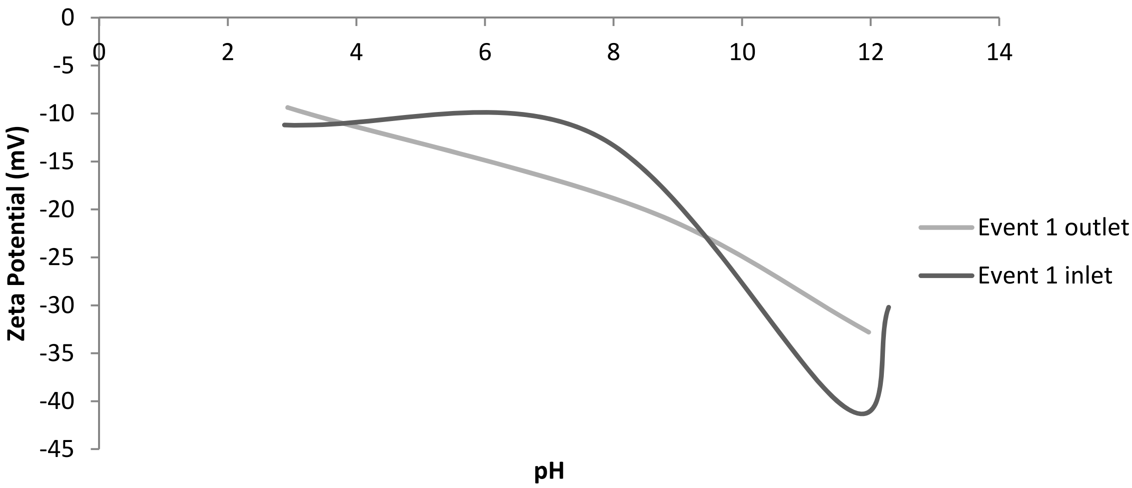

Figure 4: Nanoparticle Zeta Potential for event 1 inlet and outlet.

To determine the stability of the particles, measured on the Zetasizer, zeta potential measurements have been made on the inlet and outlet samples for event 1, Figure **4**. Zeta potential is used to describe the electrical potential interfacial layer between a solid and a liquid in an aqueous solution. If the zeta potential is between -30 mV and 30 mV the particle is considered unstable, given that the interfacial layer are not strong enough to separate particles and they will attract each other. The zeta potential is also a useful indicator of surface charges of the particles (Cho et al., 2012).

The measurements shows that the particles found in the samples collected are having a negative surface tension, both in the inlet and outlet water, consistent with a composition of organic acids (fulvic and humic acids), clay and sand. It is also seen that the particles are considered stable with pH from 10. However, Aryal et al. showed that the nano-PSD (20-500 nm) in stormwater were susceptible to changes in pH, reflecting potential dissolution of fulvic-organic matter and aggregation of humic-organic matter (Aryal et al., 2012). So, the nanosized particles here are thought to be susceptible to cationic coagulants. Other treatments that may be relevant, but not explored here, is membrane filtration and/or ultrafiltration. Consequently, the proposed coagulation/flocculation as alternative but not the only one. Future work should also cover investment and operation/maintenance costs.

4 CONCLUSIONS

Particle size distribution showed that about 95 % of the particles were <10 µm. The nanosized particles were found to be in the range of 100 nm, and anionic charged.

The physical treatment paradigm for merely particle filtration at 10 µm is not sufficient to remove the small particles identified in this project.

The consequences of not removing these small particles are jet unknown, but a side effect of not removing them could be transportation of pollutants adsorbed to the particles, thought the treatment facilities and into surface water.

Hence, coagulation and subsequently flocculation with a cationic coagulant is suggested as one process to add in order to improve the observed removal efficiency.

5 ACKNOWEDGEMENT

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