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SERVICES ENABLING INNOVATION
IN THE WATER SECTOR

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D21.3 Technical conclusions from testing during site specific development and specifications for final design

Cheng Sun, Inrigo AS, February 2017

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039

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TITLE OF THE REPORT

D21.3: Technical conclusions from testing during site specific development and specifications for final design

SUMMARY

An innovative high rate filtration (HRF) system has been developed and applied for treatment of a combined sewer overflow (CSO) by Inrigo AS from Norway. In the EU-project DESSIN, a container type HRF plant was built to investigate and later demonstrate the treatment efficiency for treatment of CSO. The HRF plant was placed at Hoffselva, Norway, where site specific testing has been performed to give basis for final design. Eleven (11) CSO events were recorded during the testing and demonstration period, so far from September 2015 until May 2016. Test results indicate that HRF solution is a promising technology to reduce emissions of particulate pollutants from CSO. Up to 80% of suspended solids (SS) removal and 75% of chemical oxygen demand (COD) removal were documented during the first flush. The overall removal of SS and COD were about 47% and 56%. Nutrient removal is relatively low because of the major soluble nitrogen and phosphorus compositions in CSO. However, 6.3% total nitrogen (TN) and 15% total phosphorous (TP) were retained together with particles. The HRF system also shows promising treatment efficiency of heavy metals with 48% Al, 48% Zn, 57% Cu, and 31% Cr removed, respectively.

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List of Acronyms and Abbreviations

BOD – Biological Oxygen Demand

COD – Chemical Oxygen Demand

CSO – Combined Sewer Overflow

ESS – Ecosystem Services

HRF – High Rate Filtration

SS – Suspended Solid

TN – Total Nitrogen

TP – Total Phosphorus

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Executive summary

An innovative high rate filtration (HRF) system has been developed and applied for treatment of a combined sewer overflow (CSO) by Inrigo AS from Norway. In the EU-project DESSIN, a container type HRF plant was built to investigate and later demonstrate the treatment efficiency for treatment of CSO. The HRF plant was placed at Hoffselva, Norway, where site specific testing has been performed to give basis for final design. Eleven (11) CSO events were recorded during the testing and demonstration period, so far from September 2015 until May 2016. Test results indicate that HRF solution is a promising technology to reduce emissions of particulate pollutants from CSO. Up to 80% of SS removal and 75% of COD removal were documented during the first flush. The overall removal of SS and COD were about 47% and 56%. Nutrient removal is relatively low because of the major soluble nitrogen and phosphorus compositions in CSO. However, 6.3% TN and 15% TP were retained together with particles. HRF system also shows promising treatment efficiency of heavy metals with 48% Al, 48% Zn, 57% Cu, and 31% Cr removed respectively.

1. Introduction

1.1 About DESSIN work package WP 21

Demonstrating ecosystem services (ESS) enabling innovation in the water sector (DESSIN) is an integrated research project funded by the European Union (EU). Over the course of four years, 21 partners in seven different countries base their work on five demonstration sites across Europe.

DESSIN aims to develop an Ecosystem Services Evaluation Framework, which will enable a standardized evaluation of impacts and benefits from innovations, integrating the environmental, economic and social dimensions to generate additional arguments for market uptake and practical implementation of innovations.

DESSIN is centered on five carefully selected demonstration sites across Europe, which represent the global major water challenges. Hoffselva, located in Oslo, Norway, is one of the five demonstration sites and includes demonstration of high rate filtration (HRF) CSO treatment and ESS evaluation.

In the DESSIN Work Packages WP 21, WP 31 and WP 32, the application of innovative HRF system for enhancement of treatment of combined sewer overflow (CSO) was the focus of interest. In Work Package WP 21, a container type HRF demonstration plant was constructed and investigated on real CSO conditions at Hoffselva.

This report of Work Package WP 2.1 describes the tests conducted by the DESSIN project partner Inrigo AS. After a short background introduction of HRF system developed and applied in wastewater and its practical approaches to CSO treatment, the container type HRF plant is described and the test results are documented and discussed.

1.2 High rate filtration (HRF) in wastewater: a short review

Wastewater treatment in principle is a matter of particle separation. Therefore, it is essential to remove particles as much as possible at acceptable costs in primary step to considerably reduce the organic and particle loading to the following biological steps with benefits in space and energy saving. Although there are many processes that can enhance particle separation from raw wastewater, high rate filtration (HRF) with coarse media turns out to be a proper solution in that filtration rate can be rather high (more than 20 m/h) and the chemical dosage can be relatively low or not necessary. Various synthetic plastic media have been applied in several investigations in the last decade.

Tanaka et al. (1995) investigated a ring-shaped polypropylene net with high porosity (90%) and low specific density (0.93) for filtration of municipal sewage. It was found that the Suspended Solid (SS) and Biological oxygen demand (BOD) removal were 80-90% and 44% at filtration rate of 1000 m/day (41.7 m/h) and dosage of cationic polymer at 2-3 mg/l.

Wessman (1997) investigated floating media filters for primary treatment. When filtration rate is 25 m/h, Pall rings give 80% SS removal at 10 mg Al^{3+}/l and 3 mg/l polymers and 60% SS removal without chemicals. The KMT K1 media did not work well with polymer for big flocs formed and blocked in bed, but 73% SS removal was obtained when no chemical addition.

Lerch (1998) investigated a HRF (20-50 m/h) by a two-stage floating filter set-up consisting of filter I with either Pall rings or KMT K1 carrier or CSIRO star, and filter II with either PP discs, KMT K1, PS balls, or PE fibers. In two stage filters SS removal of 80-85% was achieved at 30 m/h without chemical addition and SS removal up to 90% when dosing 1.5 mg/l polymer. COD reduction of round 60% is reached as well.

However, HRF solutions have not been widely applied for primary treatment in wastewater treatment projects around the world mainly because they are very easy to clog, resulting short filter running time. At the same time, traditional HRF needs high water flow rate to effectively backwash the clogged filter bed. The rate of wash water could be as high as 40% of filtered effluent.

Interception and blocking in pores are the main reasons for filter clogging in coarse media filters. The high blocking potential of large particles results in considerable decrease in available porosity for deposition and water flow. The key to the optimization of HRF with coarse media is to consider the particle size distribution and pore size distribution to find out the proper media and filter bed configuration (Liao Z., 2002)

An innovative HRF system was developed based on special media design and unique/patented operation technology by Inrigo AS. Inrigo is currently approaching this HRF system to handle CSO to minimize waste emissions and thus enhance the ecosystem services during DESSIN project.

2. High rate filtration (HRF) system for CSO

2.1 Combined sewer overflow (CSO)

During storm events, the flow in a combined sewer system can exceed the capacity and, thus, a CSO will occur. During a CSO raw wastewater is discharged to surface water. This wastewater is a mixture of raw sanitary wastewater, raw industrial wastewater, and rainwater. The receiving water will be polluted by dissolved as well as undissolved pollutants. Therefore, a CSO can cause damage to the ecological and biological state of the receiving water thereby causing public health risks. To prevent these negative effects treatment of CSO will be necessary.

Different methods mainly adapted from wastewater primary treatment techniques have been tried and applied for CSO treatment around the world. Some techniques only remove the relatively larger particles and debris, like coarse screens, sieving treatment, and inclined bar screen. While, the advanced treatments such as up-flow lamella clarification with coagulant, Hydrodynamic vortex separation, and Actiflo process need chemical addition to achieve high pollutant removal and stable treatment efficiency.

2.2 HRF system development

A good CSO treatment facility need to be reliable, robust, automatic, sustainable, cost effective, and simple to operate. The facility should reduce pollution streams and must have a small footprint. An HRF system with coarse media has various advantages such as simple operation, high particle removal and less maintenance, which make it to be a promising solution.

Based on many years' experience and confidence in water and wastewater treatment, Inrigo AS together with our partners has improved HRF technology to make it suitable for CSO treatment.

2.2.1 Special designed media

Figure 1 Special designed media

The new HRF system for CSO has special filter media (shown in Figure 1) which are floating in the filter bed. The filter media is designed to have optimal shape to capture debris, BOD and SS with high void ratio. The media material is acid and alkali proof, which enable it to be able to handle various CSO raw water quality.

2.2.2 Simple process design

There is no chemical addition and pre-treatment required for new HRF system developed by Inrigo AS. During the operation, filtration and backwash are switched by a backwash valve that is closed and opened, controlled by inlet water level detection. Filtration water flow is not stopped during backwashing.

The whole system uses less equipment. The motorized equipment are only inlet pumps (no pumps needed if gravity flow is available) and compressor for pneumatic valves. The system is very easy for operation and maintenance as illustrated in Figure 2. During rainfall, CSO raw water comes in from the distribution channel flowing upwards through filtration layer, debris removed on the surface of filter media, and SS and BOD are removed inside of inner media. As filtration continues, and filter media becomes clog, the water level on the influence size rise, when detecting a rise in water level, the high-speed drain valve opens automatically and starts backwash. Filtrated water flows downward by gravity and discharge debris, SS and BOD accumulated in the filter media. The backwash requires only a minute to clean, and no filter media flows out during backwash.

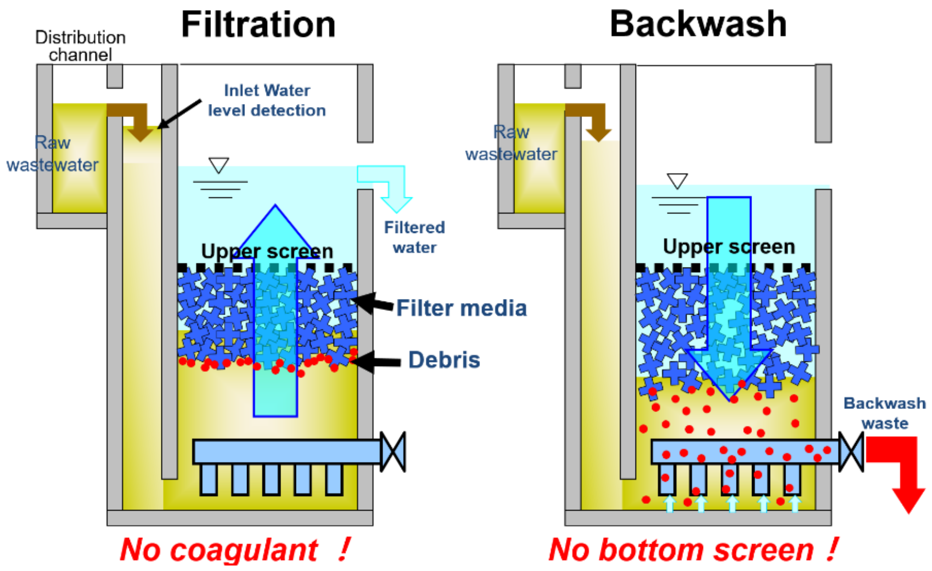


Figure 2 HRF system process diagram

2.2.3 Pilot test results

In the development phase of a new HRF system, a pilot plant was built to investigate the removal efficiency of BOD and SS on different filtration rates. BOD removal achieved 50-80% and SS removal was 50-80% when filtration rate was below 42 m/h (Figure 3 and 4). The BOD removal will drop to 20-30% and SS removed reduced to 40-60% when filtration rate increased to 63 m/h. During all the tests, 100% removal rate is obtained for debris (>1mm), shown in Figure 5. Should be mentioned that these results depend on the wastewater characteristics.

Pilot test results indicated that filtration rate with 42 m/h can achieve efficient BOD and SS removal and is therefore considered as filtration speed of full-scale HRF system for CSO treatment. This filtration rate is also applied for the demonstration plant in Hoffselva.

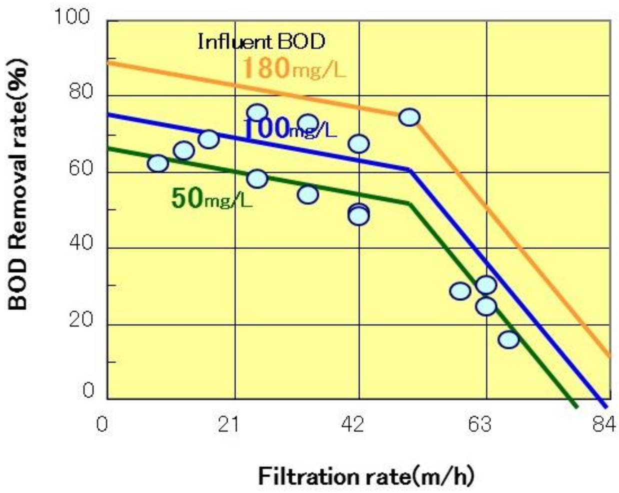


Figure 3 BOD removal on pilot test

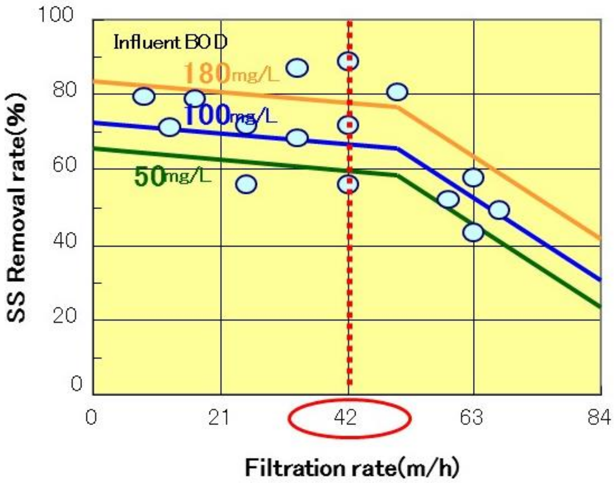
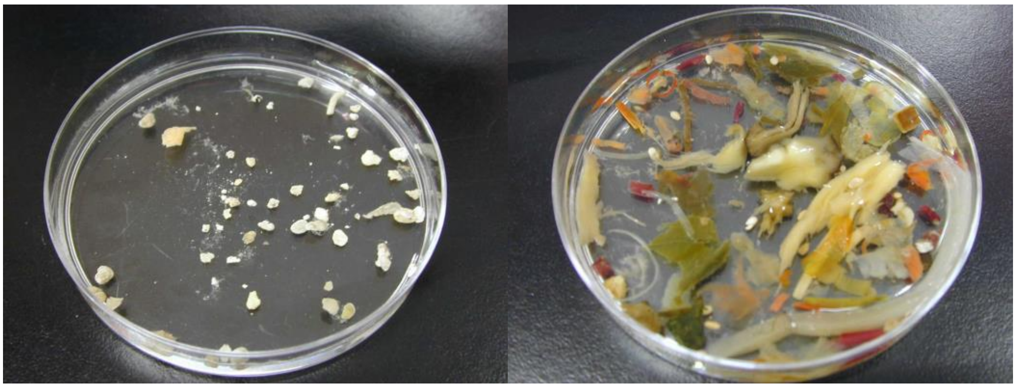


Figure 4 SS removal on pilot test

(a) (b)



(c) (d)

Figure 5 Debris removed from HRF pilot test, (a) grass, leaves, wood; (b) paper; (c) oil balls; (d) raw kitchen waste

3. Demonstration test in Hoffselva, Oslo

3.1 Site description and background

As one of the five demonstration sites in DESSIN project, Hoffselva is a peri-urban catchment with a population of 25 000 inhabitants located in an area of 1427 ha. The site is in the western part of Oslo, the capital of Norway. The sewer network consists of a separate system in the upper part and mainly a combined sewage system in the middle and lower parts. The water quality in Hoffselva is poor due to pollution from 22 combined sewage overflows (CSOs) discharging to the river during rain events.

Figure 6 Hoffselva river in Oslo

However, the Hoffselva river also provides recreational services, which are affected by water quality. Oslo municipality has measured high numbers of bacteria and elevated concentrations of nitrogen and phosphorus in the middle and lower part of the river flowing through the area with combined sewer system.

The Oslo municipality's goal for the watercourse is to have a good biodiversity with reproduction of fish where it is natural and that the sewage water should not be an obstacle for bathing water quality in the river and in the fjord (Vannmiljø, 2012). With the increasing urbanization and the effects of climate change, it is less likely to improve the water quality in the coming years, unless some measures will be taken to improve the water quality. Oslo municipality are looking for a robust and innovative solution for CSO handling.

The on-going EU-project DESSIN aims to improve the water quality by using cost effective innovative local treatment solutions, sustainable mitigation of overloaded sewer systems thereby increasing the value of eco system services. At Hoffselva, DESSIN will demonstrate HRF local treatment solutions for overflow from CSOs. The aim is to improve the water quality and ecosystem services in the catchment.

3.2 Installation of demonstration plant

The HRF demonstration plant was located close to a relatively active CSO at Makrellbekken in Oslo, which discharges into Hoffselva. The major goal in the demonstration plant test was to determine the CSO treatment efficiency of the HRF technology for Norwegian sewer and climate conditions. Next, the results from the HRF demonstration tests on CSO are used as input data for the generation of a model for evaluation of environmental, economic and social effects in and around the receiving water body of the CSO. Further, the results and experiences from the demonstration plant was utilized by Inrigo AS for the development of a full-scale underground (manhole) HRF system for CSO local treatment, with relatively low investment and operational costs.

Figure 7 Container type HRF demonstration plant

The HRF demonstration plant was installed inside two standard 20-inch containers (Figure 7), which were placed beside one of the CSOs along Makrellbekken at Hoffselva area. Figure 8 shows a simplified process diagram of demonstration plant. Water samples were taken at the inlet of the filter and after HRF treatment. The filter capacity is dependent on the filter surface area. New HRF system has a capacity of 42 $m^3/m^2/h$ for CSO treatment. The demonstration plant at Hoffselva has a filter surface area of 0.5 m2, which equals to a capacity of 21 m^3/h.

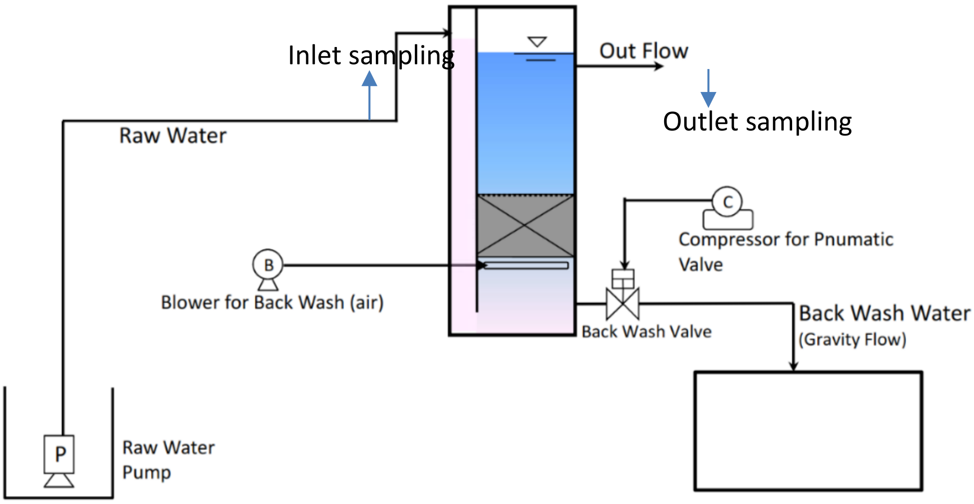


Figure 8 Diagram of demonstration plant in Hoffselva

3.3 CSO sampling and system monitoring

Under normal conditions, the HRF container plant is in standby mode. However, during weather conditions (rain or snow melting) that courses CSO the HRF plant switches to CSO mode with high filtration speed (42 m/h). A level sensor is installed in the intake manhole to monitor the water level. When the water level reaches a set point value (which is considered as CSO water level during rainfall), the plant will switch from the standby mode to CSO mode automatically. Finally, when the water level decreases after raining, the operation mode changes back to stand by.

SS, COD, BOD, E. coli. bacteria, Heavy metals, TN and TP were analysed to document the treatment performance of HRF system. All analyses were performed accordingly to Norwegian national or international standards. The water quality analysis was carried out by a commercial laboratory (Eurofins) or NIVA (Norwegian Institute of water research).

Two inline turbidity sensors are installed for monitoring the particles' concentration of the influent and effluent. The plant is also equipped with two automatic sampling machines, with a capacity to take (24 inlet samples and 24 outlet samples) CSO water samples. A refrigerator is integrated in the automatic sampling machine, so the samples were kept cold at approximately 4°C until the lab analysis where conducted. During the CSO event, the sampling machine starts automatically and takes water samples according to the pre-setting time program, shown in Table 1.

Table 1 Sampling time program for each CSO event

CSO duration	Sampling interval	Sample amount
0 -60 min	5 min	12
60 - 90 min	10 min	3
90 - 150 min	30 min	2
150 - 570 min*	60 min	7

*Total sampling time of each CSO event is 570 minutes because of the limited number of sample bottles (24 bottles) in the refrigerator.

3.4 HRF demonstration results

The HRF demonstration plant at Hoffselva was on duty, ready for CSO treatment since the beginning of September in 2015. It has recorded 11 CSO events until May of 2016. Table 2 lists the date and duration of CSO events in the demonstration period. Some CSO events (1, 7, 11) have very long overflow spilling time up to 31 hours in 2 days, which might course obvious environmental effects on surrounding waterbodies.

Table 2 CSO events during demonstration period at Hoffselva

CSO event	Date	CSO duration (min)
1	17.09.2015 – 18.09.2015	1697
2	11.10.2015	195

3	17.11.2015	267
4	28.11.2015	162
5	04.12.2015	882
6	08.02.2016	96
7	08.02.2016 - 09.02.2016	1092
8	06.04.2016	235
9	29.04.2016 (1)	193
10	29.04.2016 (2)	111
11	30.04.2016 - 01.05.2016	1852

3.4.1 Filtration characteristics of CSO event

The fluctuations of the physical and chemical water quality are of major importance for the design of CSO treatment plants, because the treatment efficiency predominantly depends on the influent water quality of the combined flows (Geiger, 1998).

During long periods of dry weather flow in the sewer, sediment deposition takes place in the network. Dissolved pollutants also attach and accumulate in the deposited sediments. The sediments therefore act as storage facilities for dissolved pollutants (especially heavy metals), which then are released into the sewer flow as the sediments are flushed during a storm event (Skipworth et al., 2000). According to Krebs, et al. (1999) the first flush effect is of major importance for the fluctuations in CSO water quality. The first flush effect denotes the high load of pollution in the overflow water, at the beginning of a storm event.

In the CSO event 1 (17.09.2015 - 18.09.2015 in table 2), a filtration characteristics study of CSO treatment was conducted. Twenty-four (24) samplings were taken both for inlet and outlet (total 48 samples); SS, COD, BOD and E. coli bacteria were analysed for each sample.

Figure 9 and 10 shows the SS and COD values of raw CSO water (inlet) and treated water (outlet). During the CSO event, the raw water SS and COD decreased with time overall trend. However, two high concentration peaks (probably coursed by variations in the rainfall intensity over time) were observed within the first 55 minutes of CSO event. The SS value was above 240 mg/l and COD value was above 140 mg/l for both the peaks. The results clearly indicated that the first flush happened during the first 55 minutes of the CSO event. After the first flush, the sewage water became more diluted, since the pollutants have been flushed out of the sewer network. Therefore, from 55 min into the CSO event the strength of the CSO water lays between the range of untreated wastewater and storm water, depending on the dilution factor caused by the storm water. Average inlet SS and COD were around 50 mg/l and 60 mg/l respectively after the first flush (diluted CSO zone, 515 minutes). In the Figure 9 and 10, the outlet from the HRF had relative stable SS and COD valves through the entire CSO event.

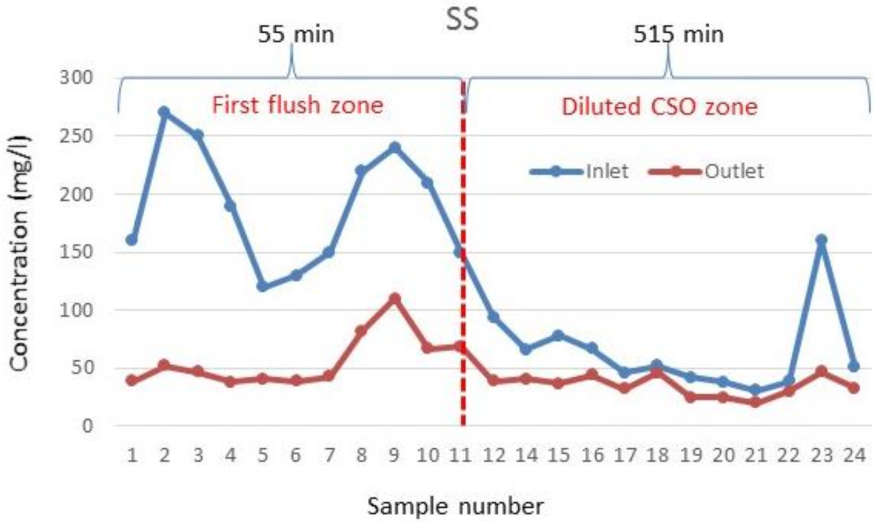


Figure 9 SS concentration of CSO event 1

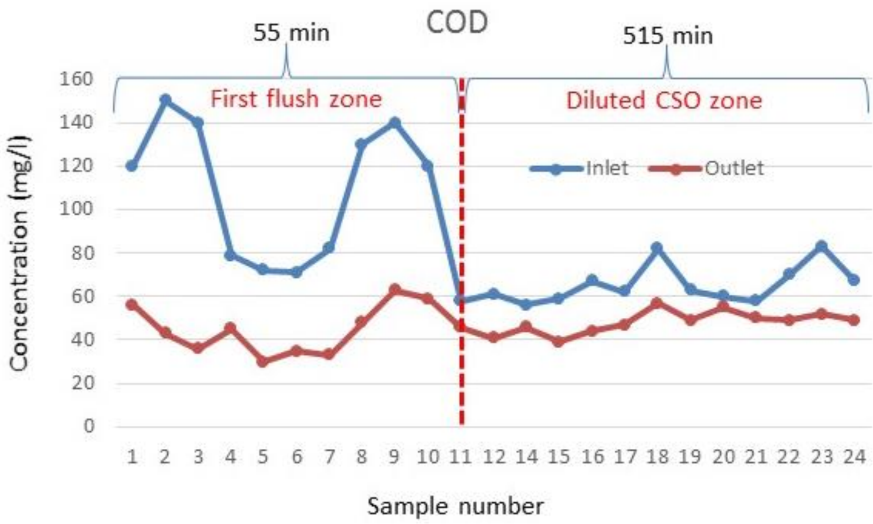


Figure 10 COD concentration of CSO event 1

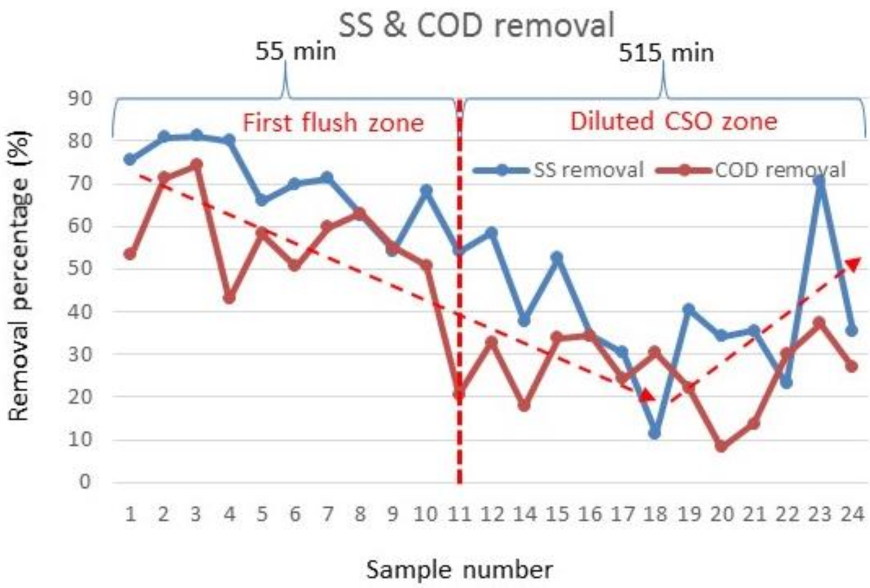


Figure 11 SS and COD removal of CSO event 1

Removal ratio is used to evaluate the removal efficiency of HRF treatment. Figure 11 shows the removal ratio of SS and COD of the CSO event 1. The removal ratio steadily decreased from the first sample until sample point 18 (approx. 400 min) and had a small increase after that. During the first flush (55 minutes), SS and COD consisted of larger particles from the sediments in the combined sewer, which can be easily retained by the filter, resulting in relatively high removal ratios (up to 80% SS and 75% COD). After the first flush, the removal decreased because of the storm water dilution and the change in the particle size distribution towards smaller particle size in the CSO water. The slight increase in removal efficiency after sample point 18 might be coursed by an increased concentration of larger particles from human activities at around lunchtime (samples taken at 11:00 am)

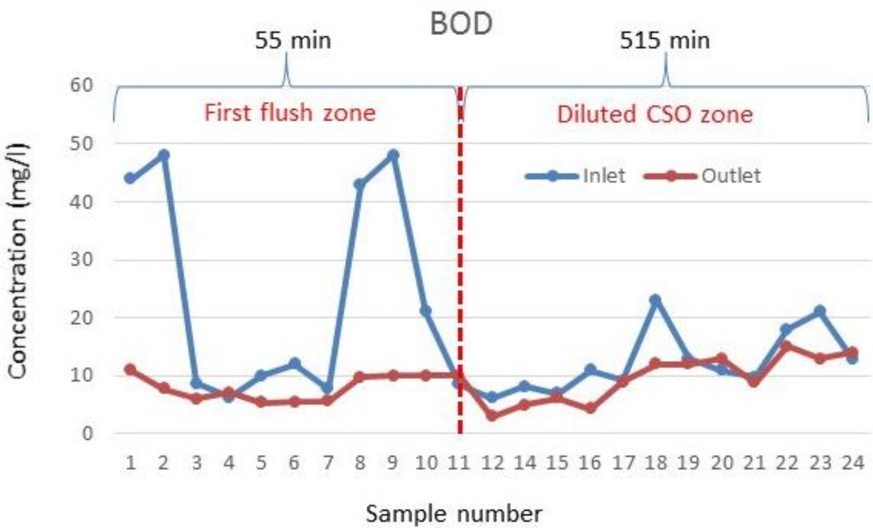


Figure 12 BOD concentration of CSO event 1

Inlet and outlet values for BOD are presented in Figure 12. BOD consists of particulate and soluble fractions. During the first flush, most of the particulate BOD (up to 48 mg/l at the two peaks) was removed by HRF treatment. Lower removal ratios for BOD was observed in the diluted CSO zone, which indicates that the majority of BOD component in the CSO water was soluble.

Bacterial indicator organisms such as total coliforms, faecal coliforms (E. coli.), and faecal streptococci are known to occur in large numbers in both wastewater and storm water. Discharges from CSO are not disinfected, and bacterial standards for recreational activity can be violated during storm events (David Butnd John, 2010). Figure 13 shows the analysis results of E. coli bacteria. The results show that the E. coli concentration is in the same range for inlet and outlet of HRF system. However, bacteria were mainly associated with particles in CSO water, a similar removal ratio as SS should be expected. The test results (Figure 13) with low removal ratio were coursed by sample contaminations during microbiological analysis.

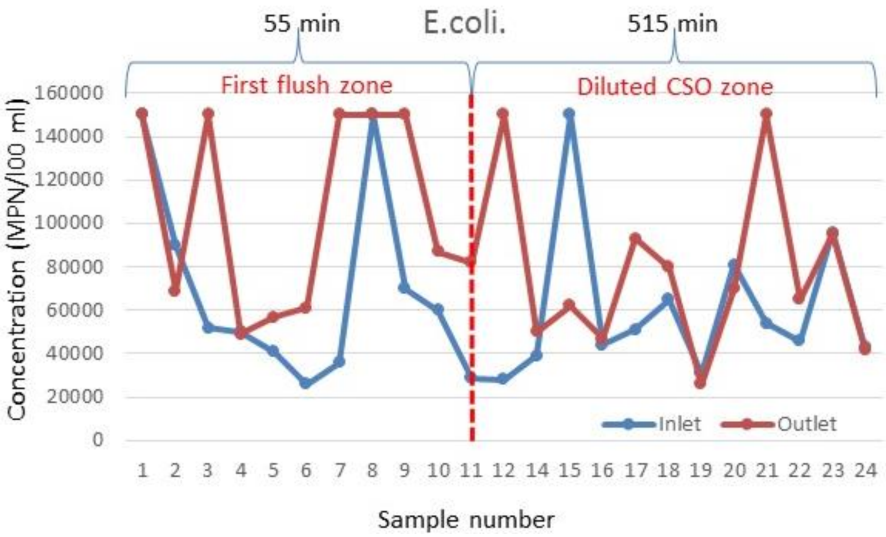


Figure 13 E. coli. concentration of CSO event 1

3.4.2 Online monitoring results

Figure 14 shows the online monitoring result from the turbidity meters. The inlet turbidity variation fits well with the tendency of SS and COD with two peaks in the first flush zone and a small increasing after sampling point 18 in the 570 minutes. However, the turbidity removal reduced to 11% at around 30 min filtration time due to less removal of colloidal particles by clean filter media after backwash. The advantage of online turbidity measurement is continually monitoring the variation of particulate content during the entire CSO event (1697 min).

The frequency of backwash depends on the - particle load from the CSO water. In the beginning of the CSO (first flush), the CSO water tends to be heavily polluted and therefore contain more debris than later in the CSO event. This leads to faster clogging of the filter thereby causing a higher frequency of backwash in the beginning. During the backwash, the inlet CSO water still enters the HRF system. However, it does not pass through the filter. The backwash water is collected in a sludge tank. Figure 15 shows the filtration head loss during the CSO event. The backwash was performed 11 times during the CSO event. In the first flush period, the filter running time was only 8 minutes before first backwash. The second backwash took place after 20 minutes' filtration. In the diluted CSO zone, the backwash interval was much longer and was between 74 minutes and 192 minutes.

Figure 16 shows the HRF filter flow rate during the CSO evert, a fixed flow 21 m^3/h is applied and corresponded to the filtration rate 42 m/h during the test.

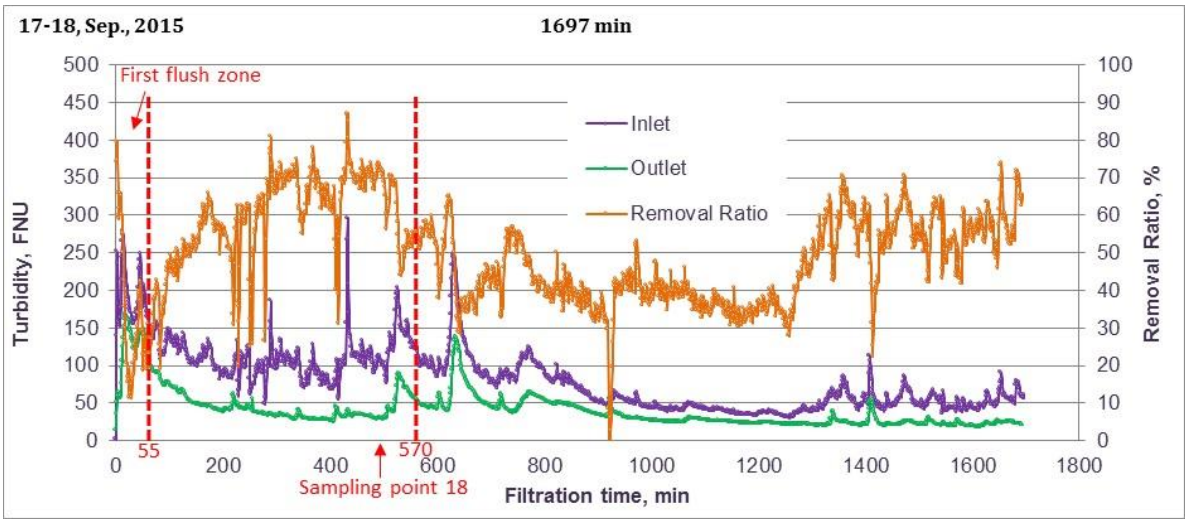


Figure 14 Online Turbidity profile of CSO event 1

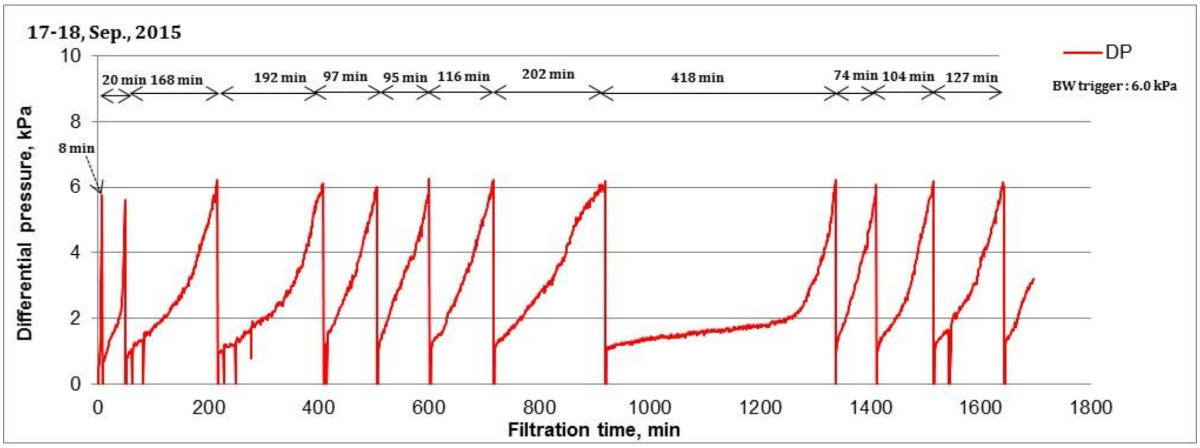


Figure 15 Filtration headloss of CSO event 1

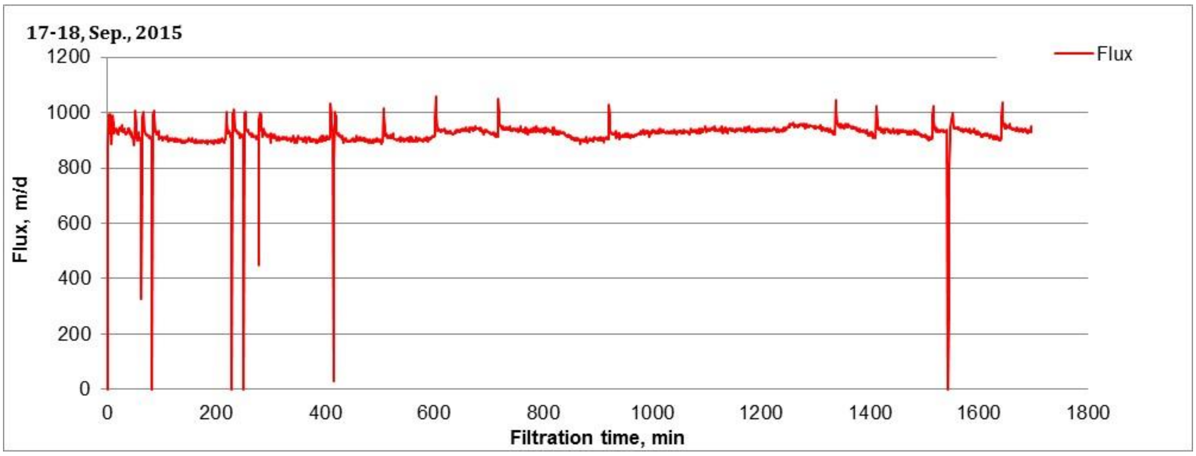


Figure 16 Filtration flow rate of CSO event 1

3.4.3 Overall COD and SS removal

Figure 17 and Figure 18 show the SS and COD loading rates for all the CSO samples during the demonstration period. The loading rate can logically be divided into two zones, one zone (diluted CSO zone) has inlet SS and COD loading rate less than 4 kg/m^2/h, and the other has inlet SS and COD loading rate above 5 kg/m^2/h, which can be defined as first flush zone. No sample points have been observed in the inlet SS and COD loading rate region between 4 and 5 kg/m^2/h.

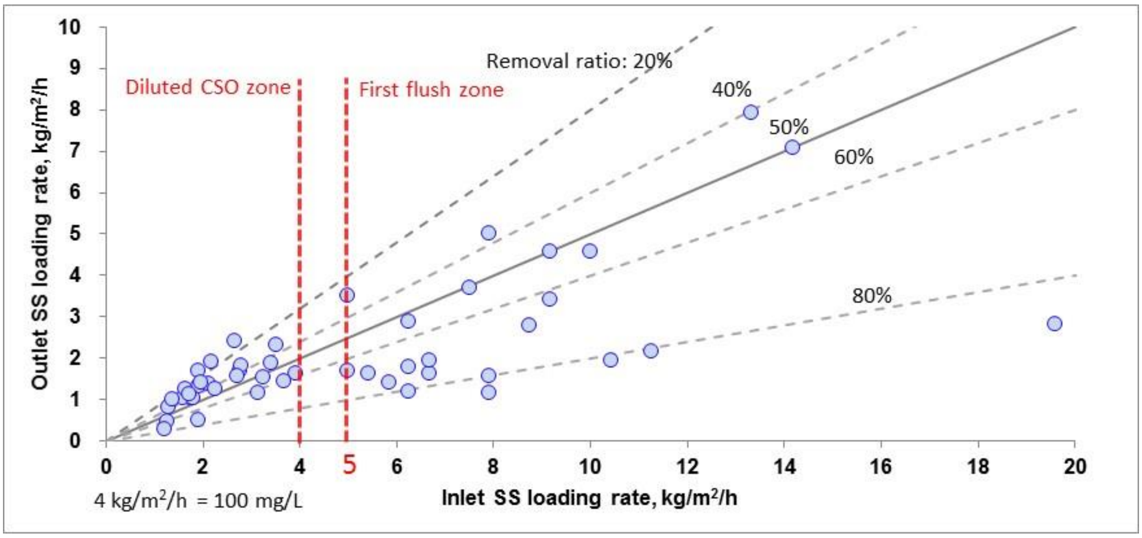


Figure 17 SS loading rate of all CSO samples

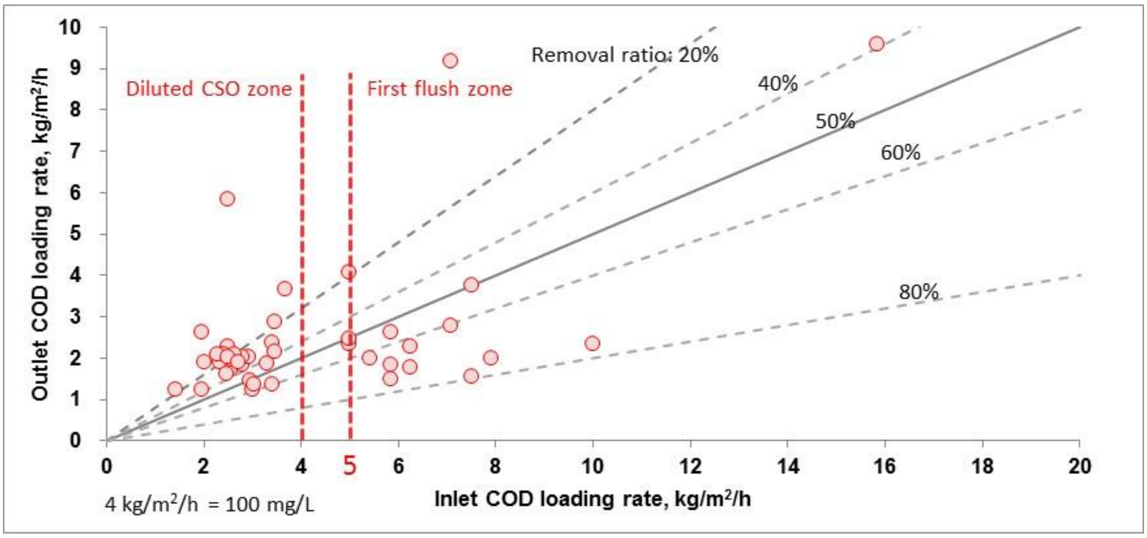


Figure 18 COD loading rate of all CSO samples

The loading rate information provided in figure 18 is not suitable to describe the overall removal efficiency of pollutants (e.g. SS, COD and BOD) by the HRF system during a CSO event. Therefore, a way of calculating the overall removal efficiency of pollutants for the HRF system is defined below:

Overall removal (%) = [Total inlet amount (kg) - Total outlet amount (kg)] ÷ Total inlet amount (kg) × 100%
Total inlet amount (kg) = $\sum$ (Inlet pollutant loading rate (kg/m^2/h) $_{(i)}$ × sampling interval (h) $_{(i)}$ × filter surface (m^2))

Total outlet amount (kg) = ∑ (Outlet pollutant loading rate (kg/m²/h) $_{(i)}$ × sampling interval (h) $_{(i)}$ × filter surface (m²))
i = sampling number

HRF system can remove most of particulate organic from the CSO. However, removal of dissolved pollutants normally required biological and/or chemical process in the treatment. The overall COD removal in HRF is highly related to suspended solid (SS) removal, which represents the particles portion in the CSO. Figure 19 shows that the overall COD removal was 47%, and 3.08 kg COD emission was reduced during CSO event 3. SS has higher removal (56%), and 4.27 kg SS was retained by filter media. The higher SS removal is contributed by better treatment efficiency on inorganic particles.

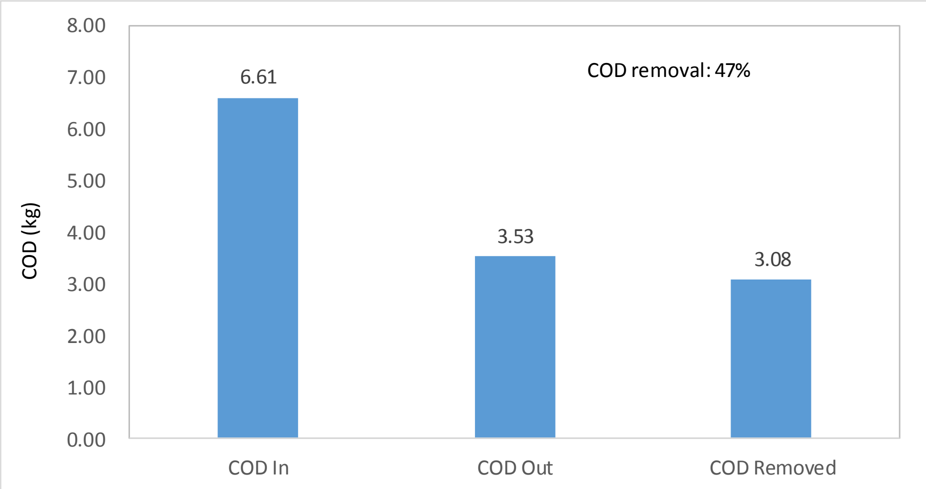


Figure 19 Overall COD removal

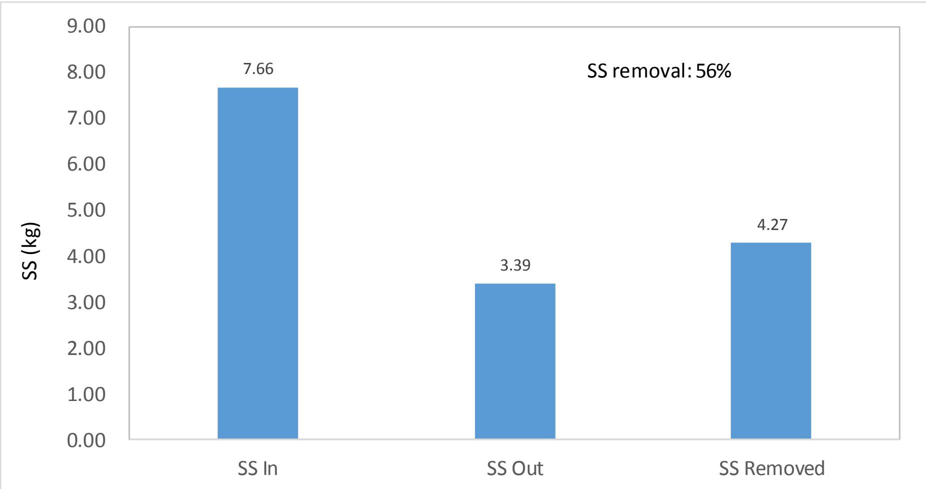


Figure 20 Overall SS removal

3.4.4 Overall Nutrient removal

Nutrient pollution is the process where too many nutrients, mainly nitrogen and phosphorus, are discharged into waterbodies and causing excessive growth of algae.

Nitrogen exist in four main forms: organic, ammonia, nitrite and nitrate. Total Nitrogen (TN) is the sum of all the four forms. Organic and ammonia nitrogen make up most of the TN in wastewater and storm water. High levels of nitrogen discharged to receiving waters can promote growth of algae and floating macrophytes and even lead to eutrophication symptoms such as water discolour, odours and depressed oxygen levels (David Butnd John, 2010).

Phosphorus exist in two forms: organic or as inorganic (ortho- and poly-) phosphorus. Total Phosphorus is the sum of the two forms. In comparison, orthophosphates are the dominant amount of the total Phosphorus. Polyphosphates consist of combinations of phosphorus, oxygen and hydrogen atoms. Orthophosphates are simpler compounds and may be attached to particles. Phosphorus-containing compounds also contribute to eutrophication (David Butnd John, 2010).

Nutrient removal investigation was carried out during CSO event 3, where TN and TP were analysed. Figure 21 and 22 show that the HRF system only has relative low removal efficiency of TN and TP, which were 6.3% and 15% respectively. During HRF process, most of particulate components can be removed, while the nitrogen and phosphate components mainly comes from soluble compositions of CSO.

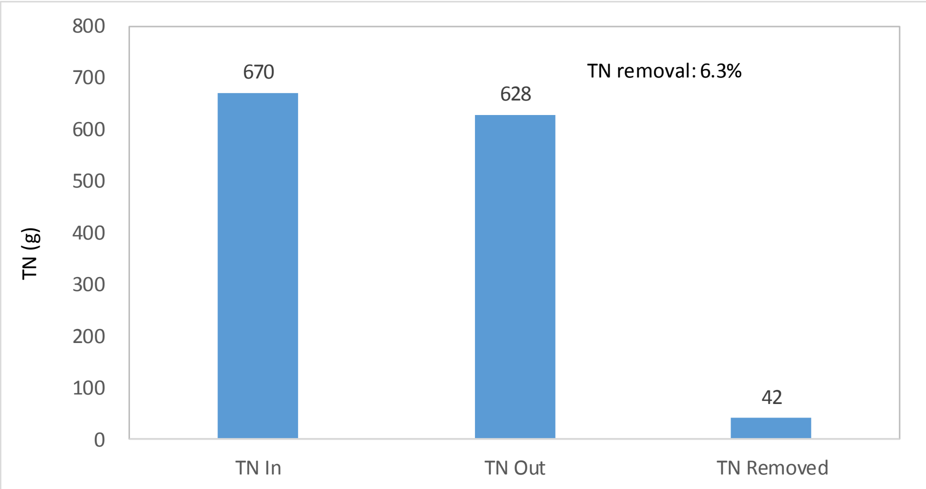


Figure 21 Overall TN removal

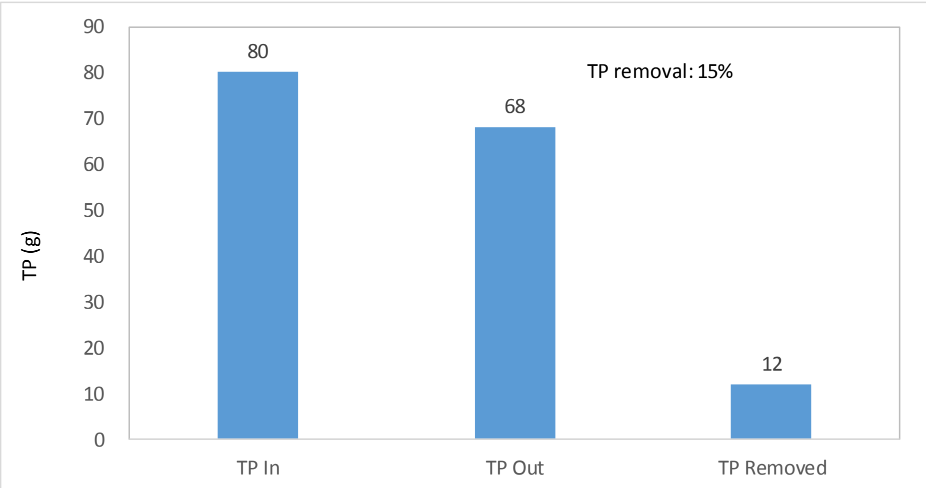


Figure 22 Overall TP removal

3.4.5 Overall heavy metal removal

Heavy metals can be found in wastewater and storm water. Metals can exist in particulate, colloidal and dissolved phases. Environmental mobility and bioavailability (and thus toxicity) of metals are highly related to their concentration in solution (Tangahu et al., 2011).

At CSO event 4, concentrations of four heavy metals (Al, Zn, Cu, Cr) were analysed. Aluminium and Zinc are wildly used in industry and found in wastewater and CSO. During 162 minutes of CSO event, 153 g of Al and 3.01 g of Zn in raw CSO flowed into HRF system, and 48% of removal both for Al and Zn was achieved (Figure 23 and 24).

Copper is a typical runoff derived compound and occurs in CSO streams. Over the CSO event 4, 849 mg corresponded to 58% of Cu was removed by HRF system (Figure 25). Chromium in runoff water arises from industrial discharges. It occurs in the trivalent and hexavalent forms, the latter being the more toxic form. 303 mg corresponded to 31% of Cr was removed by HRF system (Figure 26) at the same CSO event.

Heavy metals removals are associated to the particulate portion in the CSO. The HRF technology provides a relatively high treatment efficiency on heavy metals in particulate and colloidal phase.

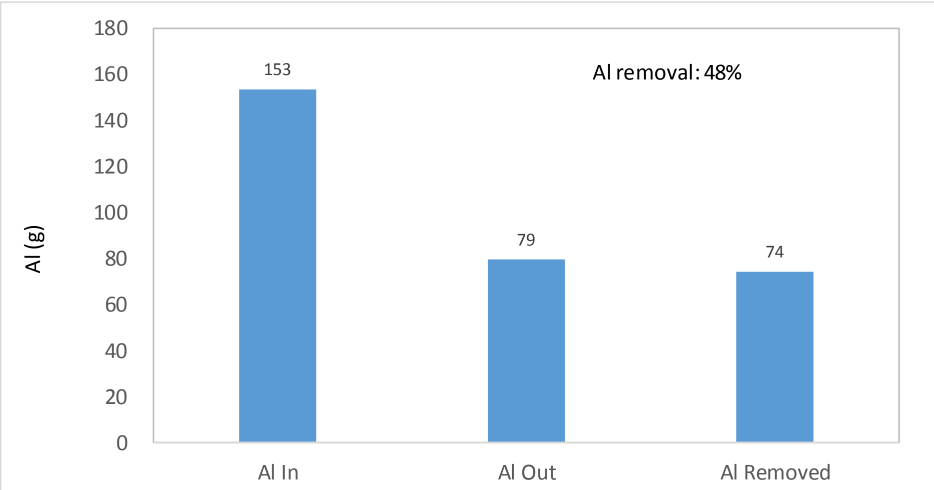


Figure 23 Overall Al removal

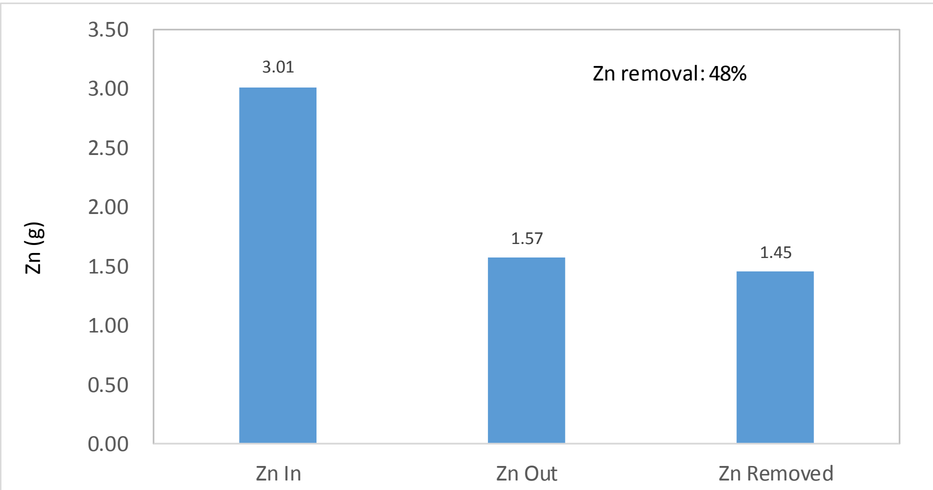


Figure 24 Overall Zn removal

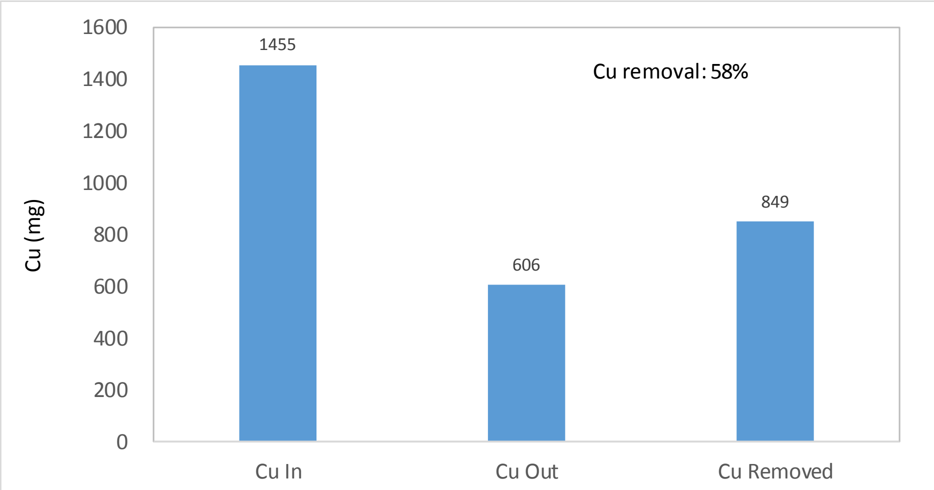


Figure 25 Overall Cu removal

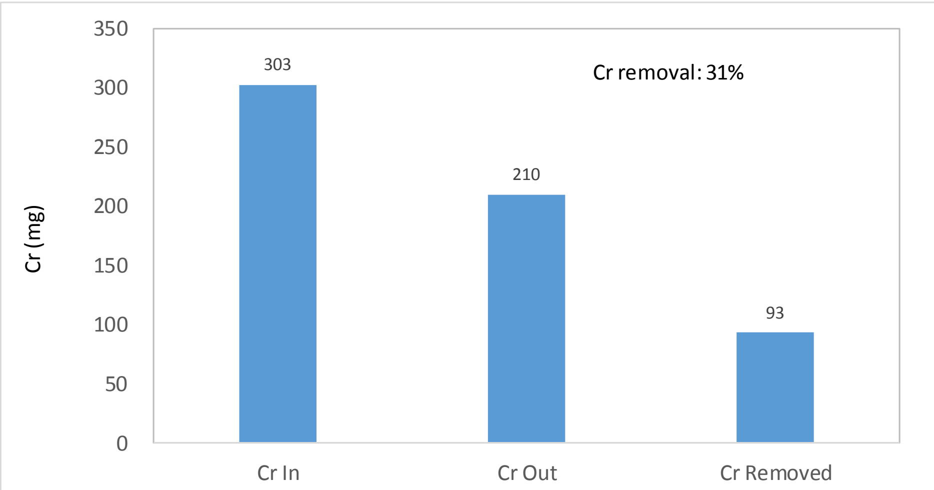


Figure 26 Overall Cr removal

4. Conclusion

An innovative HRF solution including special designed filter media and unique operational process is developed and applied for CSO treatment by Inrigo AS from Norway.

In EU-project DESSIN, as one of the five demonstration sites, a container type HRF plant was build up to investigate and demonstrate the treatment efficient of CSO at Hoffselva, Norway. 11 CSO events were recorded through the demonstration period. Sample analysis and online measurement of water quality parameters were performed to investigate the HRF treatment efficiency. Test results indicate that HRF solution is an efficient technology to reduce emissions of particulate pollutants from CSO. Up to 80% of SS removal and 75% of COD removal were documented during the first flush of CSO event. The overall removals of SS and COD were about 47% and 56%. Nutrient removal is relatively low because of the major soluble nitrogen and phosphorus compositions in CSO; however, 6.3% TN and 15% TP were retained together with particles. HRF system also shows promising treatment efficiency of heavy metals with 48% Al, 48% Zn, 57% Cu, and 31% Cr removed respectively. HM are normally associated with part.

The new HRF is a reliable and robust solution for CSO treatment. The further efforts will be focus on reducing footprint and simplifying maintenance.

5. References

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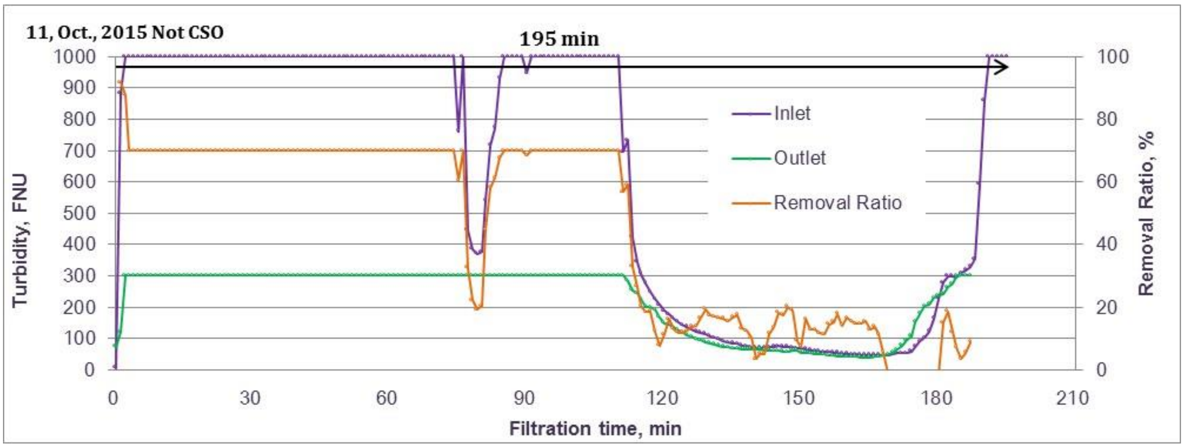
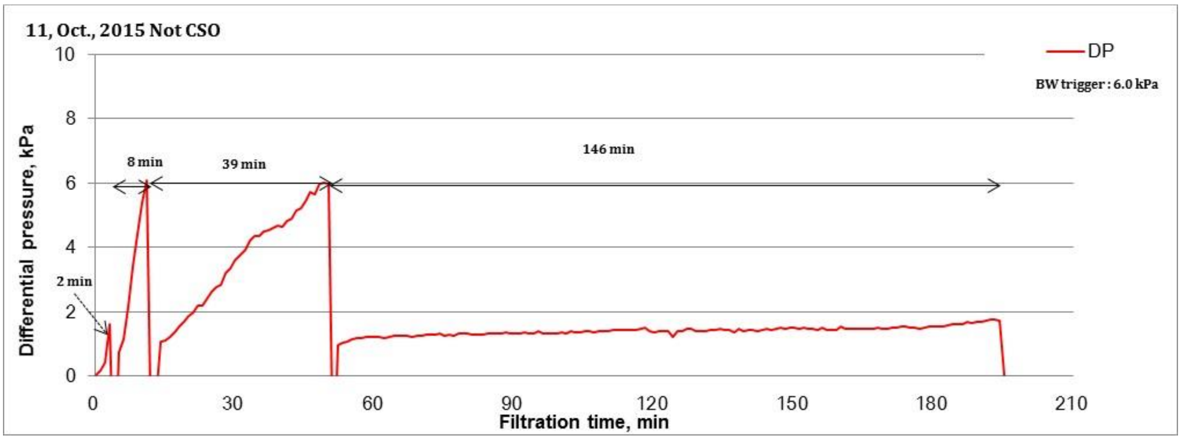
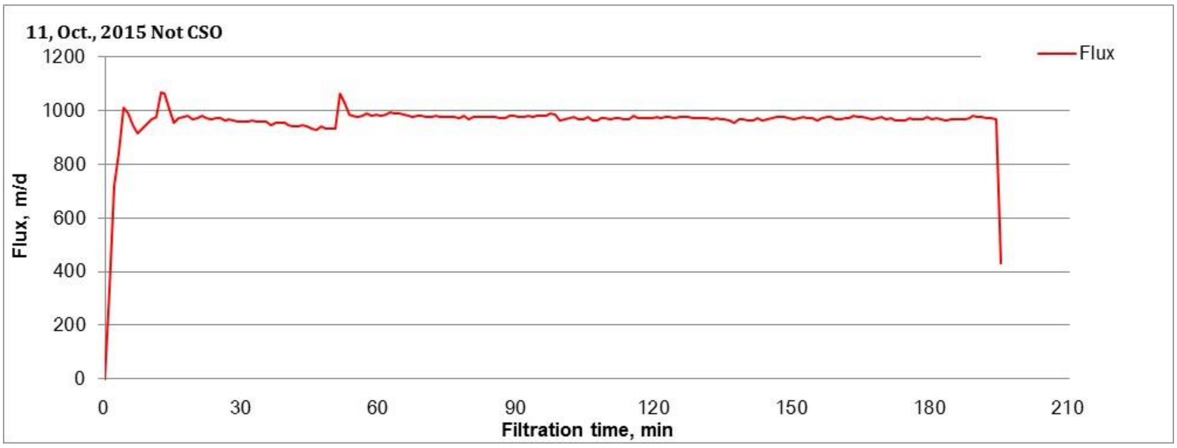
ANNEX A: CSO events (2-11) during demonstration period

CSO event 2

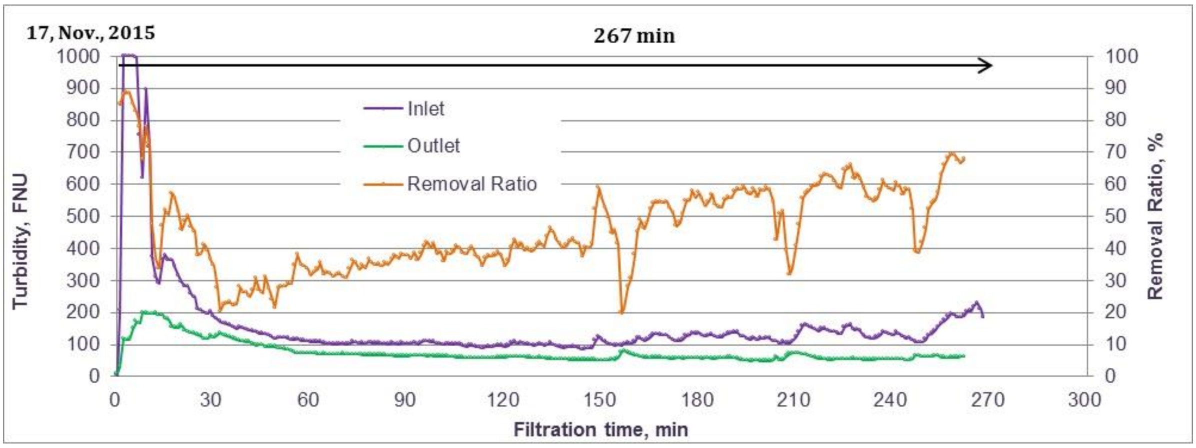


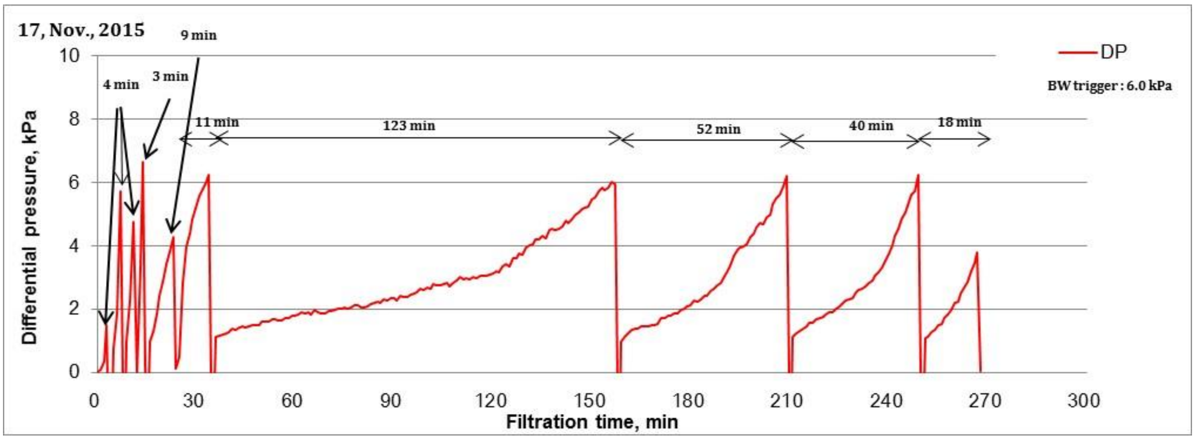


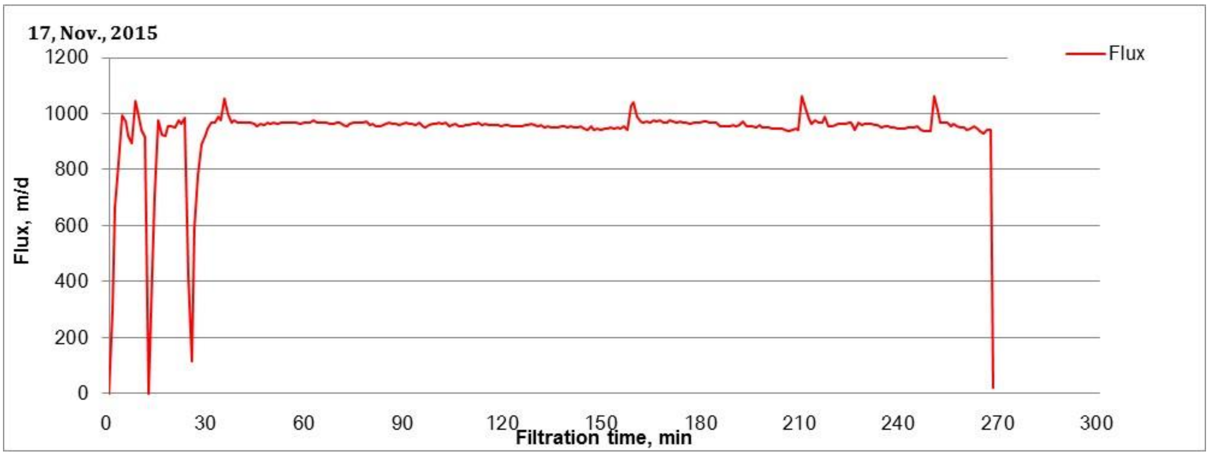


Note: Inlet Turbidity extremely high > 1000 FNU, outlet Turbidity > 300 FNU, both exceed the measurement range of online Turbidity meters.

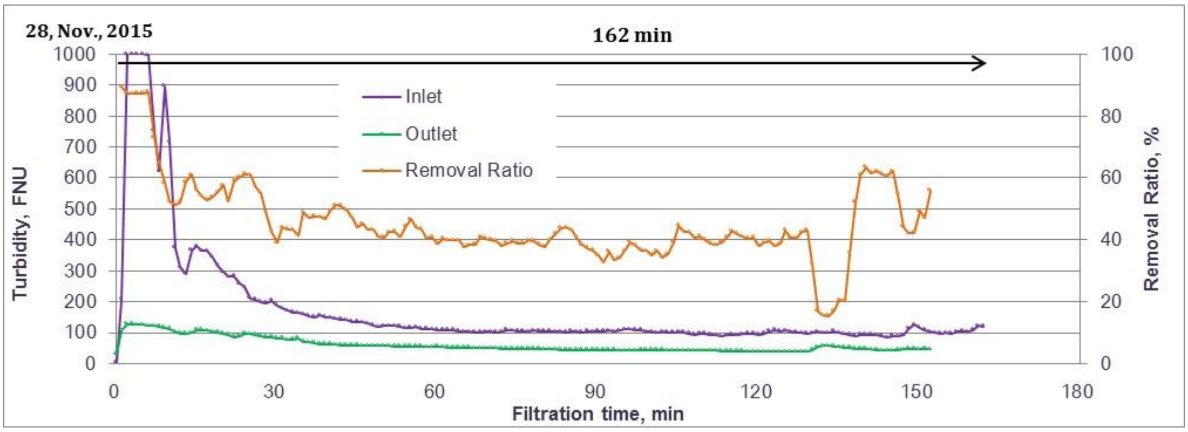
CSO event 3

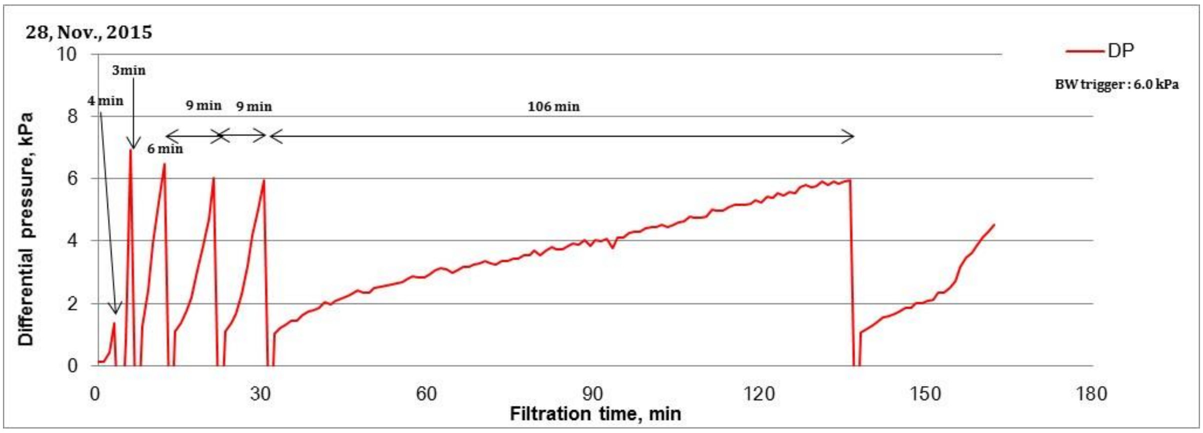

17, Nov., 2015
267 min
Inlet
Outlet
Removal Ratio
Turbidity, FNU
Removal Ratio, %
Filtration time, min

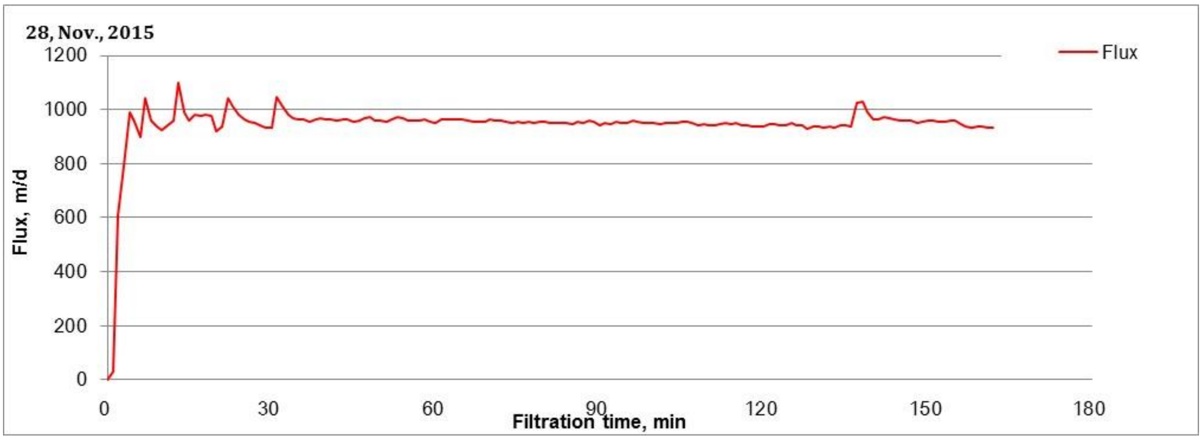

17, Nov., 2015
9 min
4 min
3 min
11 min
123 min
52 min
40 min
18 min
DP
BW trigger: 6.0 kPa
Differential pressure, kPa
Filtration time, min


17, Nov., 2015
Flux
Flux, m/d
Filtration time, min

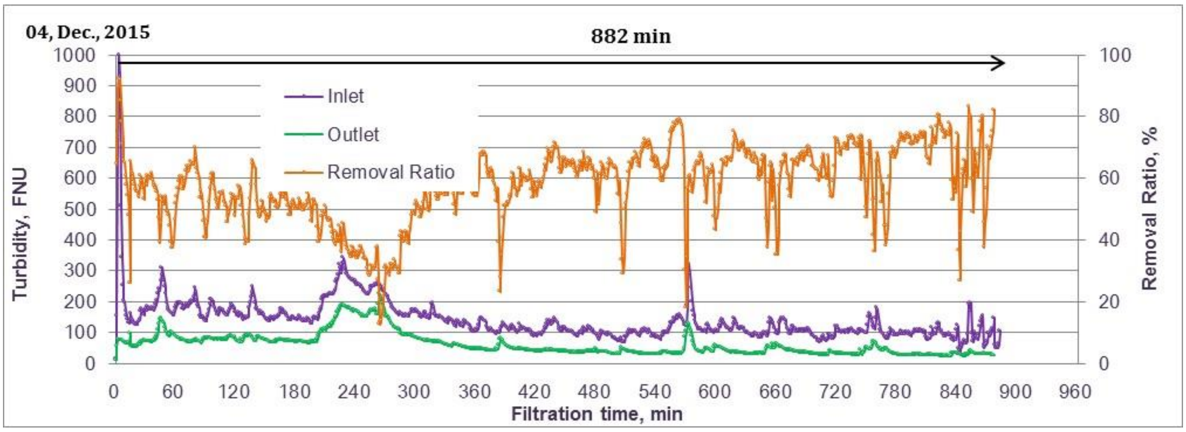
CSO event 4

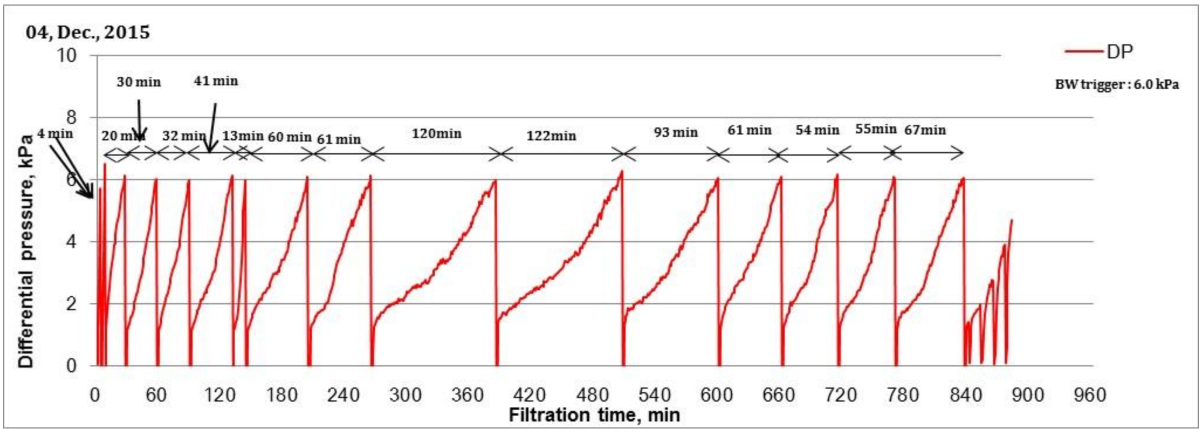

28, Nov., 2015
162 min
Inlet
Outlet
Removal Ratio
Turbidity, FNU
Removal Ratio, %
Filtration time, min

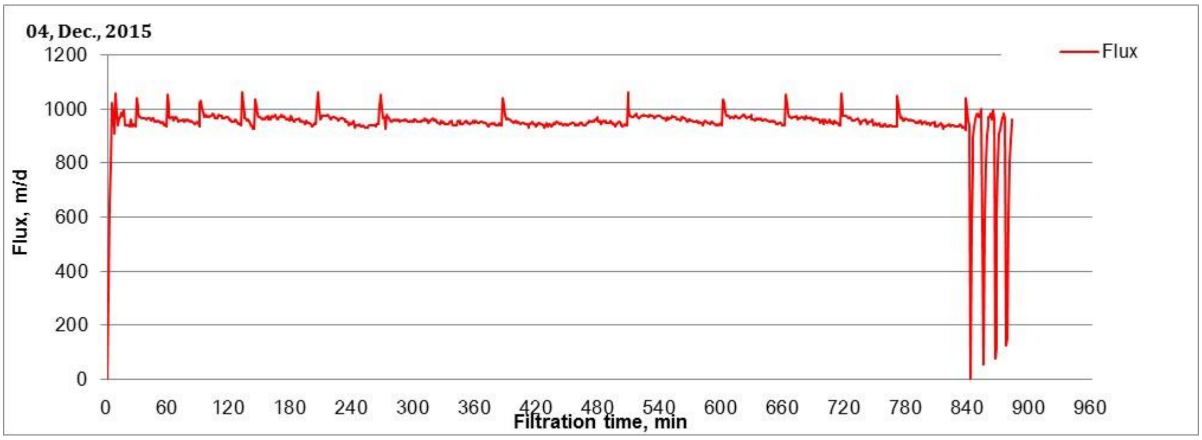

28, Nov., 2015
DP
BW trigger : 6.0 kPa
4 min
3min
6 min
9 min
9 min
106 min
Differential pressure, kPa
Filtration time, min


28, Nov., 2015
Flux
Flux, m/d
Filtration time, min

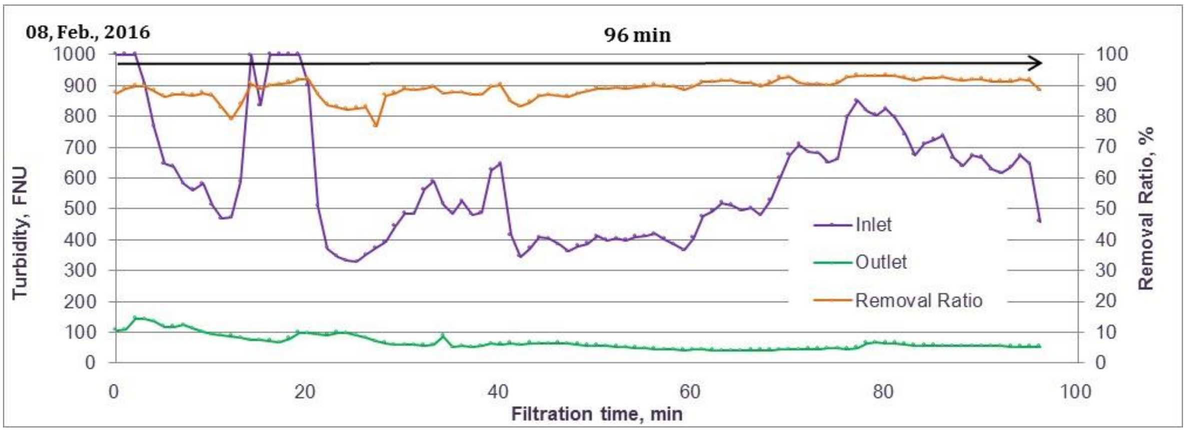
CSO event 5

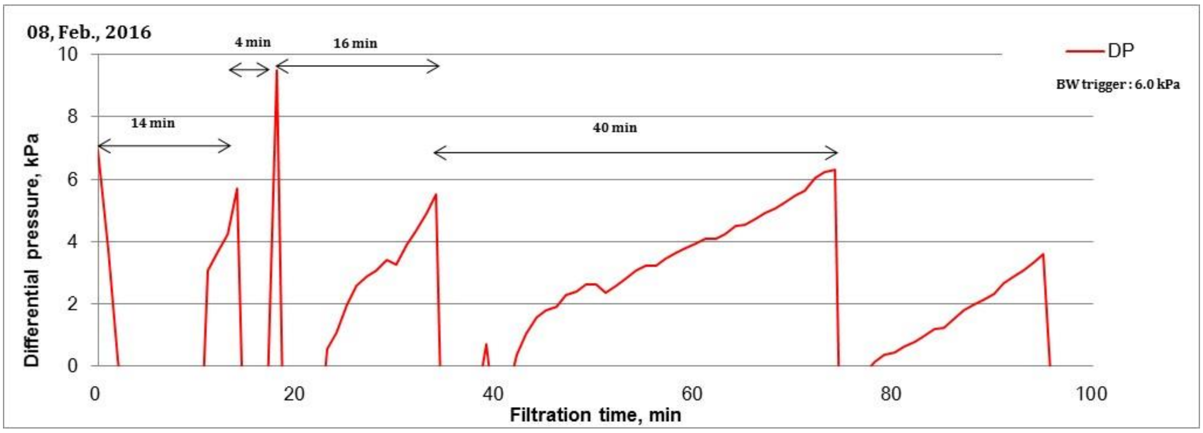

04, Dec., 2015
882 min
Inlet
Outlet
Removal Ratio
Turbidity, FNU
Removal Ratio, %
Filtration time, min

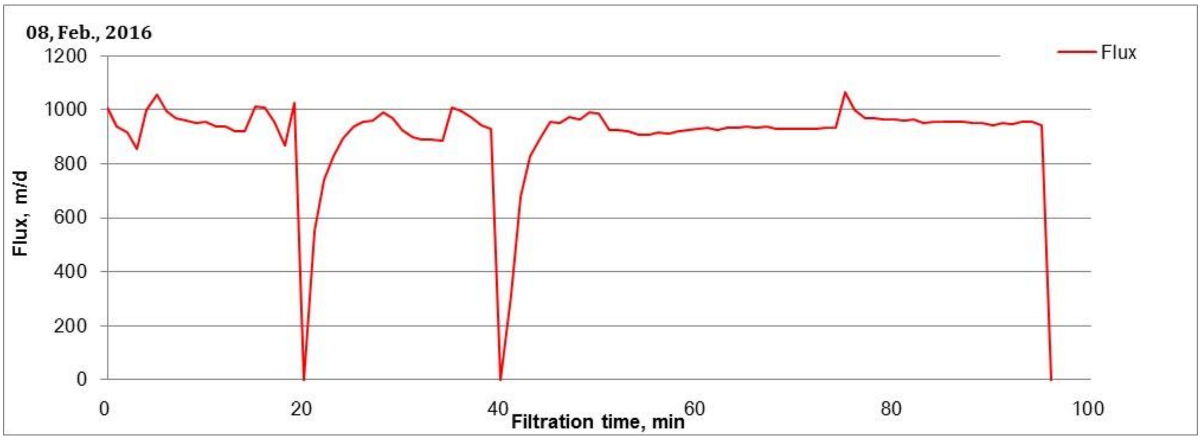

04, Dec., 2015
DP
BW trigger : 6.0 kPa
4 min
20 min
30 min
32 min
41 min
13min
60 min
61 min
120min
122min
93 min
61 min
54 min
55min
67min
Differential pressure, kPa
Filtration time, min


04, Dec., 2015
Flux
Flux, m/d
Filtration time, min

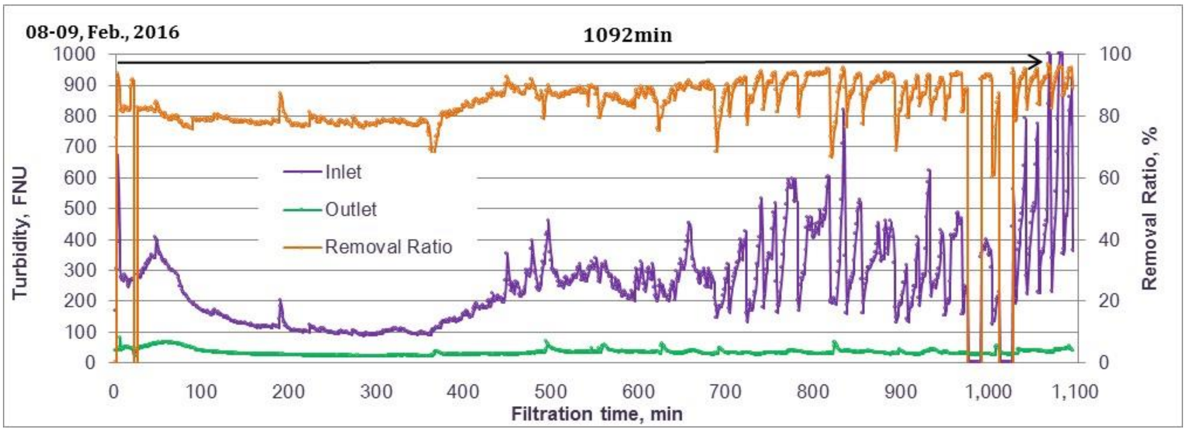
CSO event 6

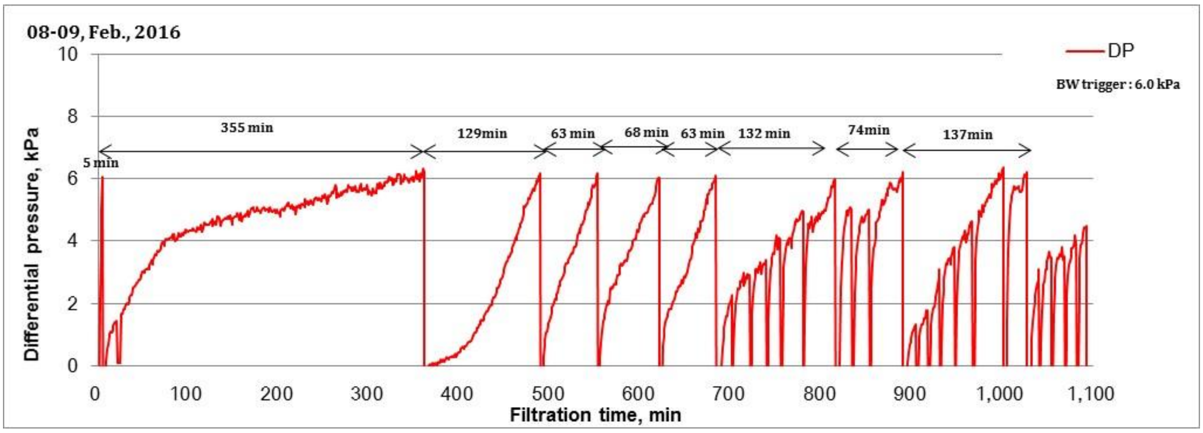

08, Feb., 2016
96 min
Turbidity, FNU
Removal Ratio, %
Inlet
Outlet
Removal Ratio
Filtration time, min

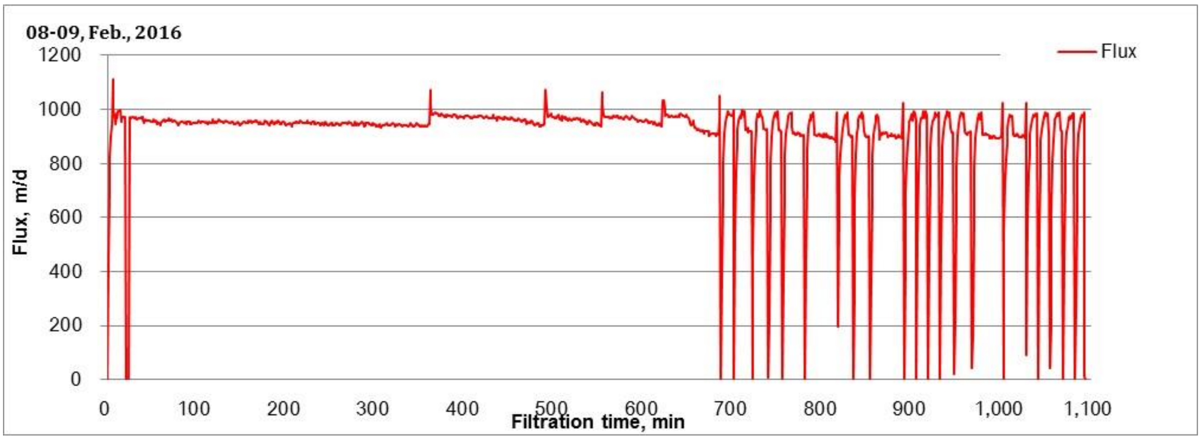

08, Feb., 2016
4 min
16 min
14 min
40 min
DP
BW trigger : 6.0 kPa
Differential pressure, kPa
Filtration time, min


08, Feb., 2016
Flux
Flux, m/d
Filtration time, min

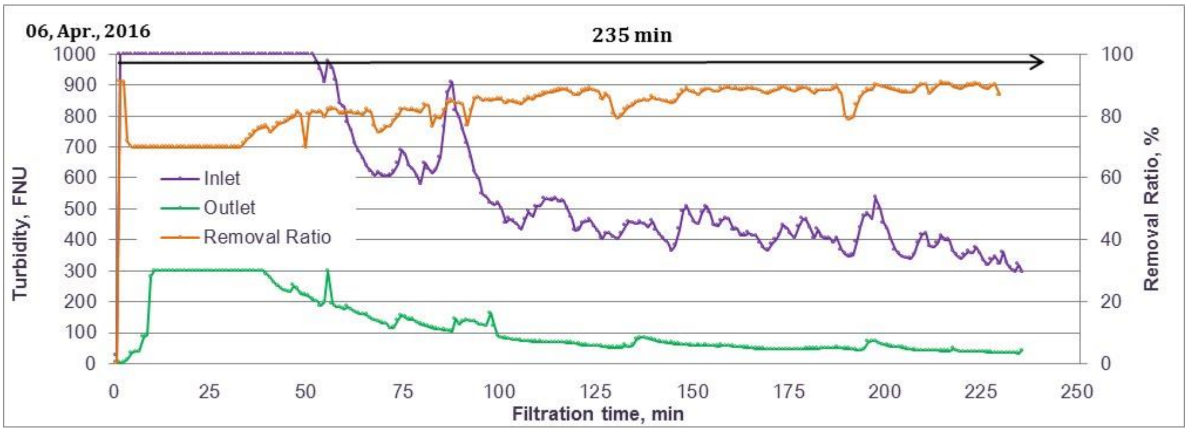
CSO event 7

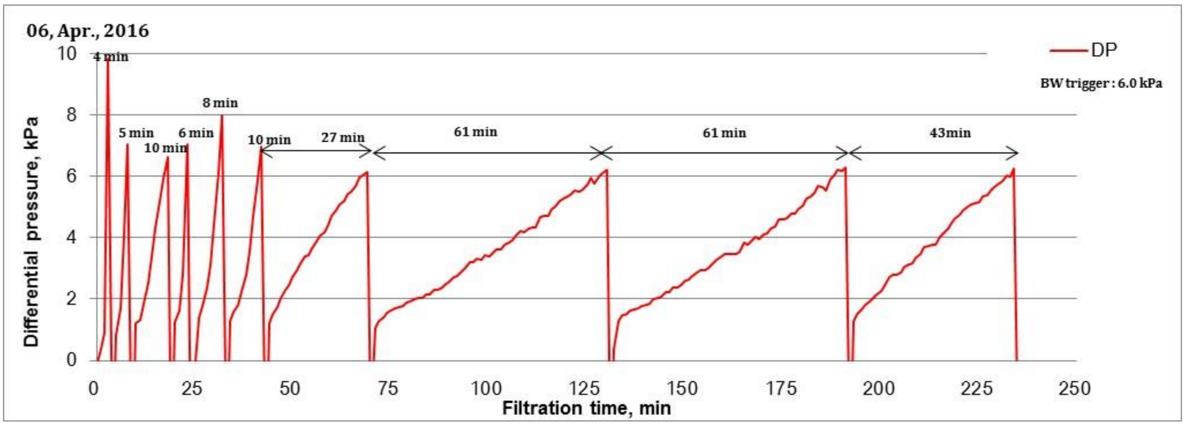

08-09, Feb., 2016
1092min
Inlet
Outlet
Removal Ratio
Turbidity, FNU
Removal Ratio, %
Filtration time, min

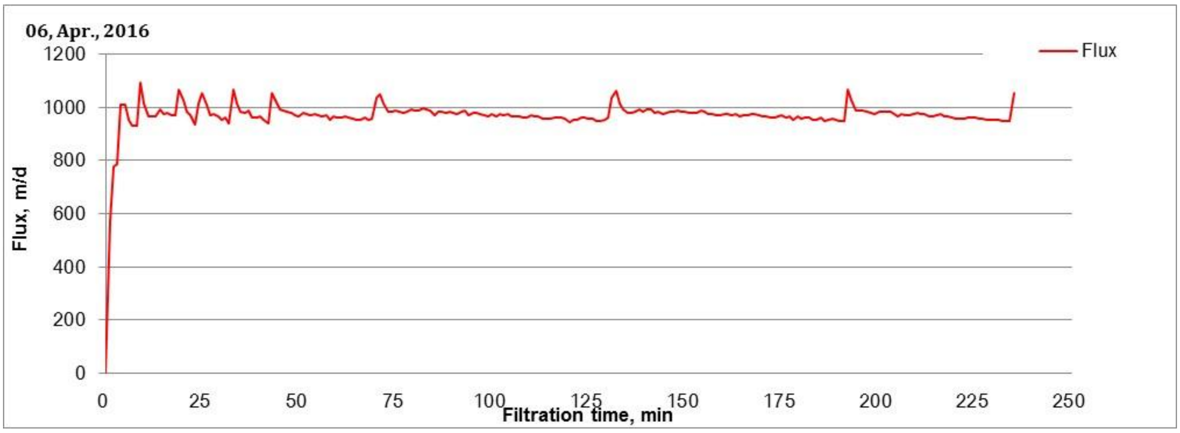

08-09, Feb., 2016
DP
BW trigger : 6.0 kPa
355 min
129min
63 min
68 min
63 min
132 min
74min
137min
5 min
Differential pressure, kPa
Filtration time, min


08-09, Feb., 2016
Flux
Flux, m/d
Filtration time, min

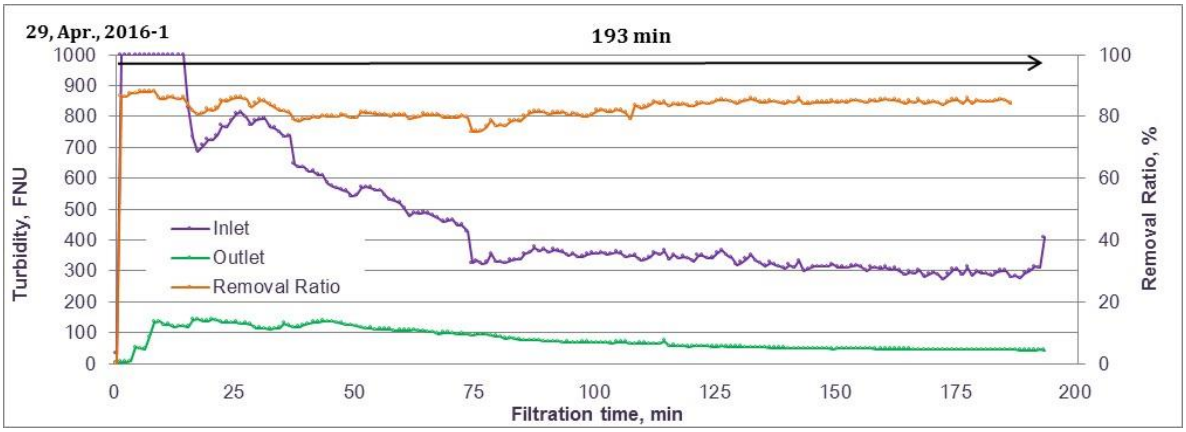
CSO event 8

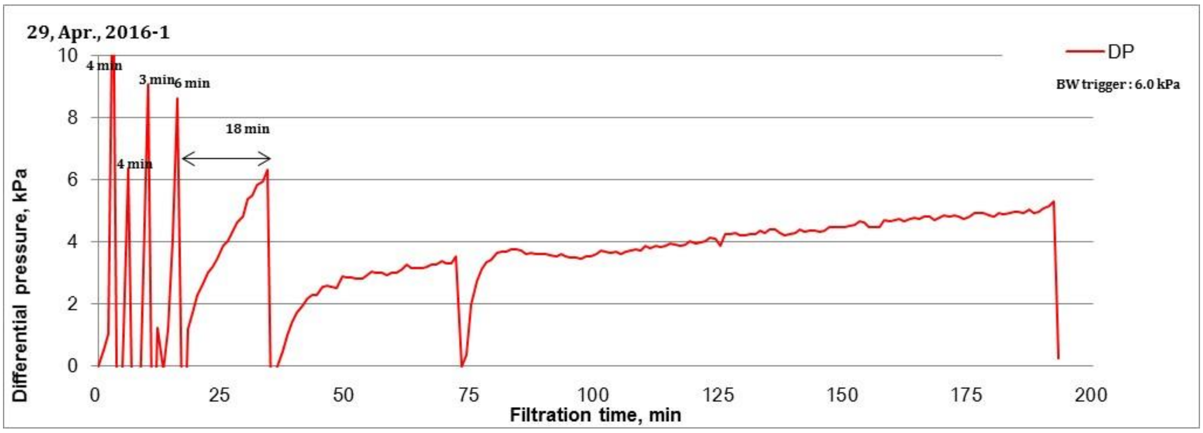

06, Apr., 2016
235 min
Turbidity, FNU
Removal Ratio, %
Inlet
Outlet
Removal Ratio
Filtration time, min

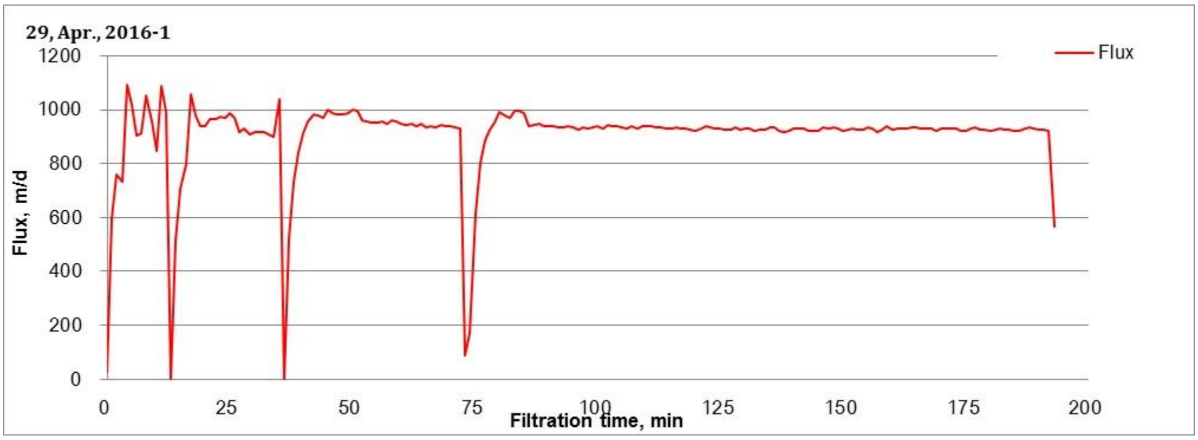

06, Apr., 2016
DP
BW trigger : 6.0 kPa
4 min
5 min
10 min
6 min
8 min
10 min
27 min
61 min
61 min
43min
Differential pressure, kPa
Filtration time, min


06, Apr., 2016
Flux
Flux, m/d
Filtration time, min

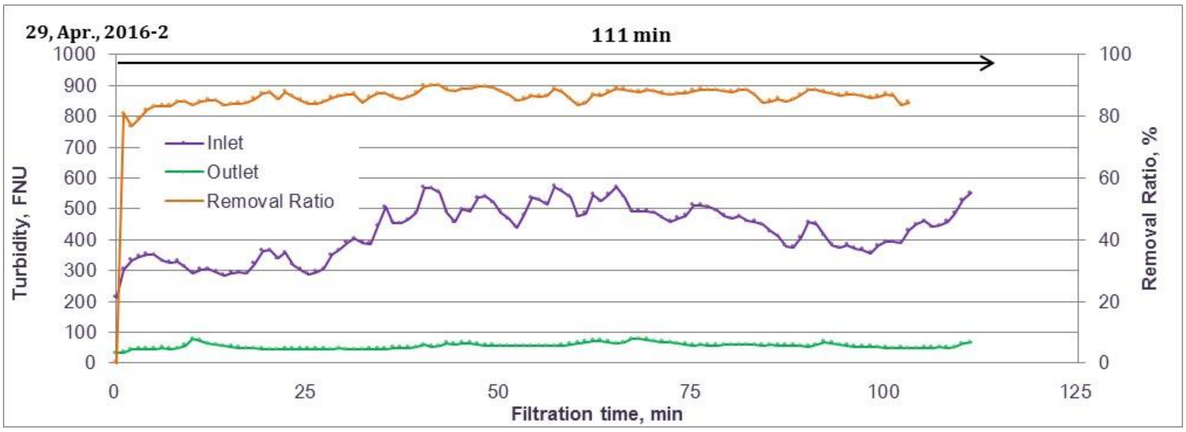
CSO event 9

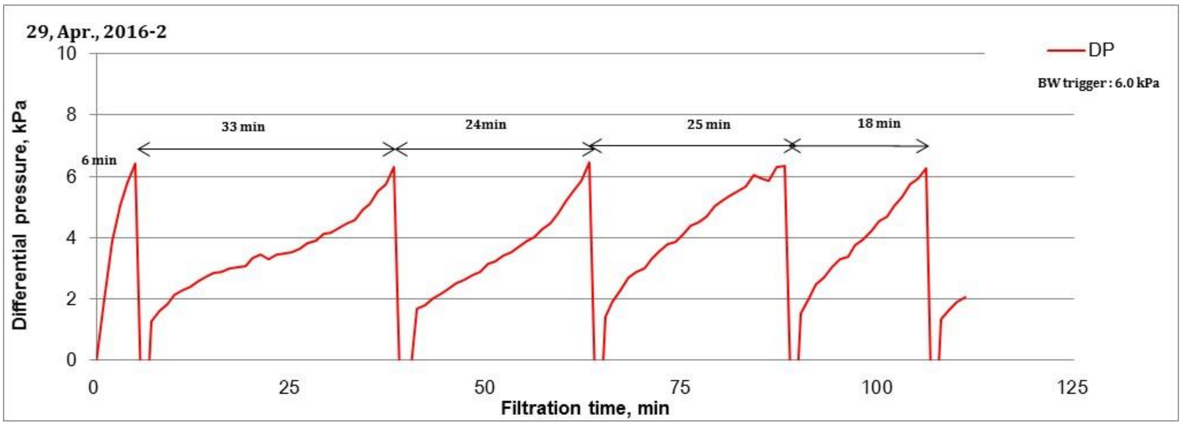

29, Apr., 2016-1
193 min
Turbidity, FNU
Removal Ratio, %
Inlet
Outlet
Removal Ratio
Filtration time, min

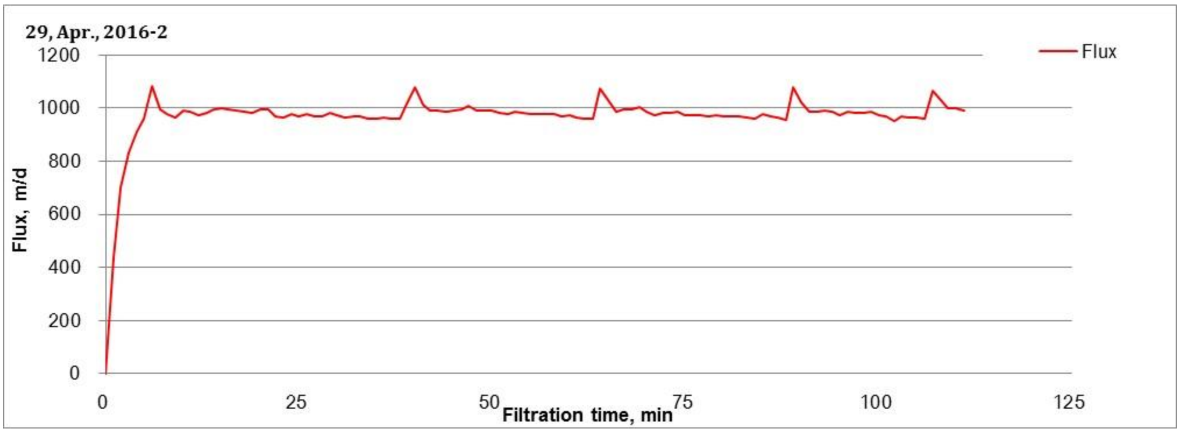

29, Apr., 2016-1
DP
BW trigger : 6.0 kPa
4 min
3 min
6 min
4 min
18 min
Differential pressure, kPa
Filtration time, min


29, Apr., 2016-1
Flux
Flux, m/d
Filtration time, min

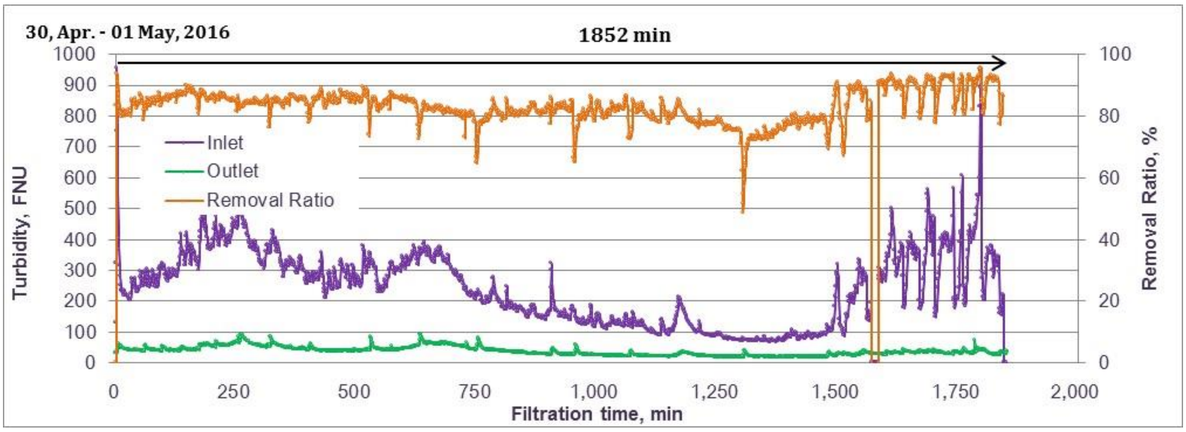
CSO event 10

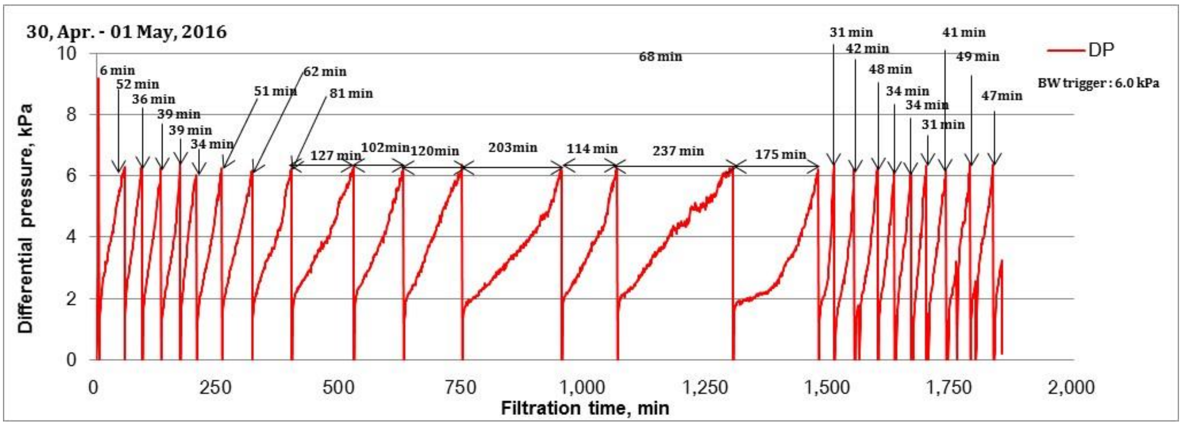

29, Apr., 2016-2
111 min
Turbidity, FNU
Removal Ratio, %
Inlet
Outlet
Removal Ratio
Filtration time, min

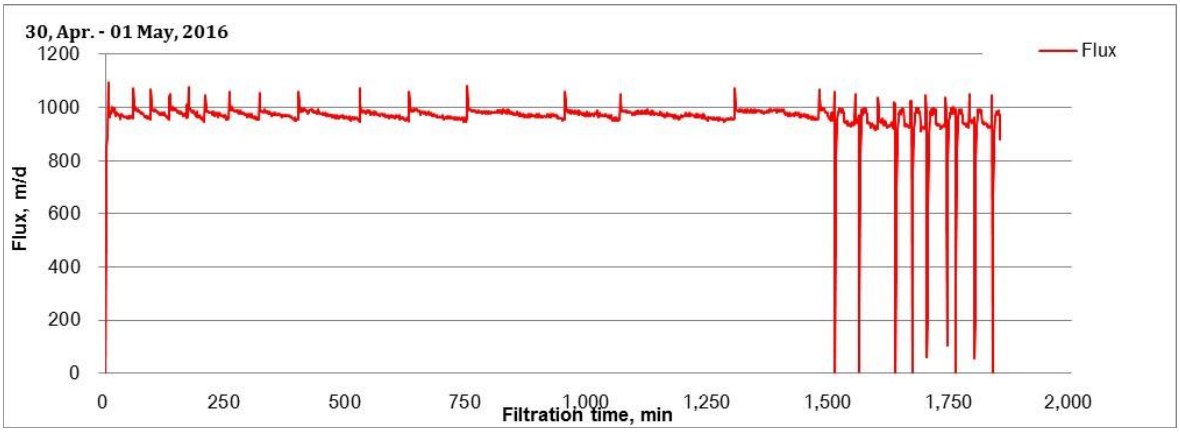

29, Apr., 2016-2
DP
BW trigger : 6.0 kPa
6 min
33 min
24min
25 min
18 min
Differential pressure, kPa
Filtration time, min


29, Apr., 2016-2
Flux
Flux, m/d
Filtration time, min

CSO event 11


30, Apr. - 01 May, 2016
1852 min
Inlet
Outlet
Removal Ratio
Turbidity, FNU
Removal Ratio, %
Filtration time, min


30, Apr. - 01 May, 2016
DP
BW trigger : 6.0 kPa
Differential pressure, kPa
Filtration time, min


30, Apr. - 01 May, 2016
Flux
Flux, m/d
Filtration time, min

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