DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

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D32.1 Design criteria and documentation of performance for local CSO overflow treatment

Final Report on Demonstration Tests of High Rate Filtration (HRF) system and Cross-Flow Lamella Settler (CLS) in Hoffselva, Oslo

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1: INRIGO, 2: UFT, 3: SINTEF, 4: LKI, January 2018

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

D32.1: Design criteria and documentation of performance for local CSO overflow treatment
Final report on demostration tests of high rate filtration (HRF) system and cross-flow lamella settler(CLS) in Hoffselva, Oslo

SUMMARY

High rate filtration (HRF) system and cross-flow lamella settler (CLS) have been demonstrated for CSO local treatment at Hoffselva River (Oslo Area, Norway). The demonstration results indicate that after the storage volume has been filled the HRF plant has 50% particle separation efficiency, while CLS plant has 10% particle separation efficiency. CSO local treatment can be considered as a promising approach to reduce the emission of particulate pollutants. At the end, the design criteria including plant dimension and investment cost are proposed based on HRF and CLS local treatment technologies for high priority CSO locations at Hoffselva.

DELIVERABLE NUMBER	WORK PACKAGE
D32.1	WP32
LEAD BENEFICIARY	**DELIVERABLE AUTHOR(S)**
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QUALITY ASSURANCE	
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PLANNED DELIVERY DATE	**ACTUAL DELIVERY DATE**
31/12/2017	19/01/2018
DISSEMINATION LEVEL	☒ PU = Public ☐ PP = Restricted to other programme participants ☐ RE = Restricted to a group specified by the consortium. Please specify: ________________________________ ☐ CO = Confidential, only for members of the consortium

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List of Acronyms and Abbreviations

COD – Chemical Oxygen Demand

CSO – Combined Sewer Overflow

CLS – Cross-Flow Lamella Settler

ESS – Ecosystem Services

HRF – High Rate Filtration

NOK – Norwegian Kroner

TSS – Total Suspended Solid

TKB - Thermotolerant Coliform Bacteria

TN – Total Nitrogen

TP – Total Phosphorus

WQ – water quality

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Executive summary

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 (ESS). At Hoffselva, DESSIN will demonstrate HRF and CLS local treatment solutions for overflow from CSO. The aim is to improve the water quality and ecosystem services in the catchment.

The innovative high rate filtration (HRF) system and cross-flow lamella settler (CLS) have been investigated in parallel for local treatment of CSO discharge at Hoffselva. 13 CSO events have been recorded during the demonstration period in 2017. Online Turbidity measurement and water quality lab analysis were performed to document the treatment efficiency. The demonstration results indicate that the local CSO treatment is an effective method to reduce the emission of particulate pollutants into river. Finally, the design criteria of HRF and CLS plants are proposed for CSO local treatment at Hoffselva.

1. Introduction

1.1 About DESSIN work package WP 32

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 and Sustainability Assessment (SA) 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 global major water challenges. Hoffselva, located in Oslo, Norway, is one of the five demonstration sites and includes demonstration of high rate filtration (HRF) and cross-flow lamella settler (CLS) for combined sewer overflow (CSO) treatment.

The main objective of WP32 is to demonstrate the feasibility and effect on the ecosystem services of different innovative local solutions for CSO treatment to improve water quality in Hoffselva, which includes:

- Enable local treatment of CSO with an innovative high rate filtration (HRF) system.
- Enable local treatment of CSO with an innovative cross-flow lamella (CLS) settler.
- Enable integration of local CSO treatment by innovative monitoring and data communication.

Deliverable D32.1 describes the demonstration tests conducted by the DESSIN project partners Inrigo AS, UFT, LKI and SINTEF. The design criteria and cost evaluation of CSO local treatment by using HRF and CLS in Hoffselva are proposed and discussed.

1.2 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 untreated wastewater is discharged to surface water recipient. The CSO discharge is a mixture of untreated wastewater and runoff caused by rain. The receiving water will get polluted by dissolved as well as undissolved pollutants. Therefore, CSO discharges can cause damage to the ecological and biological state of the receiving water and cause public health risks. To prevent these negative effects treatment of CSO discharge or other measures 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.

A good CSO treatment facility needs to be reliable, robust, automatic, sustainable, cost effective, and simple to operate. The facility should reduce pollution streams and must have a relative small footprint. During the DESSIN project, two innovative local CSO treatment technologies were developed:

1. A high rate filtration (HRF) system based on special media design and unique/patented operation technology by Inrigo AS, Norway.
2. A cross-flow lamella settler (CLS) based on special lamella plate design and cleaning technology by UFT, Germany.

1.3 High rate filtration (HRF) system

A 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 partners, has improved HRF technology to make it suitable for CSO treatment.

Figure 1 Special designed media of HRF

The 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, COD and TSS 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.

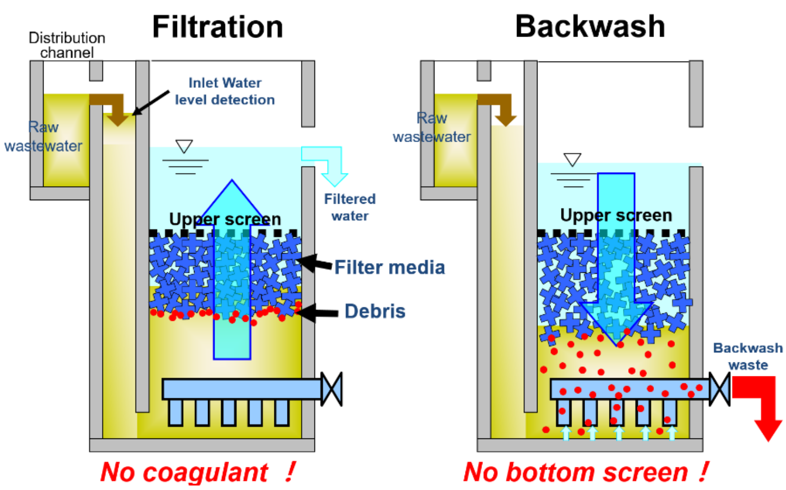


Figure 2 HRF system process diagram

There is no chemical addition and pre-treatment required for the HRF system developed by Inrigo AS. During the operation, filtration and backwash are switched by a backwash valve which 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 has easy 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 TSS and COD are removed inside of inner media. As filtration continues, and filter media becomes clogged, the water level on the influent side will 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, TSS and COD accumulated in the filter media. The backwash requires only a minute to clean, and no filter media flows out during backwash.

1.4 Cross-flow lamella settler (CLS)

In order to increase the sedimentation efficiency of CSO tanks, designed to store and thereby hold back discharge, lamella can be used inside the tank volume. Within DESSIN project, a new type of lamella settler – the cross-flow settler (CLS) – was developed and tested.

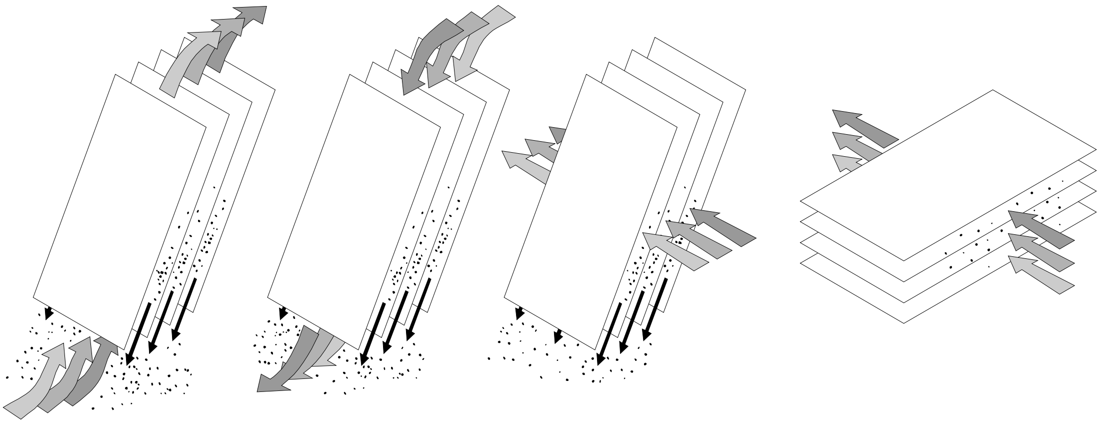


Figure 3 Up-flow, down-flow, cross-flow and horizontal plate lamella settlers

Figure 3 shows basic arrangements for lamella settlers made from plate arrays. Except the horizontal plate settler, the plates are inclined to allow the settled sludge to slide finally down into a sludge sump from where it can be removed. Most popular are up-flow settlers. In this case, also honeycomb profiles or tube arrays are used. Cross-flow settlers are used less frequently. They are made from plates, either flat or corrugated. Their advantage is that sediments which are sliding down laterally do not mix with the inflow, an effect which occurs rather pronouncedly in model tests with up-flow settlers. In the present project DESSIN, cross-flow plate settlers are investigated.

In most structures, integral (rigid non-movable) up-flow settlers were used. It is thus a big issue how to clean the lamella, since particularly in CSO applications considerable accumulation of sludge and gross solids will take place. The DESSIN cross-flow lamella settler has thus also a special cleaning mechanism, shown in Figure 4.

After some time of operation, accumulation of sludge must be expected on the lamella. In order to enforce sliding down of this sludge, a pivoting mechanism is used which pivots both modules while the container is still water-filled so that the modules are still immersed. The sludge layer is loosened by the swaying motion. Finally, the lamella are pivoted in vertical position and the sludge may settle down to the bottom of the container. Finally the container is emptied via a motor-driven emptying valve into a sanitary sewer and the sludge is going this way, too. A tipping flusher is filled with clean water and cleans the dry-fallen bottom.

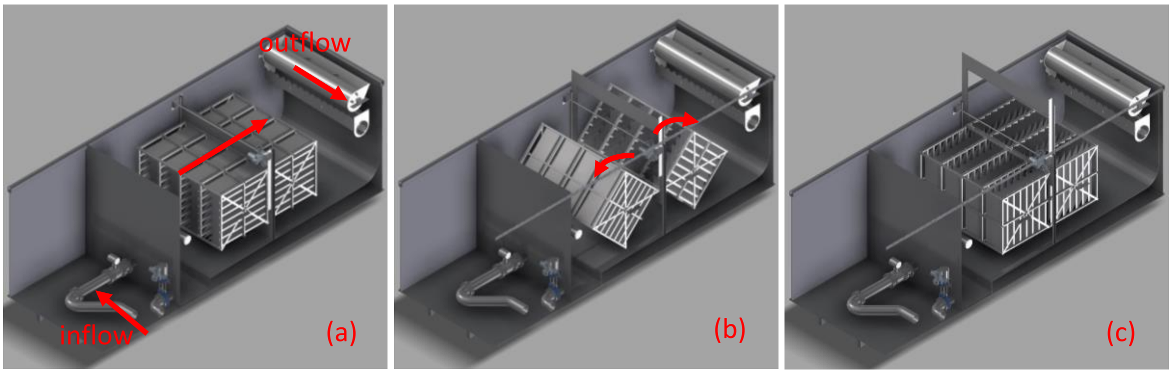


Figure 4 CLS process diagram (a) flow direction, (b) Lamella pivots under water for cleaning, (c) Lamella in vertical position, allowing settling of sludge

2. Demonstration site and plants installation

2.1 Site description and background

As one of the five demonstration sites in DESSIN project, Hoffselva (Figure 5) 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 25 combined sewage overflows (CSOs) discharging to the river during rain events.

Figure 5 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. 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 management.

The HRF and CLS demonstration plants were 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 local CSO treatment efficiency for Norwegian sewer and climate conditions. The results from the demonstration tests on CSO have also been used as input data for an ecosystem service evaluation in and around the receiving water body and a sustainability assessment of the two demonstrated solutions.

2.2 Installation of HRF and CLS demonstration plants

The HRF demonstration plant was installed inside two standard 20-foot containers (Figure 6), which were placed beside one of the CSOs along Makrellbekken at Hoffselva area. Figure 7 shows a simplified process diagram of demonstration plants. Water samples were taken at the inlet of the filter and after HRF treatment. The filter capacity is dependent on the filter surface area. The 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 m^2, which equals to a capacity of 21 m^3/h.

Figure 6 Container type HRF (green containers) and CLS (blue container) demonstration plants

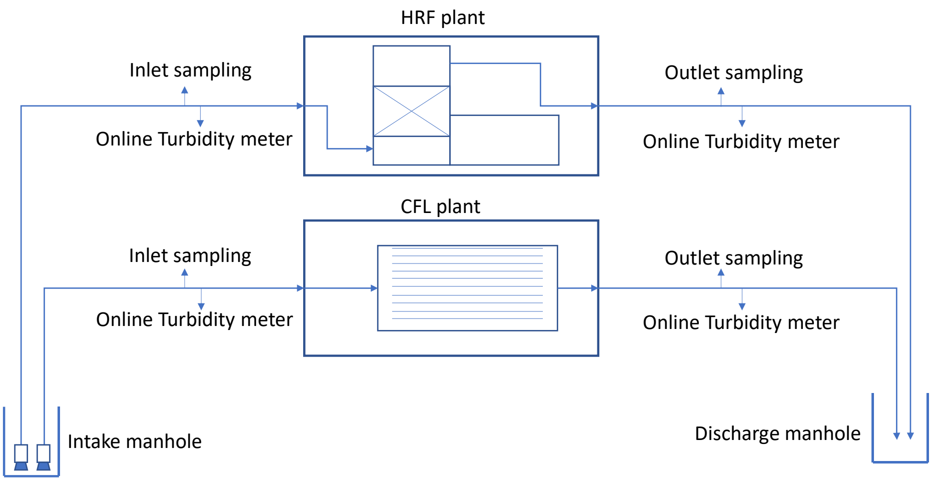


Figure 7 Diagram of HRF and CLS demonstration plants

The CLS demonstration plant was installed inside a 20-inch open container (Figure 6), which was placed beside the HRF container plant. Water samples were taken at the inlet and outlet of CLS (Figure 7). The treatment capacity is dependent on the lamella projected surficial area. The CLS has a design surficial load of 4 m/h for CSO treatment. The demonstration plant at Hoffselva has a projected surficial area of 33.1 m^2, which corresponds to a capacity of 132.4 m^3/h. However, the CLS plant operated at 0.5 m/h surficial load because of limited CSO flow available in the intake manhole during demonstration period at Hoffselva.

2.3 Online measurement and data logging

The HRF plant was installed first and an online turbidity flow-through sensor on the inlet and another on the outlet were mounted. These units had a continuous self-cleaning system that made sure that the surface of the sensors was not clogged event through phases of no flow. In addition to the two turbidity measurements, we did also record the level in the intake pump manhole, the level in the different tanks inside HRF plant and the flow when the plant was in operation.

When the CLS plant from UFT was installed, two other turbidity sensors, one by the side of the inlet diffuser and one just below the outlet channel were mounted. We did also install a float switch that should start the sample extracting units when the plant was in operation. This was since we might face the situation that the system started, but the flow dropped so the container was not filled and the test run was then terminated. Also, a control valve for cleaning water was installed to rinse the system after each run.

For the CLS plant, one level sensor was placed in the intake manhole and one level sensor was mounted inside the container itself, so all these data were recorded in parallel with the Inrigo container. We also installed a SMS based system called “ring hytta varm” which made it possible for SINTEF to start the sampling system from remote when the flow of CSO water was sufficient. This was then coupled to the two sampling units in CLS plant. One problem which we saw after the tests were finished was the build-up of deposits on the sensor surface since they were left dry for longer period between each test run. This might have given a slightly higher value for these two measuring points.

All signals from HRF and CLS plants were stored in the logger and downloaded to a computer once every hour for remote downloading possibility.

2.4 Communication and remote control of demonstration plants

The objective of the communication infrastructure is to provide the following services related to the demonstration plants:

A. Internet connection between Inrigo (HRF) Control System at demonstration site and Inrigo's Office Remote Control System
B. Remote access to LKI's on-site PC in HRF Container, that is used to access LKI's data logger
C. SMS alarms to selected project members when an CSO event occurs, based on live information from the Inrigo Office Remote Control System
D. Remote control of water sampler (ISCO 3700) located at the measurement station HOF5 (in the lower parts of Hoffselva).
E. Remote control of the Lamella settler system in CLS Container located at demonstration site.

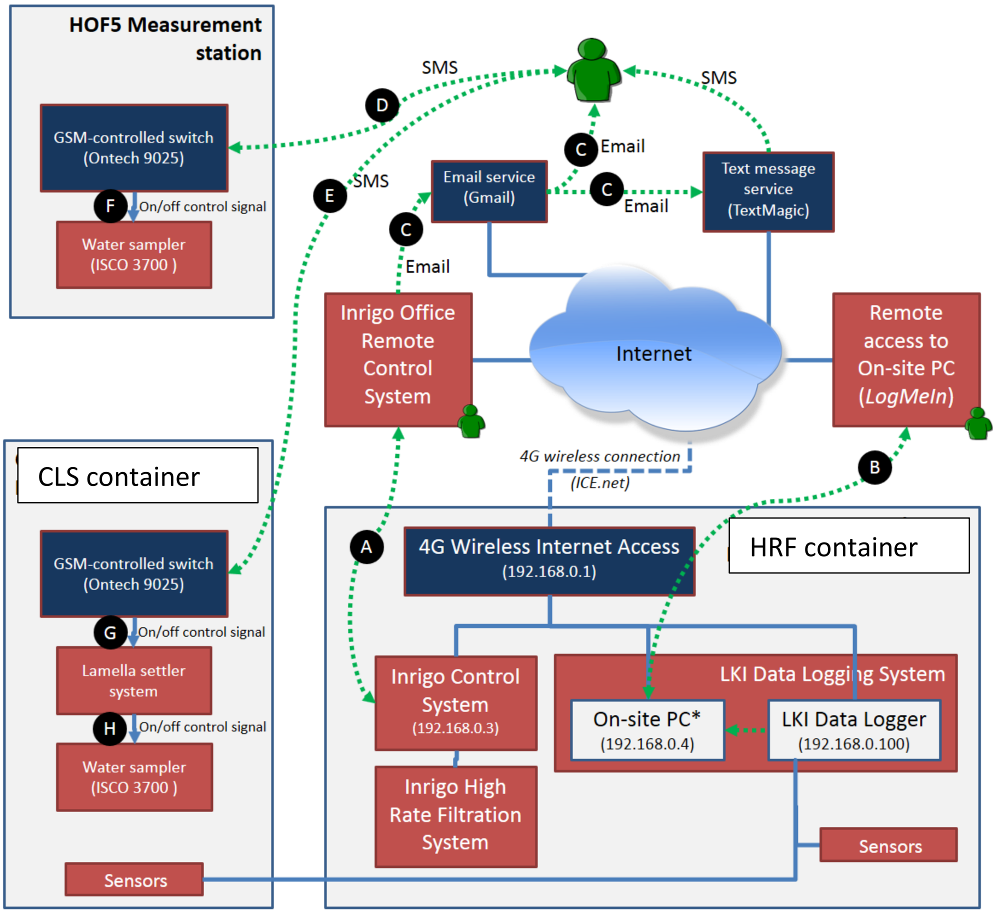


Figure 8 Communication system architecture of demonstration plants

The details of the communication infrastructure and service implementation are described in the subsequent sections, with Figure 8 presenting the overall communication architecture. Letters A to E are used to denote the main five services, while letters F to H denote internal control signals.

2.4.1 Wireless Internet Access [letters A and B]

To provide wireless access to both Inrigo's on-site Control System (letter A) and LKI's on-site PC (letter B), the container has been equipped with a wireless internet connection using a public cellular network (ice.net). The basic component of this service is a broadband modem/router (4G Smart router A1) which accesses the internet using the cellular network, and provides in-container coverage using either Wi-Fi or Ethernet. Both the Inrigo Control System and the LKI on-site PC are connected to the router using Ethernet.

To ensure that loss of connection will be discovered, an online monitoring service from Anturis (www.anturis.com) is installed on the on-site PC. Thus, if the connection to the on-site PC is lost for more than 30 minutes, this will be reported to the project team.

2.4.2 SMS and email alarms in the event of an CSO [letter C]

CSO events will be detected by the Inrigo (HRF) Control System and subsequently being reported (using the 4G Wireless Internet Access) to the Inrigo Office Remote Control System (letter A). To inform the project team of an CSO event (letter C), the Inrigo Office Remote Control System will issue an email to a dedicated email account (hosted by Gmail, www.gmail.com). This notification email will then be forwarded to the relevant project members both by email and SMS, the latter by using an email-to-SMS service provided by TextMagic (www.textmagic.com). Hence, the project team will immediately be informed of any CSO event.

2.4.3 Remote control of water sampler in the HOF5 Measurement Station [letters D and F]

The ISCO 3700 water sampler at HOF5 can be remotely activated and deactivated (letter F) by SMS commands (letter D). The SMS activation is implemented using an Ontech 9025 SMS-controlled switch, and an SMS to activate the ISCO 3700 water sampler is typically sent after receiving an SMS alarm indicating an CSO event (letter C).

Technically, the activation of the water sampler (letter F) is performed by having the Ontech 9025 SMS-controlled switch disconnect two connector pins of the ISCO 3700 water sampler. The water sampler has a 6-pin connector, labelled A-F by the manufacturer. When no operation is required (normal mode), Pin F of the water sampler is connected to ground (Pin B). To enable operation (sampling mode), the connection between Pin F and ground will be opened (i.e. disconnected).

2.4.4 Remote control of CLS settler [letters E, G and H]

The CLS control system is connected to an Ontech 9025 SMS-controlled switch, allowing the CLS settler system to be turned on and off (letter G) by SMS commands (letter E). As the CLS settler system is configured to operate autonomously, turning it on and off will typically be done only at the start and end of test periods.

The CLS control system is further connected to an ISCO 3700 water sampler by a 6-pin connector (letter H). By default, the control system connects Pin F of the 6-pin connector to ground (Pin B). When the control system is active, a water level switch will provide input on when to enable the water sampler. The activation of the water sampler is achieved by disconnecting Pin F from ground, making the water sampler start a pre-programmed sampling sequence.

3. Demonstration results

Four inline turbidity sensors are installed to monitor the particles' concentration of the influent and effluent, two for HRF plant and two for CLS plant, shown in Figure 7. The demonstration plants are also equipped with automatic sampling machines. During the CSO event, the sampling machines start automatically and take water samples according to the pre-setting time program.

TSS, COD, Turbidity, Ammonium, TN and TP were analyzed in selected water samples to document the treatment performance. All analyses were performed accordingly to Norwegian national or international standards. The water quality analysis was carried out by SINTEF lab.

3.1 CSO events during demonstration period

The HRF demonstration plant at Hoffselva was on duty, ready for CSO treatment since the beginning of September in 2015. It had recorded 11 CSO events until May of 2016. 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 show promising treatment efficiency of heavy metals with 48% Al, 48% Zn, 57% Cu, and 31% Cr removed respectively (Details see DESSIN Deliverable, D21.1).

The CLS demonstration plant was installed beside HRF plant for the parallel test at Hoffselva since September of 2016. There was no CSO event recorded from September to December of 2016 because of dry weather. Therefore, the demonstration period was extended to the end of September of 2017. There were 13 CSO events recorded on the extended demonstration period, shown on Table 1.

During the demonstration period at Hoffselva, the HRF plant operated at the maximum design filtration speed 42 m/h, while the CLS plant operated at projected surficial load 0.5 m/h because of limited CSO flow into intake manhole. The design projected surficial load is 4 m/h for CLS plant.

Because of system failures and limited CSO flow at the demonstration site, only the CSO event on 16.07.2016 has complete set of flow and water quality date for both HRF and CLS plants. The two plants where equipped with level sensors place in the intake pump manhole. The start set-point could not be set to exactly the same level due to different resolution of the level sensors. The difference in start set-points was smaller than 10 mm water level, however, when the first plant started the water level in the intake manhole would stop increasing or even decrease, and the second plant failed to start because the start set-point was not reached. This occurred on several occasions as seen in Table 1. Initially the CLS had a slightly lower set-point and the HRF failed to start on the CSO events 27th July and 4th August. The notification system (see section 2.4.2) was connected to the HRF, and the start set-point for the CLS was therefore increased by 1 cm to ensure that a notification would be sent when there was a CSO event. However, none of the following CSO events were large enough to support running of both plants resulting in a series of events where the HRF started but the CLS failed to start due to limited flow into the intake pump manhole.

Table 1 CSO events during parallel test period (2017) at Hoffselva

Event date	Operational		Additional info
	HRF	CLS	
05.04.2017	No	Yes	CLS test run
18.05.2017	Yes	Yes	HRF started; CLS started; CLS outlet sampler was jammed, only 1 outlet sample was analyzed
10.06.2017	Yes	Yes	HRF started; CLS started; CLS sampler had problem, no samples were sent to the lab
16.07.2017	Yes	Yes	HRF started; CLS started; complete set of flow and WQ data for both HRF and CLS
27.07.2017	No	Yes	CLS started; HRF failed to start (not enough water in intake manhole); no WQ samples were sent for analysis
04.08.2017	No	Yes	CLS started; HRF failed to start (not enough water in intake manhole); no WQ samples were sent for analysis
09.08.2017	Yes	No	HRF started; CLS failed to start (not enough water in intake manhole); no WQ samples were sent for analysis
15.08.2017	Yes	No	HRF started; CLS failed to start (not enough water in intake manhole); no WQ samples were sent for analysis
18.08.2017	Yes	No	HRF started; CLS failed to start (not enough water in intake manhole); no WQ samples were sent for analysis
19.08.2017	Yes	No	HRF started; CLS failed to start (not enough water in intake manhole); no WQ samples were sent for analysis
09.09.2017	Yes	No	HRF started; CLS failed to start (not enough water in intake manhole); no WQ samples were sent for analysis
11.09.2017	Yes	No	HRF started; CLS failed to start (not enough water in intake manhole); no WQ samples were sent for analysis
12.09.2017	Yes	No	HRF started; CLS failed to start (not enough water in intake manhole); no WQ samples were sent for analysis

3.2 Online Turbidity measurement

During the parallel test period, online Turbidity data were recorded if both HRF and CLS plants started when the CSO event took place. The HRF plant operated under the design filtration speed 42 m/h, while the CLS operational surficial load was 0.5 m/h because of small CSO flow (the design surficial load was 4 m/h). Table 2 shows the online Turbidity separation efficiency of two plants. HRF plant has separation efficiency from 3.8% to 51.8% with average of 26%. CLS plant has separation efficiency from 4% to 16.2% with average of 9%. The Turbidity separation efficiency varies because of different CSO raw water quality of CSO events. Normally, higher raw water turbidity was responding to higher separation efficiency for both HRF and CLS plants.

On the other hand, the inlet CSO flow was very limited into the intake pump manhole, when both HRF and CLS were running, the water level decreased in the intake manhole, resulting the stop of HRF inlet pump. HRF inlet pump started again when the water level increased, and then repeated stopping and starting. The inlet turbidity measurement of HRF became incorrect because of noncontinuity flow. When the inlet flow stopped, particles in the raw water might settle down inside the measurement chamber of turbidity meter, the Turbidity measurement value became much lower. The HRF filter media also expanded when the flow stopped, affecting the particles separation efficiency. These might explain why HRF had much lower inline Turbidity separation efficiency when HRF and CLS plants were operated in parallel. During the HRF demonstration period on 2015-

2016, the inline Turbidity separation efficiency was between 43% and 84% with average of 53% for 11 CSO events when only HRF plant was operated.

Table 2 Water quality measurement condition and online Turbidity separation efficiency (2017)

Event date	Online Turbidity		Water quality analysis		Turbidity separation efficiency (%)*	
	HRF	CLS	HRF	CLS	HRF**	CLS***
05.04.2017	No	Yes	No	Yes	n.a.	8.5
18.05.2017	Yes	Yes	No	No	24.4	11.9
10.06.2017	Yes	Yes	No	No	3.8	8.2
16.07.2017	Yes	Yes	Yes	Yes	14.7	16.2
27.07.2017	No	Yes	No	No	n.a.	5.0
04.08.2017	No	Yes	No	No	n.a.	4.0
09.08.2017	Yes	No	No	No	10	n.a.
15.08.2017	Yes	No	No	No	27.4	n.a.
18.08.2017	Yes	No	No	No	39.2	n.a.
19.08.2017	Yes	No	No	No	48.8	n.a.
09.09.2017	Yes	No	No	No	37.1	n.a.
11.09.2017	Yes	No	No	No	51.8	n.a.
12.09.2017	Yes	No	No	No	59.1	n.a.

* Turbidity separation efficiency = (∑ online inlet Turbidity - ∑ online outlet Turbidity) / ∑ online inlet Turbidity
The online Turbidity data were recorded every 10 seconds during CSO event.
** HRF operated under the design filtration speed 42 m/h during test period.
*** CLS operational surficial load was 0.5 m/h during test period.

3.3 Lab analysis data

There is only one CSO event on 16.07.2017 with complete set of lab analysis data. Water quality parameters Turbidity, TSS, COD, Ammonium, TP and TN were analyzed for inlet and outlet samples of HRF plant (Figure 9) and CLS plant (Figure 10). The sampling interval was one hour during CSO event.

Figure 9 and 10 also show separation efficiency of each CSO sample. Separation efficiency varied through the CSO event depending on the inlet CSO water quality. Besides, an overall separation efficiency concept is applied to understand the total pollution deduction through the whole CSO event.

Overall separation efficiency (%) = [Total inlet amount (mg) - Total outlet amount (mg)] ÷ Total inlet amount (mg) × 100%

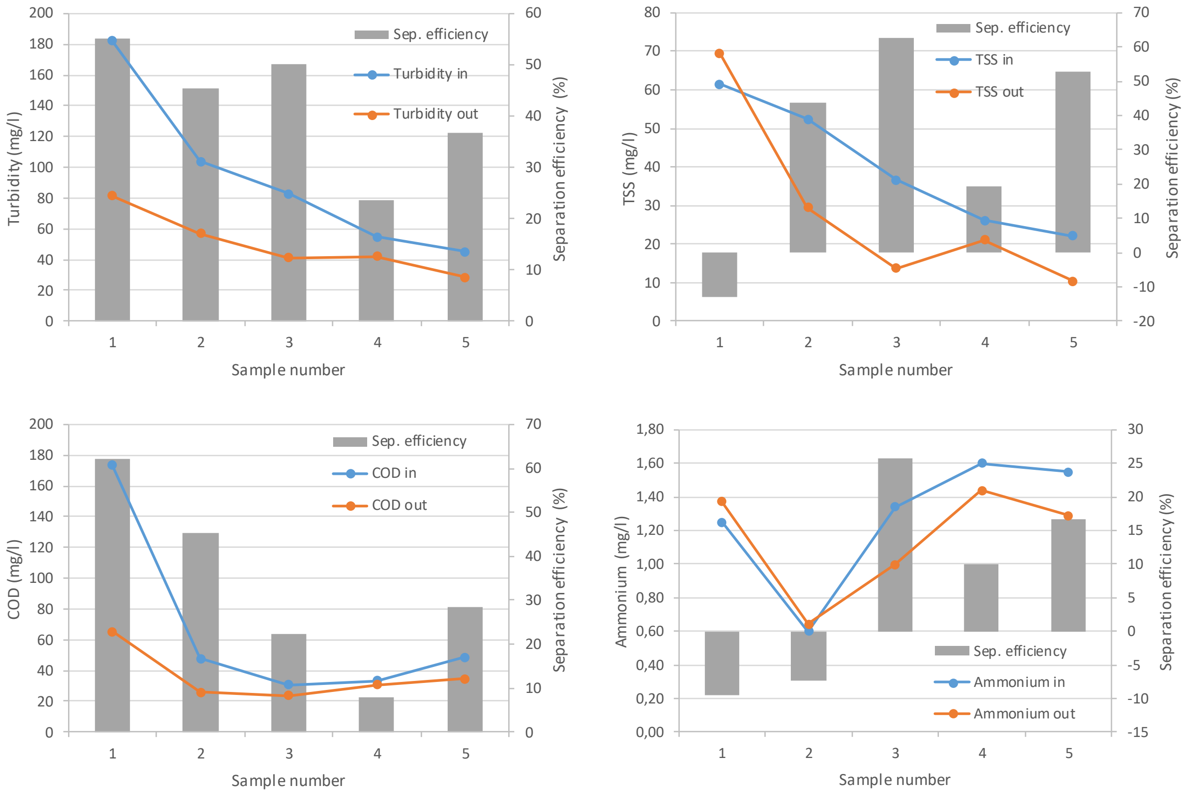
- Total inlet amount (mg) = ∑ [Inlet pollutant concentration (mg/l) (i) × sampling interval (h) (i) x flow (l/h)]
- Total outlet amount (mg) = ∑ [Outlet pollutant concentration (mg/l) (i) × sampling interval (h) (i)) x flow (l/h)]
- i = sample number

3.3.1 HRF plant water quality

Figure 9 shows the inlet and outlet water quality of HRF plant at CSO event on 16.07.2017. Turbidity, COD, TP and TN have the highest separation efficiency at the beginning of CSO event with highest inlet pollutants concentration, identified as first flush of CSO event. During the first flush, the turbidity separation efficiency was 55%, COD separation efficiency was up to 62%, TP separation efficiency was 38% and TN separation efficiency was 31%. However, a negative TSS separation efficiency was observed, which might be caused by a measurement error in the lab.

When considering the overall separation efficiency of the whole CSO event on 16.07.2017, overall Turbidity separation efficiency was 47%, overall COD separation efficiency was 46%, overall TSS separation efficiency was 27% (TSS separation efficiency 27% is uncertain data), the corresponding numbers for TP, TN and Ammonium were 27%, 14% and 9%, respectively.

Demonstration results indicate that the HRF plant can remove most of the bigger particulate pollutants from the CSO. After the storage volume has been filled, about 50% of TSS and COD can be separated by HRF system under the design filtration speed 42 m/h.



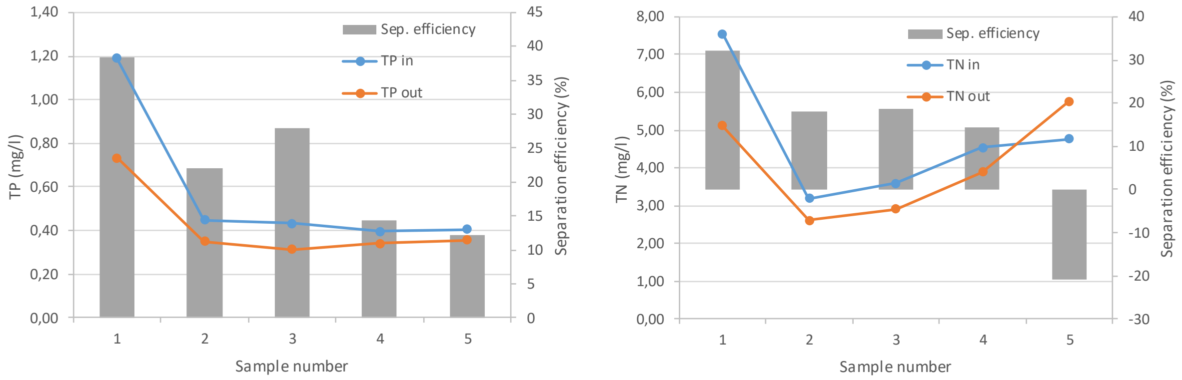
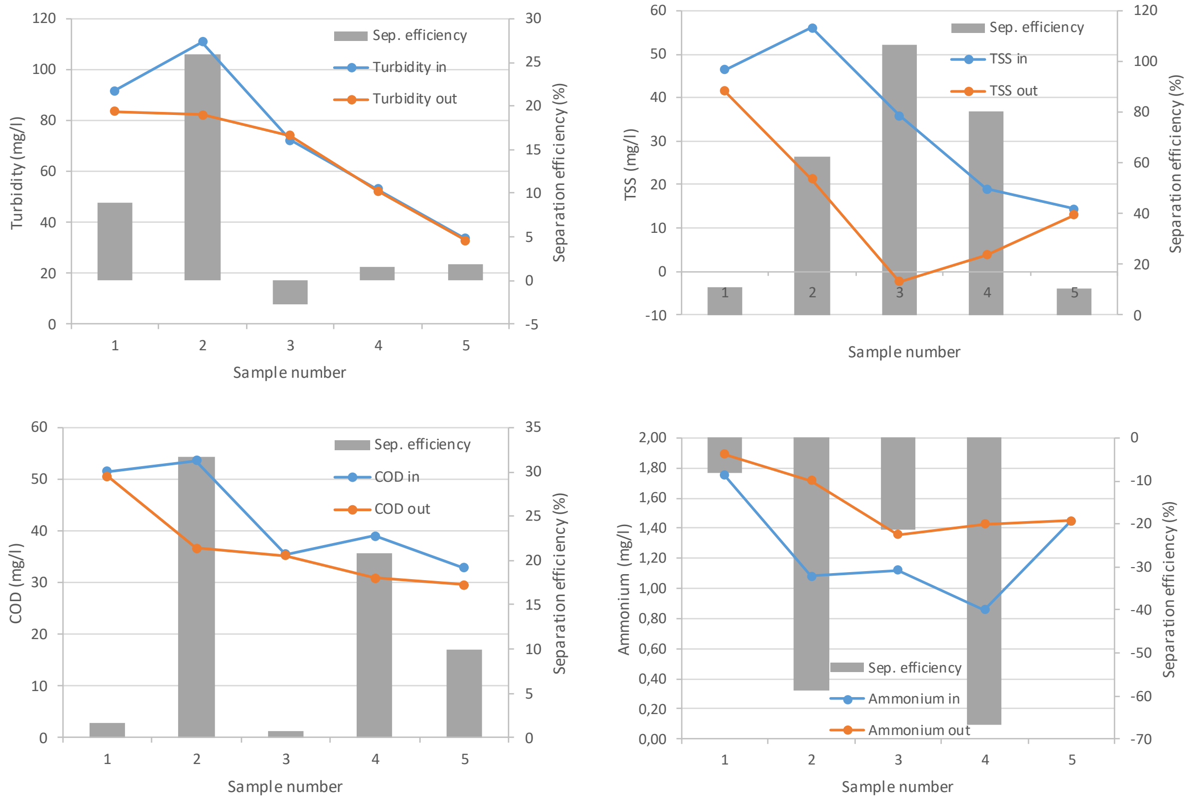


Figure 9 HRF plant water quality lab analysis on 16.07.2017

3.3.2 CLS plant water quality

Particulate pollutants in CSO can settle down in CLS plant and a separation efficiency may be achieved as shown in Figure 9. The overall Turbidity separation efficiency after the storage volume has been filled was 10% for the whole event on the 16th July. The corresponding numbers for COD and TSS were 13% and 55% (TSS separation efficiency 55% is uncertain data), respectively. TP, TN and Ammonium have negative overall removal values and can be considered as no removal.



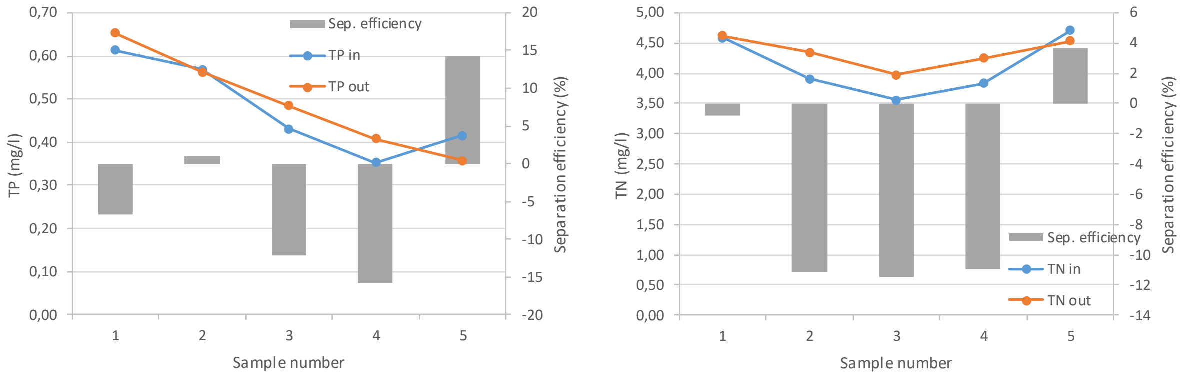


Figure 10 CLS plant water quality lab analysis on 16.07.2017

Since there is only one set of lab data available from parallel running of the HRF and CLS plants, one cannot conclude based on the laboratory samples alone. Also, when considering the total removal, one must consider the effect of the storage volume in the CSO tank. This has not been considered here but has been discussed in D32.2.

In the demonstration period at Hoffselva, the CLS operational surficial load was 0.5 m/h. With a surface load of 4 m/h (design value of CLS plant), a 10% separation efficiency of particulate pollutants (TSS and COD) after the storage volume has been filled may be expected based on the results from the online measurements during several CSO events reported in section 3.2 above.

4. Design criteria of CSO local treatment

Two innovative CSO local treatment technologies (HRF and CLS) have been demonstrated in Hoffselva. Hoffselva is a peri-urban catchment in Oslo, where there are 25 CSO locations. It will be a huge investment to apply local treatment to all the CSO locations. On the other hand, the local conditions are different for CSO sites. All the surrounding factors such as geological structure, soil types, underground pipe network, ground conditions, and buildings will influence the selection of optimized CSO treatment solution. The approach to solve the CSO problem in Hoffselva should be step by step and may require a combination of different methods.

Based on two years return period CSO flow modeling result in Hoffselva, Oslo VAV (water and wastewater department of Oslo municipality) points out three high priority (red) CSO locations (Ho6, Ho16, Ho61) for treatment. This report will propose two CSO local treatment solutions (HRF and CLS) for the three locations respectively, including plant dimension and investment cost.

It has been agreed that the design flow capacity of local treatment facility should be the maximum real-time flow of two years return period, shown in Table 3:

Table 3 High priority CSO locations with maximum flow at Hoffselva

CSO location	Maximum CSO flow, m^3/h
Ho6	909
Ho16	680
Ho61	580

4.1 HRF design criteria

High rate filtration (HRF) system for CSO local treatment is a prefabricated underground manhole type modular plant. Treatment capacity increases by adding more manhole modules, shown in Figure 11. Normally, the modular plant consists of intake manhole (yellow), filter manhole (green), and valves & control manhole (blue). The intake manhole (yellow) can be neglected if the gravity inlet flow is available.

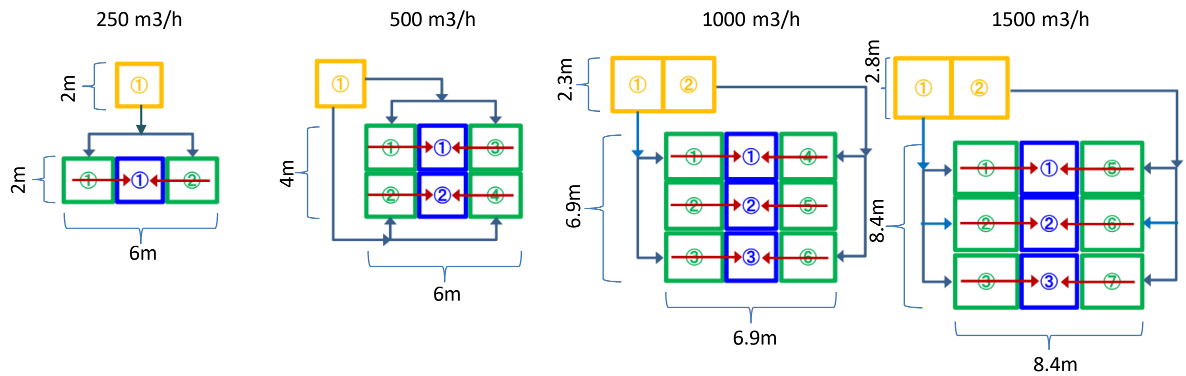


Figure 11 HRF manhole type modular plant

The HRF system for CSO treatment has a filtration speed of 42 m/h. The plant surface area and structure volume are related to the treatment flow capacity. Figure 12 shows the linear correlation between flow capacity and plant dimension (area and volume).

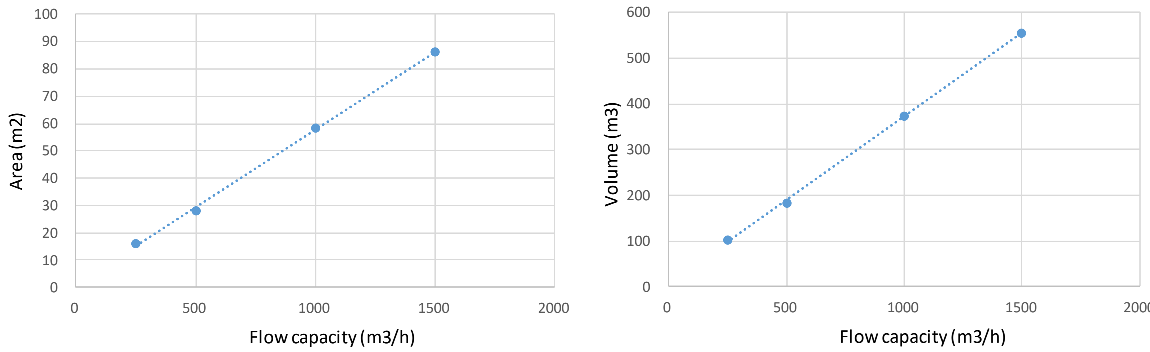


Figure 12 Correlation between flow capacity and HRF plant dimension (area and volume)

The investment cost also has linear correlation with flow capacity (Figure 13). Investment costs includes all the equipment such as the pre-fabricated (concrete) modular manhole, filter media, valves and control cabinet, etc. Plant Investment cost currently excludes installation cost, tax, civil work cost, transportation, and piping cost outside HRF plant.

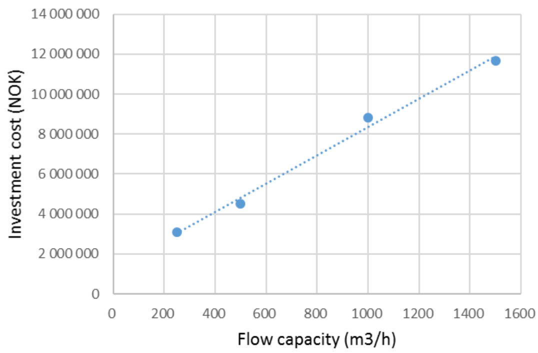


Figure 13 Correlation between flow capacity and HRF plant investment cost

The operational cost includes water consumption cost used for HRF cleaning. Manhour operational cost comes from plant inspection once per month, which is the same for all size HRF plants. The total operational cost is about 30 000 - 40 000 NOK/year for each plant. Pumping energy consumption is about 0.052 kwh/m^3 when gravity inlet flow is not available. The HRF plant dimension and investment cost has been summarized in Table 4 for high priority CSO locations at Hoffselva.

Table 4 The design criteria and investment cost of HRF plant for Ho6, Ho16, and Ho61

CSO location	Capacity m^3/h	Plant surface m^2	Plant volume m^3	Investment cost* NOK
Ho6	909	53	339	7 433 266
Ho16	680	40	255	5 812 564
Ho61	580	34	218	5 104 834

*This cost must not be used as a price list! Each project requires individual calculation.

4.2 CLS design criteria

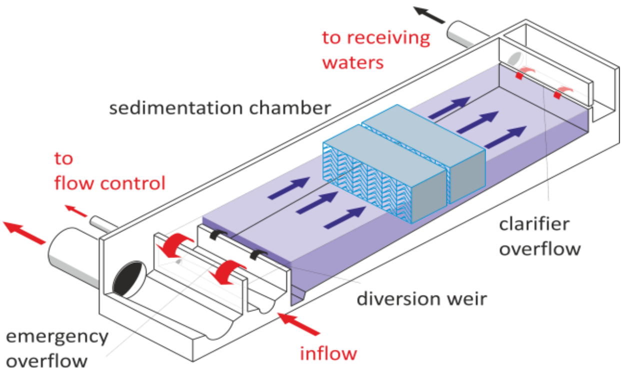
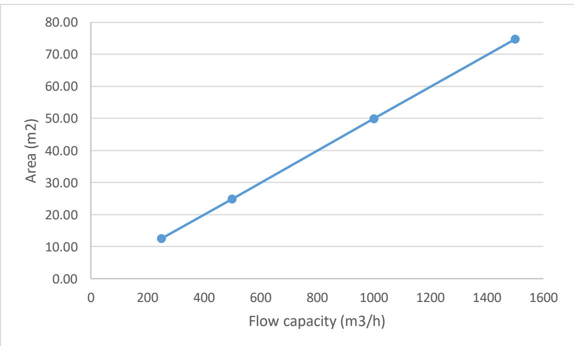


Figure 14: CLS settler installed in underground container

The cross-flow lamella (CLS) settler can be installed underground inside CSO container (Figure 14). The design sedimentation surficial load is 4 m/h for CSO treatment (Surficial load was 0.5 m/h during demonstration at Hoffselva). The lamella projected settling surface can be calculated by:

Projected settling surface = flow capacity ÷ sedimentation surficial load

The CLS plant dimension is correlated to the projected settling surface. Roughly, 6 m^2 projected settling surface need 1 m^3 installation volume and 1.75 m^3 service volume. The CLS plant has 2.3 meter in Height. For example, for CSO treatment capacity 1000 m^3/h, projected settling surface is 1000 m^3/h / 4 m/h = 250 m^2. The lamella installation volume is 250/6= 42 m^3, service volume is 42 x 1.75=73.5 m^3, the total CLS plant volume is 42 +73.5 = 115.5 m^3, the plant surface area is 115.5 / 2.3 = 50.2 m^2. Figure 15 shows the linear correlation between flow capacity and CLS plant dimension (area and volume).



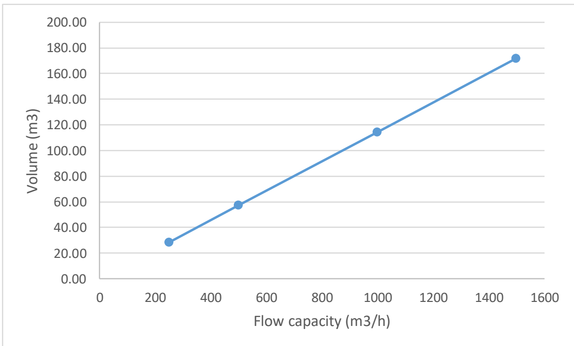


Figure 15 Correlation between flow capacity and CLS plant dimension (area and volume)

The investment cost of CLS plant mainly includes lamella plate cost, concrete container cost and control cabinet cost. the lamella plate cost can be calculated from Figure 16. The concrete container cost is estimated about 20 000 NOK/m^3. The control cabinet is about 400 000 NOK each. The total investment cost has a linear correlation with flow capacity of CLS plant, shown in Figure 17. Plant Investment cost currently excludes installation cost, tax, civil work cost, transportation, and piping cost outside CLS plant.

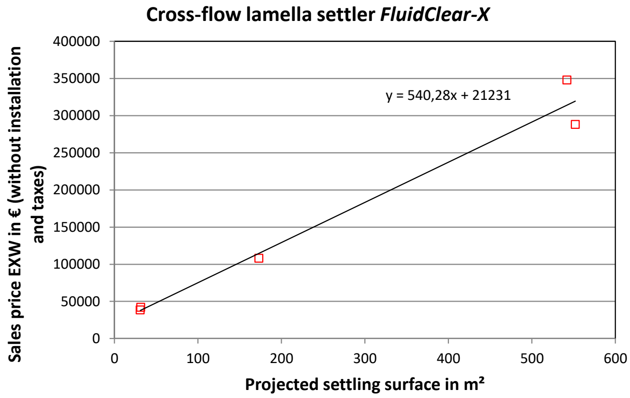


Figure 16 Lamella plate cost

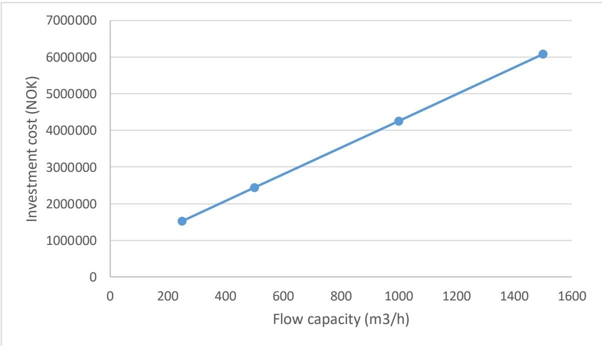


Figure 17 Correlation between flow capacity and CLS plant investment cost

The operational cost is given mainly for tap water cleaning and electrical power consumption. Manhour operational cost comes from plant inspection once per month, which is the same for all size CLS plants. The total operational cost is about 30 000 - 40 000 NOK/year for each plant. The CLS plant dimension and investment cost has been summarized in Table 5 for high priority CSO locations at Hoffselva.

Table 5 The design criteria and investment cost of CLS plant for Ho6, Ho16, and Ho61

CSO location	Capacity m^3/h	Plant surface m^2	Plant volume m^3	Investment cost* NOK
Ho6	909	45	104	3 922 585
Ho16	680	34	78	3 088 643
Ho61	580	29	66	2 724 477

*This cost must not be used as a price list! Each project requires individual calculation.

4.3 Design summary

Table 6 The design summary of HRF and CLS plants for CSO local treatment

Questions	HRF	CLS
What is needed of space (footprint and volume) underground?	See section 4.1	See section 4.2
Need power supply?	Yes	Yes
Need clean water supply?	Yes	Yes
What is needed of operation and how often (in the field)?	Once per month	Once per month
Can the plants be remote controlled and monitored?	Yes	Yes
What is the treatment (separation) efficiency on first flush?	100% removal during the storage volume filling, after that up to 80% SS removal and 75% COD removal, see deliverable D21.3	100% removal during the storage volume filling, after that no data available for 4 m/h surface load, see deliverable D31.1 for more information
What is the treatment (separation) efficiency on average?	50% for TSS and COD	10% for TSS and COD
What loading rate can the plants tolerate?	42 m/h filtration speed	4 m/h lamella sedimentation surface load
To what degree do the plants withhold sewage garbage and for how long?	Sewage garbage will be removed and sent back to sewer after each CSO event	Sewage garbage will be removed and sent back to sewer after each CSO event
How will sludge management be (what, how often, how etc.)?	Sludge will be discharged back to sewer after each CSO event	Sludge will be discharged back to sewer after each CSO event
Investment cost?	See section 4.1	See section 4.2
Expected lifetime and LCC?	10 years for valves, pumps, and filter media, etc.	10 years for valves, pumps, etc.
Suitability for small CSOs (small diameter pipes, limited flows)?	Yes	Yes
Suitability for large CSOs (main sewers, culverts, tunnels, etc.)?	Yes	Yes
Treatment efficiency is measured for particles (SS). Will it be possible to analyses also Tot-P, COD and TKB/E.coli?	See section 3.3.1	See section 3.3.2

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5. Conclusion

The innovative high rate filtration (HRF) system and cross-flow lamella settler (CLS) have been demonstrated in parallel for CSO local treatment at Hoffselva. The demonstration results indicate that the HRF plant has 50% separation efficiency for particulate matter after the storage volume has been filled, while the corresponding value for the CLS plant was 10%. The overall total removal for *e.g.* TSS and COD will be influenced by the storage volume in the two solutions and this has not been assessed here. Local CSO treatment can be considered as an effective method to reduce the emission of particulate pollutants into the river. At the end, design criteria including plant dimension and investment cost, are proposed for HRF and CLS local CSO treatment technologies based on high priority CSO locations at Hoffselva.

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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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