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High rate filtration for local treatment of combined sewer overflow

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ABSTRACT

Combined sewer overflows (CSOs) pollute receiving waters and have a negative impact on ecosystem services. In urban areas rehabilitation of the sewer system to avoid CSOs is associated with high investment costs. Furthermore, not all CSOs can be closed due to the need for hydraulic reliability of the system. Local treatment of CSO with high rate filtration offers an alternative to rehabilitation of the sewer system that is flexible with respect to design and has lower investment cost than separating sewage and storm water runoff. Results from DESSIN, a 4-year EU demonstration project, are presented. The results showed on average 50% removal of particulate matter during CSO events, with higher removal (80%) in the initial first flush period. Other constituents, for example heavy metals, were removed through their association with particles. Potential impacts on ecosystem services in the catchment and the sustainability of the solution were assessed.

Key words | combined sewer overflow, high rate filter, on-site treatment

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INTRODUCTION

State of the art in combined sewer overflow (CSO) technology for large scale sewers consists of sedimentation in the CSO tank, which is not sufficient to ensure retention of pollutants. Some studies include further treatment, for example with disinfection of treated effluent (Tondera *et al.* 2016) or constructed wetlands (Masi *et al.* 2017) However, this may require large areas, and in smaller sewer systems CSOs are commonly without a tank. Ochowiak *et al.* (2017) investigated a swirl sedimentation tank, but in most solutions no, or very limited, particle removal is achieved due to lack of a settling volume. The priority in CSO management is to reduce the overflow volumes, which can be done for example by separating wastewater and stormwater pipes. However, due to hydraulic reliability, not all CSOs can be removed. There is therefore a need for solutions that can limit the discharge from CSOs to recipient waters.

The EU project DESSIN (DESSIN 2014) has developed innovative solutions to the common challenge of poor water quality in receiving waters caused by CSO overflows. The solutions were tailored to local characteristics of a catchment and have been demonstrated in the highly urbanised Emscher area in Germany and the peri-urban Hoffselva catchment in Oslo, Norway. The aim was to demonstrate that such measures could considerably improve the water quality of the recipient water bodies and support the implementation of the European water framework directive (WFD).

In this paper an innovative high rate filtration (HRF) system, which has been developed by METAWATER Co., Ltd from Japan and Inrigo AS from Norway, is presented. An HRF pilot plant was built to investigate and demonstrate the efficiency for treatment of CSO. The HRF plant was placed at Hoffselva, an area in Oslo with a total of 22 CSOs in the sewer system. These CSOs discharge to the Hoffselva river, which is associated with important cultural

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and recreational values for the community. Downstream of the Hoffselva catchment there is a sewage tunnel transporting wastewater to a central wastewater treatment plant (WWTP). The WWTP is planned for expansion, and the sewer system is continuously upgraded and rehabilitated. However, there will still be a need for measures in the catchment to reduce impacts of CSO events and improve the quality in the receiving Hoffselva river.

METHODS

The HRF system for CSO (Figure 1) (Sun 2017) has a filter bed with special floating filter media in the shape of small crosses of a plastic material. The filter media is designed to have optimal shape to capture debris, organic material (chemical oxygen demand (COD)) and total suspended solids (SS), and with a high void ratio to give a low pressure drop during operation. The media material is acid and alkali proof, which enables treatment of feed water with various quality. There is no chemical addition or pre-treatment required for the HRF system. During the operation, switching between filtration and backwashing is done by a backwash valve which is closed and opened, controlled by inlet water level detection. Feed water flow is not stopped during backwashing.

The motorised equipment consists of inlet pumps (no pumps needed if gravity flow is available) and a compressor for pneumatic valves. During rainfall, CSO raw water comes from the distribution channel flowing upwards through the filter bed. Debris is removed on the surface, and SS and COD are removed also inside the filter bed. As the filter media becomes clogged, the water level on the influent side will rise due to the increased pressure drop over the filter bed. When the water level has increased to a predetermined set-point, a high-speed drain valve opens automatically and starts backwash. Filtrated water flows downward by gravity and discharges debris, SS and COD accumulated in the filter media. The backwash requires only a minute to clean the filter bed of sludge, and no filter media flows out during backwash.

An HRF pilot plant was put in operation at a CSO in the Hoffselva catchment in Oslo, Norway. This is a peri-urban catchment with forested areas in the upper part and increasingly urbanised areas as one follows the Hoffselva river towards the outlet in the Oslo fjord. The middle section has residential housing, and there are office buildings and industry in the lower part. The HRF pilot plant was placed at a CSO in a residential area with runoff mainly from gardens and paved surfaces. During the 2-year operation period, the plant started when the water level in the sewer increased to the level where the CSO became active and ran until the level fell after the rain event.

The pilot plant was equipped with online sensors for turbidity in the inlet and outlet water, and pressure sensors

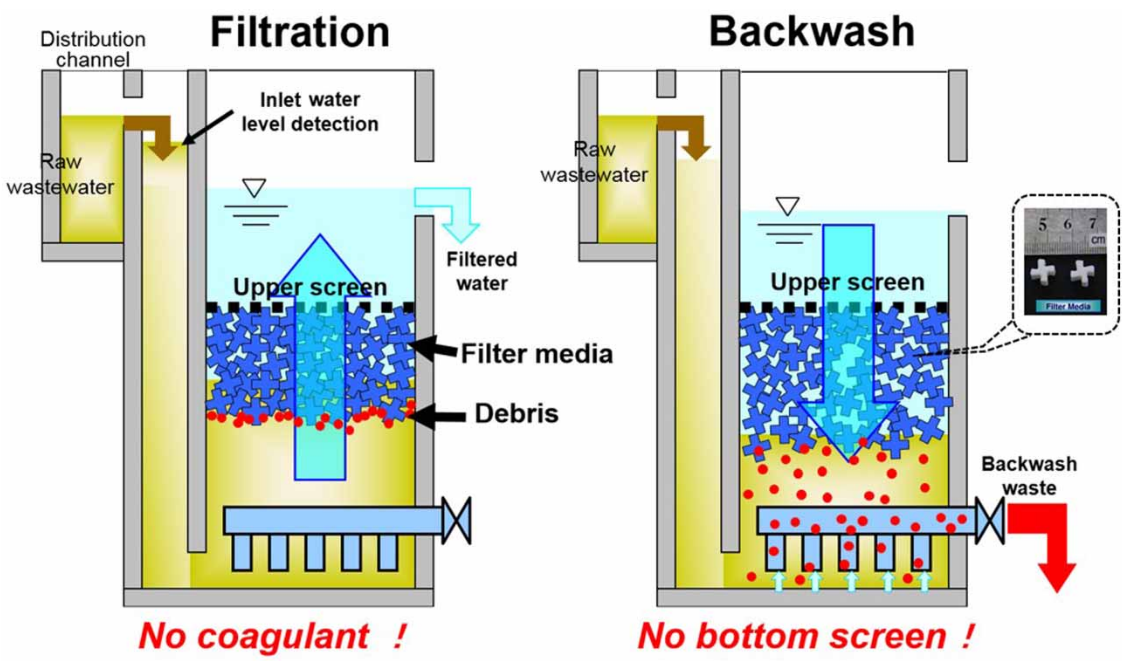

Figure 1 | Illustration of the high rate filter for CSO treatment with detailed picture of filter media.

to monitor water levels and pressure drop in the filter. Inlet and outlet water samples were collected with automatic samplers placed in refrigerators and sent for laboratory analysis of SS and COD. Total phosphorus (Tot-P), total nitrogen (Tot-N) and metals: aluminium (Al), zinc (Zn), copper (Cu) and chromium (Cr) were analysed on selected samples. Water samples were also collected in the downstream section of Hoffselva at Skøyen, and sent for laboratory analysis of SS, COD, Tot-P and Tot-N. All analyses were performed according to Norwegian Standards.

The effect of implementing local CSO treatment with the HRF system in the Hoffselva catchment and the sustainability of the solution were evaluated based on the results from the demonstration period using a tool for ecosystem services evaluation and sustainability assessment developed in DESSIN (Anzaldua *et al.* 2018).

RESULTS AND DISCUSSION

A total of 24 CSO events have been recorded during the testing and demonstration period, from September 2015 until September 2017 (Sun 2017; Sun *et al.* 2018). During the test period, online turbidity data were recorded when the CSO event took place. Figures 2 and 3 show typical development of online data.

The instantaneous separation efficiency typically varied between 20% and 80%, The turbidity separation efficiency varied with different feed water quality during the CSO events. Normally, higher feed water turbidity corresponded to higher separation efficiency. Mean turbidity separation efficiency in the demonstration period was 53%. As expected, removal of suspended solids followed the same trend as turbidity. Analysis of water samples collected at different filtration times demonstrated that up to 80% removal of suspended solids (SS) (Figure 4) and 75% removal of COD (data not shown) was achieved during the first flush. During a typical CSO event with an average SS removal of 56% in the HRF, the average COD removal was 47% (Figure 5). This is in accordance with Ødegaard *et al.* (2003) who reported SS removal efficiencies of around 75% for coarse media filtration of wastewater without use of chemicals for enhanced separation.

The nutrient removal (data not shown) was relatively low because the major nitrogen and phosphorus species in the CSO feed water were soluble. The HRF solution showed promising treatment efficiency for heavy metals, with removal efficiencies of 48% for Al and Zn. Corresponding data for Cu and Cr were 57% and 31%, respectively. Aryal *et al.* (2010) reported that iron, aluminium, copper, and zinc were significantly reduced in high rate treatment of stormwater in a fibre filter with inline flocculation using ferric chloride ($FeCl_3 \cdot 6H_2O$).

Rakings and gravel in the CSO were not a problem during the demonstration. In general, the design of the HRF should provide access to the bottom of the filter chamber for periodic maintenance. The upwards flow through the filter bed will allow for example gravel to settle to the bottom of the filter chamber where settled material that is not removed in the normal backwashing of the filter bed can be removed periodically.

The effect of implementing local CSO treatment with the HRF system in the Hoffselva catchment was evaluated for two levels of implementation based on the results from the demonstration period. The CSOs in the catchment had

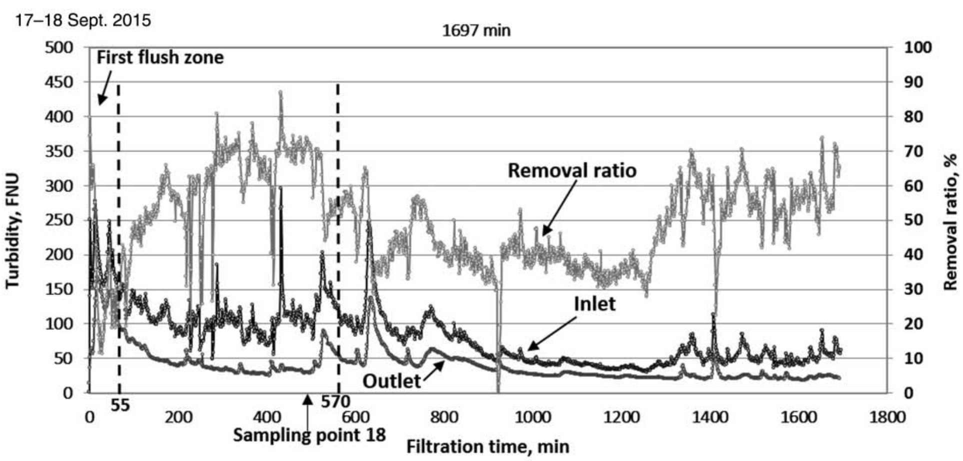

Figure 2 | Online data for inlet and outlet turbidity and calculated instantaneous separation efficiency.

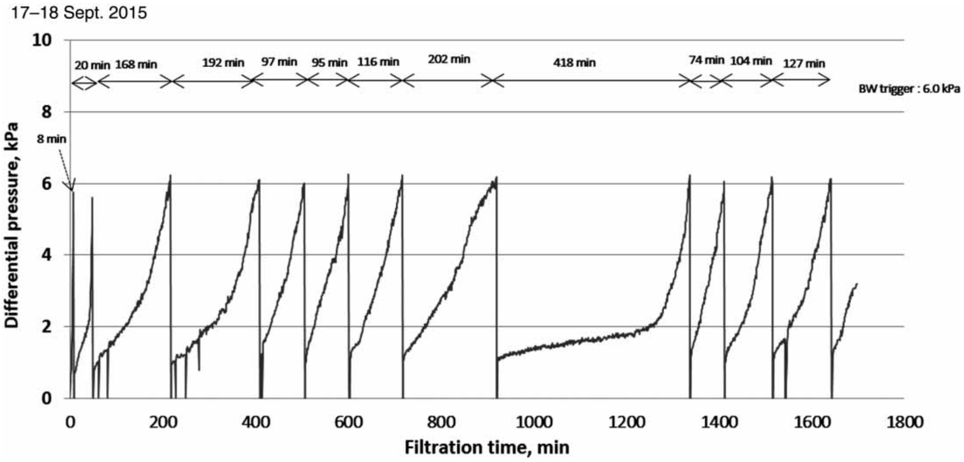

Figure 3 | Online data for pressure drop (BW: backwash).

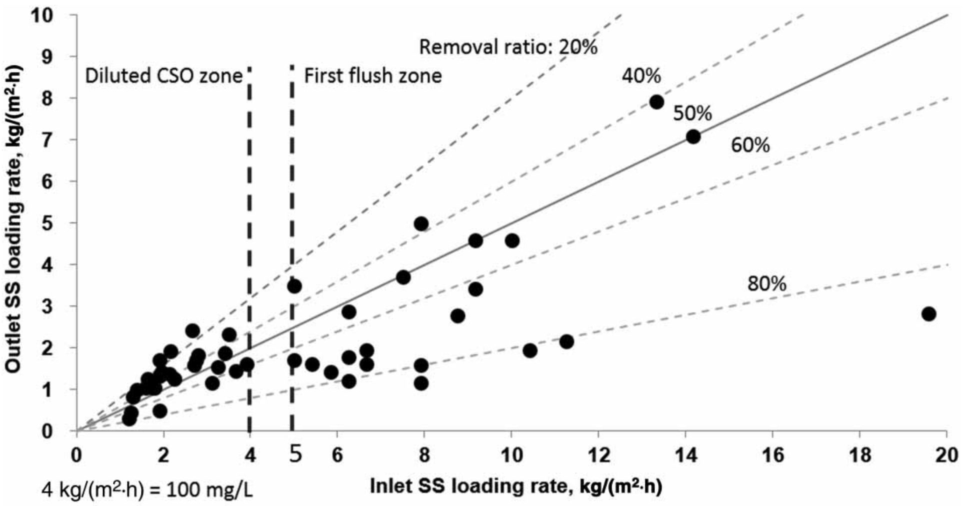

Figure 4 | Suspended solids loading rate of all CSO samples.

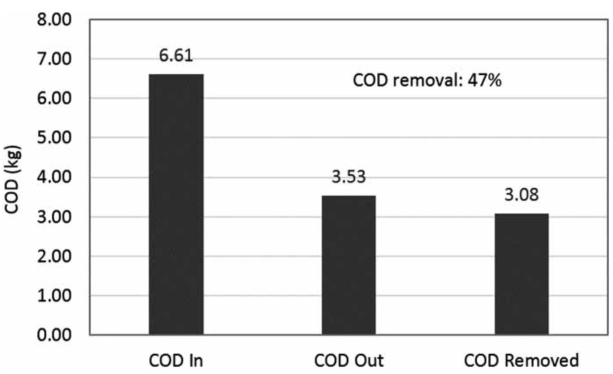

Figure 5 | Overall COD removal during a CSO event.

been classified according to undesired impacts according to a multicriteria risk evaluation, and grouped in 'red', 'yellow' and 'green' categories (Figure 6) where the 'red' category had the highest risk of undesired impacts. In the evaluation, a case with implementation of the HRF solution at all the CSOs classified as red was compared to a case where the HRF solution was implemented at all CSOs classified as red or yellow.

The designs of the HRF solution for the CSOs were based on the flows of a CSO event with a 2-year return period (Sun *et al.* 2018). Implementation of these designs according to the two cases were thereafter evaluated with respect to effects on two different rains with return periods of 2–3 months and 1 year that had occurred during the demonstration period. In addition, the 2-year rain was evaluated.

The HRF solution was assessed with regard to technical performance and potential effect on river water quality, benefits and co-benefits in terms of ecosystem services

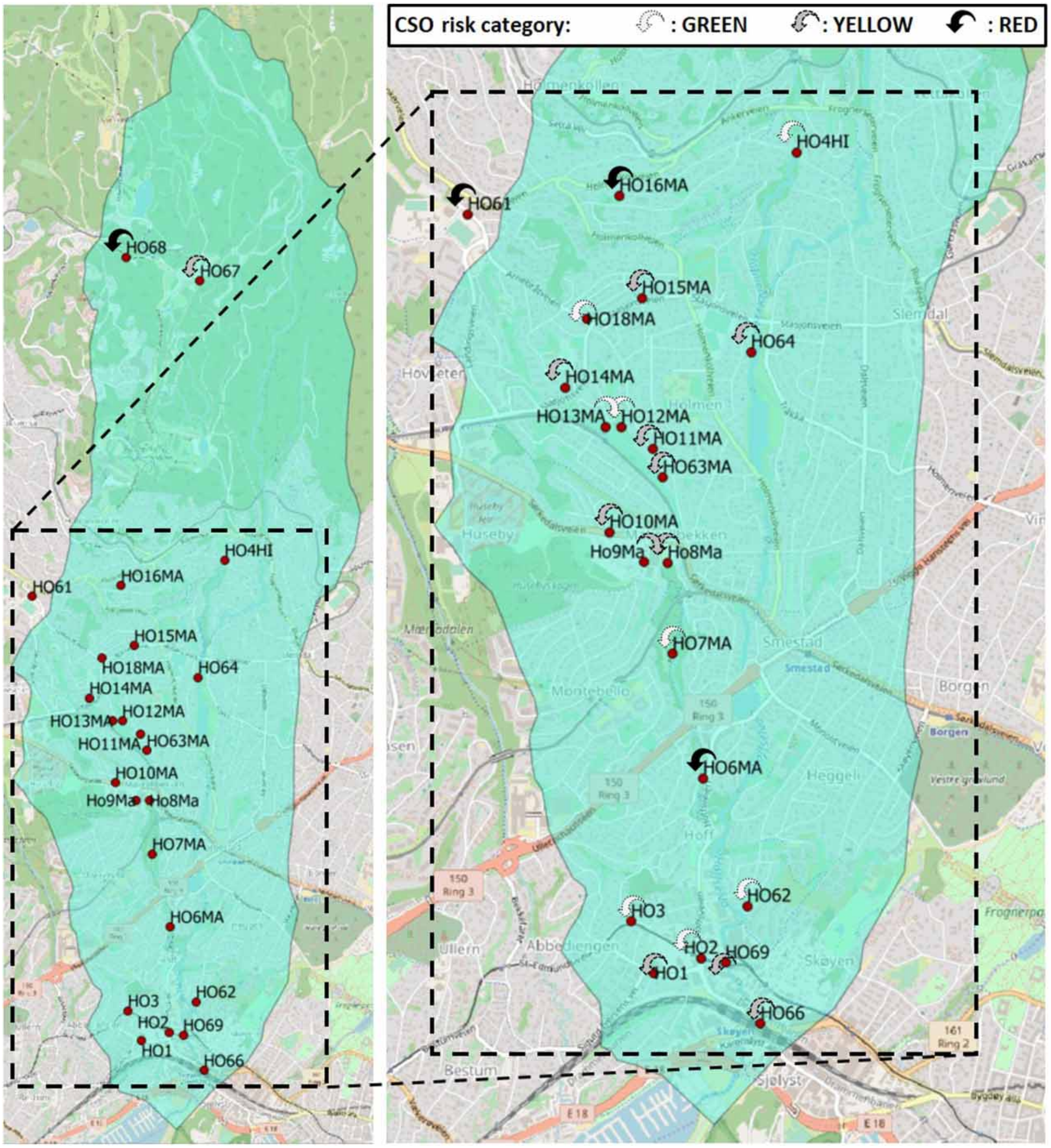

Figure 6 | Classification of the CSOs in the Hoffselva catchment according to a multicriteria assessment of risk of undesired impacts. 'Red' classification indicates the highest risk and 'green' classification indicates the lowest risk. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wst.2019.121.

(ESS) provided by the river, and the sustainability associated with the life-cycle of the technology itself (Helness *et al.* 2018). In the evaluation of ESS, a value of 252 mg SS/L was applied as a typical peak concentration of suspended solids in the Hoffselva river during situations with CSO discharge before any implementation of the solutions. Similarly, a value of 8 mg SS/L was applied as a typical concentration of SS during conditions without any CSO discharge.

An estimate of the concentration during CSO discharge with distinct levels of implementation of the HRF solutions was found based on the reduction in mass discharge. The accumulated discharge from a CSO with an HRF solution will be the combined effect of storage volume introduced by the HRF solution and the discharge by the filter effluent after the volume is filled (Figure 7). For very short CSO events the volume may not be filled giving 100% reduction in mass load to the recipient, while for very long CSO

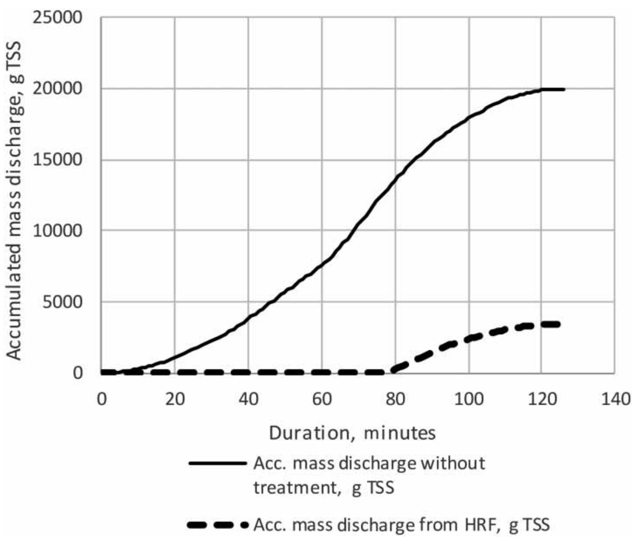

Figure 7 | Illustration of accumulated mass discharge from a CSO with and without implementation of an HRF solution for a given CSO event and HRF design.

events the mass load reduction will approach the 50% instantaneous separation efficiency of the HRF.

The results for the whole catchment confirmed the importance of storage volume and illustrated the importance of the degree of implementation. With the duration of the evaluated rain events, the separation technology, i.e. the HRF, was found to have a contribution of 10–21% to the total mass load reduction in the whole catchment, which was 27–86%. The results also indicated, as expected, the highest improvement for the implementation alternative with most CSOs, with 73–86% mass load reduction compared to 27–59% for the alternative with only CSOs classified as red.

The potential value of reduced discharges from CSO for beneficiaries was substantial. It was related both to regulation & maintenance and to cultural ESS categories. Considering the direct effects of the demonstrated solution, the cultural ESS associated with aesthetic appreciation of the river water itself and riverbank area, i.e. ESS associated with transparency of the river water, and the visual impression of the water and riverbank were most significantly influenced by removal of particles and sewage garbage and therefore considered most improved.

Using the DESSIN ESS assessment tool, the potential value to local beneficiaries were summarised adapting a structured qualitative assessment method with four steps: (1) identify impacts, (2) map their spatial range or 'physical' extent, (3) assess the importance of the impact to society, and (4) assess the overall impact or value of the measure in question, considering the results from the preceding steps (Table 1).

Applying the sustainability assessment module of the tool showed that the differences in sustainability indicators were mainly related to overall removal and compliance with the WFD versus investment and operational costs. Some sustainability indicators, e.g. population affected, could not be differentiated depending on the degree of implementation, and others measured specific properties of the solution, e.g. energy consumption per m^3, and were selected for comparison with the baseline (no implementation) and with other alternative solutions. As expected,

Table 1 | Consequence mapping for local CSO treatment in the case of Hoffselva

ESS category	ESS	Capability	Strength	Range	Value	Type of value
Regulation & maintenance	Water purification (visual impression)	SS and sewage garbage removal	++++	++++	++++	Indirect (use and non-use)
	Water purification (reducing odour)		+	+	+	Indirect (use and non-use)
	Maintaining populations and habitats (sustaining fish)	Sewage garbage and SS removal, and in addition removal of nutrients and other pollutants associated with particles	++	++	++	Indirect (use and non-use)
	Maintaining populations and habitats (preserve biodiversity)		+	++	++	Indirect (use and non-use)
Cultural	Aesthetic appreciation	SS and sewage garbage removal	++++	+++++	++++	Direct (non-use)
	Recreation	Sewage garbage and SS removal, and in addition removal of nutrients, other pollutants and bacteria associated with particles	+	+	+	Indirect (use and non-use)
	Spiritual, heritage preservation		+	++	++	Direct (non-use)

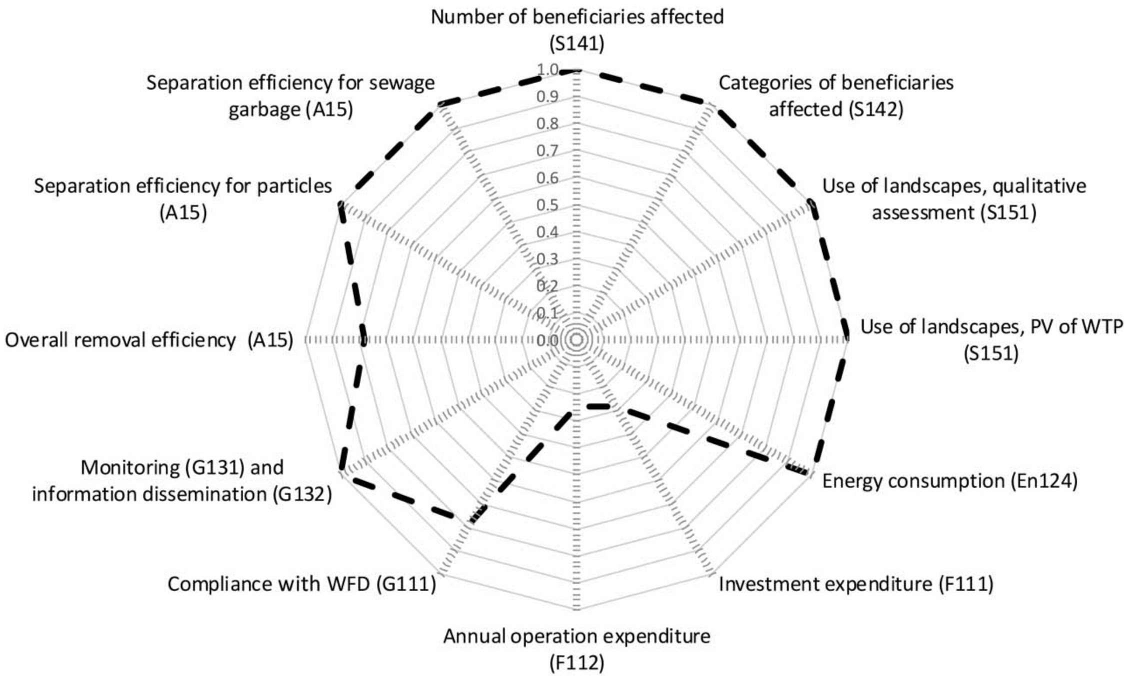

Figure 8 | The ratio of selected sustainability assessment indicators for the 'red' and the 'red + yellow' implementation cases (WTP: water treatment plant; PV: present value of investment). Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wst.2019.121.

these did not show differences in the comparison using ratios of selected sustainability assessment indicators for the two implementation cases (Figure 8).

CONCLUSIONS

The innovative high rate filtration system has been demonstrated for local CSO treatment at Hoffselva in Oslo, Norway. The results indicated that the HRF plant had 50% separation efficiency for particulate matter after the storage volume had been filled. The overall total removal for SS and COD will be influenced by the storage volume in the solution. Local CSO treatment can, however, be considered as an effective method to reduce the emission of particulate pollutants into the river.

The potential value of reduced discharges from CSO was substantial in the case of Hoffselva. It was related both to regulation & maintenance ESS and to cultural ESS. Considering the direct effects of the demonstrated solution, the Cultural ESS associated with aesthetic appreciation of the river water itself and riverbank area, i.e. ESS associated with transparency of the river water, and the visual impression of the water and riverbank were considered most improved.

The sustainability assessment of the two implementation cases showed that the differences were mainly related to overall removal and compliance with the WFD versus investment and operational costs. Other sustainability indicators selected for comparison with the baseline (no implementation) and with other alternative solutions did not, as expected, show differences between the two implementation cases.

The HRF solution demonstrated in DESSIN may be an addition to the 'toolbox' of alternative measures that a municipality may use for future adaptation of the water infrastructure, and the DESSIN ESS evaluation tool may be a useful supplement to the conventional evaluations of such measures.

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