DESSIN

DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

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D32.2: Hoffselva Demonstration: Improving water quality in the peri-urban Hoffselva area

Conclusions from the demonstrations with projected effects on water quality, ESS and sustainability

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TITLE OF THE REPORT

D32.2: Conclusions from the demonstrations with projected effects on water quality, ESS and sustainability: Conclusions from the demonstrations with projected effects on water quality, ESS, and sustainability of the demonstrated solutions and the overall governance/policy implications if local treatment of CSO overflows is implemented on catchment scale.

SUMMARY

The European water research project DESSIN demonstrates and promotes innovative solutions for challenges related to water scarcity and water quality, and a methodology for evaluation of ecosystem services (ESS) and sustainability. Innovative solutions are tested at five demo sites across Europe. The demo site owner at Hoffselva in Norway and the utility operating the sewer system, was the Water and Sanitation Agency of Oslo Municipality (VAV). Two solutions have been demonstrated in the Hoffselva demo. One is a high rate filter developed by the Norwegian company Inrigo AS (Inrigo) combined with on-line monitoring and wireless data communication supplied by the Norwegian company LKI. The other is a cross flow lamella settler developed by the German company Umwelt- und Fluid-Technik Dr. H. Brombach GmbH (UFT), also in combination with on-line monitoring and data communication from LKI. The potential value of reduced discharges from CSO for beneficiaries is substantial. It relates both to Regulation & Maintenance and to Cultural ESS. The results show that the differences between the two solutions are mainly related to the differences in the separation technologies. The differences in overall removal and thereby also compliance, can be expected to be larger between implementation alternatives than between solutions for a given implementation alternative. The solutions demonstrated in DESSIN may be additions to the 'toolbox' of alternative measures that Oslo VAV may use in assessing options for future adaptation of the water infrastructure, and the DESSIN ESS and sustainability assessment (SA) methodologies may give additional inputs to the traditional evaluations of alternatives.

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List of Acronyms and Abbreviations

Al	Aluminium
CLS	Cross-flow lamella settler
COD	Chemical oxygen demand
Cr	Chromiume
CSO	Combined sewer overflow
Cu	Copper
DN	Diameter
ESS	Ecosystem services
HRF	High rate filter
Inrigo	Inrigo AS
LKI	Leif Kølner Ingeniørfirma AS
NPRA	Norwegian Public Roads Administration
Ortho-P or PO_4-P	Ortho phosphate
PLC	Programmable logic controller
PV	Present value
SA	Sustainability assessment
TOC	Total organic carbon
Tot-P	Total phosphorus
TSS or SS	Total suspended solids
TSS fine	Fine total suspended solids
VAV	Water and Sanitation Agency of Oslo Municipality
UFT	Umwelt- und Fluid-Technik Dr. H. Brombach GmbH
WFD	Water framework directive
WTP	Willingness to pay
WWTP	Waste water treatment plant
Zn	Zinc

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Executive summary

The Hoffselva river (Oslo area, Norway) suffers from discharge of combined sewer overflow (CSO) during high rain events, with a negative impact on water quality and the recreational value of the area. Within DESSIN, two innovative solutions and their benefits to improve that situation were demonstrated: i) a high rate filter (HRF) developed by the Norwegian company Inrigo AS (Inrigo) combined with on-line monitoring and wireless data communication supplied by the Norwegian company LKI, and ii) a cross flow lamella settler (CLS) developed by the German company Umwelt- und Fluid-Technik Dr. H. Brombach GmbH (UFT), also in combination with on-line monitoring and data communication from LKI. The demo site owner at Hoffselva and the utility owning and operating the sewer system, was the Water and Sanitation Agency of Oslo Municipality (VAV).

On the one hand, the solutions were assessed with regard to their technical performance and potential, since no discharge to the river from the demo plants was allowed in the demonstration period, direct effect on river water quality, but also with regard to their benefits and co-benefits in terms of the Ecosystem Services (ESS) provided by the river, and with regard to their sustainability.

Water samples were collected in the downstream section of Hoffselva at Skøyen, and at the inlet and outlet of the demo plants. The performances of the demo plants were also monitored on-line with sensors for turbidity and operation parameters such as relevant water levels and pressure drops. The instrumentation, data logging and communication equipment facilitated remote monitoring and control of the demo plants.

In the evaluation of ESS, a value of 252 mg SS/l has been applied as a typical peak concentration of suspended solids in the river during situations with CSO discharge before any implementation of the solutions. Similarly, a value of 8 mg SS/l has been applied as a typical concentration of suspended solids during conditions without any CSO discharge.

An estimate of the concentration during CSO discharge with distinct levels of implementation of the two solutions has been found based on the reduction in mass discharge. Several sources of uncertainty have been identified. The results, however, illustrate the importance of the storage volume. The separation technologies, *i.e.* the CLS and the HRF, were found to have a relatively small contribution to the total load reduction. The results also indicated that the implementation alternative, *i.e.* the number of CSOs where the local treatment is implemented and the risk classification (see ch. 2.1.1.) of these, is of higher importance than the choice between the two solutions demonstrated in this study, *i.e.* implementation at many CSOs with the CLS solution will probably improve the conditions more than implementing at a few CSOs with the HRF solution despite a higher separation efficiency. As expected, the highest improvement is indicated for the implementation alternative with use of the solution with highest separation efficiency at most CSOs.

The potential value of reduced discharges from CSO for beneficiaries is substantial. It relates both to Regulation & Maintenance and to Cultural ESS. Considering the direct effects of the demonstrated solutions, the Cultural ESS associated with aesthetic appreciation of the river water itself and riverbank area, *i.e.* ESS associated to transparency of the river water, and visual impression of water and riverbank, were selected as final ESS.

The pair-wise comparisons of results show that the differences between the two solutions are mainly related to the differences in the separation technologies, but that the overall removal for a given implementation alternative, and thereby the effect on compliance, is similar. There are also some differences in energy consumption and costs. As expected, larger differences in costs are found in the comparison between implementation alternatives irrespective of solution. The differences in overall removal and thereby also compliance, can also be expected to be larger between implementation alternatives than between solutions for a given implementation alternative.

The solutions demonstrated in DESSIN may be additions to the 'toolbox' of alternative measures that Oslo VAV may use in assessing options for future adaptation of the water infrastructure, and the DESSIN ESS and SA methodologies may give additional inputs to the traditional evaluations of alternatives.

1. General introduction

Water scarcity and quality issues are a concern in many regions in and outside of Europe. New technologies may provide solutions for these issues. If the benefits of technical solutions are clear, they are more likely to be implemented.

The European water research project DESSIN demonstrates and promotes innovative solutions for water scarcity and water quality related challenges, and demonstrates a methodology for the evaluation of ecosystem services (ESS) and sustainability. Innovative solutions are tested at five demo sites across Europe.

Within the DESSIN project, a framework has been developed for the evaluation of changes in ESS and sustainability as a result of the implementation of new technical or management solutions (D11.2). This framework is applied on the five European demo cases. It is one of the first times that a harmonised evaluation framework for ESS and SA has been applied on several international cases at once.

This document contains the ESS and SA evaluation report of one of the demo cases. The evaluations have been conducted with the help of the DESSIN Cookbook (D11.2 Part A & B) There is also a specially developed ESS toolkit for the MIKE Workbench software (D23.3).

The objective of this report is to show how the technical solution(s) affect ecosystem services, and to perform an (economic) evaluation of the changes in ESS provision and use. Furthermore, the sustainability of the measure(s) is assessed and implications regarding governance and policy are discussed. After that, opportunities and challenges related to governance and policy are discussed, and novel financing mechanisms are proposed.

2. High rate filtration or cross flow lamella settling with monitoring and data communication for local CSO discharge treatment - Case Hoffselva

At Hoffselva, the demo site owner and the utility owning and operating the sewer system was the Water and Sanitation Agency of Oslo Municipality (VAV). The suppliers demonstrating solutions were the Norwegian company Inrigo AS (Inrigo) and Leif Kølner Ingeniørfirma AS (LKI), and the German company Umwelt- und Fluid-Technik Dr. H. Brombach GmbH (UFT).

In the DESSIN demo case at Hoffselva, local treatment solutions for discharge from combined sewer overflows (CSOs) have been demonstrated, combining technologies acting at local and system level to enable cost-efficient implementation of the EU water framework directive (WFD). DESSIN has gone beyond the state of the art by developing solutions to the common challenge of poor water quality caused by CSO overflows. These solutions have been tailored to the characteristics of the demo site:

i. A modular cross-flow lamella settling (CLS) unit for the local treatment of combined sewer overflows from tanks, developed by UFT;

ii. A high rate filter solution (HRF) that can be installed on the CSO outlet pipe for smaller structures without a holding tank, developed by Inrigo;

iii. An integrated instrumentation and data communication package for monitoring performance and operation of local treatment units, supplied by LKI.

Either of the treatment technologies combined with the instrumentation and data communication constitute solutions for local treatment of CSO and are evaluated in this report using the ESS and sustainability assessment (SA) methodology developed in DESSIN.

An overview of how the solutions have been evaluated with the ESS and SA methodology is shown in Figure 1.

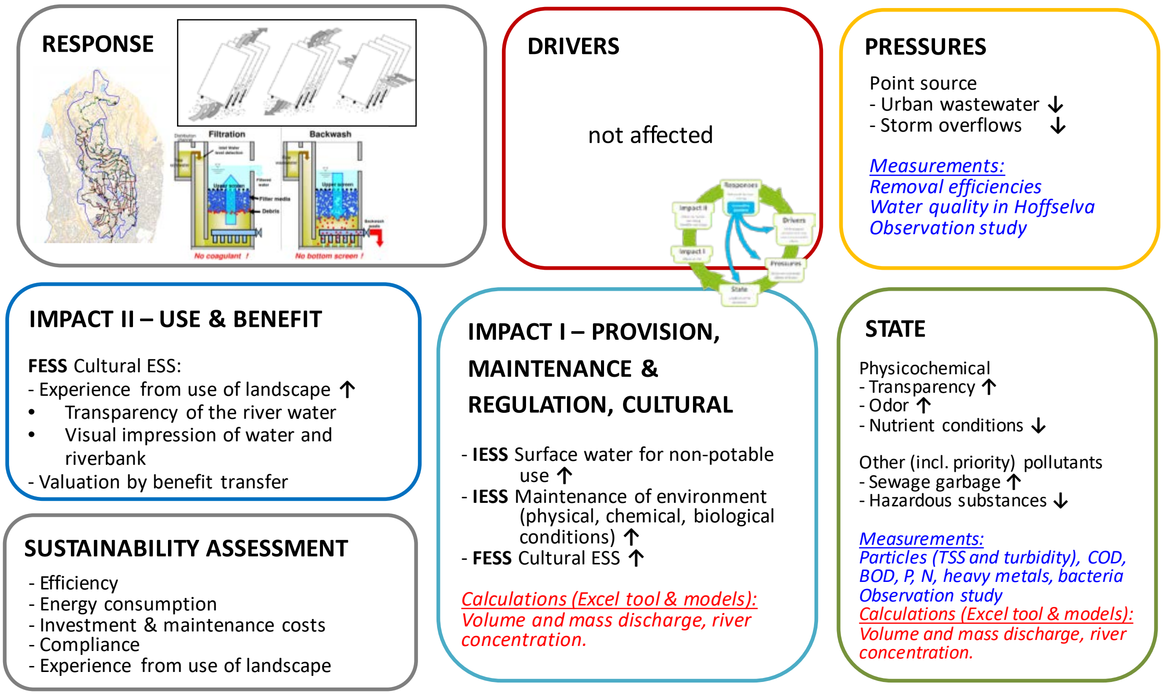


Figure 1: Overview graphic of Hoffselva demo case "Decentralised water treatment".

2.1. Part I: Study description

2.1.1. Step 1: SETTING THE SCENE

The Hoffselva river system (Oslo Area, Norway) is 10.1 km long. The river course starts from small streams flowing down the south and east side of the hill Holmenkollen and the western slope of Vettakollen. The two main tributaries Holmenbekken and Makrellbekken merge below the Dronningfossen waterfalls, near Hoff Gård, the historic main building of what used to be one of the major farms in Oslo. The part of the river running from this point and down to the fjord is, strictly speaking, the part called Hoffselva (Hoff river). Hoffselva runs through an urban area called Skøyen, where it drops under the train line and a main road junction and flows out into a narrow arm of the Oslo fjord, called Bestumkilen.

The catchment covers an area of 1427 ha, located in Oslo County (NUTS NO011), Oslo Municipality and the administration of Ullern township (lower section, from the Smestad area and down to the fjord) and Vestre Aker (upper section). In terms of water governance, the river system is part of Oslo Water Area and includes two water bodies, Vannforekomst 007-45-R which refers to the section above Smestaddammen, and Vannforekomst 007-47-R, which is the lower section, including Makrellbekken.

While its sources are in a forested recreation area, the upper section of the river flows mainly through upper and middle class residential areas, before it enters an increasingly urban environment with a mix of housing and business premises from Smestad down to Skøyen, which is heavily trafficked.

The part investigated in most detail in this study is the area from Holmenbekken down to Skøyen (Figure 2). User observations and photos were collected regularly from eight observation points in areas of special interest to the local population, including:

1. Holmenbekken/Holmendammen, the largest dam in the catchment, with a natural vegetation zone as well as a developed picnic area, pier for casting, playground and a sign-posted biodiversity trail.
2. Smestaddammen, the other major dam, closer to the community centre and surrounded by roads and paved paths, with ramps for easy access and a large population of birds.
3. Dronningfossen, a beautiful 11 m tall waterfall, close to several building complexes, but secluded in a gorge few people venture down into.
4. Åmotet, at the point below Dronningfossen where Hoffselva is joined by the more polluted Makrellbekken.
5. Hoffsdammen, a minor dam with historical significance further down, crossed by a wooden pedestrian bridge frequented by many users.

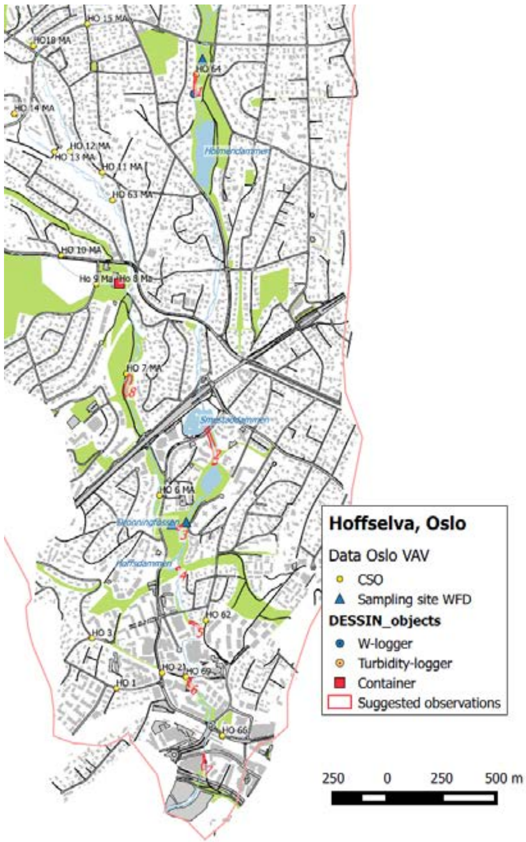


Figure 2: Hoffselva, main study area.

6. OPAK, where the river makes a turn and there is an important spawning ground, but activity by developers has threatened to reduce the river zone.
7. Tribunen, in a residential estate at Skøyen, where there is a tribune for kindergartens and school classes on excursion to sit and have their lunch, etc.
8. Hoffselvpromenaden/Glippen, at the centre by Skøyen railway station, where the river is intended as a blue/green oasis in a recently built concrete business/residence environment.

Vestre Aker has a total population of 47 000 (2016), whereas the population of Ullern township is 32 000 (2016). The population in both townships is projected to increase rapidly towards 2040 (Statistics Norway, 2017). Based on the main scenario in the population projections made by Statistics Norway (2016), the total population in Vestre Aker will be 61 600 in 2040 and the township of Ullern will have a population of 42 100 in 2040. The population of Ullern and Vestre Aker both have a higher share of elderly, and Vestre Aker also has a higher share of children below age 16, than the population of Oslo on average. There are more households with children, the share of immigrants is lower, and in both townships the living conditions are better than average for Oslo: The scores on indicators such as poverty, limited education and living in cramped quarters are as much as 50-60% lower than average for the capital (Oslo Municipality 2017).

Hoffselva is quite important to the residents and other people in its vicinity, as a blue-green thoroughfare and recreation zone, and an element imbued with historical and sociocultural significance. Outdoor leisure and staying "close to nature" are important in the cultural traditions of Norway (Damman 2008), and many, especially older and long-term residents in the area present the river as an important natural and cultural heritage. These aspects are partly reflected in the urban development plans for Ullern and the Skøyen area, where Hoffselva is prominent as a "blue-green corridor" between the waterfront and hinterland in a district that is much livelier and more densely populated than today (Oslo Municipality 2015).

The main challenge, in the context of DESSIN, in this catchment is poor water quality, not scarcity. This is caused by several factors, including discharges from CSOs (see Figure 3), and mitigation measures are required by the WFD. The ecological status of the upper section of the river system (007-45-R) is "moderate", while the chemical condition is undefined, due to lack of information (Vann-nett, 2017). The ecological condition of the lower section (007-47-R) is classified as "very bad". Despite limited information, it is concluded that a "good" chemical condition will not be reached by 2021. The deadline has been extended, as the required measures would be disproportionally expensive (Vann-nett, 2017). In the upper section, main pressures are channelling of streams, infrastructural development and invasive water weeds. In the lower section, where most of the CSOs are located, discharges from CSOs are

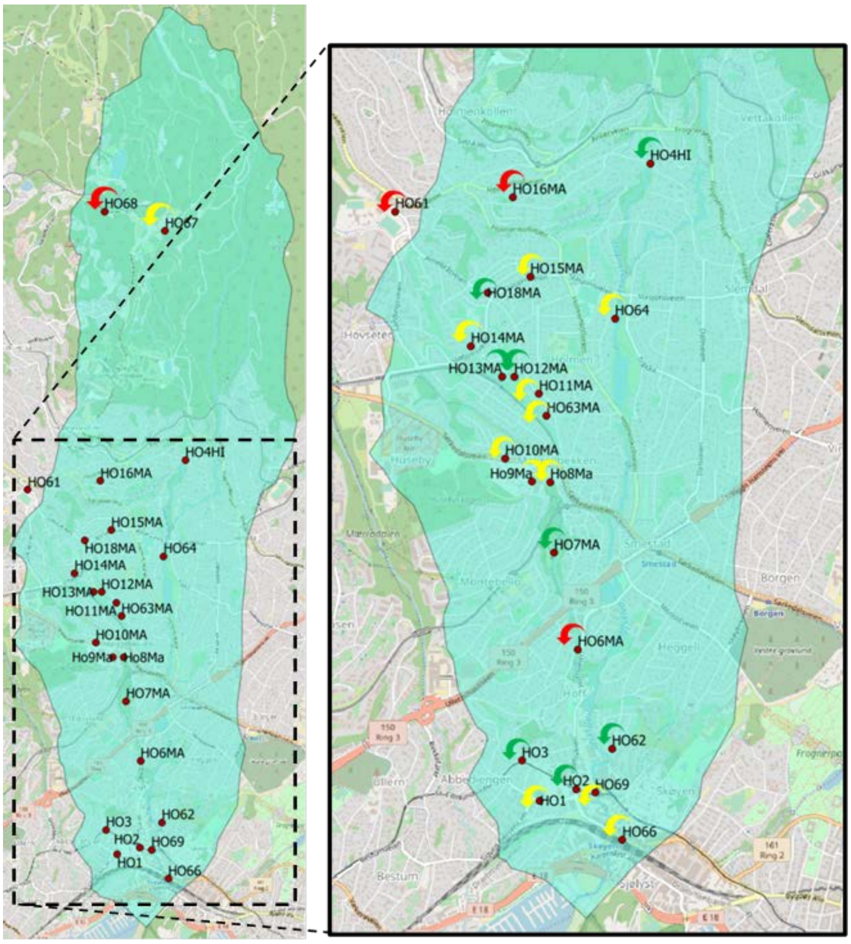


Figure 3: CSOs in the Hoffselva catchment and their 2016 risk classification.

believed to be a major influence. In addition, run-off from estates as well as run-off and discharge from traffic/infrastructure contribute, as do water weeds and various kinds of physical interventions (Vann-nett, 2017).

The sewer system in the catchment consists of a separate system in the upper part and a mainly combined system in the middle and lower parts. One reason why the water quality in Hoffselva is poor, is pollution from 25 CSOs discharging into the river during rain events. VAV has measured high numbers of bacteria, and elevated concentrations of nitrogen and phosphorus in the middle and lower part of the river. This area has a combined sewer system.

An analysis of the sewer system has shown that many of the pipes in the area have capacity problems during rain, and that the CSOs discharge too often. VAV uses a risk approach combining the probability of CSO discharge and consequence of a discharge to classify CSOs as red (highest risk), yellow (medium risk) and green (lowest risk). The probability of discharge is based on measured duration of discharge at the different CSOs. The consequence is a composite of: type of CSO; the population in the area covered by the CSO; type of recipient; and closeness to bathing site and recreational area. The first classification from 2013 was revised in 2015, and will be reviewed in 2017 when data from 2016 have been processed, (Olsen, 2017). The 2016-classification of the 25 CSOs in the Hoffselva catchment is shown in Figure 3. It should be noted that this classification is expected to be improved in 2017 when 2016-data with less uncertainty regarding duration of the discharges are incorporated in the assessment.

The utility operating the sewer system had prepared a four-year mitigation plan (Vike, 2011) based on increasing the hydraulic capacity of the system at an estimated cost of 20 million EUR. However, concerns remained regarding cost efficiency and overall effect because the downstream wastewater treatment plant was already operating at full capacity.

2.2. Part II: Problem characterization

2.2.1. Step 2: DRIVERS

Drivers are generally understood as social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption and production patterns that may produce a series of pressures, either as point or non-point sources. DESSIN has adopted the definition of MARS (2014), seeing drivers as human activities that may produce environmental effects on the ecosystem under study. The DESSIN Drivers and Pressures Catalogue lists 11 types of drivers.

As already indicated in chapter 2.1, several drivers are at work in Hoffselva. Climate change is an overriding concern. Within this century, annual precipitation in the Oslo region is expected to increase by 12%. The annual mean temperature is projected to increase by 3,4 ^{o}C, with the largest increase in winter and autumn. This will have adverse impacts on the city. According to the urban environment agency, more floods and extreme rainstorms, increased sea level and water quality challenges, both in relation to drinking water and bathing water quality, as well as new species and increased dry spells during the summer months may be expected (Oslo Municipality 2013).

Urban development is another major driver. The population of Oslo has been increasing steadily, from 520 000 in 2004 to 648 000 in the beginning of 2015. From 2014 to 2025, the city's population is expected to increase between 14.5% and 20.2%, depending on the rate of migration from other countries and other parts of Norway (Cappelen *et al.* 2017). According to projections from Statistics Norway, the rate of employment and size of the local economy will grow accordingly Cappelen et al 2017). The current urban development plan, as well as the draft plan for the period from 2017 towards 2040, emphasize the need for sustainability transition and urban densification. Oslo is to grow "from the inside and out", with more effective use of available space around existing transport veins, but also with more focus on "the green city" and strengthening of blue-green structures (Oslo Municipality 2017). Skøyen is classified as a category A development area, where space will be used from 100% and up to 125% near the public transport hub. Smestad falls in category B, development areas consisting mainly of low-rise residences where there are plans to increase the utilization of urban space, without specification of percentage. Selected areas upstream are likewise considered for densification. There is also a relatively high number of large, old villas, which are owned by people who have the knowledge and resources to renovate and introduce geothermal heating solutions. Thus energy (non-hydropower) is also, to some extent, a driver.

Transport is, however, more important. The sources of pollution in road run-off include the traffic itself (acute emissions, wear of tyres and breaks), road cover and other technical installations, operations and maintenance, as well as general atmospheric deposition. In addition, there are seasonal sources, such as salting during winter. Type of rain events, terrain, road surface and the design/dimensioning of the sewer system also matter. Run-off tends to contain heavy metals and environmental toxins, and for most substances there is a direct correlation with the amount of traffic (Statens Vegvesen 2011). As mentioned in chapter 2.1., the lower section of Hoffselva runs through areas with heavy road traffic, and according to the latest fact sheet on environmental status run-off and emissions from transport influence the water quality significantly, by way of polluted sediments, environmental toxins and salt ingress (Vann-nett 2017).

Given the costs and restrictions placed on private car use in Oslo, and increasing focus on health and the environment, people in Ullern and Vestre Aker increasingly use the roads and footpaths near the river as a thoroughfare when biking or walking to their workplace or the nearest public transport station. They also use the river areas for recreation, jogging, picnicking or walking their dogs, or engaging in organised activities such as angling, bird watching, teaching/learning and group walks. Gardening on plots near or in the riparian zone is also affecting the river areas, through changing surfaces and plant cover.

Only the drivers that result in pressures affected by the DESSIN solutions were included in the quantitative assessment of ESS. These are listed in Table 1.

Table 1: Identified drivers in the Hoffselva catchment.

Driver	Specification
Tourism & recreation	The Hoffselva river catchment is a green area which is being used for recreation, and has historical value.
Urban development	The Hoffselva catchment is rural in the upper reaches of the river with increasing degree of urbanisation further downstream ending in the urban area of Skøyen. There is increasing urban development especially in the area downstream of Holmendammen.
Climate change	Climate change is predicted to cause increased frequency and intensity of rainfall. This will increase the challenge of stormwater management in the Hoffselva catchment, which has a combined sewer system with 22 CSOs.

2.2.2. Step 3: PRESSURES

In the DESSIN framework, pressures are defined as the direct environmental effects caused by drivers, such as an effect that causes a change in water flow or a change in the water chemistry (MARS, 2014). Examples are the abstraction of water for industrial processes or an increased nutrient load caused by agricultural use of fertilizers. None of these examples are present in Hoffselva. However, the identified drivers have several pressures.

Tourism and recreation put pressures on the river and riparian ecosystem due to implementation of measures to facilitate this activity such as footpaths and organized picnic areas. However, these are not considered to have a major negative impact. More important are probably the negative effects of wear on the footpaths and littering that contribute to morphological changes and pollution, respectively.

Urbanization contributes to several pressures. Among these are changes in the natural structures in the riparian zone by *e.g.* channelling and changes in the river profile by dams and culverts. More important with respect to water quality are probably the discharges from CSOs, which constitute many pollution point sources.

Not all pressures can be localised to a specific place. Run off from roads contribute to the diffuse pollution of the river and riparian zone due to exhaust fumes and wear of tires and road surface. Transport of such pollution to the river is increased during heavy rain and the pressure has been defined as stormwater runoff in this study.

Climate change will increase the pressures from urbanisation due to increased frequency and intensity of rain events, which will lead to increased discharges from CSOs and more stormwater runoff. Climate change therefore has an indirect effect on these pressures. However, climate change may also have a more direct effect on the ecosystem *e.g.* by changing the environmental conditions for vegetation and species in the fauna.

At the local level, energy (non-hydropower) is also associated with a certain pressure, in that (illegal) discharge of drilling sludge from heat pump installations has been a repeated problem, with negative impacts on the water quality.

The pressures identified in the Hoffselva catchment that have been included in this assessment are given in Table 2.

Table 2: Identified pressures in the Hoffselva catchment.

Pressure name	Specification
Point source	CSO discharge
Other anthropogenic	Stormwater runoff
Morphological	Footpaths and erosion along the river

2.3. Part III: Response capabilities & potential beneficiaries

2.3.1. Step 4

High rate filtration solution

The innovative HRF system has been developed and applied for treatment of a combined sewer overflow (CSO) and reported in D21-3. 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. The new HRF system for CSO has special filter media which are floating in the filter bed. The filter media is designed to have optimal shape to capture debris, chemical oxygen demand (COD) and suspended solids (SS) with high void ratio. There is no chemical addition and pre-treatment required for new HRF system. 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 motorized equipment consists only of inlet pumps (no pumps needed if gravity flow is available) and a compressor for pneumatic valves. During rainfall, CSO raw water comes in from the distribution channel flowing upwards through the filtration layer. Sewage garbage is deposited on the surface of filter bed, while SS and COD removal will take place also in the internal parts of the filter bed. As filtration continues, and filter media becomes clogged, the water level on the inlet side will rise. When a predetermined maximum water level is reached, the high-speed drain valve opens automatically and starts backwash. Filtrated water flows downward by gravity and sewage garbage, SS and COD accumulated in the filter media is discharged. The backwash cycle requires only a minute, and no filter media flows out during backwash.

The state of the HRF and performance during CSO events have been monitored by logging of plant sensors and installed turbidity sensors on the inlet and outlet to a local data logger. This data logger was set to log data every 10 seconds, but had the possibility to start logging upon triggering of an alarm or set-point, and the frequency of data collection could be adjusted. The locally stored data were transferred to SINTEF using wireless transfer and an internet based access to the local computer with the logged data.

Eleven (11) CSO events were recorded during the first testing and demonstration period, from September 2015 until May 2016. Test results indicated that the HRF solution, which at this time was the only solution being tested, was 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 was relatively low because of the high fraction of soluble nitrogen and phosphorus in CSO. However, 6.3% TN and 15% TP were retained together with particles. The HRF system also showed promising treatment efficiency for heavy metals with 48% Al, 48% Zn, 57% Cu, and 31% Cr removed, respectively.

Cross-flow lamella settler solution

A test container with the CLS system was developed by UFT to test the innovative cross-current lamella settlers under field conditions with real combined sewage at the two demo sites, Castrop-Rauxel CSO Ohmstraße in the Emscher region, Germany, and the Hoffselva demo site in Oslo, Norway.

The CLS container was based on a common 40 m³ roll-off trash container design with a length of 7 m, a width of 2.5 m and a total interior depth of 2.4 m. A 2.5 m x 2.4 m stainless-steel bulkhead was built in to give a vessel of 5 m interior length. In a separate compartment accessible through the door, the electrical cabinet as well as the inflow sensor and some valve work were located. The container had been lined internally with welded polyethylene to provide watertightness as well as to avoid contamination of samples by rust. The container was operated such that an external submerged pump was connected to an inflow pipe DN 150. The maximum flow was around 30 L/s dependent on the local conditions at on site. The inflow was measured by a magnetic-inductive flowmeter and could be controlled by variable pump speed with the aid of a frequency converter. The inflow pipe passed the bulkhead by a centric pipe which was followed by an internal 90° upward pipe elbow and a T-shaped manifold pipe to ensure smooth flow distribution. Both arms of the “T” featured several outlet openings pointing towards the bulkhead wall to ensure good dissipation of the inflow momentum. The inflow was then passing horizontally through the interior lamella modules. A centric frame which was part of the cleaning mechanism prevented over- and underflow. The treated combined sewage left the container by an overflow with adjustable double-sided overflow edges.

The state of the CLS and performance during CSO events have been monitored by logging of plant sensors and installed turbidity sensors on the inlet and outlet to a local data logger. The capabilities and set-up of this data logger were the same as for the HRF solution described above. The instrumentation of the CLS were turbidity sensors located in the container volume close to the inlet and outlet. In addition, the plant's sensors for water level in the container and water level in the man-hole with the feed pump were logged. Water samplers for the inlet and outlet were installed with sampling points next to the turbidity sensors. These water samplers were activated by a level switch that was triggered when the container was full. The CLS was also equipped with a mobile phone based switch that enabled remote shut down and start of the plant. However, for security reasons there was always personnel present when the plant was started, *i.e.* setting the plant in auto-mode so that it would start when the level in the pump man-hole reached the starting set-point.

Tests in the Emscher region (D31.2) showed that the container had the highest efficiency at a flow rate of 10 l/s. The recommended surface load was thus about 1 m/h. The container started to be efficient at an inflow concentration threshold of approx. 300 mg COD/L, and the efficiency ranged from 5% (1st Quartile) to 17% (3rd Quartile) for COD. The maximal potential efficiency that was reached with the lamella settler in the tested setup was 37% (TOC), 17% (COD), 22% (TSS fine), and 19% (TSS). The particle concentration and type was of high importance for the efficiency.

Implementation alternatives evaluated in this study

Two alternatives for implementation have been evaluated in the ESS evaluation and SA. One alternative is implementation at the CSOs characterized as high-risk or 'red' in the risk assessment for 2016. The second alternative is implementation at the 'red' and medium-risk 'yellow' CSOs. The main characteristics of these two alternatives are shown in Table 3.

Table 3: Main characteristics of the evaluated implementation alternatives.

Implementation alternative	'Red' CSOs	'Red' + 'Yellow' CSOs
Sum of CSO 2 yr. disch., [m3/h]	2171	7165
Sum of HRF vol, [m3]	812	2690
HRF inv. cost, [euro]	**€ 1 858 644**	**€ 6 347 365**
HRF op. cost, [euro/yr]	**€ 8 718**	**€ 34 791**
Sum of CLS proj. area, [m2]	543	1791
Sum of CLS+storage vol., [m3]	812	2690
CLS inv. cost., [euro]	**€ 2 277 569**	**€ 7 594 080**
CLS op. cost, [euro/yr]	**€ 7 560**	**€ 30 240**

For both solutions, but especially for the CLS solution, a storage volume may be included. The storage volume will be of importance for the costs, and have considerable influence on the impact of the solution with respect to reduced discharge to the river. The reason is that there will be no discharge until the storage volume is filled, *i.e.* a 100% efficiency with respect to reduced discharge. Previously, a study conducted by DHI for Oslo VAV recommended storage volumes for the different CSOs in the Hoffselva catchment (Vike, 2011). However, the rain event selected for dimensioning in that study was not the same as the rain event selected by Oslo VAV for this study. Thus, the recommended volumes in the 2011 study are quite large compared to the discharge simulated by Oslo VAV for this study. Using the 2011-volumes would therefore be conservative with respect to storage volume. On the other hand, when dimensioning the CLS with a surface load of 4 m/hour on projected surface (Weiss, 2017) and only considering the volume required for the lamella, the CLS volume becomes unrealistically low because this solution is intended for CSOs were there is a storage volume. Since the aim of this evaluation was to compare the HRF and the CLS, and not the effects of storage volume as such, the simplifying assumption was made that there will at least be the same storage volume in the CLS as with the HRF. For the illustration in Figure 4 of the accumulated discharge from the CSO 'HO6' during the CSO-event 18th May 2017, the volume used in the calculations was 339 m^3.

The effect of the two implementation alternatives will depend on the sum of effects of all the CSO-events over a long time period. A thorough assessment of this could be made by use of hydraulic and water quality simulation models for the sewer system and Hoffselva. Efforts were made in DESSIN to model Hoffselva and use this model with simulated CSO discharges from VAV's hydraulic sewer model. The river model was calibrated hydraulically with flow measurements from Oslo VAV's station HOFF5. This yielded satisfactory results with respect to flow, however, the water quality results were not accurate showing concentrations that were much (10 times) lower than analysed from water samples. This is probably due to inaccuracies in the mass-input to the river.

For the ESS evaluation measured values for water quality parameters were therefore used together with results from the observation study. To assess the CSO discharge, simulation results from rain events in the demonstration period, provided by Oslo VAV, were used. The effects of the two implementation strategies with respect to reduction of the discharged CSO volume on two rain events in 2017 and the dimensioning rain with a two-year return period are shown in Table 4.

Table 4: Effects of the two implementation strategies with respect to discharged CSO volume.

			Implementation alternative	
	Rain event	**No treatment**	**Red' CSOs**	**Red' + 'Yellow' CSOs**
Accumulated discharge volume, [m3]	2017-05-18	731	391	210
	2017-06-10	2492	2069	1138
	2 yr. rain	4740	3960	2148
Discharge reduction due to storage effect	2017-05-18	n.a.n[1]	46 %	71 %
	2017-06-10		17 %	54 %
	2 yr. rain		16 %	55 %

1: Not a number.

The three rain events cover rains that have a return period of a few months to the two-year return period of the dimensioning rain. As expected the effect of storage is largest for the smallest rain event. However, this is not always the case as it depends on the distribution of the total discharge between the different CSOs, and ratio of discharge to storage volume at a given CSO. These are the reasons for the higher reduction in the total CSO discharge for the two-year rain compared to the rain of 2017-06-10.

For the stored CSO discharge, the removal efficiencies for polluting compound will be 100%. Thereafter, there will be a difference between the two solutions. Based on the demonstration results at the Hoffselva demo site, and also the results reported in D31.1 showing a decrease in separation efficiency with increasing loading rate for the CLS, an average separation of particulate matter in discharged CSO of 50% in the HRF has been used in this study. The corresponding value for the CLS is 10%, which takes into account that the design criteria for the surface loading rate on the CLS (4 m/h) is higher than the loading rates used in the demonstration tests. The combined removal effect of storage and separation in the HRF and CLS is illustrated in Figure 4.

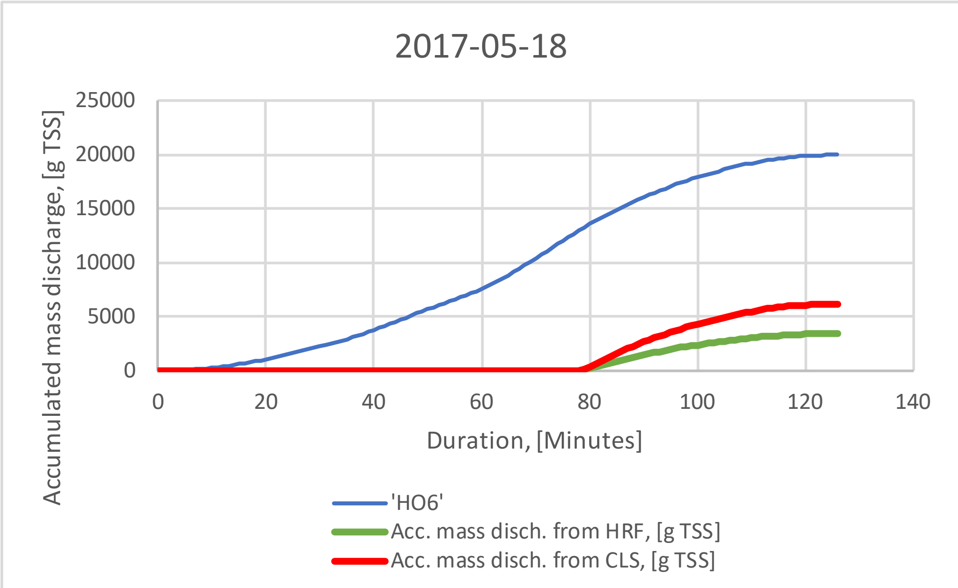


Figure 4: Simulated mass discharge from the CSO "HO6" during the rain event of 2017-05-18. The blue line shows the mass discharge without any treatment. The red and green lines show the combined effect of the chosen storage volume (339 m3) and the CLS and HRF solutions, respectively.

It should be noted that the results in Figure 4 only show the effect on one CSO during one rain event for the simplified case with equal storage volume for the two solutions, and therefore are not generally applicable. For a full evaluation, similar calculations should be performed for all CSOs for many rain events using a range of storage volumes that could be different for the two solutions.

2.3.2. Step 5

Potential beneficiaries include the Water and Sanitation Agency of Oslo Municipality (Oslo VAV), which also is the key stakeholder and decision-maker addressed in this case study. Other important stakeholders are the Agency of City Environment (Bymiljøetaten) in Oslo Municipality, Oslo County, and the County Governor's office (Fylkesmannen), which represents the national Ministry of Climate and Environment at the regional level. The County Governor plays a significant role in the implementation of the WFD. Their responsibilities include to monitor and assess water resources and their environmental state, and advise other relevant authorities in environmental matters. Given these responsibilities, they are also in charge of discharge permits for wastewater. VEAS

(Vestfjordens Avløpsselskap) is the wastewater treatment plant receiving water from the sewage systems in the Western part of Oslo, including that of Hoffselva.

There is no industrial use of the water in Hoffselva, and although there used to be a lot of industry in the area, there are no major polluters who are important stakeholders as such. However, there are a few private sector stakeholders who take a strong interest in the river. These include Hegnar Media, which has their head office at Smestaddammen, and OPAK, a consulting firm in the construction business, which is located further downstream. A smaller dam, called Bjørnebodammen and parts of the riverside further downstream are privately owned. Estate developers also have a stake in the environmental status of the river, as it influences the attractiveness of the area and the scope for riverside building activity.

Within the local community, Smestad primary school, with 670 pupils, and several kindergartens in the area are important users. Smestadhjemmet home for the sick and elderly and Ullern volunteer centre also use the area in their community services. Sport clubs use the area for outdoor training activities, and at the mouth of the river Oslo Kayak Association and a local marina have facilities and carry out activities directly in the water, thus being affected quite directly by any changes in water quality. Oslo Sportsfiskere, an association for anglers, has a cabin at Holmendammen and is using the dam for casting. Ullern, Røa and Bygdøy local history association also take a particular interest in the river, as it has historical significance and hosts several historic landmarks.

Beside the public township administrations and elected township councils (Bydelsråd), residents along the river are organized in several residents' associations, who are active in the dialogue on urban planning and future use of the river areas. Last, but not least, Hoffselvens Venner is one of several "river forums" in Oslo that work voluntarily to contribute to the conservation, rehabilitation and re-naturalization of city rivers in the building zone. Hoffselvens Venner is both a membership organization and an informal movement, with a Facebook group of more than 100 members. Their activities range from policy dialogue and education, to awareness-creation and physical work to maintain the river area.

Other potential beneficiaries of improved water quality and ESS include bathers at the nearest fjord beach and people fishing trout that spawn in Hoffselva before returning to the sea, as well as the wider population of Oslo and other visitors, who enjoy the experiential qualities associated with clean water, biodiversity and good living conditions for birds, fish and other animals.

2.4. Part IV: Impact evaluation

2.4.1. Step 6: STATE

Previous studies

The University of Oslo assessed the ecological condition of Holmenbekken-Hoffselva in 2016 (Saltveit et al 2017). The assessment was commissioned by Oslo VAV, and the results are to be used as baseline/control for assessment of future changes resulting from measures implemented to reduce pollution. Fish and bottom/benthic fauna were collected from five sampling points. The ecological condition was assessed using the ASPT index, and the EPT index was used to estimate diversity changes. The study concludes that the condition in the upper part of the river is "good", with many EPT species present. The condition has also been quite stable over the past two decades, indicating that the exposure to organic load and other pollutants is limited.

Downstream from the Smestad dam the observed level of pollution increased, and the ecological condition is characterized as bad (Saltveit et al 2017). The organic load was higher at Ho5 at Skøyen than at Ho3 above, due to inflow from Makrellbekken, which is strongly polluted at the point where it runs into Hoffselva. More species of fish were observed in previous years than in 2016. Trout is the dominating species, reproducing at all the studied localities. The number of trout in the river as a whole is stable, but at Ho5 the number has reduced gradually over time. Still the WFD target relating to fish is met in all localities. In terms of bottom fauna, the lower stations are classified as "moderate", "bad", or "very bad", whereas only Ho1, at the upper end, is classified as having "good" ecological condition. According to the WFD, the biological quality element associated with the worst condition is the one that shall be emphasized when assessing the need for measures.

Links to the wider ecosystem were not assessed. However, a publication by Friends of the Earth, Norway (Norges Naturvernforbund) and Hoffselvens Venner (Solås 2014) provides some relevant insights. According to this overview, the catchment has been a cultivated landscape since the Iron Age. Today, it hosts two vegetation types, alongside and between built areas and garden plots: Grey alder forest, typical of often-flooding rivers and streams, and elm and linden forest, as well as trees with edible fruit such as hazel, rowan and apple trees. Wild currant, raspberries and strawberries, as well as bear's-garlic are also found. The dams host several sump species, and there is a wide variety of birds, including swans at Holmendammen. There are also other animals, such as squirrels and frogs.

Due to pollution the dams are eutrophic, and they are also threatened by invasive species. In Holmendammen, repeated efforts have been made to remove black-listed water weeds (Elodea canadensis), and a lot of cattail (Typhaceae) has been dug out from Smestaddammen, impacting biodiversity negatively. Presently, the most serious situation is in Hoffsdammen, which gradually is being taken over by water weeds and other plant species. The dam has been home to trout and minnow, and the red-listed sharp-nosed frog was found a few years ago, but whether it remains in 2017 is not known (Solås 2014).

A study on water quality in the fjord, carried out by the Norwegian Institute for Water Research (NIVA) in 2014, indicated that CSO events and sewage leakages from Hoffselva had a significant impact on bathing water quality at the nearby beaches. The study focused mainly on discharge from VEAS, but argued that during and after heavy rains, discharge from Hoffselva and nearby Mærradalsbekken would have a stronger impact on the water quality in Bestumkilen and the popular Bygdøy sjøbad (beach) than discharge from the wastewater treatment plant. For two selected rain events in 2014 and a modelled 24-hour rain the same year, the study estimated numbers of *E-coli* (*E. coli*/24h) from Hoffselva of 1.3 x 10^{13}, 1.6 x 10^{13}, and 4.4. x 10^{13} respectively, and found this consistent with water samples taken from Bygdøy sjøbad in the same period (Staalstrøm et al 2014).

Activities in DESSIN to model the Hoffselva river

An initial model was developed in a MSc thesis (Arntsen, 2016). This model could, however, only reflect the lower part of the river, and was later modified and extended to cover Hoffselva below Smesteddammen and include Makrellbekken.

The main aim of the modelling activities was to create, calibrate and analyse a hydrodynamic model of the river to assess the impact on water quality from CSO discharge. Since the area is a peri-urban catchment with mainly a combined sewer network, an integrated model of the catchment consisting of the sewer network and the river would have been the preferred model type. However, Oslo VAV already has a model of the sewer system in the Hoffselva catchment implemented with MIKE URBAN software. The main input of this model is the rainfall on a specific date and it will then provide results on the activity of CSOs due to this rainfall considering a set of other hydrological parameters which can be obtained from Norwegian meteorological authorities. Hence, for completing this existing model and for performing the water quality assessment, two additional models were needed:

- A simple hydrologic model of the river to assess the flow in each tributary of the river
- A hydraulic model of the river able to perform unsteady flow analysis and water quality analysis at least on some important water quality constituents or nutrients.

It was decided to use HEC-HMS and HEC-RAS software for fulfilling these objectives. ArcGIS and QGIS were also used for the delineation of the sub-catchments and the creation of cross-sections of the river in HEC-RAS model. The general scheme of the modelling activities is illustrated in Figure 5.

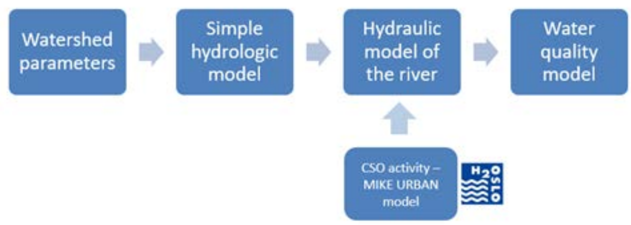


Figure 5: General scheme of modelling activities.

Simple hydrologic model

The HEC-HMS[1] which is used for hydrological modelling (Figure 6), is designed to simulate the complete hydrologic processes of dendritic watershed systems such as Hoffselva case. The publicly available software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. HEC-HMS also includes procedures necessary for continuous simulation including evapo-transpiration, snowmelt and soil moisture accounting.

[1] http://www.hec.usace.army.mil/software/hec-hms/

Supplemental analysis tools are provided for model optimization, forecasting streamflow, depth-area reduction, assessing model uncertainty, erosion, sediment transport and water quality.

In this study, we used ArcGIS to delineate the catchment and extract the first flow path by utilizing the Laser-scanned DTM of the area provided by Oslo VAV. Then, these were corrected by using data provided by the Official toolbox of the Norwegian water resources and energy directorate (http://nevina.nve.no/). This provides, amongst others, the modified streamlines in urban and peri-urban areas due to the urbanization.

The Hoffselva catchment is gauged and the corresponding data is available through Oslo VAV. The other relevant hydrological parameters such as precipitation, temperature etc. were obtained from Blindern meteorological observation site. Then, the model was set up, calibrated and validated for the two rain events in 2014 and 2017. However, we were not able to model the sewer system here rendering the results provided by this model uncertain.

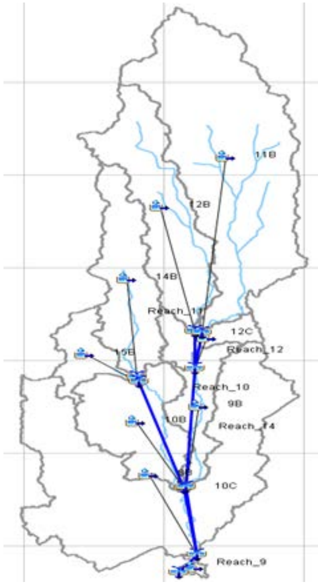


Figure 6: Hydrological model.

Hydraulic model of the river

The HEC-RAS[2] software allows the user to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modelling. In this study, we used steady and unsteady flow and water quality analysis components of the software.

The steady flow component of the modelling system is intended for calculating water surface profiles for steady or gradually varied flow. Energy losses are evaluated by friction, with the Manning's equation, and contraction/expansion with the friction coefficient multiplied by the change in velocity head. In situations where the water surface change rapidly, like hydraulic jumps, the momentum equation is used.

The unsteady flow component can simulate one-dimensional unsteady flow through a full network of open channels. It uses the momentum equation and the continuity equation to determine flow and stage at each cross-section. The unsteady flow can model storage areas and hydraulic connections between storage areas, as well as between stream reaches.

For setting up the model, data extracted from HEC-GeoRAS[3] such as cross-section data, river length, topography etc. are used directly. Cross-sections are located at intervals along a stream to characterize the flow carrying capability and its adjacent floodplain.

[2] http://www.hec.usace.army.mil/software/hec-ras/
[3] http://www.hec.usace.army.mil/software/hec-georas/

HEC-RAS uses an implicit, finite difference method to analyse the unsteady flow regime. Therefore, the interval (distance) between cross-sections should be optimally chosen in a trial and error procedure and for catchments such as Hoffselva where the elevation varies from 0 to 530 m above sea level, it may be a challenging task. Figure 7 shows a cut of the river profile and its steep slope.

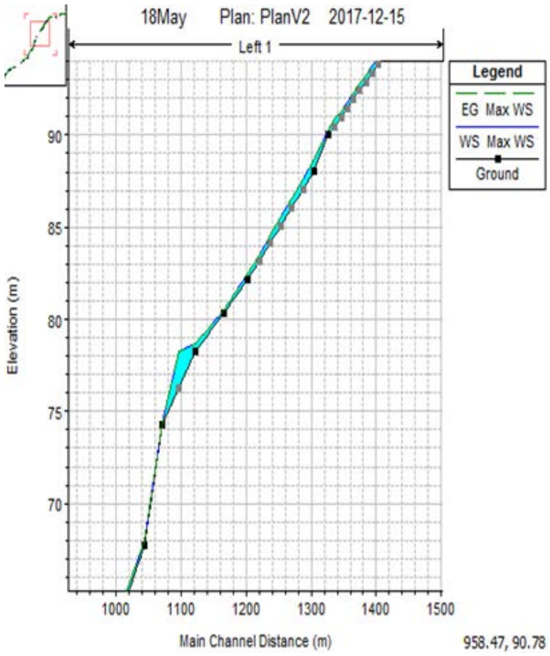


Figure 7: River profile in a section of Hoffselva.

Other assumptions should be made about the Manning's value (or roughness coefficient) and contraction and expansion coefficients considering the vegetation, urbanization, channel irregularities, obstruction, etc.

Water quality model of the river

The basis of the water quality model is the principle of mass conservation. HEC-RAS solves a 1D advection-dispersion transport module for each water quality constituent. HEC-RAS can perform temperature analyses and transport of several water quality constituents. In this study, we used two arbitrary conservative constituents: Ortho-Phosphate and suspended solid.

The water quality module in HEC-RAS (Figure 8) uses the river geometry from the hydraulic model. It divides the river into water quality cells for performing the calculation steps. The water quality cells are initially established between the hydraulic cross-sections and the computational points are located at the centre of a water quality cell.

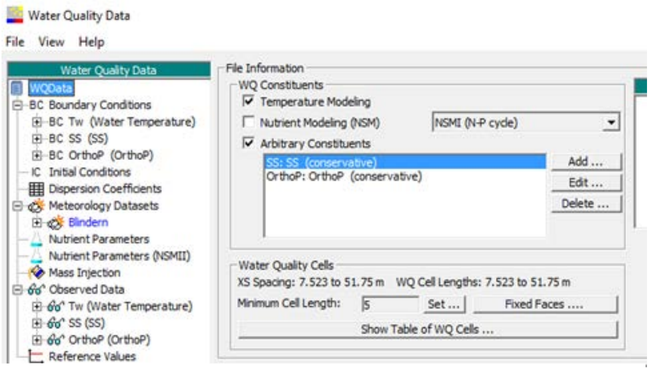
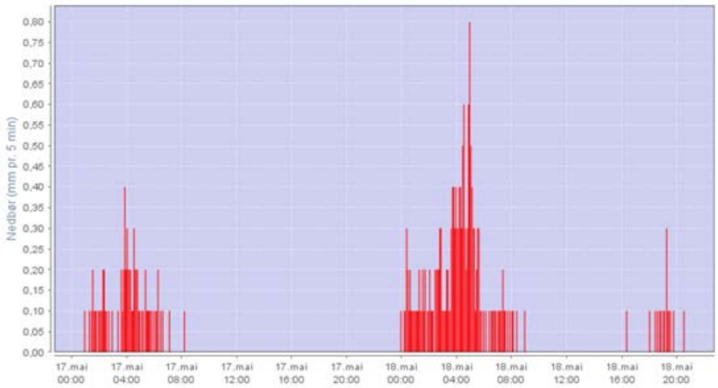


Figure 8: Water quality component in HEC-RAS.

The water quality modelling is a very data-demanding task. Model input requirements are hydrodynamic information and system geometry from the HEC-RAS unsteady flow model as well as temperature at hydrodynamic boundaries, and meteorological data (e.g. solar radiation, air temperature, vapor pressure, wind speed). In addition to assess the performance of the model, actual measurements on desired constituents should be inserted into the model to be compared to the modelling results at the end.

Chosen rain event

Considering the CSO activities, a set of rain events to be used in the modelling task were shortlisted. Finally, the rain event of 18th May 2017 was chosen as the simulation rain event considering the availability of measured data, the intensity of the rainfall and CSO discharge during this rain event.



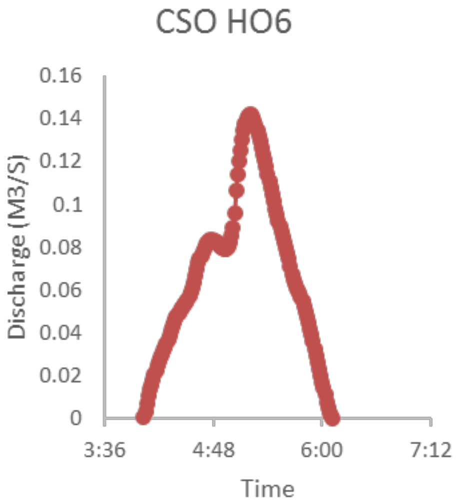


Figure 9: Left: Rain hyetograph. Right: Modelled discharge from CSO HO6 during this rain event.

Figure 9 shows the hyetograph of the rainfall (Rainfall in mm per 5 mins) (left hand figure), and modelled time series of discharge from HO6 as an example of the results provided by VAV's MIKE URBAN model (right hand figure).

The next steps of the work consist of setting up the simple hydrological model, inserting the CSO time-series as lateral inflows in the already set-up hydraulic model and to run the unsteady flow regime in HEC-RAS before setting up the water quality model.

Results of the hydrological model

Figure 10 compares the peak of observed flow at the outlet of the catchment (measured flow) in yellow, the red line represents the simulated flow for the rain event of 18th May 2017.

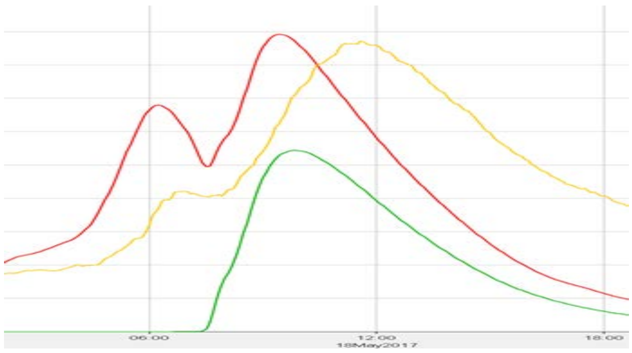


Figure 10: Peak of flow at the outlet of the catchment; simulated in Red, observed in yellow.

The other challenge was to model the storage volumes (ponds and lakes). This was not considered within our modelling activities as no data were available on the storage volumes and about the dam at Holmendammen.

Despite the uncertainty within the model, we decided to use the stream flow in the tributaries to model the impact of CSO activities on the quality of water.

Results of the hydraulic model of the river

To have a stable unsteady model, the maximum flows in both tributaries of the river were used to set up the steady model and improve the geometry of the model. Once the model is stable, the time-series of the flow in the river from the hydrological model was inserted into the hydraulic model. The unsteady model was improved in a bottom-up approach to achieve a more stable model. Figure 11 shows the variation of the water level along the main tributary of the river.

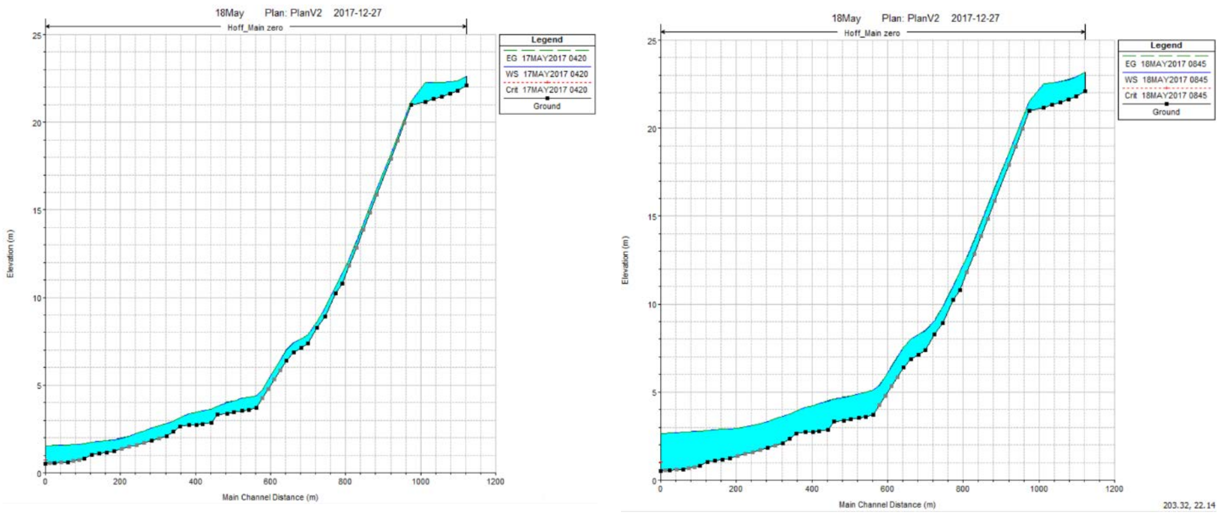


Figure 11: Flow stage at the main tributary of the river; left: before the peak flow; right: during the peak flow.

It is noteworthy to mention that CSO discharges to the river were added as lateral flows to the river. The following CSOs were active during the selected rain event according to the results provided by Oslo VAV: HO6, HO9, HO11, HO16 and HO64.

Results of water quality model of the river

First, the arbitrary constituents were defined in the model. We have chosen suspended solids and Ortho-phosphorous as modelling variables. The next step is to insert the required data into the water quality component of the model. These data are the boundary condition on water temperature, the concentration of suspended solid and Ortho-P (selected variables) in some cross-sections of the river, initial condition of the river before and during the rain event (temperature, initial concentration etc.), a set of meteorology parameters such as humidity, wind velocity, observed parameters (SS and Ortho-P) in the river at the beginning of the rain event and more importantly the mass injections as load input to the river in terms of gram per second of SS and Ortho-P.

The next figure shows a set of mass injections on Ortho-P constituent which were added to the model. It should be noted that these data are coming from measurements at HOFF5 discussed below. It reflects the mass discharge to the river due to the CSO activities.

Mass Injection

Add RS location(s) to the Table ...

Mass Injections of Arbitrary Constituents

	River	Reach	RS	Constituent	Date (DDMMMYYYY)	Time(HHMM)	Mass (g)	Duration (hrs 0=instantaneous)
1	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:13	0.571819	1.666667E-02
2	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:18	0.316516	1.666667E-02
3	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:10	0.11944	1.666667E-02
4	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:15	0.512099	1.666667E-02
5	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:21	0.103017	1.666667E-02
6	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:19	0.247838	1.666667E-02
7	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:17	0.383701	1.666667E-02
8	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:20	0.176174	1.666667E-02
9	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:12	0.50762	1.666667E-02
10	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:11	0.34339	1.666667E-02
11	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:14	0.558382	1.666667E-02
12	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:16	0.450886	1.666667E-02
13	Hoff_Main	Right2	512.399	OrthoP	18May2017	05:09	0	1.666667E-02

Figure 12: Inserting CSO activities as mass injections in the water quality component.

After setting up the model and adding the initial conditions, the simulation was performed for the rain event of the 18th May 2018. The propagation of Ortho-P is shown in Figure 13 as two snapshots of different time.

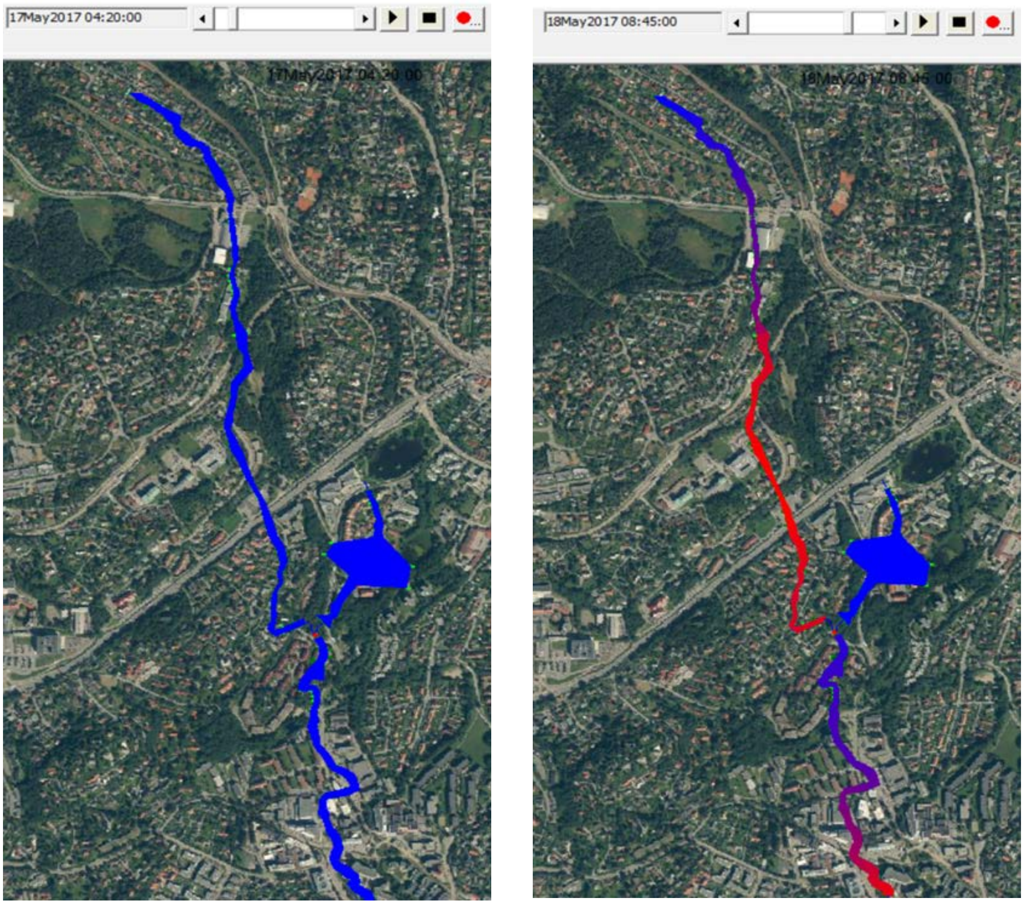


Figure 13: The propagation of Ortho-P in the river during the rain event; left snapshot: before the peak flow; right snapshot: during the peak. Red shows a higher concentration of the Ortho-P.

However, the results did not reflect measurements in the river. Measurements of several water quality parameters were performed at a point near the outlet of the river where Oslo VAV has implemented a measuring station (Figure 2). Figure 14 shows the simulated and measured Ortho-P at this point.

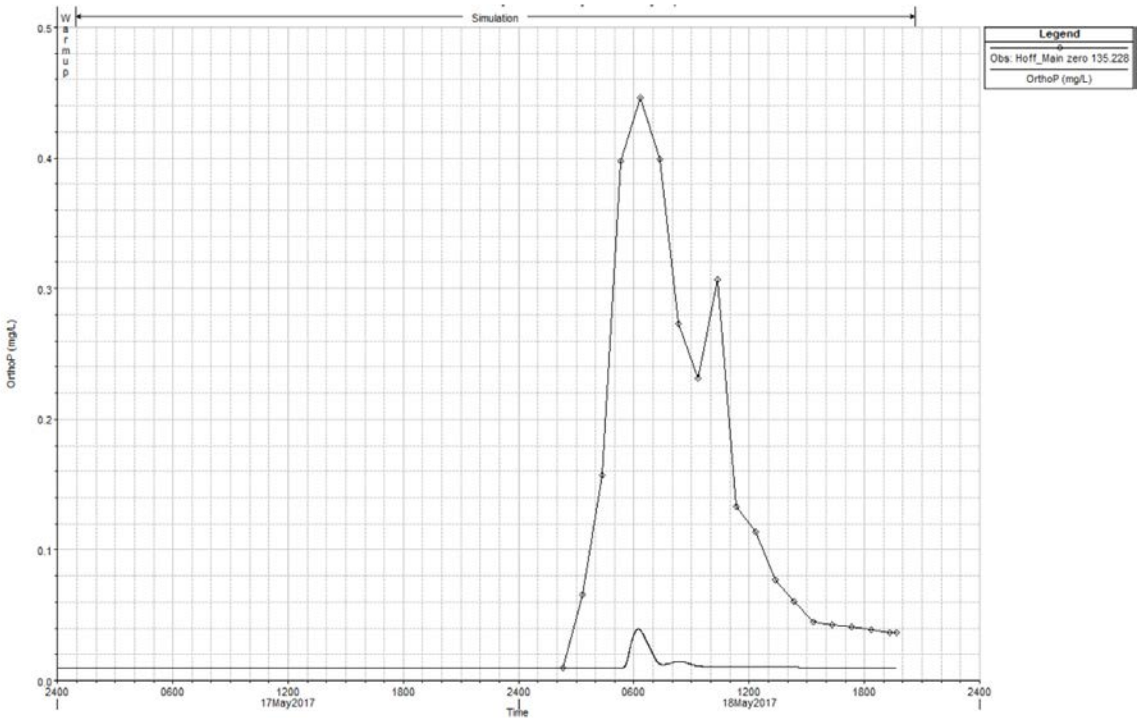


Figure 14: The concentration of Ortho-P at the measuring point near the outlet. Circles are the measured data and straight line is the simulated one.

Conclusion and perspective of the modelling activities

In this part of the work, we aimed at studying the impact of the CSO activities on the quality of the water in the river by deploying publicly available models. To this end, first we set up, calibrated and validated a simple hydrological model to estimate the time-series of the flow in the river. Then, we created a hydraulic model of the river to perform steady and unsteady hydraulic analyses based on a laser-scanned DTM of the area provided by the Oslo VAV. Afterwards, the results of the unsteady model were used to carry out the water quality analysis.

However, the concentrations in simulated event are almost 10 times lesser than those observed. Nevertheless, even though the concentration is not the same, the trend is the same between the simulated and observed concentrations. This difference can be due to one or several of the following reasons:

1- Hydrological model:
   - It is recommended to have an integrated urban drainage modelling including the river. As the simple hydrological model constructed in this study and the MIKE URBAN model of Oslo VAV are disconnected, we were not able to have a better estimation of the impact of impervious sub-catchments on the river.

- The storage areas must be modelled as the main goal is to assess the time-series of the flow in the river. In addition, measurements in other points of the river, especially at the end of other tributaries can be very helpful to improve the results of the model.
- Hence, these issues increase the uncertainty in the model. For example, Figure 14 shows the difference between the values simulated and those observed near the outlet of the catchment. Despite our efforts to optimize these values to better reflect those observed, the lack of an integrated model makes it impossible to have an accurate time-series assessment.

2- Hydraulic model:

- In this study, for the sake of simplicity, we did not include the details of the river morphology in the model such as the existing dam, flow regulators, culverts etc. these elements have a very strong impact on the spread of the nutrients and solids as they modify the residence time in the river and the flow. In addition, depending on the nature of the stressor, some of the morphological elements can also accelerate sedimentation processes.
- The model should include all the river tributaries up to the upper part of the catchments. Currently, even though it covers a good part of the catchment, it does not include all the storage areas.

3- Water quality model:

- The initial condition of the river before the event is not well documented. It is not possible to achieve a simulation equal to the measured concentration of the Ortho-P or SS near the outlet at the measuring point if we just consider that these elements are coming from the CSO activities. This river is a peri-urban one and there are several factors which may influence the concentration of a parameter of the water quality. These factors need to be investigated and reflected in the model to achieve a more realistic model providing results closer to what was measured.
- Some parameters need also to be investigated more. These parameters are initial or boundary parameters such as sun radiation on the area, water temperature at various places in the river etc.
- In total, this work was the first attempt to model the water quality of this river in Oslo. It gave some useful insights to Oslo VAV and revealed the necessity of a more integrated approach in terms of modelling.

Measured water quality at HOFF5

Water samples were collected in Hoffselva at VAV's measuring station, HOFF5, located in the downstream section of the river at Skøyen. The samples were collected by an automatic sampler collecting 1 sample every hour for 24 hours after start of the sampler. The sampler was started by an SMS-command sent by the research team when there was a CSO event. The sampler was also started to collect samples for defining the baseline with respect to river water quality under conditions without CSO discharges.

The water quality during a CSO event varied with time as shown in Figure 15 with a peak value at or shortly after a CSO event was registered at the upstream demo site and thereafter decreasing concentrations with increasing time after the CSO discharge was registered. It should be noted that there were several CSOs with discharged to the river between the demo site and HOFF5. It was therefore not possible to relate the peak in concentration at HOFF5 specifically to the CSO event at the demo site.

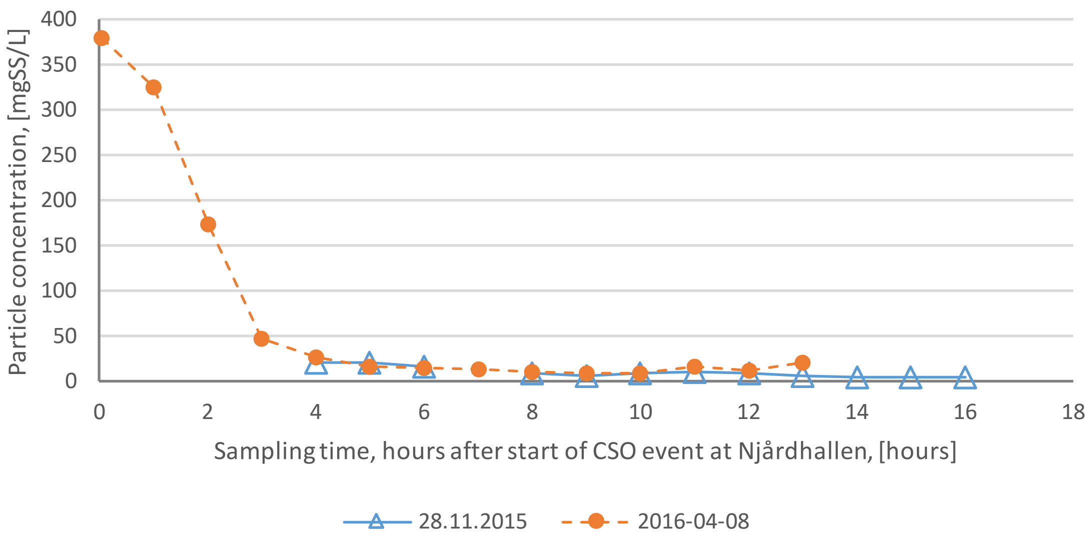


Figure 15: Concentration of suspended solids in river water samples collected at HOFF5 on two separate days with CSO discharge. Start of sampling on 2016-04-08 was immediately after registration of the CSO event at the demo site. Start of sampling on 2015-11-28 was 4 hours after registration of the CSO event at the demo site.

The samples were analysed for total suspended solids (TSS), total phosphorus (Tot-P) and in some samples ortho phosphate (Ortho-P). The average, maximum and minimum values, and the number of samples are shown in Table 5. The number of samples varies for the different parameters. This is because it was not always possible to collect sample both from conditions with CSO activity and without CSO activity on the same day/sampling run. Also, not all parameters were analysed in all samples if the results from the first samples indicated that the remaining samples would have concentrations below detection limit of the analysis.

Table 5: The average, maximum and minimum values for suspended solids, total phosphorus and ortho-phosphate in samples of river water from HOFF5. The number of samples is also given.

	TSS w/CSO [mg SS/l]	TSS wo/CSO [mg SS/l]	Tot-P w/CSO [mg P/l]	Tot-P wo/CSO [mg P/l]	Ortho-P w/CSO [mg PO4-P/l]	Ortho-P wo/CSO [mg PO4-P/l]
Average	252	8.1	0.626	0.032	0.255	0.010
Max	380	20.7	0.736	0.039	0.446	n.a.n
Min	175	1.0	0.516	0.024	0.063	n.a.n
# of samples	3	4	2	2	2	1

The demo plants were operated with discharge of both treated effluent and flushing water & sludge to the sewer system, and did not influence the discharge from the actual CSO located at the demo site (HO8). Operation of the demo plants did therefore not have an impact on the water quality in Hoffselva, and were in any case located just at one CSO. It is therefore not possible to conclude with certainty what the effect on the state of the Hoffselva ecosystem would be with implementation according to the 'red' or 'yellow' alternatives discussed previously. However, in the evaluation of ESS reported here, a value of 252 mg SS/l was assumed to be a typical peak concentration of suspended solids in the river during situations with CSO discharge before any implementation of the solutions. Similarly, a value of 8 mg SS/l was assumed to be a typical concentration of suspended solids during conditions without any CSO discharge. These were average values in river water samples taken under the respective conditions (Table 5). An estimate of the concentration during situations with CSO discharge was made based on the reduction in mass discharge to the river with the 'red' and 'red+yellow' implementation scenarios, and assuming that this would reduce the peak concentration proportionately. The results are given in Table 6.

It should be noted that the results in Table 6 are uncertain due to several factors: Uncertainties in the MIKE URBAN results with respect to discharge volumes; the use of a fixed average concentration (38 mg SS/l based on samples from the demo plants) in the CSO discharge; the use of fixed average separation efficiencies for the CLS and HRF; the use of a fixed average peak concentration in the river for all CSO events; and the very rough estimation of the reduction in peak concentration. However, the results may serve as a first estimate pending a more detailed assessment, which as discussed would preferably require a calibrated integrated model of the catchment.

The results illustrate the importance of the storage volume. As can be seen, the separation technologies, *i.e.* the CLS and the HRF, have a relatively small contribution to the total load reduction. This is especially the case for the CLS due to the lower average separation efficiency (10%) compared to the HRF (50%). The results also indicate that the implementation alternative is of higher importance than the choice between the two solutions demonstrated in this study, *i.e.* implementation at many ('red' + 'yellow') CSOs with the CLS solution will probably improve the conditions more than implementing the HRF solution at a few ('red') CSOs despite a higher separation efficiency. As expected, the highest improvement is indicated for the implementation alternative with use of the solution with highest separation efficiency at most CSOs ('red' + 'yellow' CSOs with HRF).

Table 6: Mass discharge and reduction of load with different implementation alternatives.

	Rain event	No treatment	Implementation alternative	
			Red' CSOs	Red' + 'Yellow' CSOs
Mass discharge from CSO, [kg]	2017-05-18	28	n.a.n	n.a.n
	2017-06-10	95		
	2 yr. rain	180		
Total load reduction CLS, [%]	2017-05-18	n.a.n	49 %	74 %
	2017-06-10		21 %	59 %
	2 yr. rain		18 %	58 %
Load reduction due to improved separation with CLS, [%]	2017-05-18	n.a.n	2 %	3 %
	2017-06-10		4 %	4 %
	2 yr. rain		2 %	4 %
Total load reduction HRF, [%]	2017-05-18	n.a.n	59 %	86 %
	2017-06-10		35 %	75 %
	2 yr. rain		27 %	73 %
Load reduction due to improved separation with HRF, [%]	2017-05-18	n.a.n	12 %	14 %
	2017-06-10		18 %	21 %
	2 yr. rain		10 %	18 %
Estimated peak particle concentration in the river with CLS, [mg SS/l]	2017-05-18	252	133	71
	2017-06-10		202	109
	2 yr. Rain		207	110
Estimated peak particle concentration in the river with HRF, [mg SS/l]	2017-05-18		109	43
	2017-06-10		167	69
	2 yr. Rain		187	75

Observation study

To further assess the state and potential impacts of the DESSIN solutions, the Hoffselva case included an observation study. As mentioned in chapter 2.1, systematic observations were done at eight specified observation points along the river, ranging from a point in Holmenbekken just below HO64 and down to Hoffselvpromenaden/Glippen, near Skøyen railway station. From 1st March 2016 to 1st October 2017 Hoffselvens Venner made a total of 158 observations – some at regular intervals to capture the state under normal conditions at different points in time throughout the year, and some on call, to assess the situation during and immediately after a total of 10 registered CSO events. Each observation included filling of a log form and measurement of water depth, as well as three photos with specified scopes and angles.

The water flow and level in Hoffselva vary considerably through the year. How observers characterized various aspects of the water quality tended to vary accordingly, but on a scale from 1 to 5 they mostly rated their overall experience of the river as 5 - a very nice and valuable part of the environment. A general impression is also that in the perspective of everyday users, the river appears relatively clean most of the time. The most positive experiences were reported from the upper sections of the observation area, whereas the observations from the lower section, down towards Skøyen, were a bit more mixed, with some reports of garbage and miscoloured water. This was as expected, given that the lower section is in a more urban area, where the river is more exposed and the riparian zone for a large part is urbanised. This section of the river has several CSOs and receives the discharge of upstream CSOs in Makrellbekken. The upper section, on the other hand, included observation points near two nicely developed dams and a hidden, quite impressive waterfall – elements that tend to be associated with beauty and favoured by human users.

Although no cases of extreme pollution were observed, there were clear differences between observations during/immediately after CSO events and observations made under normal conditions (Figure 16).

Figure 16: Hoffselvpromenaden/Glippen. Left: Overflow, 06.04-2016. Right: Normal conditions, 01-06-2017.

At CSO events, the rate of flow was reported to be 4 - quite high, or 5 - very high, in most cases. Turbidity levels, likewise, were rated as 4 – quite high, and in most cases 5 – very high. The log form also included a question on the colour of the water. Apparently, this was a somewhat unreliable indicator. While some reported on the level of whitish or other unnatural miscolouring as intended, the photos showed that some also reported a high degree of miscolouring when the water turned very brown due to increased flow and high turbidity. While the research team observed whitish miscolouring near CSOs in the upper section of the observation area on some occasions, the log forms from the observation study indicate that this is more prevalent in the lower section, below the point where Makrellbekken joins the main river.

Varying levels of natural material were observed floating in the river. Human-made materials such as litter and sewage garbage were also reported, but to a limited extent. The observations were mostly classified as 3 – limited amounts, and 4 – substantial amounts, but never 5 – in plenty. Where type was specified, mostly litter of uncertain origin was observed. As to the condition of the riverside, observations also varied. More litter was observed during and immediately after CSO events, and most of this was in Smestaddammen, at Åmot below the entry of Makrellbekken, further down at OPAK (Figure 17) where the river makes a turn and slows down, and at Hoffselvpromenaden, down at Skøyen.

Figure 17: Photo taken at OPAK by the research team. Right hand picture shows litter at the outlet of a discharge pipe, believed to be from the CSO HO62.

The most interesting single indicator was that of odour, which can be related more directly to discharge of sewage water. While there were no cases of 5 – a strong, unpleasant smell in the area, rate 3 – some unpleasant smell by the riverside, and 2 – a weak but noticeable smell in immediate vicinity of the water, were reported at some observation points during and immediately after CSO events. This happened mostly at Smestaddammen, Hoffsdammen and the observation points below the entry of Makrellbekken (except Hoffselvpromenaden, where the river area is fenced). Different observers were involved and comparison with observations following a false CSO alarm do not indicate that there is any reason to suspect observer bias. It is important to note, however, that the observations on this aspect also varied: odour was mostly registered soon after notification of a CSO event. Observations made several hours after the onset of the event rarely included mentioning of any smell.

The number of people in the area was also registered. While this varied, depending on weather, season, and time of day, relatively few users were observed. The number of people and kind of activities observed varied across observation points. At Holmenbekken/Holmendammen a limited number of people, rarely more than 10, was reported. Smestaddammen, which is more accessible, has more users. Many elderly and families with small children, people in wheel-chairs, etc. come to enjoy the view and feed the birds, and between 5-10 and 10-20 co-visitors were often observed. From Smestaddammen down towards Dronningfossen, a partly hidden trail passes across semiprivate grounds, past a private dam called Bjørnebodammen, a minor waterfall, and a lush bushy area. The observation point at Dronningfossen is even more secluded. Local kids were observed building tree huts, wading and bathing. Several more mature long-term residents also tend to visit this site, but usually none or less than 5 were observed. Below Dronningfossen, at Åmot, the area is steep and fenced, and no visitors were observed. Hoffsdammen is not a place where people stop, but many pass by on their way to/from work, so between 10 and 20 users were often reported. At OPAK, watching the fish is a popular activity, both for walkers and for workers from the nearby buildings, but the observers rarely encountered more than 5 people.

After OPAK, Hoffselva becomes less accessible until it reaches the observation point we called Tribunen. Again, the river is partly fenced, but it forms an integral part of a housing estate, with playgrounds and a small 'tribune'. There is a pedestrian road, and between 5 and 10 users were often observed. Hoffselvpromenaden/Glippen, finally, has a concrete square with a nice river opening, but there is a road with heavy traffic next to it. Less than 5 other visitors were usually observed, despite the higher population density.

These variations, combined with the finding that some impacts seem quite limited in time and space, suggest that while local treatment can be of great benefit from a user's point of view, its value will depend a lot on where exactly in the sewer and river system such solutions are implemented.

Selection of case-relevant parameters of state

Based on the investigations discussed above, and those reported in D21-3 (Cheng, 2017) and D32-1 (Cheng *et al.*, 2018), physio-chemical state parameters that could be directly affected by the demonstrated solutions were identified as indicators for ESS provision. The following were selected for inclusion in the ESS-evaluation performed with the evaluation tool developed in DESSIN:

- Concentration of heavy metals
- Concentration of total suspended solids
- Turbidity
- Presence of sewage garbage

The relevant ESS based on these state parameters are discussed in the next section.

2.4.2. Step 7: IMPACT I (ESS Provision)

In the DESSIN framework IMPACT I, is defined as the effects that changes in ecosystem state have on the provision of ecosystem services (Müller and Burkhard, 2012). In the Hoffeselva demo, case relevant ESS were identified for the state parameters that could be affected by the demonstrated solutions. The DESSIN framework, distinguishes between provisioning ESS, regulation & maintenance ESS and cultural ESS.

Provisioning ESS

The water from the river is not extracted for use by society, *e.g.* for drinking water supply or non-drinking domestic (such as flushing toilets, garden watering and clothes washing) or industrial purposes. Nevertheless, the water in the river is a potential source for non-potable use. With respect to the state parameters, general physio-chemical parameters will be of importance for this service, and particle concentration was selected as indicator in this study.

Regulation & maintenance ESS

In Hoffselva there are fish, the dominant species is trout, other animals, insects and plants in the river and riparian zone. Implementation of the solutions will have a positive impact on the conditions in the river and improve the environment, which will be positive for flora and fauna. The river's capability for maintaining the physical, chemical and biological environment along its course, and supportive services (*e.g.* photosynthesis, soil formation) will be higher with improved water quality. These services are considered fundamental because they provide the basis for other ESS. With respect to the state parameters, the total pollution load from several compounds will be of importance for these services, and the concentration of heavy metals was selected as an indicator in this study.

Cultural ESS

Considering the identified stakeholders, especially cultural ESS (*e.g.* recreation, aesthetics, knowledge) was considered to be of importance in Hoffselva. These ESS are difficult to assess by technical measurements and physical and chemical analysis, which was an important motivation for conducting the observation study and interviews. With respect to the state parameters, transparency of the water itself and the visual impression of the water and river bank will be of importance for these services and can be quantified by turbidity or particle concentration, and the presence/abundance of sewage garbage, which were selected as indicators in this study.

The case relevant ESS were defined as:

- Surfacewater for non-potable use.
- Maintenance of environment (physical, chemical, biological conditions).
- Experience from use of landscape (transparency of the river water & visual impression of water and riverbank).

Of these, clear beneficiaries could only be identified for the cultural ESS. The use of ESS and benefits resulting from this will be discussed in the next section.

2.4.3. Step 8: IMPACT II (ESS Use and resulting benefits)

The DESSIN framework applies the definition of Müller and Burkhard (2012), seeing Impact II as the effects that changes in ecosystem services have on human well-being, understanding human wellbeing as the economic value derived by beneficiaries from enhanced ESS use (DESSIN

Cookbook, D11.2). ESS Use indicators should be selected considering direct and indirect use, as well as non-use economic values. This is in accordance with other studies (TEEB, NOU, 2013). Following the recommended procedure, this section will first assess these aspects qualitatively, to understand all the expected impacts that specific changes in ESS will have on the relevant beneficiaries identified in the study area. Subsequently, appropriate economic valuation method(s) to attach monetary values to the ESS Use are discussed and applied.

Qualitative assessment

As noted above, several stakeholders and potential beneficiaries were identified. Fifteen of these were contacted, and ten eventually took part in semi-structured stakeholder interviews. Some interviews were face-to-face, whereas others were conducted by phone-calls of varying length. Those interviewed were representatives of:

- Hoffselvens Venner (local river forum)
- Oslo Sportsfiskere (anglers' association)
- Local residents' associations
- Bymiljøetaten (Agency of City Environment)
- Frivillighetssentralen (volunteer centre, located by the river)
- Marina (mouth of the river)
- Ullern, Røa og Bygdøy Historielag (local history association)
- Former water bailiff (and community representative)
- Oslo VAV – operations
- Oslo VAV – planning

Beside the interviews, the qualitative assessment is based on dialogue during two stakeholder meetings, available documents, and the collaboration with Hoffselvens Venner, including reading of various postings in their Facebook group. The overall impression is that the river is associated with cultural ESS that affect and are valued by a range of beneficiaries, albeit to a varying degree. For cultural services, the benefit for people (Impact II) is also based on intermediate (Impact I) services, which are closely linked to the state of the ecosystem and include Regulation & Maintenance services. Water quality impacts significantly on the values attributed to the river, and a potential value can be ascribed to the tested solutions, based on their estimated impact on water quality.

The interviews highlighted a broad array of meanings associated with the river, which form part of the overall experience, use and value attributed to the river by various stakeholders. As illustrated in Figure 18 below, these can be sorted according to the four dimensions or existential themes which pervade the lifeworlds of all human beings: Lived space (spatiality), lived body (corporeality), lived time (temporality), and lived human relation (relationality or communality) (van Manen, 2015).

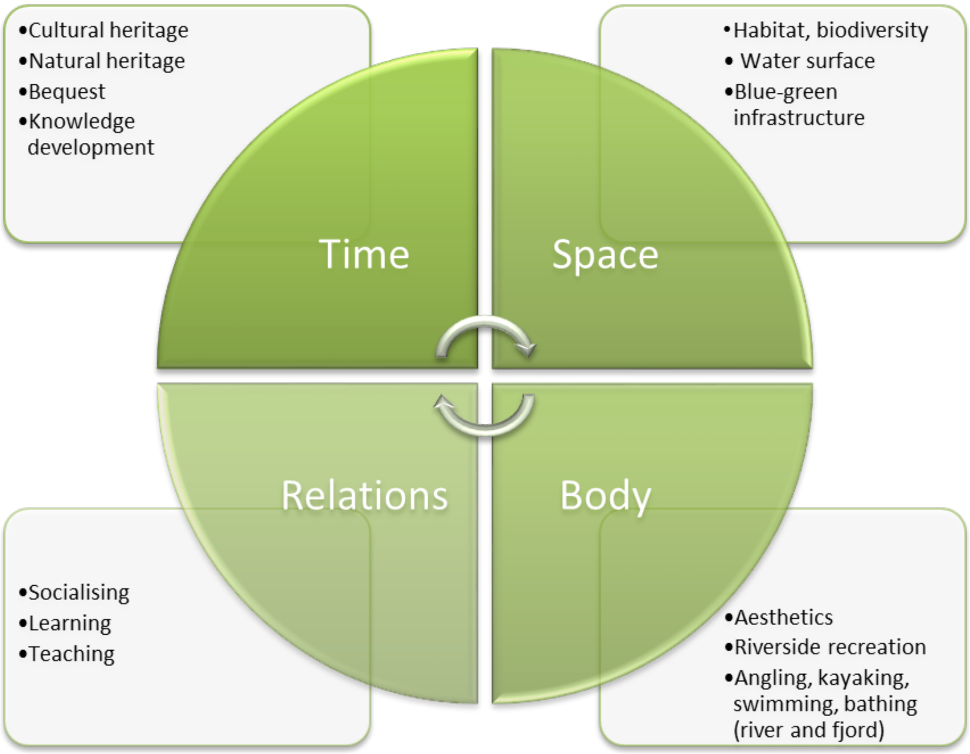


Figure 18: The four dimensions or existential themes which pervade the lifeworlds of all human beings; lived space (spatiality), lived body (corporeality), lived time (temporality), and lived human relation (relationality or communality).

Spatiality

Several stakeholders emphasized the value of the river system as habitat, or natural home and environment of a variety of animals, plants and insects. The knowledge of and preservation of this Regulating ESS was considered important, not only by professionals such as the Agency for the City Environment, but also by local users, such as Hoffselvens Venner and Oslo Sportsfiskere. It is associated both with use value, relating to licenced angling in the upper section of Hoffselva, and to sport fishing of mature trout in the fjord, and with non-use value. The experiential value of sharing space with fish and a wide variety birds is repeatedly documented through photo uploads and comments on Facebook. Some stakeholders are also much engaged on the water surface, as such. The opportunity to come close to and look out across this kind of space is valued by many; to enjoy the fish wake, birds dive and sunrays hit the water surface; to use it as a source of personal reflection (given the cultural significance associated with water in Norwegian tradition, where lakes and ponds are associated with mirroring and depth of soul, the deep unknown, monsters, fairies, etc.); and to have it available as space for leisure activities, throwing stones with kids, casting, kayaking, etc. Among those interested in urban planning, the role of the river as blue-green infrastructure, for solving urban and climatic challenges by building with nature, was emphasized even more.

The results from the testing indicate that both the HRF and CLS solutions may add value on this point, by limiting the amounts of sewage garbage and suspended solids reaching the river, as reported above. The reduction of the total load of pollution may affect fish and bottom fauna, and, to the extent that nutrients are removed, also contribute to limiting eutrophication and growth of water weeds and other plants in the dams.

Corporeality

Use as well as non-use values were highlighted also when it comes to lived body, or the corporeal dimension. While there has been a tendency in ESS assessment to focus on specific, measurable recreation activities, many stakeholders in Hoffselva considered aesthetics, understood as subjective and sensory-emotional values, such as the sight and sound of clear, running water, and the opportunity to sense the smell of fresh water and sumps in the middle of the urban environment, more important. As one interviewee stated: *"Water is important, in creating a nice environment. It brings peace to mind, like when you look into a fire."* Through their impacts on water quality, the tested solutions will have a direct impact on these aspects. Although it is not recommended, some people also take pleasure in bathing or wading in the river, on hot summer days. The values associated with use of the river area for jogging, dog-walking, angling, feeding birds or watching fish, and collecting wild berries and flowers, were also noted by many. Some individuals argued that through these uses, the river plays a key role in promoting good health, which decision-makers tend to overlook.

Although the tested solutions may not directly have an impact on use values related to riverside recreation activities, they may have a significant indirect impact, by reducing the amount of sewage garbage, improving the visual impression of the water and riparian zone, and limiting the odour associated with CSO events. While the value of these impacts is linked to Cultural ESS, they also relate to Impact I. Impacts such as improved visual impression and reduction of unpleasant smell can be associated with Regulation & Maintenance as well as Cultural ESS. The knowledge that the discharge from CSOs is reduced and the amounts of sewage water entering the river is limited is likely to affect the experiential value associated with the river. Potential long-term impacts on eutrophication, growth of invasive species and biodiversity may have further impact on the values associated with the corporeal dimension. To the extent the removal of bacteria bound to suspended solids affect water quality in Bestumkilen, this may also benefit swimmers, local boat owners and kayakers from wider areas of Oslo.

Relationality or communality

Several stakeholders emphasized that Hoffselva is an important ground for socializing. The barbeque spots and benches are used actively, especially by elderly people and families with small children. Furthermore, the river is a valuable resource for the local school, which has 'adopted' and use it for science teaching, as well as for gymnastics. Local kindergartens tend to come for walks and picnics, where they teach the children about the life and environment around the river. Hoffselvens Venner organize joint walks along the river regularly, free and open to the public, with on average 50 participants. The biodiversity trail and nature map developed by Friends of the Earth, Norway and Hoffselvens Venner have also led to more communal use of the river area again highlighting that Regulation & maintenance ESS may form the basis for Cultural ESS. Regarding relationality, too, the expected impacts of the tested solutions may contribute positively to ESS, by removing sewage garbage and improving the visual impression. Potentially this may limit negative impacts on biodiversity. While not many communal events are likely to take place in bad weather when CSOs occur, reducing the chance that people will come across sewage garbage involving health risk, and contributing to a cleaner environment may increase the value of these services.

Temporality

The local history association and Hoffselvens Venner, especially, emphasize the cultural and natural heritage associated with the river. The major dams are man-made, from the 1800s and before, testifying to the history and urban transition of the area. The remains of old mills, trees and cultivated plants carry important messages of the past; before the old farm at Smestad went into private ownership in the 1700s, the area belonged to a major convent (Hovedøya Kloster). During world war II the Germans tapped the Smestad dam down, to place one of their major military camps in the area. Bunkers from that time remain, and further towards the fjord, there are traces of the industrial era. While the area must be developed in pace with the rest of Oslo, it is important to maintain its historical dimension, and for this, many locals consider the river as key. Furthermore, some pointed to spiritual and symbolic value linked to temporality. One interviewee said that for her, the river is *"like life, flowing from its sources in the pure and natural environment up in the hills… meandering through society and emptying out into the vast fjord, where it is mixed with water from other sources and the eternal waves of the ocean."*

Many of the local stakeholders, as well as interviewees from Oslo Water and Sanitation Agency, emphasized bequest, or the value of satisfaction from preserving the river for their children, grandchildren, and future generations. Maintaining natural and cultural heritage as a source of continued knowledge development is a related aspect. The biodiversity and multiple socio-cultural values associated with Hoffselva have resulted in an increasing number of students' theses, research and media reports, through which increased environmental awareness and knowledge about nature and society are created, again highlighting the connection between Impact I and Impact II. The contribution from implementation of the solutions to reduced pollution, and thereby maintenance of the river system as habitat, will help ensure continued interest and add value also in this respect.

Further discussion

Discussing Impact II benefits in terms of lifeworld existentials brings to light how different services and impact levels work together to affect the overall experience and value associated with ESS in Hoffselva, and the potential value the tested solutions may have for local beneficiaries. It also helps ensure that all potentially relevant services are examined, throwing light on the wide variety of benefits associated with the solutions in question.

It should also be noted, however, that several interviewees found the level of engagement and use/appreciation of the mentioned services unevenly distributed in the local population. While most stated that the river means a lot to people (rate 5, on a scale from 1-5), some saw the general population as more indifferent (rate 2 or 3), and one said that even though he and others find it extremely valuable, he suspects that some may not even have noticed or passed by the river area. In line with the findings from the observation study, some noted that the actual use of the recreation areas seems limited, considering the number of people living nearby. Most felt that aesthetics is the most highly valued aspect (rate 5, on a scale from 1-5), while use of the river area for recreational activity mostly was rated 4; opportunity to enjoy birds, fish and biodiversity mostly 4; and the role of the river in maintaining local history and identity mostly 3, as many younger people would have limited knowledge.

Most interviewees suspected that the population has limited knowledge about the fact that there are CSO events resulting in discharge into Hoffselva. Half-way in 2017, the Water and Sanitation Agency reported that they only had received 3-4 complaints from residents near Hoffselva that year. While other parts of Oslo are plagued by basement flooding during severe rains when one will also have CSO events, this happens only rarely in the Hoffselva catchment. Most complaints are about sewage garbage and odour, and about cases of illegal discharge of drilling sludge.

The interviewees were further divided in their views on willingness to pay (WTP). Considering that the fees for water and sanitation in Oslo are relatively low, compared to other municipalities in Norway, some thought people would accept an increase to improve water quality, given the value that generally is associated with improving the environment. Those who dared to be specific suggested that an increase of say, 20%, could be acceptable. Others did not think people would be willing to pay, partly for principal reasons and partly due to limited concern or because they were more concerned with improvement of other public services.

The potential value of the tested solutions to local beneficiaries may be summarised adapting a structured qualitative assessment method, or form of "consequence mapping" recommended in guidelines from the Norwegian Ministry of Finance. The method originates from the Norwegian Public Roads Administration (NPRA) and their handbook for assessing non-monetized impacts of road projects (Bull-Berg *et al.*, 2014). It consists of 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 project or measure in question, considering the results from the preceding steps. The NPRA measurement scale for overall impact assessment is a 9-point scale, ranging from (----) to (++++). Table 7 below presents such a consequence mapping for local CSO treatment in the case of Hoffselva, based on the discussion above. The results in Table 7 are, however, general and do not reflect differences between the demonstrated solutions or the implementation alternatives discussed above.

Table 7: 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 to 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 to particles	+	+	+	Indirect (use and non-use)
	Spiritual, heritage preservation		+	++	++	Direct (non-use)

The potential value reduced discharges from CSO may have for identified beneficiaries in the case of Hoffselva is substantial. It relates both to Regulation & Maintenance and to Cultural ESS, but as we have seen above the impacts in terms of Regulation & Maintenance are associated with ESS Use value only indirectly, to the extent that they enter the lifeworld of human beneficiaries and thus become Final ESS. The impact in terms of sustenance of biodiversity and fish can be ascribed use and non-use economic value mainly through the Cultural ESS these services are associated with. Likewise, impacts in terms of visual impression and smell/odour of the river water gain social significance and economic value through their association with final, Cultural ESS.

Considering the direct effects of the demonstrated solutions, the Cultural ESS associated with aesthetic appreciation of the river water itself and riverbank area, *i.e.* ESS associated to transparency of the river water, and visual impression of water and riverbank, should be used as Final ESS when comparing the two solutions.

Economic valuation of ESS

To perform an economic valuation of ESS one must estimate the value of a change in the quality or amount of ecosystem services because of a measure, a policy etc. This is measured by the total economic value (TEV) and includes both use values (direct use, indirect use and option value) and non-use values (bequest, altruist and existence value) (Figure 19).

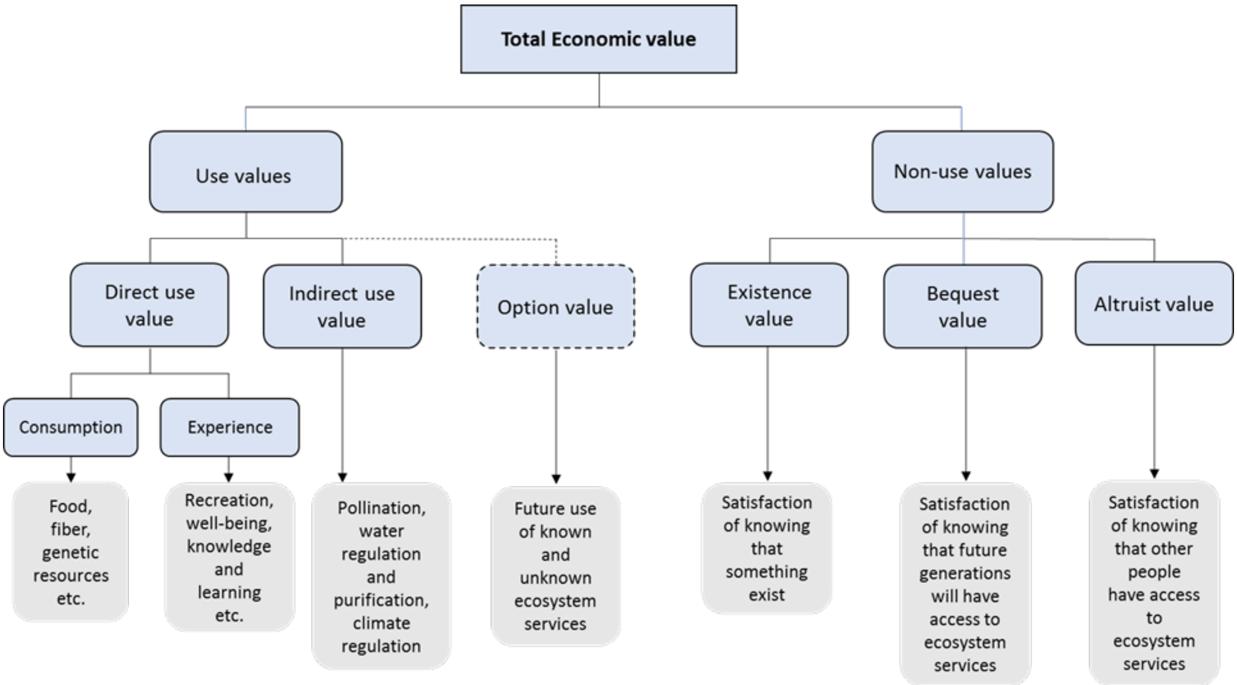


Figure 19: Total economic value (TEV)

Source: NOU 2013:10

Valuation methods

Different methods can be used to estimate the economic value of different ESS. These methods are based on individual preferences and are measured by the affected populations WTP. These methods are classified into revealed preferences or stated preferences. Revealed preference methods are based on that people's behaviour in the market will reveal their preferences towards ESS that directly or indirectly will reflect their WTP. Unlike revealed preference methods, stated preference methods are based on hypothetical behaviour with construction of a hypothetical market for a ESS by asking people about their WTP for a closer specified environmental change (e.g. enhanced water quality in a water system) that directly or indirectly will reflect their WTP. Methods based on stated preferences can be used to calculate both use- and non-use values.

However, to perform an economic valuation study and determine WTP is resource demanding and alternative more cost-effective methods have been developed. Benefit (or value) transfer refers to transferring estimates of ESS values from an earlier study carried out at a "study site" to a new "policy site". There exist two main types of valuation techniques: unit value transfer and function transfer.

Unit value transfer includes both a simple unit value transfer and an adjusted unit value transfer. A simple unit transfer involves transferring estimates of average WTP for a ESS from the original study site to the new policy site. Adjusted unit value transfer involves adjusting the value estimates to reflect obvious differences (usually income and/or prices) between study site and policy site.

Function transfer includes benefit function transfer and meta-analysis. Benefit function transfer involves transferring the whole WTP function from the study site to the new policy site. Explanatory variables included in the function might be the respondent's income, age, education and use and knowledge of the ecosystem services. If the transfer of WTP functions should give value estimates for the policy site, the explanatory variables and changes in the ecosystem services must be comparable between the study site and the policy site, and the responder preferences must be the same at the two places. Meta-analysis combines several valuation studies to estimate a common WTP function. This makes it possible to see how the WTP for an ecosystem service varies with features of the services, characteristics of the population or with the applied valuation method. One of the disadvantages with meta-analysis is that it requires many completed studies to run a regression analysis and for many ecosystem services these studies do not exist.

Quantification and valuation of beneficial impacts of improved water quality

As discussed above, Cultural ESS will be improved by implementation of the demonstrated solutions and have clear beneficiaries that will benefit from better water quality in Hoffselva. More specific, Cultural ESS associated with aesthetic appreciation of the river and riverbank area, *i.e.* the ESS associated to transparency of the river water, and visual impression of water and riverbank, will be directly affected by the implementation of the demonstrated solutions to improve the water quality.

There are few Norwegian valuation studies that have tried to derive the value of improved water quality, and many of these studies have been completed before ESS were included in environmental economy. Only recreational services and non-use values were valuated for different environmental assets, and there were not many of studies on urban water systems. The non-urban water systems are of much larger scale and not used for recreation in the same manner as urban water systems.

However, in a previous study in Kristiansand (Vista Analyse, 2014a) recreational activities were correlated with distance from the recreational area. Vista Analyse (2014b), have also assessed benefit and economic cost of different measures to reach the environmental goals of the WFD in the urban water systems of Hovinbekken and Alna in Oslo. The WTP in the study in Hovinbekken and Alna was based on results from a previous pilot study conducted by NIVA (2012) of the Aker river in Oslo. In the present study, it was decided to base the valuation of ESS on the earlier study in Oslo, and use benefit (or value) transfer as valuation method.

While non-use values may be appreciated more widely, the study in Kristiansand found that the recreation activities were highest among people living less than 300 meters from the recreation area and approximately zero for people living more than 1 kilometre from the recreation area. Table 8 shows the number of persons and the number of households living less than 100, 300 and 1000 meters from Hoffselva. There are approximately 2400 households less than 100 meters from the river.

Table 8: Number of persons[4] and households[5] (numbers are rounded to the nearest hundred) living at different distances from the Hoff river

Distance < 100 m		Distance < 300 m		Distance < 1000 m	
Number of persons	Number of households	Number of persons	Number of households	Number of persons	Number of households
5 500	2 400	16 000	7 100	45 000	19 900

Source: StatBank Oslo municipal and Oslo VAV

Counting the number of persons that live close to the river will not give a complete picture, but may be used as a rough estimate of the impact on the society of improved recreational and esthetical services at Hoffselva.

In line with findings from the stakeholder interviews in Hoffselva, the pilot study in Akerselva found that the WTP varied considerably. However, based on a small sample of 137 respondents, an average WTP of 137 (2012) NOK per year for a ten-year period to secure good bathing water quality was found. Bathing is currently not recommended in Hoffselva, and Akerselva is also bigger and more centrally located, but the two rivers are similar in that both are urban, with dams and associated recreation areas. While a large part of the area around Akerselva used to be classified as "working class" and still has many rental homes and households with limited income, Hoffselva flows through higher-income areas with many individual house owners, which potentially could increase the WTP. Both rivers are used for fishing, and both are associated with historical and cultural value. Past valuation studies show that non-use values constitute a significant part of people's WTP. Vista Analyse (2014b), in their assessment of Hovinbekken and Alna, therefore assumed that non-use values (such as bequest value) were included in the WTP from Akerselva, and that it was reasonable, given the lack of other studies, to apply this WTP also in relation to other urban rivers in Oslo.

Table 9 shows the estimated present value of total WTP for the population living 100, 300 and 1000 meters from the Hoff river. These estimates are based on an assumed WTP per household of 16 EUR (2017-prices) per year for a 30-year period. A 4 percent discount rate has been used to calculate the present value of total WTP.

[4] Based on todays (2017) population

[5] On average there are 2.25 persons in each houshold in district Ullern and district Vestre Aker (in 2016 and 2017)

Table 9: Estimated economic present value of total willingness-to-pay (WTP) for the population living at a certain distance from the Hoff river (100, 300 or 1000 meters) based on the assumption that WTP per household is 16 EUR (2017-prices) per year for a 30-year period.

	Distance to Hoffselva		
	1000 meters	300 meters	100 meters
	WTP [mio. EUR]	WTP [mio. EUR]	WTP [mio. EUR]
Total WTP for the population living at different distance from Hoffselva given as a present value (PV)	5.7	2.0	0.7

The results in Table 9 are very rough estimates of benefit expressed in form of WTP. Given the focus on bathing water quality in the study that was used as basis, the results should probably be understood as a WTP for measures that result in bathing water quality or similar quality standard.

It should be noted the NPRA based ranking in Table 7 should not be used in addition to the economic valuation because this may give double counting of impacts related to the cultural ESS. The consequence mapping and economic valuation of ESS should therefore be viewed at as two separate methods to value the benefits of improved ESS.

2.5. Part V: Sustainability Assessment

2.5.1. Step A: Scope

A SA is included in the DESSIN ESS Evaluation Framework to widen the analysis, putting the evaluated changes in ESS into a wider perspective by considering several dimensions. The dimensions include social, environmental, financial, governmental, and asset performance aspects of the examined solutions. This allows for consideration of potential disadvantages and advantages expected from implementing the solutions, that fall outside their direct impacts on water quality and related ESS.

Sustainability is thus defined as follows in the DESSIN Framework: *A given technology or solution implemented to mitigate water scarcity or water quality issues is sustainable when it can actively support the supply of ESS demand while contributing to social, environmental and financial development in a way that meets the needs of the present without compromising the ability of future generations to meet their own needs and contributing to good governance* (DESSIN Cookbook, D11.2).

In the Hoffselva demo case, SA is included both to demonstrate the methodology and to compare the demonstrated solutions in more detail. The scope is thus to assess, discuss and compare the sustainability of implementation of the two demonstrated solutions. While one could have selected comparison with other alternatives, such as building large retention basins or renewing the infrastructure and removing all CSOs in the catchment, these options are not relevant for this study. VAV, however, are looking at several measures, combined to fit landscape, building and technical conditions prevailing at different CSOs and in different river systems. The solutions demonstrated in DESSIN may be additions to the 'toolbox' of alternative measures that Oslo VAV may use in assessing options for future adaptation of the water infrastructure.

The SA considers potential impacts throughout the expected lifetime of the studied solutions, which is 30 years.

2.5.2. Step B: Selection of suitable sustainability indicators

Sustainability indicators were selected following the procedure stated in the DESSIN Cookbook, and using the DESSIN sustainability indicator list as guidance.

The social dimension

For the social dimension of sustainability, the DESSIN framework defines enhancement of quality of life as the objective. Five criteria are identified, as listed below:

- Health and Safety
- Economic impact creation
- Job creation
- Equity
- Enhance cultural services

Health and safety refers to the degree to which the solutions contribute to conditions that protect or enhance the lives and health of the people affected. In the case of Hoffselva, the Presence of microbial pathogens (S111) and Presence of toxic chemicals (S113) have been selected in the DESSIN Framework as relevant indicators. While reduced discharge of pathogens and other pollutants such as toxic chemicals to Hoffselva will be an effect of reduced discharge from CSOs, this effect is more related to the storage volume than the two separation technologies demonstrated in DESSIN. In the present assessment, the same storage volume has been selected for the two solutions so there would be no difference between the two solutions in this respect. The effect of additional separation of pathogens and other pollutants will be limited for both solutions. A general evaluation of the overall effect of storage and separation has been presented in the ESS-section (Table 7) and indicated that the main effects would be from removal of particles and sewage garbage. Effects on pathogens and other pollutants have therefore not been included in the SA in this study.

Economic impact creation (S121) may be calculated based on how the implementation of the solutions generates activity and income through supplies and services from different business sectors. For small-scale interventions, it is generally possible to make adaptations of data, derived from initial spending, to bring out the value chain behind the solutions and use input-output analysis to calculate the impact at a regional, county or individual company level. However, the pilots tested in Hoffselva have not been implemented full-scale, and there is limited information about suppliers and supplies needed. The CSOs in Oslo are also not standardized, so to some extent solutions must be customized to fit each location, making it difficult to estimate initial spending with accuracy. For these reasons, indirect and induced economic impacts were not selected for the SA in this study.

The investments for implementation of the solutions are relatively small, and the contribution of the installation and operation of the solutions in terms of employment will probably be limited. Considering also the uncertainties mentioned above, the indicator (S131) Number of jobs, amount of employment created by implementation of technology/solution was not selected for the SA in this study.

The criterion equity refers to the degree to which the services and benefits associated with the solutions are fairly distributed or contribute to a more equitable distribution of benefits in the affected communities. Proposed metrics in the DESSIN Framework are the number and categories of beneficiaries affected. For the quantitative assessment, the number of beneficiaries affected (S141) could be selected as indicator. This indicator will not differ between the two solutions, and not be affected by the degree of implementation in Hoffselva other than what is already included through selection of two implementation alternatives with CSOs of different risk categories. It would therefore be more relevant in an assessment on a spatial scale where one could differentiate between the number of people affected, *e.g.* in an assessment of which catchment that should be prioritised for implementation, than in an assessment of sustainability in a selected catchment. However, it has been included to cover this aspect of the sustainability of the solutions. The distribution of benefits on different social categories (S142) will be discussed qualitatively.

The criterion "enhance cultural services" (S15) relates to social impact in terms of realization of market and non-market value linked to enhanced cultural services. This may include economic impact derived from the Impact II ESS assessment, as well as other contributions to knowledge-building and preservation of cultural heritage. In our case, the present value relating to this criterion has been discussed as Impact II. However, a qualitative assessment of indicator (S151) Experiential and physical use of landscapes in different environmental settings, may throw light on how further value may be realized in the future, given the urban development plans for the Skøyen area.

For SA in this study, the following indicators were thus selected for the social dimension: The number of beneficiaries affected (S141); the distribution of benefits on different social categories (S142); and experiential and physical use of landscapes in different environmental settings (S151). For the last indicator, both a quantitative and qualitative assessment has been included. The quantitative assessment was performed using the same indicators as in the ESS evaluation.

The environmental dimension

The objective defined for environmental sustainability in the DESSIN Framework is efficient use of water, energy and materials. Further, environmental efficiency, in terms of life cycle emissions to water, air and soil has been included. Criteria proposed for this objective are:

- Efficiency in the use of water

- Efficiency in the use of energy
- Efficiency in the use of materials
- Life cycle emissions to water, air and soil

While neither of the solutions use materials as part of normal operation, both solutions use water for periodic cleaning. The quantity will depend on the cleaning frequency and need, and this again depends on how often the plants are operated because of CSO events, and the amount of discharge. Both solutions also use energy for operation of mechanical components (*e.g.* tilting of lamella, pumping of sludge/water during emptying of storage volume and opening/closing of valves). The energy consumption will also be dependent on the frequency of operation, and the duration of the CSO discharge.

Water consumption and energy use in operation can therefore be expected to be correlated, and the selected criterion in this study was efficiency in the use of energy.

Energy consumption (En124) per m^3 of treated discharge was chosen as the indicator.

The financial dimension

For the financial dimension of sustainability, the DESSIN Framework defines affordability (Ensure liquidity/solvency of the entity) as the objective. Only one criterion is defined:

- Cost coverage

In this study, the affordability should be assessed from the point of view of the organization implementing and operating the solution. Indicators for cost coverage can be related to investment and/or operation, which may be based on life cycle assessments. Monetary benefits derived from the solution, or other sources of financing receivable by the organization may also be used. The monetary benefits can include benefits from enhanced ecosystem services that are due to the implemented solution (*e.g.* avoided costs), where accountable.

Since VAV is the decision-maker that would consider implementing the solutions in question, and an agency that provides a public service, a cost-benefit analysis could be performed to assess the profitability of the different implementation alternatives of the HRF and CLS solutions. However, this would require that one could quantitatively differentiate between the value of benefits achieved from implementation of the different solutions and implementation alternatives. The valuation of the ESS has been based on benefit (or value) transfer from a case with focus on bathing water quality, and the demonstrated solutions are not designed to achieve such a degree of treatment. Also, the effect of the solutions on water quality in Hoffselva will depend on the degree of implementation. In the present study, the valuation method of ESS cannot differentiate sufficiently between the effect of solutions or implementation alternatives with respect to WTP, and a cost-benefit analysis has therefore not been included in the SA.

For comparison of cost coverage for the demonstrated solutions in this study, investment expenditure (F111) and annual operation expenditure (F112) were chosen as indicators.

The governance dimension

On governance, the defined objective is compliance. The core meaning of compliance is 'being in accordance with regulations'. However, the concept is increasingly taken to include the state of being in compliance, plus the processes and structures required to become and remain compliant, and it is in this sense it is applied as an objective in the DESSIN SA. Three criteria are identified:

- Compliance with relevant regulations
- Stakeholder involvement
- Transparency

The first criterion refers to the level of compliance with the relevant regulations and standards for good water governance in the EU, and for the Hoffselva case, (G111) Compliance improvement with relevant EU standards (WFD, BWD) is selected as the most relevant indicator.

The tested solutions are also associated with increased potential for stakeholder involvement and increased transparency in local water management, given that information may become available through ICT-based monitoring of the solutions and the CSOs where they are implemented. This, however, will only be assessed qualitatively, in relation to indicators (G131) Monitoring, and (G132) information dissemination.

Thus, Compliance improvement with relevant EU standards (WFD, BWD) (G111), monitoring (G131), and information dissemination (G132) were chosen as indicators.

The assets dimension

Assets is the dimension reflecting the level of performance of a given innovative solution or technology in providing an expected function. The DESSIN Framework defines two objectives for this dimension:

a) Solution reliability, adequacy and resilience
b) Solution acceptability

Several criteria are identified for the assets dimension:

- Adequate capacity of the technology/solution
- Adaptability to changes
- Safety and Health of operator/supplier
- Efficiency
- Disturbance impact of the technology/solution
- Start-up time (time from installation to effectiveness)
- Alignment with existing knowledge

As discussed in the ESS section, a main difference between the two solutions are the separation efficiency of the technologies after the storage capacity has been used. For comparison of the demonstrated solutions in this study, objective a) with focus on adequacy of the solution was chosen, and the separation efficiency (A15) was chosen as indicator. In the assessment, separation efficiencies of the technologies for both particles and sewage garbage after the storage capacity has been used, have been included. In addition, an assessment of overall removal has been included.

An overview of SA indicators for the different dimensions selected in this study are given in Table 13 in section 2.5.5.

2.5.3. Step C: In case of insufficient indicators, identify further indicators

Not relevant in this study.

2.5.4. Step D: Data collection and calculation process

The social dimension

Number of beneficiaries affected (S141): Demographic projections from the Norwegian Bureau of Statistics for Ullern and Vestre Aker have been used as basis for assessment. There will also be other beneficiaries – mainly people from other parts of Oslo who occasionally come to take part in specific activities, such as angling, kayaking, or swimming at Bygdøy Sjøbad – but as we have seen above, the recreational use and appreciation of non-use values associated with the river are mainly local.

As noted above, Ullern and Vestre Aker townships had a total population of 79 000 in 2016. This population is expected to increase up to around 104 000 by 2040 (Norwegian Bureau of Statistics 2017). The wider population of Oslo will also increase at high rate during the same period.

Categories of beneficiaries affected (S142): As noted in chapter 2.1., the populations of Ullern and Vestre Aker tend to have better living conditions and higher incomes than average for Oslo. Improved water quality will benefit privileged users, such as owners of expensive villas near Holmendammen, and boat owners at the local marina. However, according to the observation study and stakeholder interviews, elderly and families with young children are the categories that use the river areas most often and express appreciation of the non-use values in social media. Furthermore, Hoffselva is a valuable resource for Ullern volunteer centre, and one of relatively few arenas where the increasing share of immigrants to the community can engage in recreational activities with long-term residents free of charge. The population of elderly is increasing more than the general population of Oslo – the share of people above the age of 50 will increase by 55% by 2040 - and the share of immigrants is also projected to increase in the years to come (Oslo Municipality 2017). With respect to equity, a distinction between the solutions or the implementation alternatives was not made, but a general positive effect of such implementation would be expected on this criterion.

Experiential and physical use of landscapes in different environmental settings (S151): To assess this aspect, the stakeholder interviews and Impact II assessment is used as background. In addition, we are using the urban development plan for Skøyen (Oslo Municipality 2015) as source of information. Figure 20 below is an illustration from the urban development plan, showing how future Skøyen and the lower section of Hoffselva is envisaged.

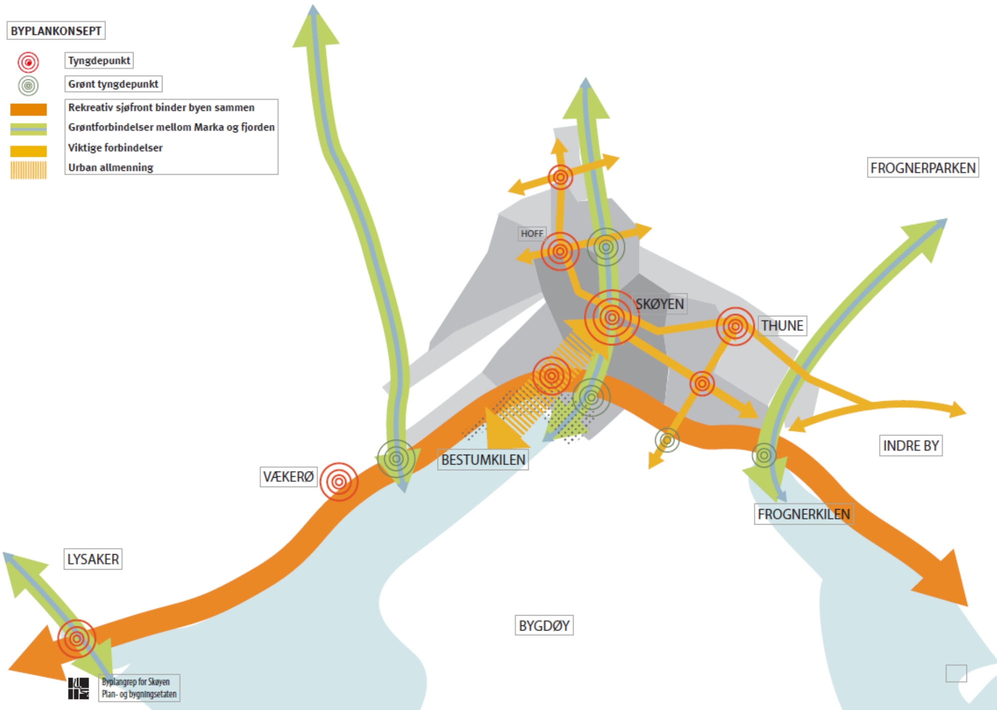


Figure 20: Illustration from the urban development plan, showing how future Skøyen and the lower section of Hoffselva is envisaged (Oslo Municipality, 2015).

At present, there are 1 500 housing units in this area, mixed with business premises and heavy traffic infrastructure. This number will be quadrupled – by 2030, there will be more than 15 000 housing units, and 10 700 more jobs in the area. The utilization of space for housing will increase from 21 to 44 percent, and there will be more high-rise buildings, with permission to build 16 floors on 10-15% of the land. The green circles on the figure indicate the location of green main points. Of these, one will be at Hoff, which is the vicinity of observation points OPAK and Tribunen. Another one will be closer to the fjord, by the marina in Bestumkilen, forming part of a recreative sea front, which is marked dark orange in the figure. The orange-coloured circles indicate main points of traffic/interaction, and the dotted areas represent a zone of "urban common".

The ESS in the lower section of Hoffselva, where both green points are planned, will be improved if the tested solutions are implemented, both if this is done only on the high-risk ('red') CSOs, and to a higher degree if local treatment is implemented at both high- and medium-risk ('red' + 'yellow') CSOs. With the changing urban context, the scope for recreational use of the river area will increase, as will the market for riverside cafés, especially near the planned seafront, where the marina currently has a small kiosk/cafeteria establishment. At the same time, the projected population increase will increase the load on the sewer system. The impacts associated with the tested solutions will therefore become more important than under present conditions, and they will most likely contribute to an increase in business opportunities and property values in selected parts of the study area.

No distinctions between the solutions or the implementation alternatives were made based on the general qualitative assessment above, but a general strong positive effect of such implementation would be expected on this criterion as also shown in Table 7.

The quantitative assessment of this criterion was based on the same indicator as in the ESS assessment, quantified by the PV of the WTP.

The environmental dimension

Energy consumption (En124) is based on the energy needed for operation of the solutions. The quantification was based on information received from the suppliers and given as volume specific energy consumption. In the case of the CLS, the volume specific energy consumption is per m^3 of water and sludge emptied from the CSO structure. The value is based on an assumed effect of 300 W for a pump with capacity of 2 l/second, resulting in an emptying time of 27.7 hours for 200 m^3.

For the HRF solution, volume specific energy consumption is for pumping of CSO discharge when gravity flow is not possible. An estimate has been given by the supplier.

For both solutions, there will in addition be energy consumption for electrical cabinet/PLS/monitoring sensors. This contribution to the energy consumption has, however, been assumed to be equal for both solutions.

The financial dimension

Investment expenditure (F111): Table 10 shows the assumptions made for calculating the PV of the cost of the solutions. A discount rate of 4 percent has been used to calculate the PV of costs. The appraisal period and the lifetime of the plants are the same, 30 years. It has also been assumed that the solutions would be financed over the municipal budgets and therefore a 20 percent tax financing fee is added to the net cost (DFØ, 2014).

Table 10: Assumptions made for the cost analysis

Parameter	Assumptions
Discount rate	4 percent
Year today	2017
Monetary value (EUR)	2017
Appraisal period	2018-2047
Lifetime of the plants	30
Inflation per year	0

In Table 11 the PV of the costs of the implementation alternatives of the HRF and the CLS solutions are presented. The investment cost only includes actual construction costs and doesn't include installation cost, civil work cost, transportation cost etc. One can see that the PV of the CLS solution, with only 'red' CSOs and both 'red and yellow' CSOs, have higher PV of costs than the HRF solution for the same implementation alternatives.

Table 11: Present value (PV) of the costs of the implementation alternatives of the HRF and CLS solutions

Solutions	Implementation alternative	PV of costs, [mio. EUR]
HRF	'Red' CSOs	2.4
	'Red and yellow' CSOs	8.4
CLS	'Red' CSOs	2.9
	'Red and yellow' CSOs	9.8

Annual operation expenditure (F112): The operating/maintenance costs (Table 12) are based on the man-hour cost to inspect and maintain the plants estimated by the suppliers. Cost for energy and for the HRF solution also tap water for cleaning, have not been included. The costs have been given by the suppliers for one typical installation and in Table 12 have been assumed to be proportional to the number of installation sites.

Table 12: Annual operating/maintenance costs for the implementation alternatives of the HRF and CLS solutions

Solutions	Implementation alternative	Annual operating/ maintenance costs, [EUR]
HRF	'Red' CSOs	2 653 x 3 = 7 959
	'Red and yellow' CSOs	2 653 x 12 = 31 836
CLS	'Red' CSOs	2 520 x 3 = 7 560
	'Red and yellow' CSOs	2 520 x 12 = 30 240

The governance dimension

Compliance improvement with relevant EU standards (WFD, BFD) (G111): The demonstrated solutions were developed as solutions to mitigate conditions with CSO discharges that cause poor water quality and problems with compliance with the WFD. Implementation of the solutions may be expected to improve the conditions in the recipient and aid in compliance with the WFD. The estimated effects in Hoffselva from implementation of the solutions in the two implementation alternatives have been presented in Table 6, and have been used as basis for a qualitative assessment of compliance.

Monitoring (G131) and information dissemination (G132) were identified as indicators for transparency. As stated in the draft urban development plan of 2017, Oslo municipality aims to develop more participatory and socially inclusive services. With the increased availability and speed of technology development in ICT, the scope for this keeps increasing. VAV, as well as other utilities, plan to introduce smart metering systems, mobile technology is available, and there is increasing focus on community dialogue and involvement, as with Hoffselvens Venner and other river forums. If the sensor data that will come with full-scale implementation of the tested solutions could be made available to the public, this would be positive with respect to information dissemination, and on-line monitoring of the CSOs where the solutions are installed would in any case be positive with respect to monitoring.

No distinctions between the solutions or the implementation alternatives were made for transparency based on the general qualitative assessment above, but a positive effect of such implementation would be expected on this criterion.

The assets dimension

Separation efficiency (A15): Due to the influence of storage volume, overall removal was assessed qualitatively based on the estimated effects in Hoffselva from implementation of the solutions in the two implementation alternatives, presented in Table 6. The assessment is thus the same as for compliance with the WFD.

Separation efficiency for particles due to the separation technologies after the storage volume of the installation is filled, were quantified as 10% and 50% for the CLS and HRF, respectively.

Separation efficiency for sewage garbage due to the separation technologies after the storage volume of the installation is filled, were quantified as 50% and 100% for the CLS and HRF, respectively.

2.5.5. Step E: Final interpretation and presentation of the results

The SA has been summarised in Table 13, showing both quantitative and qualitative indicators. In some cases, both qualitative and quantitative results are given for the same indicator or criterion to show different perspectives in the assessment of the indicator or criterion. In such cases one should be aware of double counting when the results are presented elsewhere.

Table 13: Selected SA indicators in the Hoffselva demo case.

Dimension	Indicator	Type	Metric and unit	Value for solution and implementation alternative			
				CLS, 'red'	HRF, 'red'	CLS, 'red' + 'yellow'	HRF, 'red' + 'yellow'
Social (S)	Number of beneficiaries affected (S141)	Quantitative	Population, [# people]	104 000			
	Categories of beneficiaries affected (S142)	Qualitative	9 points Likert scale, [...]	+			
	Experiential and physical use of landscapes in different environmental settings (S151)	Qualitative	9 points Likert scale, [...]	++++			
		Quantitative	PV of WTP, [mio. EUR]	5.7			
Environ-mental (En)	Energy consumption (En124)	Quantitative	Volume specific energy consumption[1], [kWh/m³]	0.042	0.052	0.042	0.052
Financial (F)	Investment expenditure (F111)	Quantitative	PV of INV, [mio. EUR]	2.9	2.4	9.8	8.4
	Annual operation expenditure (F112) based on man-hours for maintenance	Quantitative	Annual man-hour cost, [kEUR]	7.6	8.0	30	32
Governance (G)	Compliance improvement w/ relevant EU standards (WFD, BWD) (G111)	Qualitative	9 points Likert scale, [...]	+	++	+++	++++
	Monitoring (G131) and information dissemination (G132)	Qualitative	9 points Likert scale, [...]	+			
Assets (A)	Efficiency (A15) measured as overall removal	Qualitative	Overall removal, 9 point Likert scale, [...]	+	++	+++	++++
	Efficiency (A15) measured as separation efficiency for particles due to the separation technologies after the storage volume of the installation is filled.	Quantitative	Separation efficiency due to the CLS or HRF, [%]	10	50	10	50
	Efficiency (A15) measured as separation efficiency for sewage garbage due to the separation technologies after the storage volume of the installation is filled.	Quantitative	Separation efficiency due to the CLS or HRF, [%]	50	100	50	100

1) For the CLS solution, volume specific energy consumption is per m3 of water and sludge emptied from the CSO structure. For the HRF solution, volume specific energy consumption is for pumping of CSO discharge when gravity flow is not possible.

To aid comparison of the solutions and implementation alternatives four pair-wise comparisons have been made by plotting the ratio of indicator values. A value of 1 therefore implies no difference between the alternatives in the comparison. Qualitative results have been assigned a value of 1-9 according to their relative score on the 9 point Likert scale. It should be noted that these comparisons are limited to the relative comparisons between alternatives, whether the effects in Hoffselva are expected to be large or small.

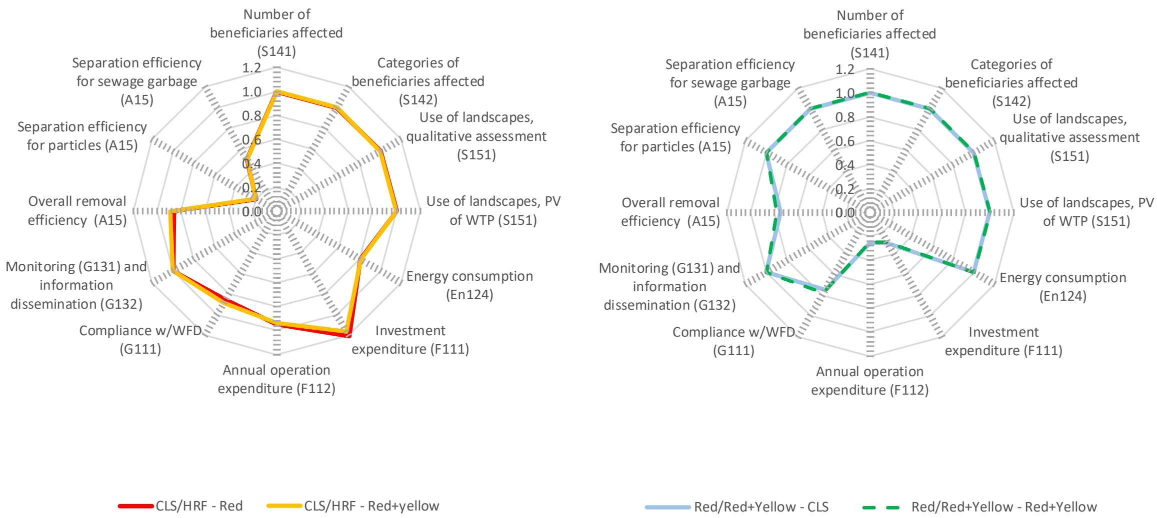


Figure 21: Pair-wise comparisons of CLS vs. HRF for the 'Red' and 'Red+Yellow' implementation alternative, respectively (left hand figure), and 'Red' vs. 'Red+Yellow' implementation alternative with CLS and HRF, respectively (right hand figure).

The pair-wise comparisons show that the differences between the two solutions are mainly related to the differences in the separation technologies, but that the overall removal for a given implementation alternative, and thereby the effect on compliance, is similar. There are also some differences in energy consumption and costs.

As expected, larger differences in costs are found in the comparison between the 'Red' and 'Red+Yellow' implementation alternatives irrespective of solution. The differences in overall removal and thereby also compliance can also be expected to be larger between the two implementation alternatives than between solutions for a given implementation alternative.

2.6. Opportunities and challenges for implementation

2.6.1. Governance & policy (incl. legislation and market issues)

The implementation of the Water Framework Directive and the increased focus on blue-green structures in urban development planning in Norway are drivers for measures to mitigate discharges from CSOs. However, mitigation of CSO discharges are part of the normal renewal of wastewater and stormwater infrastructure in Norwegian municipalities. As discussed above, VAV will in each case be looking at several measures, combined to fit landscape, building and technical conditions prevailing at different CSOs and in different river systems. Part of such evaluations will also be if local CSO treatment will be the preferred option compared to other measures such as separation of stormwater and wastewater pipes, and where one will anyhow need to have CSOs. There are therefore several alternatives available for a municipality to mitigate negative effects of CSO discharges. The solutions demonstrated in DESSIN may be additions to the 'toolbox' of alternative measures and the DESSIN ESS and SA methodologies may give additional inputs to the traditional evaluations of alternatives.

Considering the noted the stakeholder perspectives, the range of drivers identified, and the urban development plans that are outlined for the study area, linking potential benefits delivered by the solutions with the priorities of key beneficiaries of the affected ESS and other relevant actors may facilitate innovation uptake. Correspondingly, a strategy of issue linking might be useful on the side of the technology providers. This strategy has often been observed for entrepreneurs in literature, and was also observed in the mature case studies in DESSIN (Rouillard *et al.*, 2015 (D12.1)).

Another lesson learnt from the mature case studies is that coalitions can be instrumental in influencing innovation uptake. In the case of Hoffselva, the stakeholder interviews suggest that there are good opportunities for finding synergies with other actors and building coalitions to create momentum, which was identified in the mature case studies as another factor conducive to innovation uptake.

A further recommendation from the governance study of the mature case studies in DESSIN was setting up communication channels to reach out to the broader public. Communication is crucial to build legitimacy and public interest, and thereby gaining political support for innovation uptake (D12.1). The lack of awareness among potential beneficiaries about the regular occurrence and negative impact of CSO events, combined with the strong engagement to protect and develop the river system as a recreation area, suggest that improved communication about the current state of the ecosystem and potential impact of the solutions could be useful also in the Hoffselva case.

2.6.2. Novel financing mechanisms

Costs for investment in and operation of water and wastewater infrastructure in Norway are based on the principle of cost-coverage. This implies that municipalities can increase tariffs to cover required investments and operation costs.

The study on governance and novel financing mechanisms in DESSIN identified several other options, more and less innovative, such as venture capital and crowdfunding. In Norway, no new financing mechanisms in the water sector are foreseen, but there is a financing mechanism intended to aid innovation, so called innovative procurement. In this mechanism, there is the possibility to develop solutions in a pre-competitive phase, and this can aid in selection of innovative technologies as it reduces the risk of failed investments.

There are also possibilities for support to suppliers from financing agencies such as Innovation Norway.

2.7. Conclusion

Two solutions for local treatment of CSO discharges have been demonstrated in the Hoffselva demo case, where VAV has been the site owner. One solution was a high rate filter developed by the Norwegian company Inrigo AS (Inrigo) combined with on-line monitoring and wireless data communication supplied by the Norwegian company LKI. The other solution was a cross flow lamella settler developed by the German company Umwelt- und Fluid-Technik Dr. H. Brombach GmbH (UFT), also in combination with on-line monitoring and data communication from LKI.

Water samples were collected in Hoffselva at VAV's measuring station, HOFF5, located in the downstream section of the river at Skøyen, and at the inlet and outlet of the demo plants. The performances of the demo plants were also monitored on-line with sensors for turbidity and operation parameters such as relevant water levels and pressure drops. The instrumentation, and data logging and communication equipment facilitated remote monitoring and control of the demo plants.

In the evaluation of ESS, a value of 252 mg SS/l has been taken to be a typical peak concentration of suspended solids in the river during situations with CSO discharge before any implementation of the solutions. Similarly, a value of 8 mg SS/l has been taken to be a typical concentration of suspended solids during conditions without any CSO discharge.

An estimate of the concentration during situations with CSO discharge has been made based on the reduction in mass discharge to the river assuming that this would reduce the peak concentration proportionately. Several sources of uncertainty have been identified. The results, however, illustrate the importance of the storage volume. The separation technologies, *i.e.* the CLS and the HRF, were found to have a relatively small contribution to the total load reduction. This was especially the case for the CLS due to the lower average separation efficiency (10%) compared to the HRF (50%). The results also indicate that the implementation alternative is of higher importance than the choice between the two solutions demonstrated in this study, *i.e.* implementation at many CSOs with the CLS solution will probably improve the conditions more than implementing at a few CSOs with the HRF solution despite a higher separation efficiency. As expected, the highest improvement is indicated for the implementation alternative with use of the solution with highest separation efficiency at most CSOs.

The potential value of reduced discharges from CSO is substantial in the case of Hoffselva. It relates both to Regulation & Maintenance ESS and to Cultural ESS. Considering the direct effects of the demonstrated solutions, the Cultural ESS associated with aesthetic appreciation of the river water itself and riverbank area, *i.e.* ESS associated to transparency of the river water, and visual impression of water and riverbank, should be used as Final ESS when comparing the two solutions.

The pair-wise comparisons of results in the SA show that the differences between the two solutions are mainly related to the differences in the separation technologies, but that the overall removal for a given implementation alternative, and thereby the effect on compliance, is similar. There are also some differences in energy consumption and costs. As expected, larger differences in costs are found in the comparison between implementation alternatives irrespective of solution. The differences in overall removal and thereby also compliance, can also be expected to be larger between implementation alternatives than between solutions for a given implementation alternative.

The solutions demonstrated in DESSIN may be additions to the 'toolbox' of alternative measures that Oslo VAV may use in assessing options for future adaptation of the water infrastructure, and the DESSIN ESS and SA methodologies may give additional inputs to the traditional evaluations of alternatives.

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