Citizen science to enhance evaluation of local wastewater treatment – a case study from Oslo

S. Damman, H. Helness, I. L. Tyholt Grindvoll and C. Sun

ABSTRACT

The paper discusses how citizen science within an ecosystem services (ESS) framework may enhance evaluation of de-centralized water solutions. In a demonstration case in Oslo, citizens were engaged in long-term monitoring and evaluation of two solutions for treatment of combined sewer overflows. The citizens participated in the design of the study, systematic observations, and final evaluation, via interviews and workshops. A wealth of real-time information was collected, supplementing simulation data and water sampling results. The concept of ESS drew attention to benefits that tend to be ignored in standard evaluations. It is, however, most elaborate for ecological services, and less developed for social aspects. Involving the citizens complemented the framework in these areas, while providing new insights into the contextual interactions influencing ESS and benefits of local treatment. Both solutions, a cross-flow lamella settler and a high-rate filtration system, were quite efficient in removing suspended solids, with a strong impact on visual appearance. A range of wider benefits were identified. These were difficult to monetize, but the citizens' evaluation provided an alternative measure. The study highlights the benefits of citizen science in local water management and suggests the need for more research on beneficiaries in ESS evaluation.

Key words | citizen science, ecosystem services, local wastewater treatment

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INTRODUCTION

The challenges associated with climate change and other pressures require innovative water management solutions. However, the methods commonly applied for assessment of specific solutions remain limited, and in most cases either techno-economical or rather theoretical. In Norway, as in many other countries, utilities apply ISO 55000 (ISO TC 251 2014) as standard and use cost, performance and risk of unwanted events as evaluation criteria (Røstum *et al.* 2013). Despite increasing research and awareness of sustainability issues, wider impacts are usually not included, and lock-in effects related to established systems and practices may hinder adoption of more sustainable technologies (Foxon *et al.* 2002).

This paper is rooted in the FP7 project DESSIN *(Demonstrate ESS enabling INnovation in the water sector)* funded by the European Commission. While much of the previous research on ESS has focused on national assessments, DESSIN developed an ESS assessment framework to broaden the perspective in evaluation of technical or management solutions for implementation at the water body or catchment level (Anzaldua *et al.* 2018). In a demonstration case in Oslo, two treatment solutions for combined sewer overflow (CSO) were piloted and assessed in relation to the Hoffselva catchment. Beyond the formal DESSIN framework, a form of citizen science was applied, to engage the local community in the ESS evaluation. This novel approach was inspired by the kind and range of impacts expected from the solutions. The objective of the paper is to provide new knowledge of how ESS evaluation may be enhanced through citizen science, by improving the data basis, drawing attention to local contextual factors, and ensuring that different stakeholder perspectives are included in the evaluation. In the studied case, involving the citizens improved the understanding of the potential benefits and social value associated with local CSO treatment.

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doi: 10.2166/wst.2019.180

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BACKGROUND OF STUDY

The world is facing great challenges regarding water quality and water scarcity (Guppy & Anderson 2017). In urban areas, these challenges may be compounded by increasing population levels and overburdened infrastructures (Koop & van Leeuwen 2017). In Oslo, the population is projected to increase by 24% from 2018 to 2040 (Statistics Norway 2018). Increased flooding is expected, and large parts of the water infrastructure are very old. In Norway as a whole, the required investments in maintenance and development of water infrastructure for the period 2016–2040 are estimated to be 280 billion NOK, or around 28 billion EUR (Norsk Vann 2017).

Against this backdrop, there is a call for innovations, and for enhanced methods to assess their full range of impacts, costs and benefits to society. Especially in the EU, increased interest has been placed in the concept of ESS (Bouwma *et al.* 2017). Much research has been conducted, e.g. The Economics of Ecosystems and Biodiversity (TEEB 2010), the EU Working Group MAES (*Mapping and Assessment of Ecosystems and their Services*) (Maes *et al.* 2013), as well as research projects GLOBAQUA (*Managing the effects of multiple stressors on aquatic ecosystems under water scarcity*) (Navarro-Ortega *et al.* 2015), MARS (*Managing Aquatic ecosystems and water Resources under multiple Stress*) (Hering *et al.* 2015), and AQUACROSS (*Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies*) (Gómez *et al.* 2016). However, much of this work has been rather theoretical. The most advanced efforts focus on national ESS assessments, and downscaling has been a challenge (Paetzold *et al.* 2010; Potschin & Haines-Young 2013). DESSIN set out to provide an assessment frame-work for concrete measures at the local level (Anzaldua *et al.* 2018). To enable more detailed exploration of practical implementation issues, the framework links the ESS assessment to the European Water Framework Directive (WFD) and deals with freshwater ecosystems only.

The DESSIN framework builds on the Common International Classification of Ecosystem Services (CISES). In addition, elements from the Final Ecosystem Goods and Services-Classification System (FEGS-CS) (Landers & Nahlik 2013), and the TRUST project *(Transitions to the Urban water Services of Tomorrow)* (Alegre *et al.* 2012) are included. Based on a modified version of the Driver, Pressure, State, Impact, Response (DPSIR) model (EEA 1999), a five-step assessment procedure is defined (Anzaldua *et al.* 2016a, 2016b). There is no explicit consideration of stakeholder involvement, but this does not mean that stakeholders, including regular citizens, should not be engaged. In the demonstration case in Oslo, involving citizens in the design of the study and the final assessment were logical steps, considering their local knowledge and the distinction in FEGS-CS, between intermediate ESS and final ESS, which actually are used by humans in the study area.

Citizen science is defined as '*scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions*' (OED 2016). A variety of approaches exist, ranging from community-based monitoring, to soliciting contributions, to engaging large groups of people through the internet (Hecker *et al.* 2018). Citizen science is prominently applied in ecology and biogeography (ibid.), but the adoption in hydrology has been limited and mainly in water quality monitoring (Buytaert *et al.* 2014).

At the same time, citizen science may be particularly suited for ESS assessment. According to Buytaert *et al.* (2014) the complexity and dynamics of social-ecological systems require a more interactive view on knowledge production. In the context of ESS management, multiple forms of local knowledge, such as traditional knowledge (Berkes 1993), more recent situated understandings (Robertson & McGee 2003), and insights derived from individual experience (Fazey *et al.* 2006), exist within communities. Such knowledge contrasts with the more formalized scientific knowledge on ESS. Connecting these different forms of knowledge requires sustained interaction between citizens and scientists (Buytaert *et al.* 2014). In the case study in Oslo, this was achieved, with some important benefits, but also certain limitations.

THE HOFFSELVA DEMONSTRATION CASE

To address the challenge of water quality, DESSIN tested two different solutions at Hoffselva – a modular cross-flow lamella settler (CLS) for local treatment of CSO overflow from holding tanks, and a high-rate filter (HRF) solution that can be installed on the CSO outlet pipe for smaller structures without a holding tank. As traditional wastewater network design to a large extent is driven by the need to cater for peak demands, mitigation of these peaks through use of de-centralized solutions may defer investment and substantially reduce capital costs (Marlow *et al.* 2013). Hoffselva was selected as demo site by Oslo Water and Sanitation Agency since the water infrastructure is old, with many problematic CSOs. The catchment covers an

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area of 1,427 ha. The sources of the 10.1 km river are in a forested recreation area. From there, the river flows through upper- and middle-class residential areas into an increasingly urban housing and business district and under one of Oslo's main traffic hubs, before it enters the fjord at Bestumkilen, where there is a marina and nearby beach. The study focused on the middle and lower section of the catchment, as depicted in Figure 1. Around 80,000 people live in this area, and the population is expected to increase rapidly towards 2040.

The main challenge in the catchment is poor water quality. Climate change is a major driver: from now and to the end of this century, precipitation in the Oslo region is expected to increase by 12%, and the temperature will increase 3.4%. Urban development, transport, and recreation also cause pressures in the form of increased CSO discharge, stormwater runoff, footpaths, littering and erosion.

The solutions were mounted at a separate test site (marked by triangle square in the right of Figure 1), where the HRF was tested for two years (2015–2017) (Helness *et al.* 2019) and the CLS for one year (2017). Their performance was monitored by logging of plant- and turbidity sensors at the inlet and outlet. Data were compared with water sampling from the treatment plants (CLS and HRF), and the main river during and after major rain events, with a focus on total suspended solids (TSS) and chemical oxygen demand (COD). An assessment to estimate the impact of full-scale implementation at a number of CSOs was also carried out, via simple hydrological and water quality modelling (Helness *et al.* 2018). The results were limited to specific CSO-events but provided a certain picture of the mass discharge and reduction of load with different implementation alternatives.

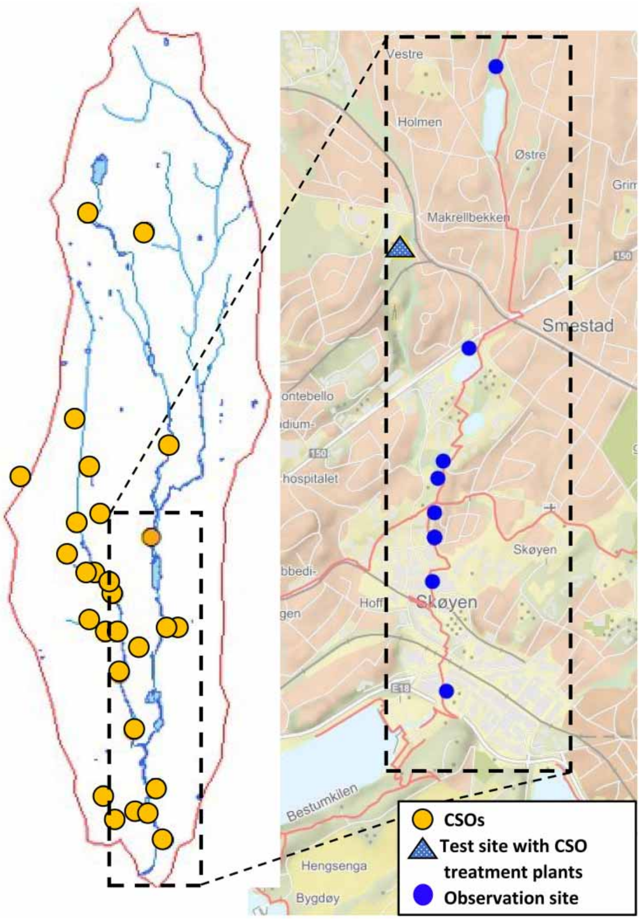

Figure 1 | Hoffselva catchment and CSOs (left) and main study area with observation sites (right).

Local citizens were brought in to carry out parallel observations in the main river on a voluntary basis, through the Hoffselva 'river forum'. Oslo has several such forums, that receive minor grants to organize volunteers for conservation, development and social activity related to the city's rivers. Initially, the forum suspected they were asked to do '*free work for the municipality*', but once the research purposes were properly explained, they came on board and also contributed actively to the research design (selection of observation sites, log form, level of interaction, etc.), in what may be classified as collaborative citizen science (Hecker *et al.* 2018).

A team of 16 observers, recruited through the forum's Facebook page, were trained to make observations at eight specified sites along the river (see Figure 1). The sites were selected based on their social significance and proximity to CSOs. The team made observations during normal conditions, once every month. In addition, they received SMS calls every time sensors at the test site indicated that there was a CSO event. Then, each individual would make observations as soon possible. From 1st March 2016 to 1st October 2017, the team made 158 observation rounds, including observations during and immediately after 10 registered CSO events. Each observation involved filling of a log form on water flow, turbidity, colour, odour, weather, number of people and their activities, garbage in the water and/or riverbank, and their overall experience of being by the river, as well as measurement of water depth and three photographs with specified scopes and angles. Each qualitative aspect was assessed using a Likert scale (1–5). There were four stakeholder meetings. Experiences from the study, as well as more general information about the state and use of the river was further exchanged through the forum's Facebook page, which has more than 100 followers.

In 2017, 15 stakeholder representatives were contacted, and 10 eventually took part in semi-structured interviews on

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potential benefits of the solutions and their value in terms of improved ESS. Some of the interviews were face-to-face, whereas others took the form of phone-calls. Beside Hoffselva river forum, those interviewed were representatives of residents' associations, an anglers' association, a volunteer centre, a marina at the mouth of the river, the local history association, a former water bailiff, the Agency of City Environment, and representatives from the operations and planning departments at Oslo Water and Sanitation Agency.

ESS AND POTENTIAL BENEFITS OF LOCAL CSO TREATMENT

The water from Hoffselva is not extracted for use by society or industrial purposes. However, with respect to provisioning ESS the river is a potential source for non-potable use. There are fish, other animals, insects and plants, and the river's capability to regulate, maintain and support the physical and biological environment is considered as fundamental, also in providing the basis for cultural ESS, which in this case was the only category with clearly identified beneficiaries.

The water flow varies considerably through the year. How the observers characterized different aspects of the water quality varied accordingly, but on a scale from 1 to 5 they mostly rated their total experience of the river as 5 – a very nice and valuable part of the environment. The most positive observations were from the upper sections of the study area, whereas observations from the lower section were more mixed, with some reports of garbage and miscoloured water. This could be expected, given that the lower section is heavily urbanized, while the upper section contains two nicely developed dams and a secluded, quite tall and impressive waterfall.

There were clear differences between observations during/immediately after CSO events and under normal conditions. At CSO events the rate of flow was reported to be 4 – quite high – or 5 – very high, in most cases. Turbidity rates were also high, and while whitish miscolouring near CSOs in the upper section was observed on some occasions, this was more prevalent in the lower section. More human-made materials such as litter and sewage garbage were also reported during/after CSO events – mostly rated as 3 – limited, or 4 – substantial amounts, but never as 5 – in plenty. This happened mostly at the lower dam, and below the entry of the Makrellbekken tributary further down (see Figure 1).

The most interesting single indicator was that of odour, which can be related directly to discharge of sewage water. While there were no cases of rate 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 sites during and immediately after CSO events. This was the case at two of the dams, but not at the lowest observation site, where the river is fenced. Odour was mostly registered soon after notification of a CSO event, and rarely experienced more than a couple of hours later. Different observers were involved and comparison with observations following a false CSO alarm indicated no observer bias.

The number of people and kind of activities observed varied across the sites. At the largest dam, which is most accessible, 5–10 or 10–20 users were usually observed. The secluded waterfall was only visited by a few playing kids and elderly people, who came to enjoy the tranquility. The next site had very many passers-by, but few who stopped. At the site below, nearby workers, anglers and others came to spot at an important spawning ground for local trout. Further down, the river forms an integral part of a larger housing estate, with playgrounds and a small 'tribune'. Then it reaches the final observation site, at a concrete square where there is a nice river opening, but usually fewer than five persons around, probably due to heavy road traffic.

The interviews highlighted a broad array of ecosystem services and values associated with the river. 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 relations (relationality or communality) (van Manen 1990). Regarding spatiality, several stakeholders emphasized the role of the river as habitat to a variety of animals, plants, and other organisms. This was associated with use value, related to angling as well as sport fishing of mature trout in the fjord, but even more with aesthetic and experiential values linked to sharing space with fish and birds. Some stakeholders also emphasized the significance of the water surface: the value of seeing fish wake, birds dive and sunrays hit the water; and using the surface as a source of personal reflection, in a cultural setting where lakes and ponds are associated with mirroring and depth of soul, the deep unknown, monsters, fairies, and the like. Among urban planners, the role of the river as blue-green infrastructure, for solving urban and climatic challenges by building with nature, was emphasized even more.

When it comes to lived body, there has been a tendency in ESS assessment to focus on specific, measurable

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recreation activities. However, stakeholders in Hoffselva also emphasized subjective and sensori-emotional values, such as the sight and sound of clear, running water, and the opportunity to sense the smell of fresh water and wetlands in the middle of the city. One interviewee said, '*It brings peace to mind, like when you look into a fire.*' Although it is not recommended in Hoffselva, some people took pleasure in bathing or wading. Values associated with jogging, dog-walking, angling, feeding birds or watching fish, and collecting wild berries and flowers, were noted by many, and some argued that through these uses, the river plays a key role in promoting good health.

As to relationality, Hoffselva is an important meeting ground. There are several barbeque spots and benches that are used actively, especially by elderly people and families with small children. Furthermore, the river is an important resource for the local school, which has 'adopted' it for teaching, as well as for local kindergartens and sports associations. The river forum organizes joint walks along the river regularly, which are free and open to the public, with an average of 50 participants. There is a biodiversity trail and nature map developed by the river forum and Friends of the Earth, which also have led to more communal use and highlight the connection between cultural, regulating and maintaining ESS.

Furthermore, the river forum and the local history association, especially, emphasized the cultural heritage associated with the river. The major dams are from the 1800s and earlier, testifying to the history and urban transition of the area. There are remains of old mills, trees and cultivated plants from an ancient convent, as well as old farm houses, bunkers from World War II and various 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. For this, the river is considered as a key. Some stakeholders also pointed to spiritual and symbolic aspects linked to temporality, by statements such as '*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 stakeholders, including Oslo Water and Sanitation Agency, further emphasized bequest value, related to preserving Hoffselva for future generations. Maintaining the natural heritage has also resulted in an increasing number of students' theses, research and media reports, through which environmental awareness and knowledge are created.

The pilot testing indicated that both the HRF and CLS solution could enhance ESS by reducing emissions of particulate pollutants from CSOs. With the HRF solution, removal efficiencies up to 80% for suspended solids (TSS) and 75% for chemical oxygen demand (COD) were documented during the first phase of the CSO event, while the overall removal of SS and COD were 47% and 56%. Six point three percent of total bound nitrogen and 15% of total phosphorus were retained together with the particles. For the CLS solution, the maximal potential efficiency was 37% total organic carbon (TOC), 17% (COD), 22% (SS fine) and 19% (SS). For the assessed implementation strategies, the CLS would come with a local storage volume, and for the stored CSO the removal efficiency would be 100%, whereas the average separation of particulate matter in the subsequent discharged overflow was estimated to be 10%. For the HRF, the latter value was estimated to be 50%.

To the extent that they hinder pollution, full-scale implementation of the tested solutions may help maintain the river system as a habitat. Thereby, cultural ESS associated with lived space or spatiality for local stakeholders may also be enhanced. By limiting the amounts of sewage garbage and suspended solids reaching the river, and to some degree limiting eutrophication and growth of water weeds, the living conditions for local fish and other animals and the extent of open water surface may be maintained, despite increasing pressures.

Also, while they may not impact directly on use values related to riverside recreation, the tested solutions may have a significant indirect impact on these ESS, by improving the visual impression of the water and riparian zone and limiting the odour associated with CSO events. Knowing that the number of CSO events and amounts of sewage discharge would be reduced is also likely to increase the experiential value associated with the river. To the extent that the removal of bacteria bound to suspended solids affect water quality at the river mouth, this may also benefit swimmers, boat owners and kayakers from other parts of Oslo, who are using the nearby fjord.

While not many communal events are likely to take place in the bad weather when CSO events occur, contributing to a cleaner environment by the main dams and reducing the chance that children come across sewage garbage involving health risk may enhance the cultural ESS associated with relationality. Maintaining or improving the visual impression of the water and riparian zone will also be important to maintain the river's attractiveness and the public interest in preserving the natural and cultural heritage associated with it.

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It should be noted, however, that calculations of mass discharge and reduction of total load for selected rain events indicated that the local treatment solutions would make a relatively small contribution to reducing the total pollution in the river. As noted above, the impact would be higher immediately after the onset of a CSO event than later. The kind of ESS, number of users, and potential benefits of local treatment also varied significantly across observation sites. This suggests that the value of local treatment will depend a lot on where exactly in the sewer and river system such solutions are implemented.

CITIZEN SCIENCE ENHANCING ESS EVALUATION

The detailed insight into the ecological characteristics and social significance of various sites along the river could not have been gained without close dialogue with the Hoffselva river forum. The interaction during the stakeholder workshops and the wealth of real-time information gathered via Facebook helped ensure that a wide range of potentially relevant services and beneficiaries were examined, instead of limiting the perspective to a set of predefined categories. On this basis, it was decided to discuss the final ESS in terms of lifeworld existentials, which shed light on how different services and impacts work together, and how the benefits of local CSO treatment may reach beyond specific water quality improvements and established categories of cultural ESS.

It should also be noted, however, that the appreciation of the mentioned services may be unevenly distributed in the local population. While most stated that the river means a lot to people, some stakeholders saw the general population as more indifferent. One interviewee suspected that some residents may not even have passed by the river area. Some noted that the actual use of the recreation areas seems limited, considering the number of people living nearby. The majority felt that aesthetics is the most highly valued aspect (rate 5, on a scale from 1–5). Use of the river area for recreational activity and the opportunity to enjoy birds, fish and biodiversity were considered as important, but slightly less so (rate 4). The importance of the river in maintaining local history and identity was considered to be less widely acknowledged (rate 3), as many younger people and in-migrants would have limited knowledge.

Several interviewees also suspected that the population has limited knowledge about the episodic discharge of sewage water into Hoffselva. Halfway through 2017, the Water and Sanitation Agency had received only 3–4 complaints from residents. These, as well as most complaints in previous years, were mainly about sewage garbage, odour, and illegal discharge of drilling sludge by local entrepreneurs.

To make an economic valuation of a measure in terms of ESS, one must assess the total economic value (TEV), including both use and non-use values. The DESSIN framework provides an overview of valuation methods, including stated preference, which is based on broad surveying of hypothetical behaviour, asking people for their willingness to pay (WTP) for a specified environmental change. Benefit transfer is a less resource-demanding alternative, where estimated WTP values from an earlier study are transferred to the new case. In the present study, it was decided to base the valuation on an earlier study of another river in Oslo, called Akerselva (NIVA 2011), which also has been applied in subsequent studies (Vista Analyse 2014). Based on the assumption that WTP for enhanced water quality-related ESS per household was 16 EUR (2017 prices) per year for a 30-year period, the estimated economic present value of total WTP for the population living within 100 m from Hoffselva was EUR 0.7 million, and for the population within 1,000 m from the river: EUR 5.7 million.

However, the consulted stakeholders were quite divided in their views on willingness to pay. Considering that the fees for water and sanitation in Oslo are relatively low, some thought people would accept an increase in order to improve water quality. Those who dared 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 more concern for other public services. While in many ways comparable, Hoffselva is less central, with a different history than Akerselva, which flows through a former working-class area that has received prolonged and nation-wide cultural attention. Hoffselva is less profiled, but in a higher-income township with a more stable and educated population.

The potential benefits of local CSO treatment would also vary considerably, depending on site, range and the relative values associated with specific ESS improvements. To better account for these nuances, the value of local CSO treatment was also assessed in an alternative way, by adapting a qualitative 'consequence mapping' recommended by the Norwegian Ministry of Finance (Bull-Berg *et al.* 2014). The method has four steps: (1) identify impacts, (2) map their spatial range, (3) assess the importance of the impact to society, and (4) assess the overall value of the measure, considering the results from the preceding steps. The measurement scale is nine-point,

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ESS category	ESS	Strength	Range	Importance	Overall value
Regulation & maintenance services	Maintaining populations and habitats	++	++	++	++
	Preserving biodiversity	+	+	++	++
Cultural services	Enhancing lived space (aesthetics, quality of living environment)	++++	+++	++++	++++
	Enhancing lived body (recreation, health)	++	++	++	++
	Enhancing lived relations (communality)	+	+	++	++
	Enhancing lived time (preserving natural heritage)	+	++	++	++

Figure 2 | Consequence mapping for local CSO treatment in Hoffselva.

ranging from (− − − −) to (++++). Figure 2 presents such a mapping for local CSO treatment in Hoffselva, based on the discussion above.

While disregarding the slight performance difference between the tested solutions, the assessment shows that local CSO treatment will enhance the ESS and water quality challenges local stakeholders were most concerned with, namely the visual impression and amount of sewage garbage in the water and riparian zone. While the strength and range of other benefits may be more limited, this suggests that local treatment may be a relevant solution for urban areas where replacing old combined sewer systems with designs that excludes surface runoff from sanitary sewers is too expensive or not feasible.

Beside the core ESS evaluation, the DESSIN assessment framework includes a module to assess the sustainability associated with production, operation and end-of-life of the technical solutions in question. In the Hoffselva case, comparison of the two solutions indicated that there were slight differences in energy consumption and costs. These were related to the difference in separation technologies, but the overall removal for a given implementation alternative, and thereby the effect on compliance, was quite similar. The urban development plan for the area suggests that the benefits and value of local CSO treatment may increase sharply in the coming years: by 2030, the number of housing units will be quadrupled, and there will be 10,700 new jobs in the lower section of catchment. Two major 'green points' will be developed near the river, and the scope for recreational activity will increase, in parallel with increasing load on the sewer system. This further highlights the importance of taking the perspectives and plans of local stakeholders into consideration.

While the most immediate benefits for researchers and utility managers may be help with data collection, this study confirms the benefits of citizen science in terms of exchange and co-generation of knowledge, noted in previous research (Berkes 1993; Robertson & McGee 2003; Fazey *et al.* 2006; Hecker *et al.* 2018). The encounters with multiple generations of citizens drew attention to established local knowledge as well as very recent observations on details in the socio-ecological system, such as developments in the population of fish, birds and rare and invasive plant species. They also shed light on cultural ESS that tend to fall outside the scope of the major systems for ESS classification and assessment.

According to Buytaert *et al.* (2014), citizen's questions can be quite different from those of professional scientists. In this case, their main concerns were preserving the river system and encouraging more people, including decision-makers in Oslo municipality, to see and develop Hoffselva as a resource for the local community. They were also keen to find out if the tested solutions eventually could be implemented and lead to noticeable water quality improvements, such as achieving bathing water quality. Participating in the research increased their knowledge about water quality and ESS. Some noted and appreciated that the research project generated increased interest in Hoffselva. Some also valued the experience personally, as

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an opportunity to get to know the river, relive old memories from it and/or socialize with others.

For a few, the excitement waned over time, as there were few dramatic observations and long periods without CSO events, when there was limited interaction in and with the professional research team. A core group of 10–12 observers stayed on, but during the summer of 2017 their activity, too, went down. This was understandable, given the lack of major CSO events and limited opportunity to compare the observations with water sampling results. They may also have felt undervalued as research participants, a challenge that has been noted in other studies (e.g. Rotman *et al.* 2014). When connecting different branches of science with citizen-derived knowledge there will always be power issues (Keeley & Scoones 2000; Karpouzoglou & Zimmer 2011).

The nature and quality of data in citizen science may be quite different from that of other sources, and not adhere to the same evaluation and validation criteria (Dunn *et al.* 2008; McKinley *et al.* 2017). This was not a problem in this case. The observations carried out by the citizens were highly structured. While designed to supplement water sampling and sensor data with photographs and objective measurements, their main purpose was systematic collection of information about subjective user experiences. The long-term duration and overlap of individual observations worked against bias. However, more modern technology for a wider range and more accurate data collection, as well as better means of visualization and communication during the research, could no doubt have improved the results.

The initial dialogue on how to design the observation study and long-term interaction with citizens in and around the river forum facilitated exchange and co-generation of knowledge. Where, as noted in Anzaldua *et al.* (2018) much research on ESS is rather theoretical, and quickly can become decontextualized 'expert knowledge' reinforcing certain policies and institutional logics (e.g. Büscher 2012), the engagement with the citizens around Hoffselva ensured that details of the local socio-ecological context were taken into account. Furthermore, it brought attention to the close connection between intermediate and final ESS, and how this varied, depending on the natural and built environment, as well as actual use of different sites along the river. The focus on local knowledge shed light on a broader range of cultural ESS than those addressed in formalized assessment frameworks. The interviews also highlighted how the benefits and value attribution linked to cultural ESS may be unevenly distributed between stakeholders. While some of the citizens were very resourceful and already in dialogue with relevant decision-makers, others would not normally be heard in ESS and water management.

Generally, it may be difficult for citizen science accounts to feed into decision-making, even when the knowledge is generated through an institutionalized process (McKinley *et al.* 2017). However, ESS as a structured and widely acknowledged approach, may help increase knowledge uptake and provide a fruitful link between citizen science, academic production and decision-making. The approach taken in this study ensured that knowledge was co-generated in a process with several feedback loops, as recommended by Buytaert *et al.* (2014). However, the reduced enthusiasm over time underscores the need for more knowledge on how to balance relationships and optimize the process of cooperation and learning between disparate knowledge systems, as noted by Pahl-Wostl *et al.* (2007).

CONCLUDING REMARKS

The importance of water resources for human development, and the threats that emerge from environmental change, population growth, urban development and other pressures highlight the need for more knowledge on socio-ecological interactions. The concept of ESS may shift attention from immediate costs and benefits and on to the wider and more long-term benefits associated with innovative solutions, thereby enabling uptake and contributing to more sustainable water management.

The pilot testing and ESS assessment of two different solutions for local CSO treatment in Hoffselva indicate that local treatment can be a relevant alternative in cases where full replacement of old combined sewer systems is not an option. To supplement expert knowledge based on sensor data, water sampling and pre-defined ESS assessment methods, long-term citizen science was included in the evaluation. The citizens were involved in the design of the study, data collection, analysis and final ESS evaluation associated with the solutions.

The citizens' participation strengthened the ESS assessment by including local knowledge and throwing light on contextual interactions at the local level. Calculations of mass discharge and reduction of total load for selected rain events indicated that the solutions would make a relatively small contribution to reducing the total pollution in the river. However, the observation study and wider stakeholder interaction showed that there was considerable variation in the environmental characteristics, human activity and social significance associated with different

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parts of the river. While local treatment of CSOs near some sites may be of limited value, implementation at other CSOs, such as near the main spawning ground for trout or by the largest dam in Hoffselva, which means a lot to a high number of people, could be of very high value for society.

The study underscores that citizen science may make valuable contributions to knowledge development and evaluation of new water management solutions. Increased attention to local knowledge and diverse stakeholder perspectives may prove useful in continued efforts to downscale and make ESS assessment more relevant for evaluation of concrete measures and solutions at a local level.

ACKNOWLEDGEMENTS

We are thankful to the river forum 'Hoffselvens Venner' and the other citizens who participated in this research. The research received funding from the European Union Seventh Framework Programme (FP7) under grant agreement No. 619039.

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First received 22 February 2019; accepted in revised form 16 May 2019. Available online 30 May 2019

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