Analysing consequences of infiltration and inflow water (I/I-water) using cost-benefit analyses

Kristin Jenssen Sola, Jarle T. Bjerkholt, Oddvar G. Lindholm and Harsha Ratnaweera

ABSTRACT

The Municipality of Asker (Norway) is at risk of not meeting the water quality targets set by the European Union Water Framework Directive within the stipulated timeframe. While there are multiple factors negatively impacting water quality in the municipality, wastewater is likely to be a major contributor. Infiltration and inflow water (I/I-water) leads to a number of unwanted consequences, of which direct discharge of untreated wastewater through overflow points is particularly important. In Aker municipality the portion of I/I-water is about 63%, while the goal is to achieve a level of about 30%. This study utilises a socio-economic cost-effectiveness analysis of measures to prevent sewer overflows into waterbodies. The most effective alternative identified in the analysis is a complete renovation of old pipes in combination with troubleshooting for faulty stormwater connections, when compared to alternatives considering upsizing/retention. I/I-water cost the municipality of Asker NOK34 million in 2017, when using a price of NOK16,434 for each kg of total phosphorus (Tot-P) let into the recipient water bodies. If the phosphorus cost is equal to or less than NOK17,806/kg Tot-P, then it will not be socio-economically justified to reduce I/I-water.

Key words | cost-benefit, I-I-water, sewer, wastewater

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HIGHLIGHTS

- The article identifies three different measures against consequences of I/I-water and does an analysis of what measure provides the best cost/benefit ratio.
- In addition we have done a calculation of what the I/I- water cost the municiplity of Asker in 2017.
- In the article we provide a literature study of previous studies considering the willingness to pay to achive better water quality in the recipient waterbodies.

INTRODUCTION

Urban sewer systems

A traditional sewer system consists of both public and private pipelines as well as pumping stations, wastewater treatment plants and overflows. In overflow points (combined sewer overflow (CSO), sanitary system overflow (SSO)), wastewater can be released into water recipients such as rivers, the sea or groundwater. These overflows become operational if the sewer system is overloaded, commonly due to heavy rainfall. Non-sewage water (rainwater, groundwater and drinking water) that leaks into the sewer system is in sanitary sewer systems defined as infiltration and inflow water (I/I-water). A sanitary sewer system, henceforth referred to as a 'separate system', is not dimensioned to handle I/I-water. Ideally there should be

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no I/I-water in a separate system as stormwater would be transported in a separate stormwater drainage system. Meanwhile, a combined sewer system is dimensioned to handle the influx of certain quantities of I/I-water. In most Norwegian municipalities we find both combined sewer systems and separate sewer systems.

I/I-water may have significant economic and environmental impacts. The economic aspect relates to increased maintenance costs at pumping stations and wastewater treatment plants (WWTPs) as well as compensation payments due to basement flooding caused by insufficient capacity in the wastewater system. The environmental impact relates to discharge of wastewater to recipients through CSOs/SSOs as well as increased discharge from the WWTPs. I/I-water finds its way into the wastewater pipeline system through leaking or cracked pipes and manholes as well as incorrectly connected stormwater drains. In many wastewater systems, the volume of I/I-water depends on the amount of rainfall. Increased rainfall intensity and volumes as a consequence of climate change may therefore contribute to more I/I-water (Sola *et al.* 2018). The groundwater level is of great importance to the level of I/I-water (Karpf & Krebs 2011). Even so, this factor is only rarely measured in Norway (Sola *et al.* 2019). In a typical Norwegian trench, the stormwater pipe is situated at the bottom, below the drinking water pipe and below the sewer pipe. Therefore the storwater pipe is underneath the sewer pipe. It is, therefore, reasonable to assume that a large proportion of the I/I-water in Norwegian wastewater systems originates from incorrectly routed stormwater, leakages from drinking water pipes or from infiltrated rainwater and not so much from groundwater (Sola *et al.* 2019).

Measures, such as renovating municipal and private pipes and troubleshooting for incorrectly connected stormwater drains, will help reduce infiltration and inflow to the sewer system. Upsizing various components in the wastewater system and establishing retention basins may potentially prevent CSO/SSO but will not prevent I/I-water from entering the system and thus targets the symptoms rather than the causes of I/I-water.

Wastewater and the marine environment

Managing wastewater systems also means managing water resources. 'Lost' wastewater may have negative impacts on recipient waterbodies. The wastewater industry is governed by EU directives and Norwegian law. Of particular importance is the EU Water Framework Directive (the Water Directive, WFD), which has been incorporated into Norwegian legislation through the Water Regulation (Vannforskriften). The purpose of the Water Regulation is to 'ensure protection and sustainable use of the marine environment, and if necessary, implement preventive or enhancing environmental measures to safeguard the state of the environment…' (Vannportalen 2018). Among other things, working within the framework of the WFD entails carrying out status surveys on the water quality and developing water resource management plans. The WFD and Norwegian Water Regulation are therefore essential to take into account when setting priorities for the Norwegian wastewater industry.

International work on ecosystem services in Norway has been followed up by the Norwegian Official Report 213:10 '*Nature's Benefits – on the Value of Ecosystem Services*' (Magnussen 2016). The concept of ecosystem services highlights both the monetary and non-tangible value of the resources an ecosystem provides for human welfare. Ecosystem services thus include both physical goods and services as well as usable and non-usable values (Magnussen 2016). As such, ecosystem services are attempts to attach societal benefit values to all the services provided by an ecosystem. In many ecosystem services the marine environment plays a key role. For instance, one ecosystem service is 'recreation, mental and physical health'. This service may be linked to two environmental targets previously used for freshwater bodies in Norway, namely bathing water quality and recreational fishing (Andersen *et al.* 1997).

Socio-economic cost-benefit analyses

Socio-economic analyses entails assessing costs and beneficial effects related to possible actions, such as – in this case – abatement measures to reduce the consequences of I/I-water. The purpose is to calculate the socio-economic profitability of different measures in order to rank and compare the assessed measures (Direktoratet for økonomistyring (The Norwegian Government Agency for Financial Management) 2018). Under the term 'socio-economic analyses' we find a range of tools that may be utilised when making decisions in the public sector: cost-benefit analyses, cost-efficiency analyses and cost-effectiveness analyses (Direktoratet for økonomistyring (The Norwegian Government Agency for Financial Management) 2018). Such socio-economic analyses are based on the premise that the benefit received from a measure is likely to correspond to the willingness to pay (WTP) in the population impacted by a given policy. The benefit to households in receiving an increase in quantity

or quality of an environmental good may therefore be measured as WTP (Navrud 2016).

Environmental goods are public goods which by definition are non-exclusionary and non-rivalrous. This means that if a good is available, it is available to everyone and use by one individual does not prevent the use by another (Navrud 2016). Since environmental goods cannot be distributed through markets, market rates, which would indicate their value, do not exist (Hagen & Volden 2016). Accordingly, in socio-economic analyses, the economic consequences we reap from environmental interventions are not priced directly in the market. Instead the economic consequences can either be quantified and given a monetary value or their value can be calculated without market pricing (Hagen & Volden 2016). In cases where there are no markets or reliable studies on the WTP, the valuation of marginal, external costs associated with pollution emissions may be determined by the *damage cost method*, *costs of mitigation measures* or the *abatement cost method* (Ibenholt *et al.* 2015).

The aim of the presented study is to reflect on the impacts of I/I-water in wastewater systems, and how the consequences of I/I-water may be limited. The study looks into how the costs associated with phosphorus emissions and potential mitigation measures can be quantified in order to guide decision-making in mitigation efforts. A cost-efficiency analysis has been performed, evaluating the costs and benefits associated with different measures that aim to limit the negative consequences of I/I-water and thereby prevent phosphorus discharge into waterbodies. Other indicators, like bacteria, could also have been used, but the main focus in the presented study has been the nutrient phosphorus. Reduced phosphorus emissions are likely to contribute to improved water quality in recipients. The study therefore also includes an appraisal of the population's WTP for this improvement.

The presented study is based on actual figures from Asker Municipality, Norway, and 2017 was used as the year of calculation.

METHODS

Methodology

This study was conducted in three phases, where phase 1 and 2 are illustrated in Figure 1. The third phase consisted of a literature review of potential benefits gained from improving water quality in recipients.

Phase 1: Cost-efficiency analysis:

1. Identify potential measures to reduce consequences of I/I-water
2. Calculate investment costs of measures identified in step 1
3. Calculate phosphorus emissions for all alternatives, including the baseline scenario (alternative 0)

Phase 2: Put a price-tag on I/I-water:

4. Quantify wastewater emissions due to I/I-water
5. Quantify operating costs (e.g. pumping costs) due to I/I-water
6. Calculate the cost of emissions caused by I/I-water and the total cost related to I/I-water

The third and final phase examined the benefit value of the measures identified in phase 1. The benefit value of the measures assessed in this study relate to water quality improvements. The value of improvements in water quality is examined through studies of WTP. However, we have not carried out a WTP study for the purpose of this paper, but instead relied on previous studies from which it is possible to transfer values. Value transfer entails transferring both the benefit and disadvantages values between different studies.

Changes in producers' surpluses and authorities' surpluses are not considered to be relevant to this study. As previously discussed, water quality improvements may have positive impacts on several ecosystem services where water plays a crucial role. Good bathing water quality, water suited for recreational fishing and water which may be used for irrigation are all relevant services in this regard. All of these services are valued through WTP. Reduced risk of basement flooding due to I/I-water is also included in the study. Phosphorus is a non-renewable resource, and an important component in fertilisers. By recovering phosphorus from wastewater and limiting discharges one could potentially save money. In 2015, the price of one kilogram of phosphorus in mineral fertiliser was about NOK25 (Grønlund *et al.* 2015). The sales price of phosphorus in Norway is low, and therefore this factor is not included in the calculations.

With regard to basement flooding, the current compensation costs have been used as an expense in alternative 0, while WTP to prevent basement flooding is used as a benefit value in alternatives A, B and C. When calculating benefit values for water recipients in Asker, it was assumed that all the inhabitants of the municipality would benefit from the measures considered in all alternatives.

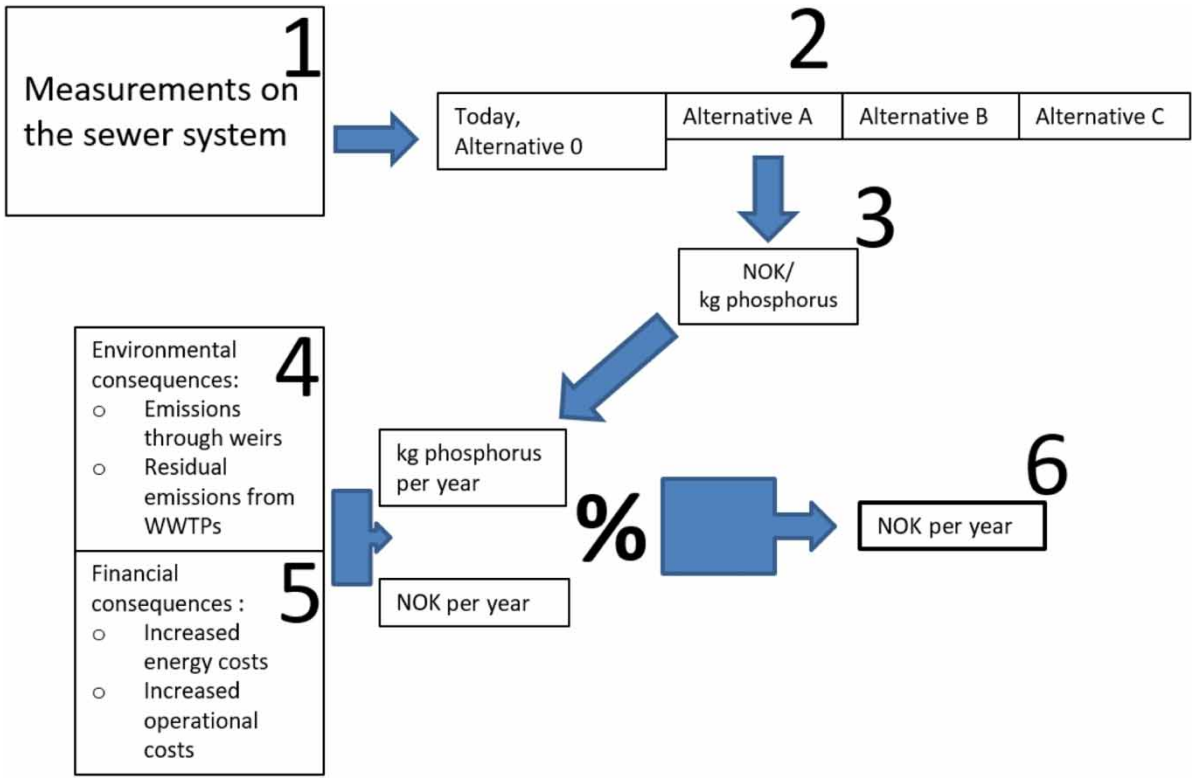

Figure 1 | Flowchart illustrating the method used to quantify the consequences of I/I-water.

Identification of pipe quality

In order to identify which pipes to renovate, several methods can be used. CCTV (closed circuit television) and distributed temperature sensing are both methods that can be used in order to locate defects. In Asker, there is extensive use of CCTV, and the municipality aims to inspect all sewer pipes. The reports generated from the CCTV inspections form the basis for selecting which pipes to renovate.

Hydraulic calculations

Due to large amounts of I/I-water, the sewer system in Asker functions as a combined sewer system, even if it is designed and operated as a separate sewer system. Figures on water volumes and capacities in the wastewater pipeline system were generated by performing calculations with a hydraulic model utilising the program Rosie, which uses Mouse (DHI software) as a calculation engine.

Pollution statement

The causes of poor water quality in Asker have been investigated by accounting for the chemical parameter of phosphorus. Elevated phosphorus emissions may cause eutrophication in freshwater and seawater (Universitetet i Oslo 2017). On the other hand, it is also a valuable resource, recovery of which is increasingly attempted due to its value as a fertiliser and rapidly diminishing mineral reserves. Phosphorus was previously used as an indicator of environmental health for freshwater bodies in Norway, and is therefore often used in pollutant calculations, particularly for freshwater bodies. For this reason phosphorus has been used as an indicator of emissions in this study. Other indicators, such as nitrogen and bacteria, could have been chosen instead.

The total phosphorus (Tot-P) discharge from Asker caused by a suboptimal wastewater system in 2017 was as follows (Asker kommune (Municipality of Asker) 2018):

Overflow (SSO):	209 kg Tot-P/year
Leakages from the sewer system:	844 kg Tot-P/year

The overflow volumes are calculated using a hydraulic model. The model is well calibrated in the areas where most of the weirs are situated and is for these areas considered to be reliable. Figures on leakages from the sewer

system are based on historical figures from Norway, using standard values for specific years of construction of the sewer pipes. The figures on leakages from broken wastewater pipes are associated with uncertainty. Further analyses therefore only examine discharges caused by overflow, both from the municipality and the wastewater treatment plant VEAS. VEAS (Vestfjorden Avløpsselskap) has calculated the discharge of Tot-P via overflow to be 2.7 tonnes in 2017 (VEAS AS 2017). Asker's share of this amounts to 223 kg. Even though VEAS's emissions from overflows do not flow into Asker Municipality, Asker's share of these discharges is included in the calculations performed in the presented article. In addition, treated wastewater from the WWTP carries phosphorus into water recipients. Treated wastewater from VEAS amounted to 22.1 tonnes of Tot-P in 2017 (VEAS AS 2017). Asker's share of this was 1,828 kg Tot-P. In 2017 the total amount of emissions caused by I/I-water sums up to 1,584 kg Tot-P.

Study area

The cost-efficiency analysis performed in this study is restricted to the sewer system in Asker Municipality. Asker is located in southeast Norway, just to the southwest of Oslo, the Norwegian capital. Asker Municipality, which as of the end of 2017 had about 60,000 inhabitants, was Norway's 11th-largest municipality at the time. A map of Norway and Asker, and the sewer pipes in Asker, is shown in Figure 2.

Asker Municipality owns 70 wastewater pumping stations, about 330 km sewer pipes and about 75 km stormwater pipes. Most of the pipe system was built in the 1960s and 1970s. There are stormwater pipes in some areas, but not all. Stormwater management is based on both piping and sustainable urban drainage systems. The system also consists of about 100 weirs.

The entire wastewater pipeline system in Asker consists of a separate system. In a well-functioning separate system, there should be no exfiltration of wastewater or I/I-water. A study carried out in 2018 found that the proportion of I/I-water in the wastewater system in Asker was 63% in 2016 (Sola *et al.* 2018). The method used to calculate the share of I/I-water was the water balance method (Sola *et al.* 2018). Due to high amount of I/I-water the sewer system in Asker is functioning more like a combined wastewater system than a separate system.

The wastewater system in Asker routes wastewater through a central tunnel to the WWTP VEAS. VEAS is located in Slemmestad in Asker and receives wastewater from parts of Oslo as well as all of Asker and its northern neighbouring municipality Bærum. Asker's share of the wastewater treated at VEAS amounted to 8.27% in 2017 (VEAS AS 2017). VEAS has a CSO located at Lysaker in Bærum, which discharges into the recipient 'Indre Oslofjord'.

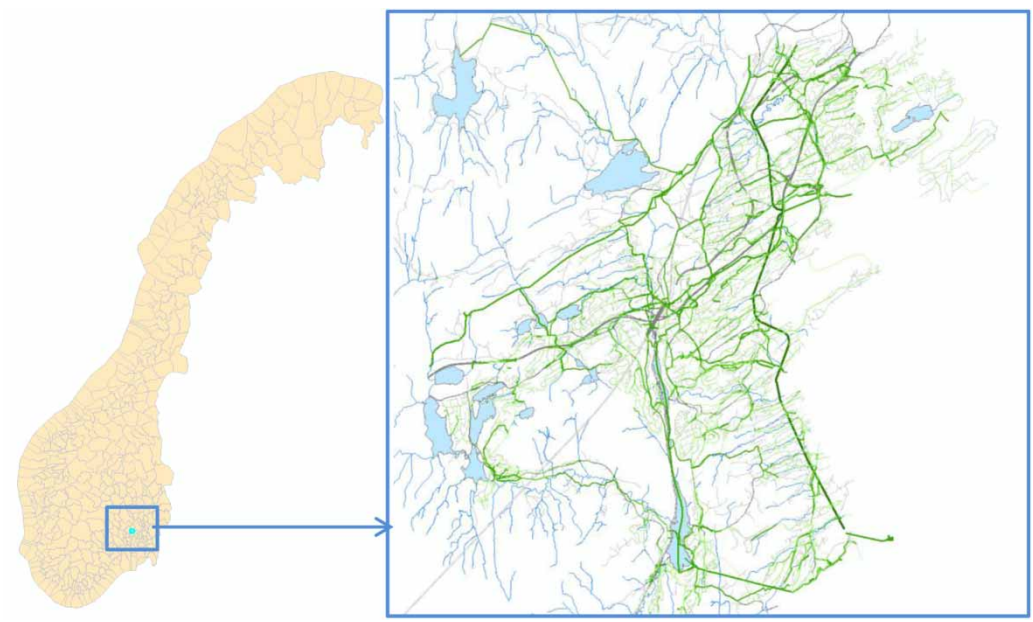

Figure 2 | Map of Norway and sewer pipes in Asker (Geodata 2018).

The County Governors in Norway may guide the municipalities regarding the level of I/I-water, and even impose measures when the level of I/I-water is too high. In 2012 the County Governor of 'Oslo and Akershus' urged the municipalities to take action against I/I-water if the level exceeded 30% as an average over the year (Fylkesmannen i Oslo og Akershus 2011). In order to combat this I/I-water it is necessary to renovate pipes, but to achieve the goal of 30% I/I-water set by the County Governor, a combination of different measures probably is necessary. The reduction in Asker has to be about 50% in order to achieve the goal.

Surveys indicate that the water quality in the Inner Oslo Fjord may be deteriorating (Lundsør *et al.* 2018). The water quality in Asker has been monitored since the year 2000, with a particular focus on chemical parameters. The development in water quality has been poor in some areas, and as of the end of 2017, Asker is not on track to meet the obligations of the WFD with regard to the biological and chemical quality of its waterbodies.

RESULTS OF THE COST-EFFICIENCY ANALYSES

Identification of different alternatives

Through the cost-efficiency analyses presented in this study, we aim to identify potential measures to reduce emissions of phosphorus caused by I/I-water.

The presented alternatives are differentiated by varying investment costs and operating costs, but they all aim at reducing the phosphorus discharge by 50%.

Alternative 0 is equal to the present situation and entails transport of pollution from the wastewater system to water recipients. In the event that no action is taken, it is likely that phosphorus discharges will increase. This increase will be driven by continuing deterioration of the wastewater system and increased frequency of sewer overflow events due to increased rainfall and volumes of I/I-water (Sola *et al.* 2018). In alternative 0, the municipality renovates a recommended minimum of pipelines, specifically 1% of the wastewater pipes per year (Norsk Vann 2015). Asker Municipality owns 70 wastewater pumping stations. Alternative 0 entails a simple upgrading of all the pumping stations over the entire 40-year period. Renovation of pumping stations is an ongoing effort similar to renovating wastewater pipes and troubleshooting for faulty connections. The costs of compensations associated with basement flooding are included in the calculations. The costs for operating municipal wastewater pumping stations and operating costs for VEAS are also included in the calculations.

Alternative A entails a complete restoration of all pipes assumed to be in poor conditions. This amounts to 65 km of pipelines, which corresponds to approximately 20% of the wastewater pipes in Asker. These pipes are being restored over a 5-year period. This is ambitious but achievable. In Asker the normal renovation rate is about 2% per year. Alternative A entails a minimum cost for renovating all the pumping stations. Alternative A is expected to reduce infiltration. In theory, this alternative would eliminate overflow both from the municipal wastewater system and from the VEAS WWTP. For this to happen, incorrectly routed stormwater must also be eliminated. This is not possible with restoration only and fieldwork is required to identify cross-connections between the stormwater network and the wastewater network. Such fieldwork is included in Alternative A. The fieldwork includes two persons working 2 days a week trying to locate and remove faulty stormwater connections. Therefore, it is assumed that this alternative will halve the volume of I/I-water.

An assumption in the calculations is that the share of I/I-water for 2017 is the same as in 2016, i.e. 63%. We further assume that if half of the I/I-water is eliminated, the reduction in discharge through overflow will correspond to the reduction in I/I-water, i.e. 32%. It is also assumed that 32% of Asker's share of I/I-water entering the VEAS facility is eliminated. This measure will accordingly reduce the Asker share of residual discharge from VEAS by 32%. The measure is assumed to eliminate the risk of basement flooding caused by I/I-water. Operating costs for the municipality will be reduced by 32%. For VEAS the operating cost will be reduced somewhere between 0 and 32%. The operating cost for VEAS will vary by 1% when using a reduction between 0 and 32%. This variable is of minimal importance to the total costs. In the calculation it is assumed that the reduction will be 20% for VEAS.

Alternative B entails increasing the pump capacity of all undersized pumping stations as well as upsizing the pipes connected to these stations that lack sufficient capacity. In total, this alternative covers 33 municipal pumping stations and approximately 3,600 metres of pumping pipes. In addition, 10 local overflow points and a total of 2,000 metres of pipes connected to local SSOs will be upsized. Furthermore, a retention basin will be built at VEAS to prevent overflow-related discharge. These upsizing projects and the establishment of a retention basin will be carried out over the course of a 5-year period. This measure comes with a minimum cost for renovating the remaining

pumping stations as well as renovating 1% of the pipes per year.

Alternative B will eliminate local discharge from overflow events and as a consequence transport increased amounts of wastewater to VEAS. Since a retention basin will be built at VEAS, the overflow discharge there will also be eliminated. The basin at VEAS will be dimensioned to handle the additional quantities of water pumped into VEAS as well as Asker's share of overflow at VEAS. Alternative B will eliminate the risk of basement flooding due to poor capacity in the wastewater pipeline system. Operating costs for the municipality and VEAS will increase.

In **alternative C**, local retention basins will be established in different locations around the municipality as well as at VEAS. The basins will be connected to the SSOs that are most prone to overflow. For the sake of simplicity, the costs have been calculated for a single, representative basin. This measure will not affect exfiltration from wastewater pipes or residual discharge from VEAS. A basin will also be established at VEAS to handle Asker's share of overflow discharge there. The retention basins will be established over 5 years. This measure also comes with a minimum cost for renovating the remaining pumping stations as well as renovating 1% of the pipes per year.

Investment costs

The annuity method is used to calculate the annual cost an investment will have over the course of the period which the system is assessed to run for. The present value of the system is distributed over the entire lifespan of the system. Pipes installed today are expected to have a 100-year lifespan. Pumping stations are generally assumed to have a 50-year lifespan. Nevertheless, the lifespan of all the components in a wastewater system is set to 40 years (Det kongelige finansdepartement (The minestry of Finance) 2014). In all projects where future impacts need to be assessed, a discount rate should be applied. By using a discount rate, future benefit values and costs are assigned a lower value in the analysis than the present-day value would be. The discount rate for public sector initiatives is determined by the Norwegian Ministry of Finance and has been set to 4% (Det kongelige finansdepartement (The minestry of Finance) 2014).

Costs relating to pipe restorations

Alternative 0: The average price to restore one metre of pipe has been set on the basis of experiences through different projects carried out in Asker. For no-dig renovation projects, the price per metre has been set to NOK10,000, and for full re-digging, the price has been set to NOK23,000 per metre. We assume that the recommended renovation rate of 1% a year is sufficient, and that these pipes will be renovated in the simplest and cheapest way.

Alternative A: The number of pipes that require upgrading has been retrieved from the municipality's database, Gemini VA. Sixty-five kilometres of pipelines are assumed to be in poor condition. These are mainly concrete pipes installed before 1970. Further, it is assumed that half of these pipes can be restored in the easiest and simplest way while the other half must be dug up and replaced with new pipes.

Alternative B: In alternative B, a cost has been included for renovating pipes similarly to alternative 0, starting from year 6. Included in this calculation are all the pipelines that will not be upsized.

Alternative C: In alternative C the cost for renovating pipes is equal to alternative B.

Costs associated with upsizing of pipes and pumping stations

Upsizing of undersized pipes will cost around NOK23,000/metre, and it is estimated that there are 5,600 metres of pipes that require upsizing (2,000 metres of gravity pipes and 3,600 metres of pumping pipes). The cost of upsizing 33 pumping stations has been calculated to a total amount of NOK250 million.

Costs of establishing a retention basin at VEAS

In 2017, a project was carried out to assess the possibility of establishing a new wastewater tunnel in Asker. The purpose of the tunnel would be to retain water from some of the largest CSOs in the municipality. The cost of this tunnel was estimated to be NOK119 million for 60,000 m^3 (Serch-Hanssen *et al.* 2017). Calculations based on the 10-year rainfall projection show that approximately 33,000 m^3 of water overflows from the municipality's SSOs. A review of annual reports from VEAS shows that Asker's share of the overflow discharge from the wastewater treatment plant averaged 130,000 m^3 annually during the period of 2009–2018 (VEAS AS 2018). In total, the retention basin has to be dimensioned for 163,000 m^3, and the estimated cost is NOK323 million. This applies to alternative B.

Cost of establishing local retention basins

In alternative C, a local retention basin will be established at an estimated cost of NOK65 million. An additional retention

basin will be established at VEAS to handle Asker's share of overflow discharge for a cost of NOK258 million.

Operating costs

I/I-water amounted to 63% of all wastewater in Asker in 2016 (Sola *et al.* 2018). The additional operating costs due to I/I-water for the municipality are mainly driven by extra pumping. Calculations performed by Asker Municipality show that, in 2017, the municipality's wastewater pumping stations required 5,050,867 kWh (Sommerro 2018). Given a price of NOK1.12/kWh, this corresponded to a price of approximately NOK5.66 million. Operating costs at VEAS in 2017 amounted to NOK324 million. Of this, 'maintenance' made up NOK73 million of the costs and 'electrical power' made up approximately NOK15 million (VEAS AS 2017). Other costs associated with operation of the plant are unlikely to be significantly impacted by reductions in I/I-water and are therefore not taken into account (Johansen 2019). Both maintenance and electrical power are assumed to be reduced by 20% when reducing the amount of I/I-water.

Operating costs, municipal

Alternative 0: Operating costs due to I/I-water amounted to NOK5.66 million in 2017, which corresponds to municipal operating costs in alternative 0. Over the entire 40-year period, the operation of pumping stations will cost approximately NOK113 million in alternative 0.

Alternative A: If the volume of I/I-water is halved, the amount of wastewater pumped will be reduced by 32%. The maximum reduction in pumped wastewater will be achieved when all the measures in this alternative have been fully implemented. The construction period is set to 5 years. The calculated operating costs per year from (and including) 2024 amounts to NOK3.85 million. From the years 2019 up to and including 2023, the operating costs will gradually decline on an annual basis. The operating cost of the municipal pumping stations is estimated to be approximately NOK81 million for the entire period. This alternative also includes cost due to increased fieldwork. We assume that two people work twice a week troubleshooting for faulty stormwater connections, following up on house owners etc.

Alternative B: If we opt for upsizing the system rather than renovating, the costs related to pumping operation will increase. If we assume that upsizing will result in a 50% increase in operating costs, then this amounts to NOK8.49 million per year. There will be a gradual rise in pumping costs from the year 2019 up to the year 2024. In total, these costs will amount to NOK164 million.

Alternative C: This alternative will result in increased pumping costs. Because the water is retained locally, each station connected to a basin will have to pump more than in alternative 0. In addition, a basin will become an additional operating point for the municipality. An additional cost is added for operations for alternative C.

Operating costs, WWTP-VEAS

Alternative 0: Asker's share of I/I-water costs at VEAS amounted to approximately NOK7 million in 2017, which corresponds to alternative 0.

Alternative A: It is uncertain how much of a reduction in costs can be expected if the I/I-water into the plant will be halved, but in the following a reduction of 20% is assumed. Therefore, in alternative A, the operating costs for VEAS fall to NOK5.6 million after the year 2024.

Alternatives B and C: In alternatives B and C, we assume that the operating costs will increase by 50%, meaning a gradual increase to NOK10.5 million per year after the year 2024.

In Table 1 the results of the cost calculations are shown.

The analyses shows that alternative A, including a full renovation of all bad sewer pipes and increased efforts to remove faulty stormwater, will be the cheapest measure. There is only NOK68 million between alternative A and C.

It is possible that an I/I-water reduction of 50%, which was used in alternative A, is a somewhat high figure. In the event that we would have to restore an even higher percentage of the pipes in order to achieve the goal of 50% reduction in I/I-water, the total cost of all considered alternatives will be as shown in Table 2. We have investigated the costs when renovating 20, 25 and 30% of the sewer pipes.

If we have to restore more than 20% of the sewer pipes in order to reduce the level of I/I-water by 50%, alternative C will be the most profitable. If we have to restore more than 25% of the pipes in order to reduce the level of I/I-water by 50%, then also alternative B will be more profitable than alternative A.

Wastewater emissions due to I/I-water

Calculations of overflow and pollution transport

The included amounts of overflow are in the presented study caused entirely by I/I-water, but the included part

Table 1 | Results from cost calculations

	Alt. 0	Alt. A	Alt. B	Alt. C
	Present value in NOKmillions			
Financial costs				
Renovating pipelines, 1% a year	−560			
Renovating old pipelines		−955	−579	−579
Field work		−8		
Upsizing pipelines			−115	
Renovating pumping stations	−125	−125		−125
Upsizing pumping stations			−223	
Operating pumping stations	−113	−81	−164	−164
Continuously renovating, VEAS	−253	−253	−253	−253
Operating costs, VEAS	−140	−114	−203	−198
Establishing retention basin, VEAS			−285	−231
Establishing retention basin, locally				−53
Compensations payments				
Total costs	**− 1,191**	**− 1,536**	**− 1,822**	**− 1,604**

of the residual emissions from VEAS is based on the share of I/I-water, 63%. Based on these prerequisites the current discharges for Asker Municipality associated with I/I-water sums up to 1,584 kg Tot-P in 2017. By including the measures in alternative A, B or C the emissions will be reduced. The development of I/I-related emissions of phosphorus in all alternatives is shown in Table 3.

Alternative A will be the alternative where most phosphorus is being removed.

The costs associated with removal of phosphorus in the different alternatives calculated in this study, indicated as the value in NOKper kg of removed phosphorus, sums up to:

Table 2 | Total cost for all alternatives when renovating 20, 25 or 30% of the sewer pipes in alternative A

	Alt. 0	Alt. A	Alt. B	Alt. C
	Present value in NOKmillions			
Total costs, 20% renovation in alternative A	−1,191	−1,536	−1,822	−1,604
Total costs, 25% renovation in alternative A	−1,191	−1,795	−1,822	−1,604
Total costs, 30% renovation in alternative A	−1,191	−2,030	−1,822	−1,604

Alternative A: Rehabilitation of pipelines/ troubleshooting for stormwater:	NOK79,060
Alternative B: Upsizing locally and establishing retention basins at the WWTP:	NOK110,127
Alternative C: Retention locally and at the WWTP:	NOK104,863

Alternative A is the best alternative in relation to cost-efficiency.

RESULTS OF THE COST CALCULATION OF I/I-WATER

Pricing of phosphorus discharge

Emissions of phosphorus may be priced using different methods. For example, one can identify a price per kilo of phosphorus treated in a wastewater treatment plant through indirect public valuation (Karstensen 2015). In 2017, VEAS treated 364 tonnes of Tot-P at an operating cost of NOK268

Table 3 | Discharges of phosphorus due to I/I-water in all considered alternatives

	2017, kg Tot-P	2059, kg Tot-P	2019–2059, kg Tot-P
Alternative 0	1,584	1,584	64,929
Alternative A	1,584	1,077	45,498
Alternative B	1,584	1,152	48,384
Alternative C	1,584	1,152	48,384

million. This cost also includes, for instance, removing of nitrogen and bacteria, but for the simplicity we assume that the cost is only related to removal of phosphorus. This results in a price of NOK736 per kg of treated phosphorus. One can also compute the annual cost of establishing a new wastewater treatment plant. Karstensen (2015) estimates this cost as NOK1,241/kg (Karstensen 2015). The 2017 value of NOK1,241 per kg (2015) is NOK1,337 per kg. This is the annual cost for both establishing and operating a new plant, similar to the existing WTP Bekkelaget in the municipality of Oslo. Through the 'Action Lake Mjøsa' project (1975), the goal of which was to reduce pollution in Lake Mjøsa, the authorities set an upper limit of NOK3,000/kg reduction in Tot-P for the measures they wished to fund (Karstensen 2015). This is equivalent to NOK16,434/kg in 2017 value.

Total costs due to I/I-water

The costs due to I/I-water for a specific year, when using different prices on emissions of phosphorus, are calculated according to formula (1):

$$\text{Total costs of I/I-water} = \text{operating costs due to I/I-water} + \text{emissions costs due to I/I-water} \quad (1)$$

The costs due to I/I-water for Asker in 2017 are summarised in Table 4. The figures in alternative A, B and C are based on the present value over a period of 40 years.

By using the figures that emerge from the calculations presented in this study, the cost related to I/I-water will range between NOK137 million and NOK187 million. If one uses more conservative estimates, such as the figure of NOK16,434 per kg of phosphorus from the Action Lake Mjøsa project, the cost of I/I-water in Asker Municipality will be NOK34 million for 2017.

Table 4 | Summary of costs generated from I/I-water for Asker Municipality in 2017

Source	Costs per kg phosphorus (NOK)	Costs related to I/I-water in 2017 (million NOK)
Operating the WWTP (literature)	736	9
Establishing new WWTP (literature)	1,241	10
Authorities' WTP, Action Lake Mjøsa project (literature)	16,434	34
Alternative A	79,060	138
Alternative B	110,127	187
Alternative C	104,863	178

By including emissions of phosphorus in alternative 0 and A, and by using the cost of NOK16,434/kg phosphorus, the total costs for these alternatives will amount to:

Alternative 0: NOK1,190 million + (64,929 kg Tot-P × NOK16,434/kg Tot-P) = NOK2,258 million

Alternative A: NOK1,524 million + (45,498 kg Tot-P × NOK16,434/kg Tot-P) = NOK2,272 million

Implementing measures to combat I/I-water will not be profitable in this example.

When using the value of NOK79,060 per kg of removed phosphorus, as calculated for alternative A, the total costs of the alternatives will amount to:

Alternative 0: NOK1,190 million + (64,929 kg Tot-P × NOK79,060/kg Tot-P) = NOK6,323 million

Alternative A: NOK1,516 million + (45,498 kg Tot-P × NOK79,060/kg Tot-P) = NOK5,113 million

When using the price of NOK79,060/kg Tot-P it will be profitable to implement measures according to alternative A.

We can examine the limiting value for phosphorus costs by comparing the costs for alternative 0 and alternative A, as shown in formula (2).

$$\begin{aligned}&\text{Alternative 0: present value of investments} \\ &+ \text{present value of operating costs} \\ &+ \text{emissions (kg Tot-P)} \times \text{emissions costs (NOK/kg Tot-P)} \\ &= \text{Alternative A: present value of investments} \\ &+ \text{present value of operating costs} \\ &+ \text{emissions (kg Tot-P)} \times \text{emissions costs (NOK/kg Tot-P)}\end{aligned} \quad (2)$$

$$\text{NOK 1,190 million} + (64{,}929\,\text{kg Tot-P} \times \text{NOK X/kg Tot-P}) = \text{NOK 1,536 million} + (45{,}498\,\text{kg Tot-P} \times \text{NOK X/kg Tot-P})$$

$$X = \text{NOK 17,806/kg Tot-P}$$

As such, if the phosphorus cost is equal to or less than NOK17,806/kg Tot-P, then it will not be socio-economically justified to reduce I/I-water.

RESULTS OF CALCULATIONS OF BENEFITS

Valuation of satisfactory fishing conditions. Norwegian conditions

In 2018, a study was carried out which among other things assessed the benefit value as the WTP for extermination of invasive fish species such as pike and minnow in efforts to improve conditions for indigenous fish populations in

Trøndelag, Norway. Participants in the study indicated a WTP for such a measure not only in local fishing areas, but also for the rest of the country (Magnussen *et al.* 2018). The quoted amounts represent a lump sum per household.

Pike, the whole country:	NOK1259–1,893
Pike, just own county:	NOK909–1,362
Minnow, the whole country:	NOK1,034–1,659
Minnow, just own county:	NOK737–1,185

Valuation of clean water. Norwegian studies

In 2015, an assessment of benefits and cost of environmental measures for urban waterways was published (Magnussen *et al.* 2015). The authors conclude that WTP for an improvement in water quality among people living closer than 1,000 metres from the waterways Alna (70,000 people) and Hovinbekken (30,000 people) in Oslo (Norway) amounted to NOK1,400 per person and NOK2,467 per person respectively (Magnussen *et al.* 2015). The study does not differentiate between the various benefits of an improvement in water quality. In other words, it covers everything from better bathing water to better cultural experiences.

A study from 2010 carried out 10 sample surveys in Europe, one of which was carried out in Østfold/Akershus (Barton & Holen 2010). The study was a part of the project AQUAMONEY, and focused on the recreational use of lakes, and investigated local residents' WTP for improvements in the ecological status of those environments. The study found that the WTP among the respondents ranged from NOK1,070 to NOK2,000 per household per year for the lakes Vansjø and Storefjorden. The study also showed that WTP fell by approximately NOK25/km and NOK72/km the further away from the lakes a person lived (Barton & Holen 2010).

In a study by Holen *et al.* (2011), for Sørum Municipality, it was found that the public's WTP had to amount to approximately NOK5,700 per household per year for at least 40 years for the benefit value of measures to improve the water quality in waterways within the municipality to be socio-economically justifiable (Holen *et al.* 2011).

Valuation of bathing water quality: European studies

There are several European and international studies which have examined WTP for better bathing water quality. The presented study has only used results from European studies. The figures vary from NOK86/person per year (Ireland) to NOK1,176/person per year (Denmark) (EVRI 2019). A study on WTP was carried out by Swanberg and Wallström, in Gothenburg, Sweden in 2018. The study concludes that WTP for improvements to water quality ranges between SEK50 and SEK58 per household per month (Swanberg & Wallström 2018). This corresponds to approximately NOK260–303 per person per year.

Valuation of prevented basement floodings

Basement floodings can be a great burden on those affected, both financially and psychologically. People who have experienced floodings are often anxious of it happening again. A study carried out in the Norwegian municipalities Øvre Eiker and Nedre Eiker established that the difference between the WTP between a broader insurance against flooding and physical initiatives to prevent flooding amounted to NOK92/year per household (Grann 2011). When converted from 2011 values to 2018 values, this figure is NOK112. In 2017, a study was carried out in Norway which established that uncertainty costs related to flooding can be valued at NOK400 per household per year for houses located more than 1 km from areas that have previously experienced flooding. For houses located in areas particularly vulnerable to flooding, a figure ranging from NOK800 to NOK900 per household per year was indicated (Torgersen & Navrud 2017).

In further analyses the following figures are being used to quantify basement floodings due to poor capacity in the wastewater pipeline system:

- NOK400 per house per year for houses located 1–5 km from properties which have previously experienced flooding
- NOK800 for houses located closer than 1 km from houses which have previously experienced flooding

Summary of relevant WTP studies

Table 5 provides a summary of relevant studies relating to WTP.

The benefit value of water quality improvement in this study uses the average value of NOK554 and NOK2,709, i.e. NOK1,632 per person/year. The total number of affected properties corresponds to the total number of persons living in Asker, i.e. 61,400 (Statistisk Sentrabyrå (Stastistics

Table 5 | Summary of figures used in the calculations in relation to WPT (2018)

Valuation field	Country	Lower limit (NOK)	Upper limit (NOK)
Good fishing conditions (lump sum)	Norway	734 (pike)	1,893 (minnow)
Improved water quality (person/year)	Norway	554	2,709
Improved bathing water quality (person/year)	Ireland/ Denmark	86	1,176
Improved water quality (person/year)	Sweden	260	303
Avoided basement floodings (per house)	Norway	400	800

Norway) 2018). This sums up to a total of NOK1,999 million. This monetary value is used in all the considered alternatives. All alternatives will lead to the same improvement in water quality.

COST-BENEFIT ANALYSIS

Table 6 provides a summary of the calculated values discussed in this chapter. Values for WTP for avoided basement floodings, as well as compensation payments for basement floodings, have not been included as there were no reported cases of basement floodings caused by poor capacity in the wastewater pipeline system in 2017.

If one takes the beneficial value into account, then all considered alternatives are profitable from a socio-economic perspective.

DISCUSSION

The level of I/I-water in many Norwegian municipalities is high. The reasons for this are likely to be a combination of many factors. Old pipes, large portions of leakages from drinking water and incorrectly routed stormwater are all

Table 6 | Summary of costs and benefits for all alternatives

	Alt. 0	Alt. A	Alt. B	Alt. C
	Present value in NOKmillions			
Financial benefit value				
WTP to avoid basement floodings				
WTP to achieve improved bathing water quality, low				
WTP to achieve improved bathing water quality, medium		1,999	1,999	1,999
WTP to achieve improved bathing water quality, high				
Avoided costs due to basement floodings				
Total benefit value	**0**	**1,999**	**1,999**	**1,999**
Financial costs				
Renovating pipelines, 1% a year	−560			
Renovating old pipelines		−955	−529	−529
Fieldwork		−8		
Upsizing pipelines			−115	
Renovating pumping stations	−125	−125		−125
Upsizing pumping stations			−223	
Operating pumping stations	−113	−81	−164	−164
Continuously renovating, VEAS	−253	−253	−253	−253
Operating costs, VEAS	−140	−114	−203	−198
Establishing retention basin, VEAS			−285	−231
Establishing retention basin, locally				−53
Compensations payments				
Total costs	**− 1,191**	**− 1,536**	**− 1,822**	**− 1,604**
Net benefits	**− 1,191**	**475**	**177**	**395**

variables that are likely to contribute. Renovating sewer pipes and manholes will improve the situation. It is possible that renovating drinking water pipes will be an even more cost-efficient measure due to the fact that this also will limit the amounts of lost drinking water. This should be investigated.

There is significant uncertainty associated with the amount of I/I-water that can be eliminated through renovating pipes. The amount of I/I-water that can be eliminated through pipe renovation should, therefore, be examined for each specific drainage area/municipality. There is also uncertainty associated with the amount of I/I-water that can be eliminated through fieldwork. Although numerous methods may be used when searching for I/I-water, some of these methods require quite an extensive use of fieldwork. If we would have to renovate a higher percentage than 20, as included in alternative A in the presented study, then alternative C would be the most profitable one.

A cost-benefit analysis can be a helpful tool to highlight costs and benefits that are not traditionally valued in wastewater projects. A cost-benefit analysis can contribute to a greater recognition of issues such as the non-tangible value of the marine environment and ecosystem services and, in doing so, lay the foundation for increased efforts to prevent the discharge of wastewater. Specific studies of WTP have not been carried out. The figures that have emerged regarding WTP are therefore associated with some uncertainty. The monetary value of improvement in water quality is also assumed to be the same for all considered alternatives.

The valuation of preventing basement floodings is also an important factor which ought to be included in the assessment of benefits and costs in urban wastewater projects. The costs associated with compensation payments and benefit values resulting from savings related to basement floodings were found to be negligible in this study. For other municipalities, this contribution could be significant.

The analysis carried out in this study shows that there is probably a basis for setting the target restoration rate of the wastewater pipeline system higher than 1%. Adding an extra expense to the present wastewater fees and earmarking that money to upgrading the wastewater system would increase the chances of achieving the objectives set in the EU Water Directive. The current strategy is unlikely to prevent the current system from declining while making improvements at the same time. Previously conducted studies of WTP for improvements in water quality suggest that it is possible to shift some of the costs for further efforts to improve water quality on to the inhabitants of Norway.

A risk and vulnerability assessment of the wastewater pipeline system in Asker has previously been carried out. The analysis provides an overview of the critical discharge points in the wastewater system. The analyses performed in this study could have taken into account and weighted the consequences of discharges, which would have provided a more representative picture. For example, VEAS's overflow discharges and residual discharges into deep water do not have as big an impact as local discharge points.

The figures used in the presented study are based on constructions built in Asker. The figures are considered reliable when it comes to local conditions in Asker. In other cities the conditions might be quite different. It is important to use figures retrieved from experiences with local constructions. The most reliable figures on investment costs from Asker emerge from pipe renovation. When it comes to building retention basins, both locally and at the

Table 7 | Reliability of input data

	Data reliability		
Factor	**High**	**Medium**	**Low**
Pipe quality	x		
Volumes of overflow in Asker		x	
Volumes of overflow from VEAS	x		
Share of I/I-water	x		
Reduced share of I/I-water			x
Reduced operating costs Asker	x		
Reduced operating cost VEAS		x	
Costs of upsizing pumping stations	x		
Costs of building retention basins		x	
Cost of renovating pipes	x		

WWTP, experience show that it is more likely that expenses will be higher rather than lower than what is calculated in this study. This goes in favour of alternative A.

The data reliability related to figures used in the presented study is illustrated in Table 7.

By eliminating the factors related to some uncertainty the results in the presented study would be even more reliable. The most important factor to investigate further is how large a share of I/I-water could be eliminated through renovation of pipes.

CONCLUSIONS

The presented study shows that there are a number of possible measures that could be implemented to minimize the consequences of I/I-water. We found that alternative A, which entails an increased rate of sewer pipe restoration in combination with fieldwork, provides the highest net benefit value. A cost-efficiency calculation also shows that this alternative would be the most favourable. In alternative A, it would cost NOK79,060 to remove 1 kg of phosphorus, while the most expensive alternative, which includes upsizing and retention, amounts to NOK110,127 per kg.

The presented study indicates that the cost of I/I-water in Asker Municipality amounted to NOK34 million in 2017, assuming a price on emissions of phosphorus of NOK16,434 per kg. The price of I/I-water is dependent on the price on emissions of phosphorus. When using the price of NOK79,060/kg phosphorus, calculated in alternative A, the I/I-water cost NOK138 million; however, we found that reducing I/I-water will be profitable as long as the price of phosphorus emissions exceeds NOK17,806/kg.

A review of previous studies regarding WTP for improved water quality indicates that there is probably room to increase the annual water and wastewater charges in Asker by NOK1,632 per household. On this basis all the considered alternatives would be socio-economically profitable.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Andersen, J. R., Bratli, J. L., Fjeld, E., Faafeng, B., Grande, M., Hem, L., Holtan, H., Krogh, T., Lund, V., Rosland, D., Rosseland, B. O. & Aanes, K. J. 1997 In: *Klassifisering av miljøkvalitet i ferskvann (Classification of Environmental Quality in Freshwater)* (J. L. Bratli, ed.). Statens forurensningstilsyn, Oslo, Norway.

Asker kommune (Municipality of Asker) 2018 *Forurensningsregnskap 2018 (Accounting for Different Sources of Pollution)*. Kommunalteknisk avdeling, Asker, Norway.

Barton, D. N. & Holen, S. N. 2010 *Verdsetting av nytten ved å oppnå god vannkvalitet i innsjøer (Valuing the Benefit by Achieving Good Water Quality in Lakes)*. *VANN* **45**, 345–356.

Det kongelige finansdepartement (The Ministry of Finance) 2014 *Prinsipper og krav ved utarbeidelse av samfunnsøkonomiske analyser (Principles Regarding Financial Analyses in Norway)*. Det kongelige finansdepartement, Oslo, Norway.

Direktoratet for økonomistyring (The Norwegian Government Agency for Financial Management) 2018 *Veileder i samfunnsøkonomiske analyser (A Guide in Socio-Economic Analyses)*. Direktoratet for økonomistyring, Oslo, Norway.

EVRI 2019 *Environmental Valuation Reference Inverntory*. Available from: http://evri.ca (accessed 2 January 2019).

Fylkesmannen i Oslo og Akershus 2011 In: *Fremmedvann i kommunale avløpssystemer (I/I-Water in Public Sewer Systems)* (Department of Environment, ed.). The County Governor of Oslo and Akershus, Oslo, Norway.

Geodata, A. S. 2018 *Kartverket, Geovekst og kommuner (Maps and Municipalities)*. Available from: https://www.kartverket.no/data/Vegvisar-til-gratis-kartdata/ (accessed 4 June 2018).

Grann, S. L. 2011 *Utrygghet for flom-en betinget verdsettingsstudie (Vulnerability to flooding-a conditional valuation study)*. NMBU, Ås, Norway.

Grønlund, A., Brod, E. & Hanserud, O. S. 2015 Potensial for gjenvinning og resirkulering av fosfor (The potential for recovery and reuse of phosphorus). *VANN* **50**, 197–200.

Hagen, K. P. & Volden, G. H. 2016 Innleding og oversikt over boken (An overview of the book). In: *Investeringsprosjekter og Miljøkonsekvenser (Investments and Environmental Impacts)* (K. P. Hagen & G. H. Volden, eds). Ex ante akademisk forlag, Trondheim, Norway.

Holen, S. N., Magnussen, K. & Seifert, I. 2011 Økonomiske aspekter ved gjennomføring av vanndirektivet- eksempler fra Sørum kommune (Financial aspects of the implementation of the Water Directive). *VANN* **46**, 470–480.

Ibenholt, K. *et al.* 2015 *Marginale eksterne kostnader ved enkelte miljøpåvirkninger (Marginal External Cost for Some Environmental Impacts)*. Vista Analyse, Oslo, Norway.

Johansen, H. 2019 *Fremmedvann og drift av VEAS (About Operating the WWTP VEAS)*. VEAS AS, Slemmestad, Norway.

Karpf, C. & Krebs, P. 2011 Quantification of groundwater infiltration and surface water inflows in urban netwok based on a multiple model approach. *Water Research* **45** (10), 3129–3136.

Karstensen, H. 2015 *Økonomiske konsekvsener av fremmedvann i avløpssystemet. En casestudie av Bekkelaget rensedistrikt (Finanicial Consequences of I/I-Water. A Case Study of Bekkelaget Wastewater District)*. NMBU, Ås, Norway.

Lundsør, E., Dolven, J. K. & Haugestøl, G. L. 2018 *Overvåkning av Indre Oslofjord i 2017 (Monitoring of Inner Oslo Fjords in 2017)*. Norconsult, Horten, Norway.

Magnussen, K. 2016 Verdsetting av naturkapital og økosystemtjenester. In: *Investeringsprosjekter og miljøkonsekvenser (Investments and Environmental Impacts)* (K. P. H. G. H. Volden, ed.). Ex ante akademisk forlag, Trondheim, Norway.

Magnussen, K., Seifert-Dähnn, I., Reinvang, R. & Lindhjem, H. 2015 Hvordan vurdere nytte og kostnader ved miljømål for byvassdrag (How to assess the benefits and costs of environmental goals). *VANN* **50**, 65–75.

Magnussen, K., Skjeflo, S. W., Dombu, S. V., Gierløff, C. W., Hesthagen, T., Dandlund, O. T., Aronsen, E. & Chen, X. 2018 Verdsetting av miljøulempene ved fremmede ferskvannsfisk – et pilotprosjekt (Valuation of environmental impact from foreign freshwater fish). Menon-Publikasjon, Miljødirektoratet, Oslo, Norway.

Navrud, S. 2016 Miljøverdsetting. Verdsettingsmetoder og verdioverføring (Environmental values. Methods of valuing and value transfer). In: *Investeringsprosjekter og Miljøkonsekvenser (Investments and Environmental Impacts)* (K. P. Hagen & G. H. Volden, eds). Ex ante akademisk forlag, Trondheim, Norway.

Norsk Vann 2015 *Behov for satsing på vann- og avløpsinfrastrukturen (Need to Focus on Water and Wastewater Infrastructure)*. Available from: https://norskvann.no/images/tones/PDF/NV_mener_Fornyelsesbehov.pdf (accessed 19 April 2019).

Serch-Hanssen, C., Asting, G., Føyn, T., Fridsteinsson, J. Ø. & Urke, I. 2017 *Avskjærende avløpstunnel Slependen-Holmen (Wastewater Tunnel Slependen-Holmen)*. Norconsult, Bærum, Norway.

Sola, K. J., Bjerkholt, J. Y., Lindholm, O. G. & Ratnaweera, H. 2018 Infiltration and inflow (I/I) to wastewater systems in Norway, Sweden, Demnark and Finland. *Water* **10** (11), 1–17.

Sola, K. J., Kvaal, K., Bjerkholt, J. Y., Lindholm, O. G. & Ratnaweera, H. 2019 Identifying factors influencing Infiltration and Inflow-water (I/I-water) in wastewater systems using multivariate data analysis. *VANN* **54** (4), 263–278.

Sommerro, Ø. 2018 *Om kommunale pumpestasjoner i Asker.* Asker, Norway.

Statistisk Sentrabyrå (Stastistics Norway) 2018 *Kommunefakta (Facts About Norwegian Municipalities)*. Available from: https://www.ssb.no/kommunefakta/ (accessed 2 January 2019).

Swanberg, Å. S. & Wallström, J. 2018 *Värdering av vattenförekomster i Göteborg (Valuation of Waters in Gothenburg)*. Anthesis Enveco AB, Gothenburg, Sweden.

Torgersen, G. & Navrud, S. 2017 *Sustainable Planning to Reduce Urban Floding – an Interdisciplinary Approach in Faculty of Science and Technology.* NMBU, Ås, Norway.

Universitetet i Oslo (University of Oslo) 2017 *Fosfor (Phosphorus)*. Available from: https://www.mn.uio.no/ibv/tjenester/kunnskap/plantefys/leksikon/f/fosfat.html (accessed 6 December 2018).

Vannportalen 2018 *Om vanndirektivet (About the Water Directive)*. Available from: http://www.vannportalen.no/regelverk/vanndirektivet/ (accessed 4 December 2018).

VEAS AS 2017 *Årsrapport 2017 (Annual Report 2017)*. Available from: https://www.veas.nu/global/upload/rBPPQ/files/VEAS_a%CC%8Arsrapport_2017.pdf (accessed 29 December 2018).

VEAS AS 2018 *Årsmeldinger (Annual Reports)*. Available from: https://www.veas.nu/om-veas/arsmeldinger (accessed 29 April 2019).

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