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Contents

Contents 5

Preface 7
  Organisation of the project 8

Summary 9

Part I Contaminants in wastewater streams and recipients in Tromsø, Tórshavn, Reykjavík and Sisimiut 13

1. Introduction 15

2. Selecting indicator pollutants 19

3. Methods 21
  3.1 Compounds analysed 22
  3.2 Presentation and evaluation of data 25

4. Study areas 27
  4.1 Tromsø 27
  4.2 Tórshavn 29
  4.3 Reykjavík 30
  4.4 Sisimiut 32
  4.5 Sampling 34
  4.6 Tromsø 38
  4.7 Tórshavn 41
  4.8 Reykjavík 42
  4.9 Sisimiut 45

5. Results – By contaminants and with focus on wastewater 51
  5.1 Phosphates 51
  5.2 Ammonium, NH_4^+ 51
  5.3 Total Organic Carbon- TOC 52
  5.4 LAS 53
  5.5 Alkylphenols and alkylphenol ethoxylates 55
  5.6 Cadmium 56
  5.7 Mercury, Hg 57
  5.8 PAH 57
  5.9 Phthalates 59
  5.10 Quaternary alkyl compounds, QAS 60
  5.11 Per- and polyfluoroalkyl 62
  5.12 Contaminants flow to and from WWTPs 65
  5.13 Contaminants carried by effluents 67

6. Results – Contaminants in recipients for wastewater 69
  6.1 QAS in receiving water 69
  6.2 Tromsø 70
  6.3 Tórshavn 75
  6.4 Reykjavík 78
  6.5 Sisimiut 83
  6.6 The wastewater impact 87

7. Discussion 91
    7.1 Eutrophication agents- nitrogen and phosphate 91
    7.2 Metals and organic contaminants 92
    7.3 High concentrations of contaminants in Sisimiut effluents 93
    7.4 In some cases concentrations in recipients followed a linear trend 94
    7.5 Efficiency of the sewage treatment plant 94
8. Conclusion 97
    8.1 Co-operation; transfer of knowledge and skills 98
9. References 99
Part II Options for improved wastewater purification in selected areas 101
10. Introduction 103
    10.1 Considerations around the wastewater handling issue with particular reference to Sisimiut 103
11. Description of test sites 107
    11.1 Klettagarðar and Hafnafjördur (Iceland) 107
    11.2 Ulkebugten, Sisimiut (Greenland) (GL-1) 108
    11.3 Breivika, Tromsø (Norway) (NO-1) 108
    11.4 Sersjantvíkin, Tórshavn (Faroe Islands) (FO-1) 109
12. Wastewater treatment and pollutants 111
    12.1 WWTP treatment 111
    12.2 Pollutants 113
    12.3 Micropollutants 113
13. Purification options for Klettagarðar and Hafnafjördur (Iceland): Microplastics 117
    13.1 Microplastics definition 117
    13.2 Microplastics in the environment 118
    13.3 Microplastics in WWTPs 118
14. Purification options for Ulkebugten, Sisimiut (Greenland) 125
    14.1 Redirecting the wastewater to another outlet 125
    14.2 Establishing primary treatment 126
    14.3 Redirecting the wastewater and establishing primary treatment 128
15. Breivika, Tromsø (Norway) 131
    15.1 Activated Sludge (AS) 133
    15.2 Sequencing Batch Reactor (SBR) 134
    15.3 Moving Bed Biofilm Reactor (MBBR) 134
    15.4 Integrated fixed-film activated sludge (IFAS) 135
    15.5 Further considerations 136
16. Sersjantvíkin, Tórshavn (Faroe Islands) 137
    16.1 Optimizing the septic tank solutions 137
    16.2 Upgrading to a secondary treatment step 138
    16.3 Upgrading to a tertiary treatment step 140
    16.4 Further considerations 141
17. References 143
Sammenfatning 147
Acknowledgements 151
    Tromsø 151
    Tórshavn 151
    Reykjavík 151
    Sisimiut 151
Appendices 153
    Method description PFAS analyses 153
    Protocol for water sampling for PFAS analysis 154

Preface

A common goal for the management of sewage and other kinds of surplus or waste material from a municipality is to keep a clean and healthy environment. In coastal areas relying heavily on harvest from the seas, like those areas participating in the present project and which may be described as a part of Nordic arctic areas, it is natural that the marine environment is in particular focus. Earlier surveys and visual inspection has indicated that in certain areas of the municipalities in these regions, the environmental status may not meet the goal. One important source of pollutants to the sea is the wastewater discharged. In the areas taking part in this project, the wastewater treatment may be pretty well up-to date or more or less non-existent, Figure 1. However, as the populations grow and the nature of the wastewater changes- not least with regard to the high and increasing content of pharmaceuticals and personal care products- the assumption that the recipient may be regarded as unaffected may be wrong. The project brings together representatives from bodies responsible for wastewater treatment and expertise in environmental pollution issues in cities from the northern part of Norway, Faroe Islands, Iceland and Greenland. This group served as a forum for knowhow exchange and steered the project, which aimed to describe to what extent the present level of wastewater treatment is sufficient to protect the marine environment in the vicinity of the cities/villages. For this end, analyses of samples from the recipients at various distances from the discharge points and at various seasons were carried out. The analytes chosen may be seen as indicator pollutants typically stemming from households, public services including hospitals and small-scale industry. The indicators chosen represent man-made and ecotoxicologically relevant chemicals, e.g. surfactants stemming from for instance household detergents, phthalates used as plasticisers, and PAHs arising from transportation and heating. The report comprises as part II an assessments of options for improved wastewater treatment for selected wastewater treatment sites. In order to concretise the discussion in terms of which kind of purification step that needs to be implemented, the assessment was based on a selection of sample pollutant groups. The selections were partly based of the findings of the first part of the report, and partly on recent analyses in comparable wastewater treatment plants. The results of the part II assessment are meant to form the basis for more in-depth discussions of possible abatements solutions. The aim is that these will be a starting point in connection with future updates of the wastewater treatment systems.

Figure 1: Somewhere between 14% and 20% of households in Sisimiut, Greenland, discharge grey wastewater directly to ditches or shore areas. The wastewater lines in place discharge to the seashore above high tide mark, with no prior wastewater purification

Photo: Hans Holt Poulsen.

Organisation of the project

The project has been supported by the Nordic Council of Ministers via grants from the Nordic Council of Ministers Arctic Cooperation Programme and the Nordic Chemicals Group. In addition, the participating municipalities, institutes and agencies have supported with man work hours, equipment and logistics.

The project has been organised by a steering group consisting of the following members:

- Norway, Tromsø: Jan Stenersen and Ingrid Berg, Tromsø kommune/Tromsø Municipality
- Faroe Islands, Tórshavn: Súni Christiansen (2013), Fríðbjørg Næss Joensen (2014, 2015), Vivie K. Davidsen (2016), Tórshavnar kommuna/Tórshavn Municipality and Maria Dam, Umhvørvisstovan/Environment Agency
- Iceland, Reykjavík: Sigurður Ingi Skarphéðinsson, Orkuveita Reykjavíkur/ Reykjavik Energy (2013) and Guðjón Atli Auðunsson, Nýsköpunarmiðstöð Íslands/Innovation Center Iceland
- Greenland, Sisimiut: Hans Holt Poulsen and Lone Kristensen, Qeqqata Kommunia/ Qeqqata Municipality

Summary

The study areas Tromsø, Tórshavn, Reykjavík and Sisimiut, have many similarities, for instance in the heavy economical reliance on marine harvest. These societies also to large extents share the same background in terms of societal structure and challenges and may be described as part of the Nordic arctic area. However, the areas included display a gradient both in climate, from oceanographic temperate in Tórshavn at 62° N to arctic in Tromsø at 69.7°N, and in population, from less than 6,000 inhabitants in Sisimiut to close to 120,000 in Reykjavík.

The four Nordic arctic cities[1] are different and far apart but their wastewaters are similar in terms of contaminants. The wastewater treatment varies quite a bit though, from screening on fine mesh, via septic tank based purification solutions, to no purification at all, as in Sisimiut. Apart from the wastewater treatment plant, WWTP, at the LSH main hospital and in the Sersjantvíkin "septic tank" type of WWTP both in Tórshavn, Faroe Islands, the biological degradation of the aqueous phase of wastewater is left entirely to the recipient. The biological treatment in the Sersjantvíkin WWTP is dependent on the activity of the microbial community present at any given time in the sewage treatment tank, and is as such poorly controlled. In approx. 15% of Sisimiut households, grey wastewater are discharged directly to terrain, whereas the black wastewater is collected by various means and subsequently discharged to sea without purification. The large majority, approx. 75%, of Sisimiut households are connected to sewage lines, which carry grey and black wastewater, but none or only very little surface water. The sewage lines discharge to sea, and the present study has included two of these, Ulkebugten and Natreno. In Sisimiut, the challenges are not merely that of environmental pollutants invisible to the naked eye, but also involves more unsightly and unhygienic pollution of the nearshore environment so the outlet sites provide very visible clues to the lacking wastewater purification.

During the project period, a range of pollutants identified as priority hazardous substances in the field of water policy within EU (Directive 2013/39/EU) have been analysed in the wastewater streams as well as in the water bodies that act as recipient for these. The priority substances analysed were: cadmium and mercury, polycyclic aromatic hydrocarbons including naphthalene (PAH), di(2-ethylhexyl)phthalate (DEHP), nonylphenol and perfluorooctane sulfonate (PFOS). The analyses included also C4-C10 perfluoroalkyl sulfonic and C4 to C14 perfluoroalkyl carboxylic acids, as well as two telomers, all these perfluorochemicals combined referred to as PFAS, and compounds that are used in every modern household in everyday detergent products, like linear alkyl benzene sulfonates (LAS). Also chemicals used for more specialised detergent purposes was analysed, as octylphenol and nonylphenol and their

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[1] Sisimiut is actually a town, but is sometimes in the present report referred to as a city.

ethoxylates, and cationic surfactants of the quaternary ammonia (QAS) type which are used in a range of disinfecting products as well as in fabric softeners. In addition, more standard wastewater parameters like phosphate, ammonium and total organic carbon content were analysed as were chloride as a proxy for salinity. These latter parameters may be used for calibration purposes in terms of assessing the relative contribution of synthetic pollutants to those excreted by humans, and for description of general physicochemical status of the water bodies. The concentration of contaminants measured in the wastewater stream before and after passage of the WWTP were compared. When properly designed such sampling and analysing will inform about the efficiency of the wastewater purification. Comprehensive assessments of the WWTPs were not within the scope of the project, but composite samples representing wastewater flow for approx. 24 hrs. was done in some WWTPs to partially fulfil the demands of representative sampling. This was combined with repeated sampling/analyses of selected compounds to support the assessment of the representativeness. Such composite sampling of influent and effluents were arranged in Breivika, Langnes and Sersjantvíkin WWTP. Overall, the concentration of the contaminants did not necessarily decreased on passage through a WWTP. The anionic detergent LAS did not decrease noteworthy in and out of the WWTPs, nor did mercury and PFAS generally, nor PAH. No reduction in octyl- and nonylphenols and their ethoxylates concentration was found to take place in the WWTPs. Neither nutrients (phosphate and ammonium) were necessarily reduced in the WWTP, though organic material, as TOC, on the other hand were generally decreased in the WWTP. Also, mercury going out of the Klettagarðar WWTP was much less than going in, and there were tendencies of decreasing PFAS in the Tromsø Langnes WWTPs. The main success story however, appears to be the reduction of phthalate in the Langnes WWTP which withheld more than 90% of DEHP. Similarly, though based on grab samples, the Klettagarðar WWTP appeared to remove DEHP from wastewater as Langnes. A modest reduction of DEHP was seen in the Sersjantvíkin WWTP, but generally the other WWTPs than Langnes and Klettagarðar performed variably, but then the concentrations of DEHPs were not as high in influents of these.

The concentrations of contaminants measured in effluents, i.e. the water discharged from the WWTP, may be used to estimate the release of contaminants to the receiving water body, the recipient. This requires that the samples may be assumed to be representative and in practise means that these should be as composite samples, and preferentially over a longer time-span. The studied WWTPs did not generally have equipment in place for such sampling, but through extended effort, composite sampling was done in selected wastewater lines mentioned above and in Sisimiut in sampling rounds 2 through 4.

The concentrations of pollutants in the receiving water bodies were analysed and the results evaluated with respect to environmental risk. The risk was assessed by comparisons to EU's Environmental Quality Standards (EQS) for the compounds for which such were defined (Directive 2013/39/EU).

Ammonium was analysed in two rounds, in April/May 2014 and September 2013. The concentration of ammonium decreased at increasing distance from the discharge sites, and this was consistently observed for the Sisimiut area. The ratio of recipient ammonium to background concentration was elevated particularly at the Natreno sites, with somewhat lower ratios in the Ulkebugten recipient waters that were similar to that of the Sersjantvíkin WWTP discharge site in Tórshavn. The recipient around the Breivika WWTP also had elevated ammonium concentrations but there were high variations between the two sampling rounds. Elevated ammonium was not observed in the Reykjavík areas. Phosphate was found at concentrations exceeding 1.5 times the local winter background in some of the samples from Tromsø, Tórshavn and Sisimiut.

LAS was analysed in three rounds and is as such the best indicator on variability between analysis rounds. In the first round, October 2013, LAS was detected in every second recipient sample, and twice as often in the Tromsø and Tórshavn samples as in the Reykjavík and Sisimiut samples. Of the in all four samples where LAS was higher than the ad hoc PNEC of 0.0025 mg/L two were from Tromsø and two from Tórshavn. QAS are a group of cationic surfactants and as such shares some qualities and uses with the LAS detergents. The QAS included in the present study were dialkyl dimethyl ammonium (DDAC), alkyl dimethyl benzyl (BAC) and alkyltrimethyl ammonium (ATAC). Of these were BAC detected in 10 of the 16 recipient samples analysed, DDAC was found in five and ATAC in three. The concentrations were however low and at most 5% of the EQS. PFAS which includes persistent fluorinated compounds used for grease and/or water proofing of paper and textiles was analysed in 24 recipient water samples, and was detected in all but four of these; two in Tromsø and two in Sisimiut. In four samples in Tromsø, two in Reykjavík and one in Sisimiut did the concentration of PFOS exceed the EQS at 0.00013 µg/L. PFAS appears thus to be a group of contaminants that warrant closer scrutiny.

Overall however, concentrations of pollutants in the receiving water masses were low; Phthalates and PAH were not detected in the recipient, at concentrations well below the EQS for anthracene and benzo(a)pyrene, the latter though only assessed in relation to the maximum allowed concentration due to limitations in analytical sensitivity. Octyl- and nonylphenols and their ethoxylates were not detected in the recipient samples, at detection limits were 10 and 100 ng/L, respectively, and were thus below EQS. Mercury was not detected in any recipient samples, at detection limit 0.002 µg/L, and were thus below EQS. Cadmium was detected in recipient samples in Tórshavn and Reykjavík, but did not exceed 50% of the EQS.

Summing up with regard to the recipient status in the four cities based on the EQS are limited by the existence of such quality surrogates, but with that as a backdrop it appears that phosphate and the contaminant groups PFAS and LAS may pose environmental risk in some of the areas studied. In Tromsø, exceedances of EQSs were occasionally observed for all three compounds. In Tórshavn, exceedances were seen in some cases for phosphate and LAS. In Sisimiut, exceedances were seen for phosphate and PFAS, and in Reykjavík, the concentration of PFOS in two of five recipient samples exceeded the EQS.

Part II of the project was dedicated to assessing ways to improve the wastewater treatment at the various sites. In order to concretise the assessment, the participants from the various areas were asked to identify which group of pollutant that should be prioritised for purification. This method was chosen, as the Part I of the project could only include a limited assessment of the environmental status of the receiving waters, both with regard to pollutants and spatial extension. As preliminary surveys had indicated that the microplastics in wastewater did pass the WWTP in Reykjavík more or less unscaled, the Icelandic representation wanted the assessment on mitigating measures to focus on microplastics. In Sisimiut, the problem with wastewater treatment was the lack of any purification measure in place, and thus the focus for this area was a suggestion for wastewater treatment that would consist of primary treatment, i.e. handle the visual contaminants as well as the nutrients and organic material in the sewage. The wastewater treatment in the Tromsø WWTPs included in the study is based on mechanical screening of the sewage, similar to the Reykjavík WWTPs concept, but using finer mesh. Due to local environmental challenges with elevated nutrients in combination with a known weakness of such WWTPs to handle water-soluble pharmaceuticals, and the fear of escalating environmental problems by micro pollutants including plastics discharged with effluents, the Tromsø representation wanted the assessment to focus on WWTP efficiency for these components. The Tórshavn wastewater treatment challenges had been identified in earlier surveys to include pharmaceuticals, phthalates and detergents, so the assessment of improved wastewater treatment was to cover a broad spectrum of potential environmental pollutants.

The solutions discussed for improving the wastewater treatment were based on literature studies, including peer-reviewed publications, governmental and sector research institute publications and commercial product descriptions and textbooks dedicated to the field of wastewater handling and recipient pollution. The purification processed and requirements were related to the EU Council Directive on urban wastewater treatment (21 May 1991, 91/271/EEC) as a document of guidance. The solutions for improved wastewater purification for the various prioritised pollutants (micro plastics, pharmaceuticals, nutrients etc.) were discussed in terms of efficiency of the various treatment steps as described in the literature. Purification options detailed to the level of purification principle suitable for the wastewater lines prioritised for the assessment were suggested. The intention with these is that they may be used as a basis for designing adapted solutions for improved wastewater purification in the selected areas as well as in other similar ones.

Part I

Contaminants in wastewater streams and recipients in Tromsø, Tórshavn, Reykjavík and Sisimiut

1. Introduction

During recent years, new information has become available on substances that are partially regarded as new contaminants, such as pharmaceuticals, phthalates, perfluoroalkyl substances and brominated flame-retardants to mention few classes of these. Some of these compound groups are lipophilic and persistent, like brominated flame-retardants, and accumulate in food webs. Other compounds, like pharmaceuticals, are water-soluble, might exert effects at low concentrations but often metabolized within hours. Some are water soluble and persistent, like perfluoroalkyl substances, and some may be regarded as more or less readily degradable like phthalates and detergents.

In a recent screening study of diethyl phthalate (DEP), in wastewater treatment plants, WWTPs, in Faroe Islands and Iceland, it was found that the effluent concentration of DEP was between 25% and 64% of that detected in the influents of the WWTPs (calculated from data in Huber et al., 2013). Another recent screening study of di-n-butyl phthalate (DBP), butylbenzyl phthalate (BBP), diethylhexyl phthalate (DEHP), di-n-octyl phthalate (DOP), di-iso-nonyl phthalate (DINP), di-iso-decyl phthalate and other plasticisers in effluents from WWTP in the Nordic countries (Remberger et al., 2013), indicated that the short carbon chain analogues were at low levels, whereas the ones with 8–10 carbons were at high concentrations; the phthalate occurring in highest concentration in effluents from the main WWTP in Tórshavn, Faroe Islands, was DINP at 27 µg/l, followed by DEHP at 12 µg/l and DIDP at 4 µg/l. Recent follow-up sampling and analyses confirmed these results and indicated that other effluents in the capital contained even higher concentrations of these longer chained phthalates where effluents containing DINP at 240 µg/l and DEHP at 140 µg/l were recorded (Dam, not published). In the screening encompassing Nordic countries (see also www.nordicscreening.org), the highest effluent DINP and DIDP concentration were detected in the Tórshavn WWTP, whereas effluents from WWTP in 10 other cities (like Esbjerg, Odense DK; Turku, Helsinki FIN, Gjøvik N, and Gøteborg, Borås SE) all contained lower concentrations of these compounds. Additionally, effluents concentration of DEHP was highest in the Faroe Islands (12–15 µg/l), only effluents from Gøteborg contained similar concentrations (14 µg/l). In the follow-up measurements above (Dam, not published), the concentration of phthalates were analysed in a number of WWTPs in Tórshavn; representing areas of newer and older buildings used mainly for residence, and areas dominated by buildings used by commerce and industry. These analyses did not indicate that wastewater from commerce/industry provided effluents with higher phthalate concentration, on the contrary; the highest phthalate concentration were found in effluents from both new and older residence buildings. This means that the lack of heavy industry does not preclude these areas from discharging significant amounts of man-made pollutants to the marine environment.

In the abovementioned screening by Huber et al., 2013, a total of 38 pharmaceuticals or metabolites of such were analysed in wastewater lines in Faroe Islands, Iceland and Greenland, along with the seven already mentioned DEP and other additives in personal care products. Among these additives were the detergents sodium laureth sulphate (SDSEO 1–4), cocoamidopropyl betaine (CAPB), and cetrimonium salts (ATAC – C16), where the ATAC C16 belongs to quaternary ammonium surfactants, QAS, group of cationic compounds. The QAS are used for instance in disinfectants and fabric softeners, while the anionic and amphoteric surfactants are used mainly in detergents and as emulsifiers and thickener in compounds for surface treatment. The risk of all pharmaceuticals could not be assessed due to lack of ecotoxicity data, but among those which could be assessed, it was found that the largest risk was posed by the detergents rather than the pharmaceuticals. In most instances, the unacceptable risk (calculated either on basis of recipient concentrations or on effluent concentrations divided by 10) was due to CAPB and ATAC C16, not because these necessarily occurred in higher concentration than the very common SDSEO 1–4, but because these are up to 100 times more toxic to aquatic life than SDSEO1–4.

In 2010, approx. 5,200 tons of QAS were used in the Nordic Countries whereof dialkyl dimethyl ammonium (DDAC) accounted for the largest volume, 2,813 tonnes, followed by alkyl dimethyl benzyl (BAC) at 1,218 tonnes and thereafter alkyltrimethyl ammonium (ATAC) with 442 tonnes, in addition to "others" at 723 tonnes (Johansson et al., 2012; Kaj et al., 2014).

A screening of surfactants of the QAS type as well as a selection of anionic and amphoteric ones was conducted in 2013 and 2014 in Finland, Sweden, Norway, Denmark, Faroe Islands, Iceland and Greenland by the Nordic Screening Group (http://www.nordicscreening.org/index.php; Kaj et al. 2014). Analyses were done in the wastewater streams, both in water and sludge, and in samples near the effluent discharge sites. Both seawater, sediment and fish from the receiving waters were analysed. Among QAS, the ATAC group of compounds were most frequently found, also in fish samples from the receiving waters. In sediment samples as in sludge samples from the Faroe Islands, DDAC were found in highest concentration, though in hospital wastewater streams BAC and ATAC were the dominating QAS. Though, the highest concentrations of QAS as well as anionic surfactants were found in the wastewater being discharged to sea in Nuuk, Greenland and next highest concentration of anionic surfactants were found in wastewater from a hospital in the Faroe Islands. The results of the survey indicated that the wastewater treatment in the Faroe Islands were less efficient in withdrawing QAS from the wastewater than treatment systems in larger Nordic cities. The results showed that the concentration of surfactants in the wastewater being led to recipients in areas with small populations may very well be large compared to that being discharged near the larger cities. The staff at the office responsible for water supply and sewage removal may find this obvious, as the waste water lines carrying these elevated concentrations of detergents are those where no purification take place before discharge to recipient, or where the purification step consists only of solid-settling step with short hydraulic residence time. The public at large though may not find this obvious as one is accustomed to automatically link pollution with larger cities. The more important question is however how the pollutant load is affecting the recipient as a recreational area for people, as habitat for marine wildlife and as production site for food.

Such considerations have been surfacing in Tromsø in recent years, a city whose rapidly growing population incur challenges for water and sewage services. The overall focus on anthropogenic impacts on the environment has received much popular and political attention also in Iceland, where particular focus is on water environmental quality off Reykjavík. Similar public focus on environmental impacts of wastewater discharged to sea may not have been prominent in Sisimiut, where waste water as in Greenland overall, is discharged to sea – or may be discharged directly to terrain or small streams if consisting of grey wastewater only. Seen in a large perspective, the recipient off Sisimiut may be regarded as unlimited in capacity, but when the wastewater is discharged to water bodies with limited exchange as in an estuary, then that supposition may not be valid. In Sisimiut, one waste water line drain into Ulkebugten, which is an estuary. In recent years, it has emerged that there are environmental impacts of the discharge which is manifested by a dead sea bottom in an area of diameter approx. 100–200 meter around the outlet.

Considerations are underway thus, on how to make an affordable wastewater treatment and a sewage structure that can incorporate an easy establishment of one or more wastewater treatment plants. These years, the Qeqqata Kommunia were Sisimiut is located, are assessing funding options for a full-scale test plant for wastewater treatment in the village Kangerlussuaq (Sønderstrømfjord). The aim is to build the next wastewater treatment plant in Sisimiut. The present project may help guiding the efforts by selecting where and what to prioritise for mitigating actions.

2. Selecting indicator pollutants

The main constituents of sewage are nutrients and organic matter and the primary aim of sewage treatment is to decrease the content of these by physical and biological processes. Therefore, nutrients like nitrate and phosphate as well as organic matter (represented by COD, BOD or TOC) are used as indicators of influx of wastewater from residence and agricultural areas to the receiving water bodies. These substances are usually not directly toxic to aquatic organisms but organic matter and algal growth caused by the fertilising nutrients induce oxygen demand. The problem arises if and when the receiving water body has insufficient exchange rate/removal capacity for the nutrients which might ultimately result in oxygen depletion and concomitant sulphide formation, conditions which are toxic/detrimental to many organisms. Apart from monitoring nutrients and organic matter, the most straightforward way to reveal if the recipient is under pressure from sewage disposal is to monitor oxygen levels in the water and possibly the accumulation of organic matter in the sediments.

Direct monitoring of nutrients levels in the recipient to elucidate and possibly highlight a potential pollution situation may be difficult since anthropogenic activities are by no means the sole source of nutrients. Nutrients are naturally occurring, and it is thus always necessary to have a solid knowledge on the natural level and variability in nutrients in order to assess potential increase caused by anthropogenic activities. Monitoring nutrients, organic matter, and oxygen levels needs therefore be rather comprehensive and spanning long periods of time to reveal effects, especially if the effects are subtle or gradually increasing. Such in-depth knowledge to local nutrient concentrations and variability is partially lacking at least for some of the areas included in the present study. However, sewage contains a large suite of natural and anthropogenic chemicals that could be used as tracers of its behaviour and fate and some of these chemicals can be detrimental to the environment/organisms due to their toxicity. The physical and biological processes of the sewage treatment may decrease at least some of these chemicals, especially those that are lipophilic and/or adsorbed onto particles. The environmental effects of these chemicals are different from the nutrients and organic matter and, therefore, information of their levels and behaviour gives a complementary picture of the possible impact of sewage discharge on the aquatic environment. Since many of the manmade chemicals have a well-documented toxicity profile the negative impact of discharging volumes of insufficiently purified wastewater may be readily assessed. The selection of indicator pollutants will be based on the list of priority pollutants in the EU water framework directive as well as on the knowledge bank established by other monitoring and ecotoxicity assessment activities already done in and around the wastewater lines/ treatment plants.

The pollutants chosen as indicators of wastewater are common in households and in industry and are such that they may be found in every one of the areas included, and are well known for their negative impact on aquatic life. The pollutants chosen were linear alkylbenzene sulphonates (LAS), which are anionic surfactants, octyl- and nonylphenols and ethoxylates (AP/APEO), as well as cadmium and phosphate. The first two groups of pollutants, LAS and AP/APEO, are indisputable indicators of anthropogenic activity, whereas cadmium and phosphate occur naturally but can be magnified due to anthropogenic activities. Both LAS, AP/APEO and phosphate are common ingredients in household and/or industry detergent products and processes. Cadmium is a ubiquitous pollutant which accompanies a range of activities in the technosphere. It is a nutrient-like element, i.e. it is taken up in phytoplankton during growth and thus behaves like for example phosphate in seawater. Therefore, a global relationship exists for dissolved cadmium and phosphate in seawater enabling contaminated sites to be revealed as a deviation from this relationship. The analytical costs of including cadmium and phosphate were quite modest in comparison to LAS and AP/APEO, which were regarded as the primary choice of indicator substance groups.

The priority list of the Water framework directive was consulted when indicator substance were chosen, as there is widespread agreement on the need to closely monitor the occurrence of these compounds in the aquatic environment with the intent to instigate mitigating measures if the concentration are found to threaten aquatic ecosystem health.

3. Methods

The compounds analysed and the detection limits as well as information about analytical methods are given below. Chemical analyses were performed by ALS Environmental, Sweden (www.alsglobal.se), except for Quaternary Ammonium Compounds which were analysed at IVL, Stockholm, and per- and polyfluoroalkyl compounds which were analysed at Örebro University.

The sampling were done in four rounds, representing the four seasons, and the sampling was done as coordinated in time as possible with the constraints of weather mainly determining the actual sampling time. Sampling immediately after heavy rainfall was avoided.

An overview of the sampling rounds and the compounds analysed are given in Table 1. Phosphate and linear alkylbenzene sulfonates, LAS, were analysed in three of the four analyses rounds. Whereas many pollutants like the alkylphenols and alkylphenol etoxylates, polycyclic aromatic hydrocarbons, per- and polyfluoroalkyl and quaternary ammonium substances were analysed in samples taken in one sampling round only.

Table 1: The analyses scheme applied for the wastewater and recipient water samples taken during the four sampling rounds

Sampling no.	Sampling month	Season	Compounds analysed
1	October 2013	Autumn	Alkylphenols and their ethoxylates, cadmium, linear alkylbenzenesulfonates, phosphate.
2	April / May 2014	Spring	Ammonium, chloride (salinity), linear alkylbenzenesulfonates, phosphate, phthalates, total organic carbon.
3	August / September 2014	Summer	Ammonium, chloride (salinity), linear alkylbenzenesulfonates, mercury, phosphate*, polycyclic aromatic hydrocarbons , total organic carbon.
4	February / March 2015	Winter	Per- and polyfluoroalkyl and quaternary ammonium substances.

Note: * was not analysed in the Faroe Islands samples on this occasion.

3.1 Compounds analysed

3.1.1 Phosphate

Phosphate-phosphor, PO4-P (orthophosphate-P), was analysed spectrophotometrically using accredited method CSN EN ISO 6878, with quantification limit 0.01 mg/L.

3.1.2 Ammonium

Nitrogen as ammonium, NH_4-N, is a naturally occurring nutrient like phosphate, and like phosphate also a useful tracer of wastewater. NH_4-N was analysed according to method based on CSN EN ISO 11732, CSN EN ISO 13395, CSN EN 13370 and CSN EN 12506, with detection limits at 0.04 to 0.050 mg/L depending on matrix, and in one instance (Norwegian samples from second round) using ISO 7150-1.

3.1.3 Total organic carbon (TOC)

In contrast to salinity, which may be regarded as originating solely from sea water and thus be a tracer of marine water masses, TOC may arise from natural processes in the recipient but is also an important measure of the organic matter in wastewater. TOC was analysed using IR detection according to accredited method based on CSN EN 1484 and CSN EN 13370, with detection limits from 0.5 mg/L to 1.5 mg/L depending on the matrix.

3.1.4 Linear alkylbenzene sulfonates

Linear alkylbenzene sulfonates, LAS (C10–C14) are used in soaps and detergents, in a wide range of household and industrial products. LAS are usually produced as a mixture of sulfonates, and as a group of anionic surfactants, they are a major component of laundry detergent, with billions of kilograms produced annually. LASs are not included among priority substances in Europe (Dir. 2013/39/EU amending Dir. 2000/60/EC). LAS were analysed by HPLC-FLD, method (SOP HM-MA-M U 2–27, accredited), with limit of quantification towards 0.0005 mg/l. The following compounds were analysed: decylbenzene sulfonate (DeLAS), undecylbenzene sulfonate (UnLAS), dodecylbenzene sulfonate (DoLAS), tridecylbenzene sulfonate (TriLAS) and tetradecylbenzene sulfonate (TeLAS).

3.1.5 Alkylphenols and Alkylphenol ethoxylates

Alkylphenols and alkylphenol ethoxylates, AP and APEO, are surfactants like LAS and applied in many of the same products. The alkylphenols analysed are given in Table 2. The alkylphenols analysed are of the branched kind, and these are included among the priority substances in the field of water policy in the EU directive 2013/39/EU along with the linear isomers. AP and APEO were using GC-MS, DIN EN ISO 18857, accredited, with limits of quantification in the range 0.01–0.1 µg/L often dependent on matrix.

Table 2: The nonylphenols, nonylphenol ethoxylates (1–3) and octylphenol, octylphenol ethoxylates (1–3) analysed

Parameter	CAS
4-tert-Octylphenol	140-66-9
iso-Nonylphenol (tech.)	84852-15-3
OP1EO	2315-67-5
OP2EO	2315-61-9
OP3EO	2315-62-0
NP1EO	104-35-8
NP2EO	20427-84-3
NP3EO	51437-95-7

3.1.6 Cadmium

Cadmium, Cd, is a common anthropogenic pollutants and a naturally occurring element. Cd is included as a priority substance in the area of water policy in EU directive 2013/39/EU. Cd was analysed using method V-3a, accredited, with limit of quantification equal to 0.05 µg/L.

3.1.7 Mercury

Mercury, Hg, is a naturally occurring metal, however it is also a ubiquitous pollutant which is biomagnified in the marine food web. Important sources for human mercury exposure is fish and in certain areas even marine mammal consumption. Mercury was analysed by AFS according to SS-EN ISO 17852:2008, with detection limit 0.002 µg/L.

3.1.8 PAH

Like mercury, polycyclic aromatic hydrocarbons, PAH, were analysed in the third sampling round, i.e. on samples taken in August and September 2014. PAH is a group of compounds with more than two benzene units fused together. Sometimes, as in the present study, even naphthalene which consisting of two fused benzene units is included in the term. PAHs are components in naturally occurring mineral petroleum, and petroleum extraction and processing and transportation are sources for PAH in the environment as are other forms of transportation fuelled by combustion of organic matter, as PAH are formed in combustion processes. PAH was analysed using GC-MS according to DIN 38407-F39 (2008), and detection limits were from 0.01 µg/L to 0.05 µg/L, with the higher limit in some effluents samples.

3.1.9 Phthalates

Phthalates were analysed in samples taken in the second sampling round, in April and May 2014.

The following 12 phthalates were analysed using GC-ECD, GC-MS; dimethyl phthalate (DMP), diethyl phthalate (DEP), di-n-propyl phthalate (DPP), di-n-butyl phthalate (DBP), di-iso-butyl phthalate (DIBP), di-pentyl phthalate (DPeP), di-n-octyl phthalate (DOP), di-(2-ethylhexyl)phthalate (DEHP), butylbenzyl phthalate (BBP), di-cyclohexyl phthalate (DCHP), di-iso-decyl phthalate (DIDP) and di-iso-nonyl phthalate (DINP). DEHP is included as a priority substance in the area of water policy in EU directive 2013/39/EU. Phthalates were analysed using accredited method DIN EN ISO 18856. The detection limits applied were in the range 0.3 µg/L to 1.0 µg/L, with the higher detection limits for DEHP, DIBP, DIDP and DINP.

3.1.10 Quaternary ammonium compounds

Quaternary ammonium compounds are compounds containing a nitrogen atom to which four alkyl or aryl groups are attached, giving the central nitrogen a permanent positive charge (Figure 2). In the compounds analysed in the present work, alkyltrimethyl ammonium chloride (ATAC), benzalkonium chloride (BAC) and dialkyldimethyl ammonium chloride (DDAC), two of the four R-groups attached to the central N were methyl-groups, and the other two, R_1 and R_2, were as defined in Table 3 and table 4. The analytical method for effluents was as described by Kaj et al., 2014. For recipient and background waters the "common extract clean-up procedure" described in chapter 3.3 in the Kaj et al., 2014 was omitted.

Figure 2: A schematic presentation of QAC, where R1 to R4 represents either alkyl or aryl-groups. In the present work, all R3 and R4 groups were equal to –CH3, i.e. methyl-groups

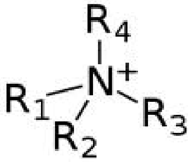


Table 3: The identity of the R1 and R2 groups of Figure 2. in the ATAC and BAC analysed

Name	ATAC-C12	ATAC-C14	ATAC-C16	ATAC-C18	ATAC-C20	ATAC-C22	BAC-C12	BAC-C14	BAC-C16	BAC-C18
R1	n-C12	n-C14	n-C16	n-C18	n-C20	n-C22	n-C12	n-C14	n-C16	n-C18
R2	Methyl	Methyl	Methyl	Methyl	Methyl	Methyl	Benzyl	Benzyl	Benzyl	Benzyl

Table 4: The identity of the R1 and R2 groups of Figure 2. in the DDAC analysed

Name	DDAC-C10	DDAC-C12	DDAC-C14	DDAC-C14:16	DDAC-C16	DDAC-C16:18	DDAC-C18
R1	n-C10	n-C12	n-C14	n-C14	n-C16	n-C16	n-C18
R2	n-C10	n-C12	n-C14	n-C16	n-C16	n-C18	n-C18

3.1.11 *Per- and polyfluoroalkyl substances, PFAS*

Like QAC, PFAS were analysed in samples taken in February and March 2015, that is in the fourth sampling round. The perfluoroalkyl sulphonates with 4, 5, 6, 7, 8, 9 and 10 carbons (PFBuS, PFPeS, PFHxS, PFOS, PFNS and PFDS) and the similarly perfluoroalkyl carboxylic acids with 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14 carbons (PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA and PFTDA) were analysed, as were PFOSA, and the polyfluoroalkyl telomers 4:2 FTS, 6:2 FTS and 8:2 FTS (see Appendix for method description).

3.1.12 *Salinity/ Chloride*

Salinity as determined from chloride content was analysed to facilitate assessment of degree of mixing of effluent with the marine water masses of the recipient. The methods applied for chloride content analyses varied, and the maximum salinity calculated indicated flaws in method accuracy. Thus, this parameter was used for interpretation only and is not included in the pollutants assessment. Chloride was analysed using ion chromatography according to CSN ISO 10304-1 and CSN EN 12506 and in one instance (Norwegian samples in second round) CZ_SOP_D06_02_075, based in CSN EN 2788, alpha 2520 B.

3.2 Presentation and evaluation of data

When the concentration of a given pollutant could not be quantified with the analytical method applied, i.e. was reported as not detected, the results may be presented as either "lower bound" or "upper bound" values. A lower bound presentation implies that the not-detected parameter has been assumed to be equal to zero, whereas in the "upper bound" presentation the assumption is made that the concentrations of the not detected agent is equal to the limit of detection. When lower bound values are applied, it is indicated by the abbreviation LB, and similarly, upper bound values with UB.

The results of the chemical analyses have been assessed in relation to available Ecological Quality Standards, EQS, as adopted by EU (Directive 2013/39/EU) or similar criteria. For the assessment of compounds or groups of compounds for which no EQS has been adopted, an *ad hoc* Predicted No Effect Concentration, PNEC, value derived using similar methodology has been applied.

Ammonium is spontaneously converted to the un-ionised form ammonia, NH_3, depending on pH, temperature and salinity, and ammonia is a neurotoxicant. There is no EQS defined for ammonia in the EU water framework directive, but UK has set forth a proposal of an EQS (long-term standard) for saltwater of 21 µg/L (UK TAG 2008) in the water framework directive regime. This may not be sufficient for the most sensitive species in poor quality waters for which a PNEC of 0.66 µg/L has been proposed (Environment Agency 2007). The Norwegian guideline for ammonia in summer surface water with salinity above 20 g/kg associates an ammonia concentration of 50 µg/L or less with a good environmental status (Molvær et al., 1997). In the present work, the analysed ammonium, NH_4-N, was converted to ammonia by the facility posted by the American Fisheries Society (2016) for the purpose of comparing the measured NH_4 concentrations to an environmental status quality guideline. With this utility, an ammonia concentration of 21 µg/L would be comparable to a total ammonium concentration of approx. 1.5 mg /L.

For LAS, a PNEC value was derived from the following data: the lowest No Observable Effect Concentration, NOEC, which was found for *Mytilus edulis* and *Crassostrea virginica* at 0.025 mg/L (UNEP 2005). Based on the availability of both acute and chronic toxicity data, an assessment factor, AF, of 10 was chosen, resulting in an estimated PNEC of 0.0025 mg/L.

For the cationic surfactants, quaternary ammonium compounds, preliminary PNECs were derived as follows; for ATAC a PNEC of 58 ng/L was arrived at using ecotox data from was Sandbacka et al. 2000 and an AF of 1000. For BAC a PNEC of 415 ng/L was derived with NOEC on *Daphnia magna* and an AF of 10 (US EPA 2006 and Kaj et al. 2015). For DDMAC a PNEC of 2,300 ng/L was derived on chronic toxicity data on fathead minnow in river water and an AF of 100 (Lewis and Wee 1983 and Lewis 1991).

In instances where ecological risk may stem from degradation of the analysed compounds, the concentration of these has been added to the one for which the EQS or the *ad hoc* PNEC refers, such as was the case with alkylphenols and alkylphenol ethoxylates.

To facilitate visual interpretation of the ecological risk imposed by the measured pollutants concentrations, figures representing the analyses results alongside relevant EQS or PNECs have been produced. For a realistic view, and in compliancy with standard methodology, the pollutants concentrations measured in effluents were assumed to be diluted 10 times upon entering the receiving water body, that is divided by 10, prior to inclusion in the figures. Thus the figures depicting the decreasing pollutants concentration in transects leading away from the point of discharge, are composed of measured data for recipient samples and adjusted measured data for effluent samples.

When assigning distances in the transects going from the WWTPs discharge site to recipient sampling sites, the distance measured as the straight line from the discharge site to the site of sampling was applied insofar as this straight line did not cross land.

4. Study areas

The societies of the study areas have many similarities in for instance the heavy economical reliance on marine harvest and share to large extents the same background in terms of societal structure. However, in this particular project, there is a gradient in the participating municipalities regarding both climate, from oceanographic temperate in Tórshavn at 620 N to arctic in Tromsø at 69.70N, and population density, from less than 6,000 inhabitants in Sisimiut to close to 120,000 in Reykjavík.

4.1 Tromsø

4.1.1 *Breivika WWTP (RA05)*

Breivika WWTP (Figure 3) was built in 2004, originally as a WWTP using primary treatment and with three Salsnesfilter type SF4000, with an effective sieving area of 3.0 m^2 and a hydraulic capacity of 240 L/s. Later, in 2005, the WWTP was upgraded to four SF6000 Salsnesfilters and a total sieving area of 8.8 m^2. The WWTP receives wastewater from approx. 18,000 PE, mainly households but also from the University Hospital of Northern-Norway and the campus of the Tromsø University. Approximately 50% of the wastewater entering the WWTP is delivered via external pumping stations and the remaining 50% enters the WWTP by gravitational flow wherefrom it is pumped up into the process-flow on the 2nd floor from which it is discharged via gravitational fall through the process line and thence to the recipient. The process line consists of a sand filter (*langsandfilter* Meva) from which the sewage distributes to four parallel sieving machines each with a capacity of 45 L/s and thus the hydraulic capacity Qdim is 180 L/s. A one-step sieving of 350-micrometre mesh is applied. The effluent is discharged to sea at 15 m below the sea surface. Sludge which is removed in the purification process is de-watered in a second sieve (*press-sil* Meva) resulting in a dry-mass content of approx. 30% when it is leaves the plant. In 2013, the sludge production was 550,000 kg.

Figure 3: Breivika WWTP in Tromsø

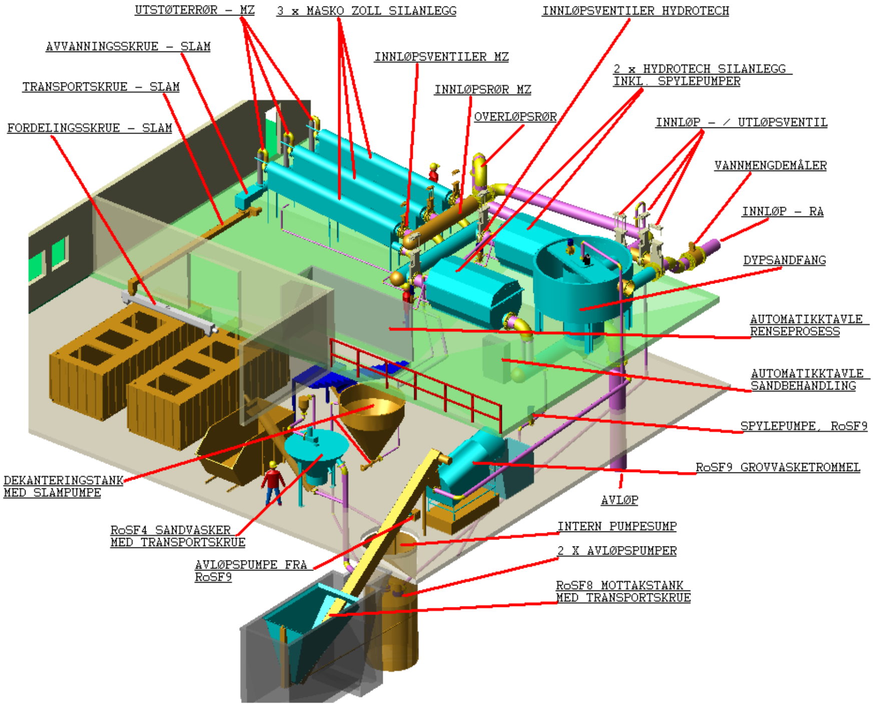
4.1.2 *Langnes WWTP (RA07)*

The Langnes WWTP was built in 2004, based on a different process-design than Breivika WWTP (above) but even this WWTP based on sieving of wastewater. The WWTP handles wastewater from 15,000 PE with a hydraulic Qdim of approx. 265 L/s. The WWTP was built as a primary treatment plant. The WWTP handles discharge from households mainly, but also from some larger shopping malls (Langnes Handelspark). The majority of the piping was placed in the period 1950 to 2000, but consists mainly of a combined urban runoff and domestic sewage. At times, the WWTP receives overflow from the Lake Prestvann.

The feeding of influent to the WWTP is via two external pumping stations. The Langnes WWTP process-line (Figure 4) is placed on 2nd floor to utilize gravitational flow to the recipient. The treatment process consists of a round sand-filter/deep sand-filter (Jones&Atwood) upon which the sewage is distributed to three parallel sieving-machines of type 6 m Maskozoll with 1.0 mm mesh, each with a capacity of 120 L/s. Following an additional sieving at two Hydrotech 1607 with 120-micrometre mesh, the effluent is discharged to sea at 17 m below the sea surface.

The sludge de-watering at Langnes WWTP is done by two steps. Sludge from the Maskozoll sieving is mechanically pressed into a Spirac-press as this material is rich in fibres. Sludge from the Hydrotech sieve contains less fibres and is initially solidified/settled in a 4m^3 settling-tank. Thereafter, the sludge (now at approx. 1% DW) is pumped up into a sludge sieve (3 m Maskozoll) where polymers are added to facilitate the de-watering. Sludge with approx. 23% DW is produced from the two sludge-removing processes resulting in approx. 1,000,000 kg in 2013.

Figure 4: A 3-d schematic drawing of the processes at Langnes WWTP (courtesy of BN Miljø AS)



4.2 Tórshavn

4.2.1 *Sersjantvíkin WWTP*

The Sersjantvíkin WWTP, Tórshavn, receives domestic wastewater from approx. 820 PE. This WWTP, Figure 5, may be described as a primary treatment step where the solids are removed by both settling floating to the surface layer. The effluent is released a few meters (5 m) below sea surface at a distance of likewise a few meters (5 m) from the shoreline.

4.2.2 *The LSH Main Hospital WWTP*

The *Landssjúkrahúsið*, LSH, Main Hospital has 180 hospital beds, and performs approx. ½ million clinical chemical analyses per year, in addition to more than 30,000 x-ray diagnostic analyses. The hospital has its own sewage treatment plant, Figure 6, which was dimensioned for 1,000 PE and built in 1962/63 but renovated in 2004 and 2011. The first part of the LSH WWTP consists of a sand filter and a mechanical prefiltration. Thereafter the wastewater enters an Emscherwell mechanical treatment and sludge separation. Finally, the wastewater in led to an aeration tank for aerobic degradation before discharge to recipient. The effluent is released 4–5 m below sea surface at a distance approx. 10 m from the shoreline.

Figure 5: Inside the Sersjantvíkin WWTP at the 1st sampling round, in October 2013

Figure 6: The LSH Main Hospital WWTP in April 2013

4.3 Reykjavík

The sewage treatment in Reykjavík and neighbouring communities is carried out in two sewage treatment plants, Klettagarðar WWTP and Ánanaust WWTP, Figure 7. In the present project, both these WWTPs are included in the sampling plan.

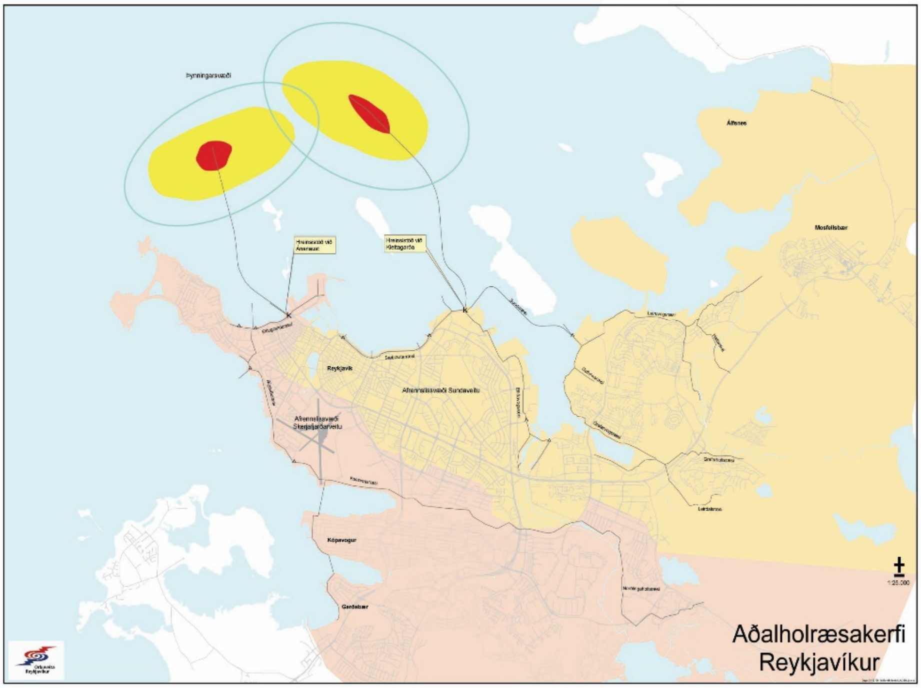
4.3.1 Klettagarðar WWTP

Klettagarðar WWTP was put in operation in 2002 and has been fully operative since 2005. It handles wastewater from approx. 200,000 PE, but it is constructed for a capacity of approx. 250,000 PE. The disposal of effluent from Klettagarðar WWTP is along a 1,000 m long diffuser extending from 4,450 to 5,500 m into the Faxaflói (Figure 8), situated at depths of approx. 30 to 35 m below sea surface (Auðunsson 2006).

4.3.2 Ánanaust WWTP

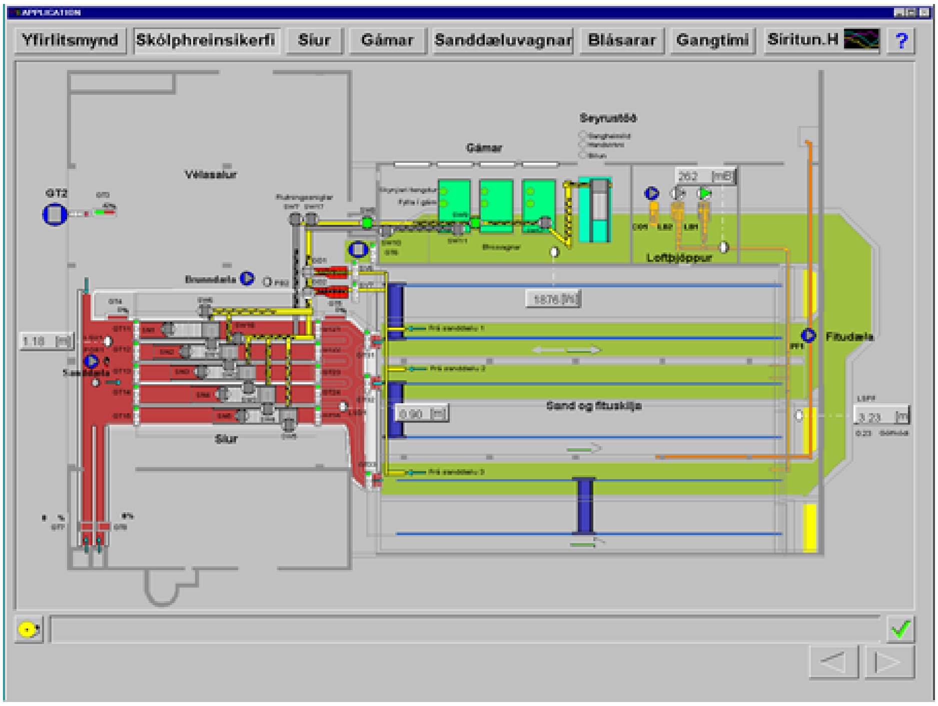
Ánanaust WWTP is the other major sewage treatment plant in Reykjavík. It came into operation in 1998. Discharge from the Ánanaust WWTP is via a diffuser of 500 m length, extending 3,600 to 4,100 m into Faxaflói (Figure 7). The diffuser is situated at a depth of between 19 m and 32 m in its farthest reaches. At present, the WWTP is handling wastewater from approx. 200,000 PE.

Figure 7: The feeding areas to and the discharge areas from the two main sewage treatment plants Klettagarðar and Ánanaust in Reykjavík are shown (Skarpheðinsson 2013)



Note: The diffusers leading the effluents into the recipient are placed between N 64°11.1958' W 21°54.3877' and N 64°11.8305' W 21°56.3717' for the Klettagarðar discharge, and between N 64°10.6058' W 21°59.2488' and N 64°11.1180' W 21°59.6302'for the Ánanaust discharge.

Figure 8: A schematic drawing of the Klettagarðar WWTP (Skarpheðinsson 2013)



4.4 Sisimiut

Sisimiut is the second largest town in Greenland, with approx. 5,600 inhabitants. Of the just below 2,200 households, approx. one fourth is not connected to sewage lines at all, but relies on other solutions for removal of human waste. The handling of wastewater consists of three systems each of partial coverage in the town:

1. A sewage line carrying both black and grey wastewater.
2. For some private households a tank solution has been installed which holds black wastewater and in some cases also grey wastewater. The total number of households with a tank based sewage system is ca. 200.
3. The rest of the private households are using a toilet solution with no running water which involves a bucket latrine equipped with a solid plastic bag (Honey bucket). The removal of the black wastewater involves a man-and-truck-based collection of the plastic bags which subsequently are emptied and the contents discharged to sea at the Natreno site (Figure 9). The grey wastewater is discharged to terrain. In early 2017, the number of households with this sewage solution was 181.

The grey wastewater from houses with bucket toilet and most of the houses with a tank collection of black wastewater is discharged directly to the terrain or to ditches. The number of households with tank-based solution which discharge grey wastewater to terrain is not known. It is assumed that somewhere between 300 and 400 households discharge the grey wastewater to terrain, i.e. in all approx. 15 ± 2% of Sisimiut households. The black wastewater in Sisimiut, whether collected by truck or led in sewage lines, is discharged to sea without treatment.

In the present study, focus has been on the wastewater discharge that takes place at Ulkebugten and Natreno (Figure 10). These sewage lines do not carry surface runoff water. At the moment, the Qeqqata Kommunia were Sisimiut is located, are assessing funding options for a full-scale test plant for wastewater treatment in the village Kangerlussuaq (Sønderstrømfjord). The aim is to build the next wastewater treatment plant in Sisimiut, probably at outlet A (Figure 10).

Figure 9: In parts of Sisimiut, the removal of the black wastewater involves a man-and-truck-based collection of the plastic bags which subsequently are emptied and the contents discharged to sea, as here at the Natreno site

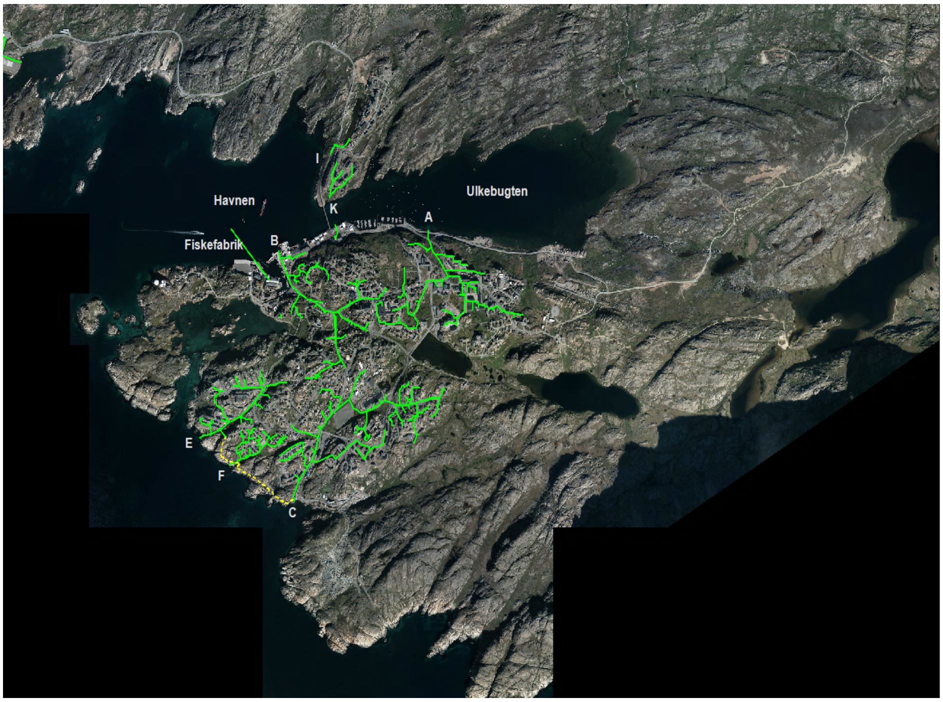
4.4.1 *Ulkebugten*

At the Ulkebugten site wastewater from approx. 1,412 PE are discharged to the estuary. The Sisimiut hospital discharge to this sewage line. The hospital has an emergency room, X-ray diagnostics, laboratory and some surgical activities and has approx. 20 beds.

4.4.2 *Natreno*

At the Natreno site wastewater from 2,246 PE are discharged to sea. The upland of the Natreno sewage line includes households and a relatively large- in local comparison- laundry. The effluent samples were taken in man-holes in the sewage lines close to the discharge points at the shore, but before the point where waste from the bucket-toilets and the tank-contents are added. Thus neither grey nor black wastewater from the approx. 600 households that has either one of the bucket or tank-solution for their wastewater handling is included in the effluent samples. However, the wastewater discharge from these are covered in the recipient samples taken outside the Natreno discharge site.

Figure 10: The existing sewage lines in Sisimiut are shown as green lines. The yellow line is a connecting line, in construction, where outlet E and F are closed and the wastewater is led to C. The letter A indicates the Ulkebugten outlet, and C the Natreno discharge site



4.5 Sampling

The purpose of the project is to assess whether the sewage treatment is adequate for the substances chosen, and that is done though analysing the pollutant in the wastewater stream and their levels in the recipient. However, the flow of wastewater and its composition varies diurnally but also during the week and with season. Likewise, varied influx will be reflected in the recipient, but currents and wave actions (wind induced as well as tidal waves) result in the mixing and dilution of the wastewater, factors that may vary seasonally, from one day to another, and within a calendar day. Thus ideally, samples should be drawn and analysed continuously and for a long period to allow a thorough assessment of the flux and concentration of wastewater born pollutants. This however, would require far more resources than available for the current project. An alternative sampling strategy utilizing time-integrated sampling could be an option. Such time-integrated samples may be drawn with automatic sampling equipment installed in newer WWTPs. However, this equipment is mostly used/intended for assessing the main constituents of wastewater (COD/BOD, TOC, SS, nitrogen, and phosphorus) but may not be suitable to draw samples for some pollutants at low levels both due to contamination and adsorption in the sampling systems including the collecting vessels themselves. In the present project not all of the WWTPs had automated sampling for both the influent and the effluent side, and automated sampling was adapted only when this could be done without adding extra uncertainty to the results. In cases where this was found to be questionable, manual sampling at pre-set intervals were applied, and the aliquots combined in one pool which thus represented a time-integrated sample.

In some of the areas in the study, recipient sampling especially during the winter months are complicated due to ice-cover. Thus, in addition to the normal sampling logistics in ice-free waters involving boat, the assistance of specially trained divers may be necessary in some areas.

Sampling were designed in the steering group which encompasses various expertise, among these chemists and experts in environmental monitoring with long experience in sampling. This brings about a common understanding of the pitfalls and possible problems in the sampling and sample handling process. A particular challenge was the time lapse from sampling to analyses, during which a certain breakage of containers and degradation of analytes may occur. Even with every reasonable effort, the transportation time could not be less than a few days when samples from areas so wide apart as Sisimiut in west and Tromsø in east must be brought together as was necessary for all samples to be analysed by the same laboratory. A sampling guideline was written by the project steering group with input from the analysing laboratory. The vessels used for samples were supplied by the laboratory as were the preservation agent when this was necessary. Samples were taken of the water bodies acting as recipient for the wastewater. Such samples were taken near two effluent discharge sites in each region. From these two effluent discharge sites samples were taken in three point transects downstream from the discharge sites.

In addition to samples from the recipient, samples were also taken from the influents and effluents of the sewage treatment plants where WWTPs were in place, i.e. Reykjavík, Tórshavn and Tromsø. Only effluent's sampling was possible in Sisimiut. At every discharge site three recipient samples were taken, one close to the discharge site, one a bit further away and a third sample at a longer distance. In addition to two such three-point-transects from the discharge sites, a sample was taken in the recipient at such a distance from the discharge site that it was assumed to represent an unaffected background site, i.e. so remote or upstream from the discharge that dilution and degradation had reduced the level of pollutants to an absolute minimum. For naturally occurring substances like phosphate the background samples are particularly useful for assessing natural background *vs.* anthropogenic input.

Sampling was done in four rounds to represent the four seasons, and the times were chosen according to the tidal currents as and the daily rhythm of most activity related to discharge of wastewater. Also, sampling was planned so as to represent "business as usual" conditions, meaning that sampling was avoided in periods with unusually high or low population density in the participating areas. The sampling was coordinated between the four participating areas so to be comparable also in terms of the treatment of the sample vessels and samples in preparation for chemical analyses. However, mainly due to local weather conditions and restrictions imposed by the transport options to the laboratory, the sampling could not be done on the same date and time in all places. Most troubling for sampling were heavy deposition, as that would inevitably reach the wastewater stream and thus dilute it but also shorten the hydrological residence time in the treatment plants. Also, strong winds and resultant high waves and unsteady working platforms would prevent sampling in the recipient. And finally, sampling in Sisimiut were at times hindered by very thick sea ice or unstable sea ice conditions.

The main difference in the sampling between the participating areas were dictated by the infrastructure on site; in the Tromsø and Reykjavík wastewater treatment sites sampling could be done using automated sampling, thus allowing flow-adjusted sampling at pre-set intervals. In Tórshavn wastewater treatment plants, equipment for automated sampling were installed for effluent samples only, and as manual sampling was required for influent sampling taking place within a few meters from where manual effluent water sampling could be done in the Sersjantvíkin WWTP, the manual solution was chosen also for effluent at this site. In Sisimiut wastewater lines, with no wastewater treatment before discharge to recipient at the Ulkebugten and Natreno sites, the sampling had to be done manually. Details about the sampling are given in Table 5.

Table 5: The wastewater (influent and effluent) sampling method in the four sampling rounds. When not otherwise specified it is assumed same sampling times/description for influent as for effluent. ns: no sampling. The time interval for the composite samples are given without reference to days, but implicit in the term is that the sample represent the wastewater stream for a day and a night, unless otherwise must be inferred from the sampling period stated

	Tromsø[1] **NO-1: Breivika** **NO-2: Langnes**	**Tórshavn[2]** **FO-1: Sersjantvíkin** **FO-2: LSH Main Hospital**	**Reykjavík[3]** **IS-1: Klettagarðar** **IS-2: Ánanaust**	**Sisimiut[4]** **GL-1: Ulkebugten** **GL-2:Natreno**
Round 1 October 2013	NO-1: Grab	FO-1: Grab, around 2 pm	IS-1: Grab	GL-1: Grab
	NO-2: Grab	FO-2: Grab, around 4 pm	IS-2: Grab	GL-2: Grab
Round 2 April / May 2014	NO-1: Composite, 9 subs. during 22 hrs. minus 00:00 to 07:00	FO-1: Composite, every 2nd hr, from noon to 10am	IS-1: Grab	GL-1: Grab, though for phthalates analyses: Composite, every 2nd hr, from 10 am to 8 am
	NO-2: Composite, 9 subs. during 22 hrs. minus 00:00 to 07:00	FO-2: Infl: Grab, around noon, Effl: Comp, autom., 2 pm to noon	IS-2: Grab	GL-2 Grab, though for phthalates analyses: Composite, every 2nd hr, from 10 am to 8 am
Round 3 August / September 2014	NO-1: Composite, 10 subs. between 10 am and 11:30 pm	FO-1: Composite, every 2nd hr, from noon to 10am	IS-1: Grab	GL-1: Composite, every 2nd hr, from 2 pm to noon.
	NO-2: Composite, 10 subs. between 10 am and 11:30 pm	FO-2: Infl: Grab Effl: Comp, autom. 9 am to am	IS-2: Grab	GL-2: Composite, every 2nd hr, from 2 pm to noon
Round 4.0 February / March 2015	NO-1: Composite, from 2 pm to 2 pm	FO-1: Composite, every 2nd hr; 2 pm to 00:00	IS-1: Grab	GL-1: Grab around 7 pm
	NO-2: Composite, from 2 pm to 2 pm	FO-2: Infl: Grab, ca. 2 pm. Effl: Comp, autom. 2:30 pm to 2 pm	IS-2: Grab	GL-2: Grab around 7 pm
Round 4.1 August / September 2015	NO-1:ns	FO-1: ns	IS-1:ns	GL-1:ns
	NO-2:ns	FO-2:Effl: 1 hr composite, drawn manually and automatically in parallel	IS-2:ns	GL-2:ns

Note:

[1] The recipient samples were taken on the day the composite wastewater sampling started (2 round), on the same day as the composite sample was collected (3 round) or on the day the composite sampling was completed (4 round).

[2] The composite sampling began the day prior to sampling in the recipient and the acquisition of grab samples.

[3] Grab samples were taken from both influent and effluent water between 13:00 and 15:00 in all rounds, effluent sampling took place few minutes after the influent sampling. The time duration of each grab sample was 10–15 min.

[4] In Sisimiut, there are no wastewater treatment, thus untreated wastewater were the only kind available, and these have been denoted effluent as this is the composition of the wastewater as it enters the recipient.

4.5.1 *Timing of the sampling*

Ideally, the sampling would be done on a "representative" day, i.e. a normal working day with no particular events taking place and with no or very little wet deposition the days just prior to the sampling. The amount of wet deposition is important because the surface water flows into the WWTPs and dilutes the wastewater and shortens the residence time. Another constraint on the sampling time which is more particular for the present work, is that sampling times would need to be adjusted to the options for transportation of the samples to a common laboratory chosen beforehand to do the analytical work for all four countries. The requirements were especially necessary as the samples could generally not be treated on-site except for some simple procedure that did not demand laboratory facilities, and thus would have to be sent as fresh samples to the laboratory. Another timing issue was that of tidal currents; for the samples to be taken downstream of the discharge sites, the tides must be taken into account. Regarding the sampling in the recipient in relation to that of the sampling at the WWTP, the timing of this could be expected to be somewhat related to the composition of the effluents, which varies somewhat during the day, but the dilution arising from mixing in the recipients due to winds and currents are likely as important. Thus, the strategy applied varied somewhat between countries and sampling rounds. In Tromsø, the recipient samples were taken on the day the composite wastewater sampling started (2nd round), on the same day as the composite sample was collected (3rd round) or on the day the composite sampling as completed (4th round). In Tórshavn, the recipient samples were taken on the same day as grab samples in the WWTPs, and on day two of the round-the-clock sampling period when composite samples were drawn from the WWTPs. In Sisimiut, the recipient samples were taken on the afternoon, at 3–4 pm, or, as in round 3, in the evening at approx. 7 pm.

4.6 Tromsø

The sampling sites for the study are shown in Figure 12 and Figure 13. The sampling methods were changed between the first and the subsequent sampling rounds. The change included going from grab samples to composite samples and from seawater sampling with wooden rod with tape fastened bottle to one with clamp fastened bottle, where the clamps was fastened to the wooden rod using metal screws. The sampling sites are described in Appendix table 21. The distance between the sampling sites are shown in Table 6.

Table 6: Distance in meters in transects of sampling stations from effluent outlet sites to sampling station further away (downstream) in the recipient. The prefix NO-1 is used for samples off the Breivika WWTP, and NO-2 for Langnes WWTP

Distance (m)	1 round	2 round	3 round	4 round
Breivika Outlet to NO-1-Rec1	160	189	137	148
Breivika Outlet to NO-1-Rec2	320	308	284	216
Breivika Outlet to NO-1-Rec3	540	696	493	428
Langnes Outlet to NO-2-Rec1	349	245	176	218
Langnes Outlet to NO-2-Rec2	473	397	420	229
Langnes Outlet to NO-2-Rec3	743	592	564	334

1 round: Sampling took place 29th October 2013, and were done as grab-samples also of effluents and influents. Sampling of seawater was done from a boat with hand-held bottle, with bottleneck immersed approx. 10 cm below surface.

2 round: Samples were taken in the recipient on 28th April 2014, and in the WWTPs during 28th–29th April. Composite samples in the WWTPs were prepared by combining nine subsamples taken manually every second hour from 14hrs to midnight on the 28th and from 07hrs to 11hrs on the 29th. The sampling in the recipient was done in the period 18–19:30 hrs. to try to "catch" the peak of anionic tensides as had been found to occur in this time span from analyses of anionic tensides done on hourly samples taken during one day in 2013 (Figure 11).

3 round: Samples were taken Monday 1st September 2014. Composite samples were taken of influents and effluents consisting of 10 subsamples drawn in the period 10:00–23:30 hrs.

4.round: Samples in the recipient were taken 3rd February 2015, and samples of influents and effluents were composite samples prepared from subsamples drawn in the period 2 pm 2nd February and 2 pm on the 3rd February 2015.

Additional sampling in the Tromsø recipient (Langnes Rec2 and Rec3) was arranged on 16th September 2015 in order for these to be reanalysed for PAFS as the initial analysing attempt on samples from February the same year were unsuccessful for some samples.

Figure 11: The concentration of anionic tensides were analysed in grab samples of effluents from Langnes and Breivika WWTPs during the day. (Berg, Tromsø Municipality 2014)

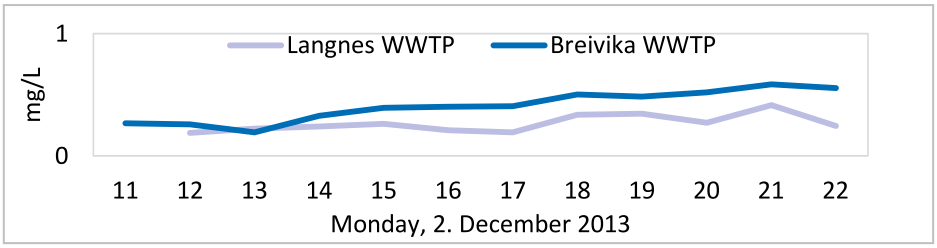


Figure 12: Sampling sites in Tromsø as applied in the 1 and 2 sampling round are shown. The Breivika WWTP is situated on the right (near samples labelled with prefixes NO-1) and Langnes WWTP at the left with sampling stations with prefixes NO-2

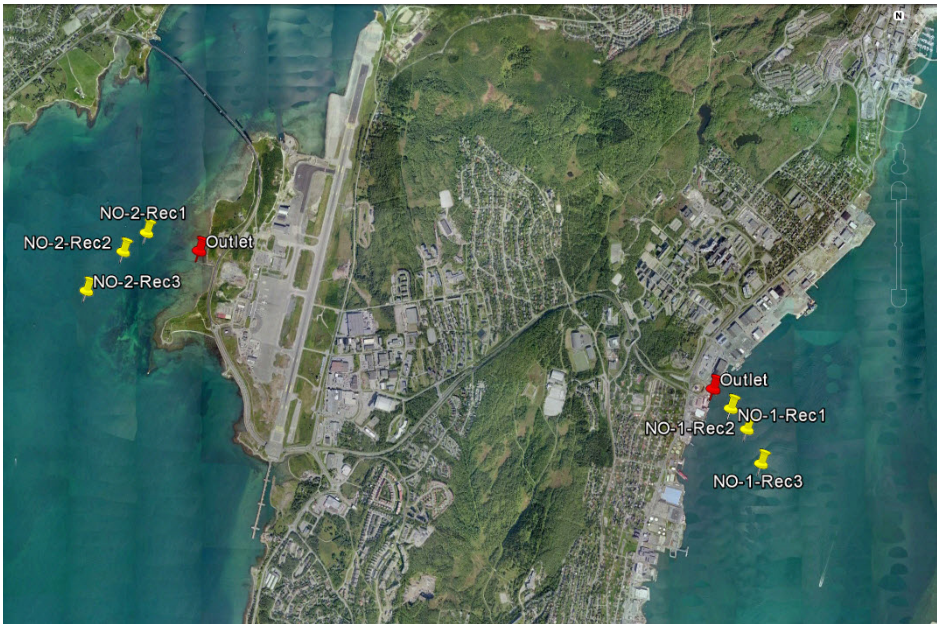
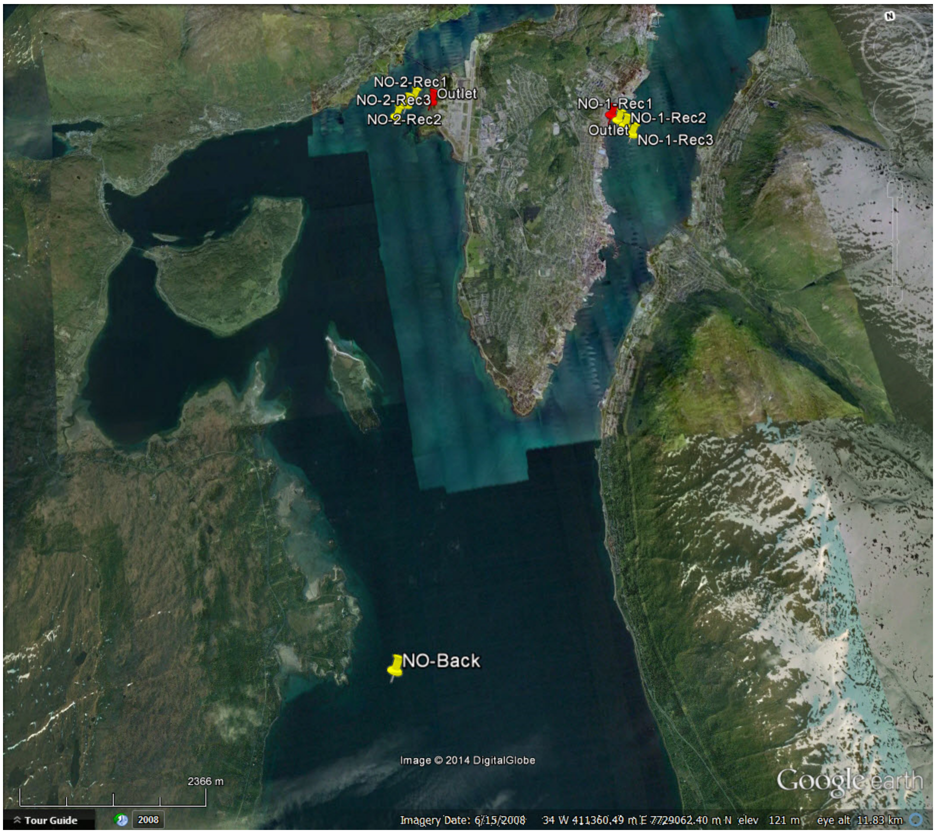


Figure 13: The location of the background station in relation to the other samples from the Tromsø area is shown



4.7 Tórshavn

The sampling sites are shown in Figure 15. Sampling event 1 took place in 22nd October 2013, and sampling event 2 in 28th–29th April 2014. Sampling for the 3 round took place 9th September 2014, and the 4 round on 9th–10th February 2015. In addition, a resampling was arranged in 27th August 2015 for renewed attempts of PFAS analyses. Samples were taken at fixed sampling sites, where the distance from the discharge points Sersjantvíkin and LSH main hospital WWTP are shown in Table 7.

Table 7: Distance in meters in transects of sampling stations from effluent outlet sites to sampling station further away (downstream) in the recipient. The prefix FO-1 is used for samples off the Sersjantvíkin WWTP, and FO-2 for LSH Main Hospital WWTP

Distance	Distance (m)
From Outlet-Sersjantvíkin to FO-1-Rec1	130
From Outlet-Sersjantvíkin to FO-1-Rec2	555
From Outlet-Sersjantvíkin to FO-1-Rec3	1885
From Outlet-LSH to FO-2-Rec1	65
From Outlet-LSH to FO-2-Rec2	310
From Outlet-LSH to FO-2-Rec3	500

Samples in the first round were taken as grab-samples, also of effluents and influents. Sampling of seawater (recipient and background samples) were done from a boat with hand-held bottle, with bottleneck approx. 10 cm below surface.

Samples of influents and effluents from Sersjantvíkin WWTP (FO-1) were drawn as mixed samples by combining sub-samples taken at 2 hrs interval during 24-hrs. Sampling in the LSH Main Hospital WWTP were done as grab sampling in influent and as combined 22 hrs automated interval sub-sampling of effluent. Samples of seawater were taken using a water sampler based on the Ruttner design (KC 11.002 volume 1.7 l, with acrylic cylinder tube), and drawn from not less than 10 cm below surface (target depth 30 cm), except in the first sampling round when sampling was done by hand held bottle. The variability of anionic tensides concentration during a typical day was analysed for a day and a half (Figure 14). During this period the flow in the WWTP varied between 41 and 45 m^3/h. With a total volume in the WWTP, this gives a hydraulic residence time of approx. 3 hrs. The low residence time was not due to wet deposition in this period, as there was no deposition in Tórshavn on the two days immediately preceding the sampling and with approx. 1 mm on day 1 of the sampling. A similar flow was noted during the sampling in September 2014, when there likewise had been no wet deposition on the two days preceding the sampling. The flow meter may have shown too high a flow, as later flow-readings in February 2015 showed flowrates in the range 20–40 m^3/h in a period when the wet deposition had been somewhat higher (approx. 3 mm on the two days immediately before sampling). Nonetheless, the assumed flow during periods with no deposition as calculated by the municipality to 12 m^3/h was not observed at any time.

Figure 14: Variation during the day of anionic tensides in effluent at Sersjantvíkin WWTP. (4th Monday and 5th Tuesday November 2013)

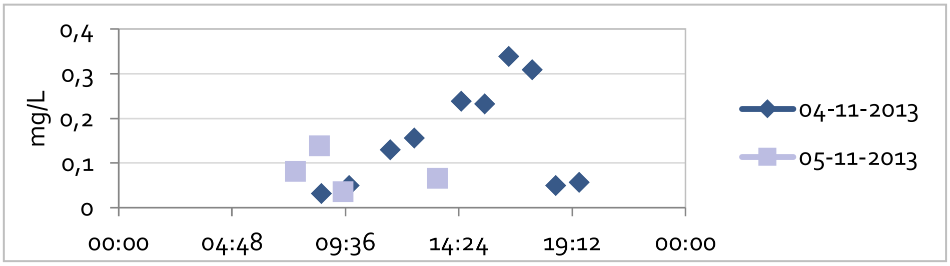


Figure 15: Sampling sites in Tórshavn are shown

4.8 Reykjavík

The sampling sites are shown in Figure 17. Sampling event 1 took place on 31st October 2013 (recipient) and 13th November (sewage) while round 2 was carried out on 15th May 2014 (recipient) and 19th May (sewage). Sampling in 3 round was done 2nd August 2014, and for round 4 on 12th February 2015 at the background site (Grótta) and the Klettagarðar WWTP related samples, and for the Ánanaust WWTP samples on 16th February 2015. Sampling was done at the same locations in all sampling rounds (Table 8). Samples were taken as grab-samples, also of effluents and influents. Sampling of seawater (recipient and background samples) was done from a boat, using a water sampler based on the Ruttner design (with acrylic cylinder tube, Figure 16). The recipient samples were drawn from a depth of 30 cm below seawater surface. The recipient samples were taken above the middle of the diffusers and at 250 and 500 m east and downstream from the diffusers. To accommodate this, the samples were taken shortly after low tide (at which concentrations may be expected to be highest) when the tidal current at both locations is towards east-northeast.

Table 8: Distance in meters in transects for sampling sites used for extracting recipient water samples in the coastal waters off Reykjavík. The prefix IS1 was used for samples taken in the first sampling round, and the letter A for samples taken in or near the Ánanaust WWTP, and the letter K near the Klettagarðar WWTP

Distance (m)	WWTP to sampling sites*	1, 2, 3 and 4 round
From Klettagarðar-Outlet to IS1-RecK1	4,710	30
From Klettagarðar-Outlet to IS1-RecK2	4,675	260
From Klettagarðar-Outlet to IS1-RecK3	4,645	523
From Klettagarðar diffuser to Background sample site		7,000
From Ánanaust-Outlet to IS1-RecA1	3,520	25
From Ánanaust-Outlet to IS1-RecA2	3,490	255
From Ánanaust-Outlet to IS1-RecA3	3,480	504
From Ánanaust diffuser to Background sample site		3,700

Note: * The distance is given as the distance from the sewage treatment plant to the site where the recipient sample closest to the actual discharge area was taken. For the other sampling rounds, the distance from the diffuser at the end of the long tube carrying the effluents from the sewage treatment site to the closest recipient sampling site is given.

Figure 16: A Ruttner type water samplers is shown to the right

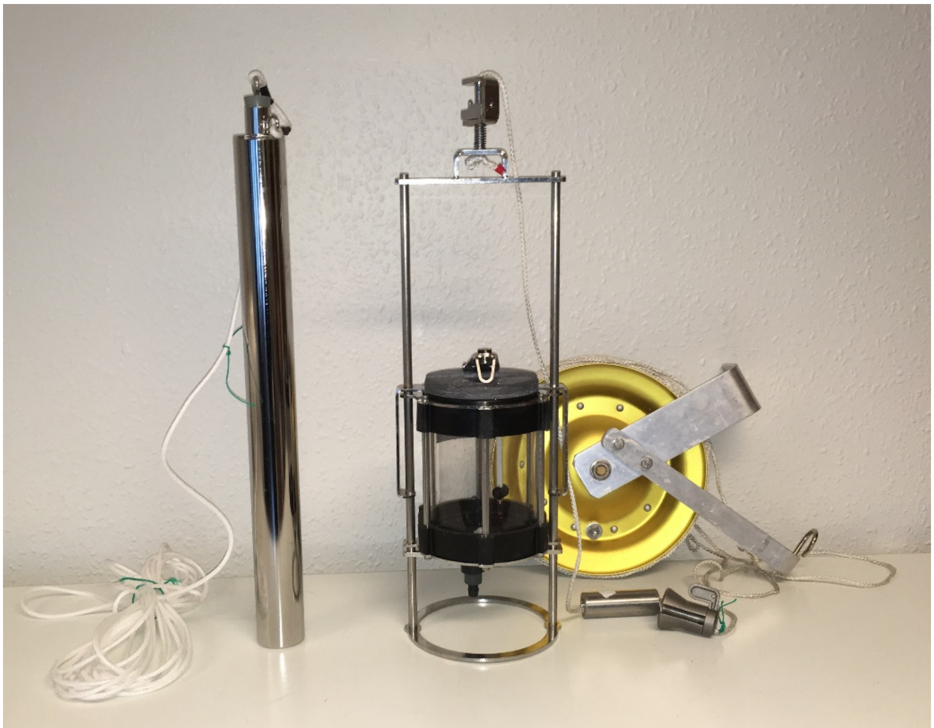
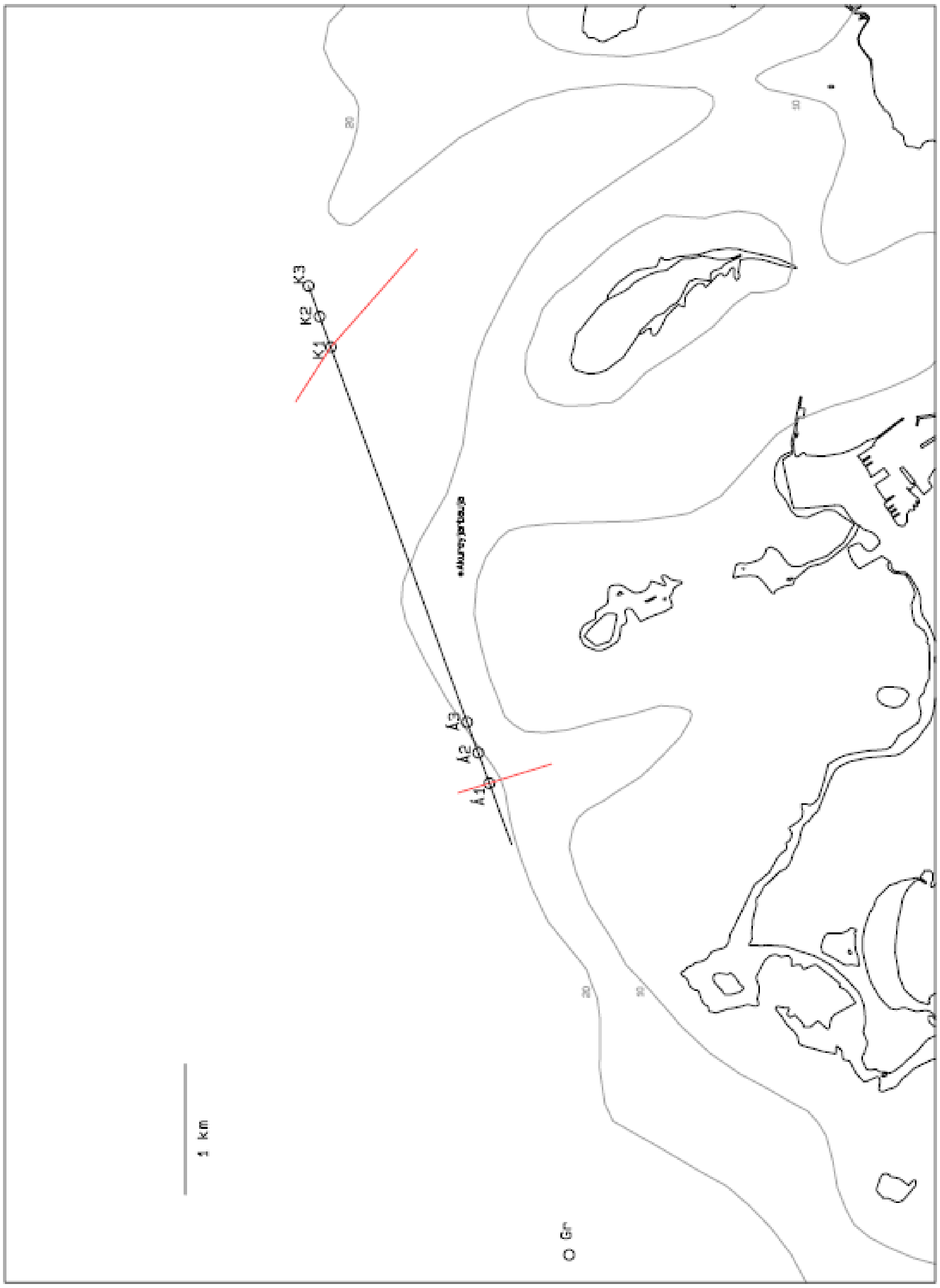


Figure 17: Sampling stations off Reykjavík are shown as circles with labels K1–K3 indicating samples in a transect downstream from the outlet of the Klettagarðar WWTP diffuser (shown as a red line), and circles with labels A1–A3 denoting samples in the transect from the Ánanaust WWTP diffuser (likewise shown as a full drawn red line). The open circle with label Gr at the lower end of the figure is where the background sample was taken



Note: Drawing by Kjartan Thors, Köfunarþjónustan.

4.9 Sisimiut

In the two chosen outlet areas, Ulkebugten and Natrenobugt, samples were taken of the following; effluent (untreated sewage)[2] and typically three seawater samples taken at increasing distance from the respective outlet (Table 19).

Sampling event 1: Took place in 21 October 2013. All samples, both from the effluent and from the seawater, were taken as grab-samples. Sampling of seawater was done from boat using hand-held bottle with sampling depth target 30 cm below surface. Sampling from both effluents were taken by use of a smaller plastic bottle, which could pass into the wells. The plastic bottle were of approved kind, not to contaminate the samples.

Sampling event 2: Took place in 26 May to 27 May 2014. Samples of the effluent in round two were taken both as a combined sample (analysed for phthalates) which consisted of sub-samples taken every second hour for 24 hrs. using the above-mentioned plastic bottle. In addition, grab-samples were taken, using water sampler ("AISI 316", stainless steel, 1 litre volume) in Ulkebugt-effluent and the plastic bottle in Natreno-effluent, as the latter site is too narrow for the water sampler. The grab samples were analysed for the other selected contaminants for this round (LAS, ammonium, phosphate etc., see also Table 1). Sampling of seawater was done using the water sampler, and were taken as grab-samples.

Sampling event 3: Took place in 31st August to 1st September 2014. The effluent samples were composed of sub-samples taken every second hour for 24 hrs. as in round 2. Seawater samples were taken as grab-samples using water sampler.

Sampling event 4: Took place in 16th March 2015. Samples of effluents were taken as grab-samples. Sampling of seawater was done as in round 3. As there were excess sampling bottles, additional recipient samples were taken from the two locations. The additional recipient sample was named rec ½ (or rec 0,5) and was taken between the site of outlet and rec 1.

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[2] In the Sisimiut samples, the term effluent is used on untreated sewage in contrast to the other sites, where the term effluent is applied to treated sewage. In all areas thus does the term effluent pertain to the status of the wastewater as it is disharged to the recipient.

Table 9: Distance in meters in transects of sampling stations from effluent outlet sites to sampling stations downstream in the recipient for wastewater discharge from the Ulkebugt (GL-1) and Natreno (GL-2) sewage lines

Sewage lines	From	To	1. sampling distance, m	2. sampling distance, m	3. sampling distance, m	4. sampling distance, m
Ulkebugt	Outlet	Rec 0,5	-	-	-	16
Ulkebugt	Rec 0,5	Rec 1	-	-	-	13
Ulkebugt	Outlet	Rec 1	67	51	47	28
Ulkebugt	Rec 1	Rec 2	68	60	22	30
Ulkebugt	Rec 2	Rec 3	66	67	31	31
Natrenobugt	Outlet	Rec 0,5	-	-	-	17
Natrenobugt	Rec 0,5	Rec 1	-	-	-	16
Natrenobugt	Outlet	Rec 1	65	68	33	33
Natrenobugt	Rec 1	Rec 2	177	125	31	31
Natrenobugt	Rec 2	Rec 3	95	82	30	29
Natrenobugt	Outlet	Background	2,000	2,040	800	380

Figure 18: Sampling sites used in 1st round in Sisimiut. The Ulkebugt sewage line outlet is in the upper right corner, and the Natreno sewage line outlet is shown in the middle of the picture

Figure 19: Sampling sites used in the second sampling round in Sisimiut

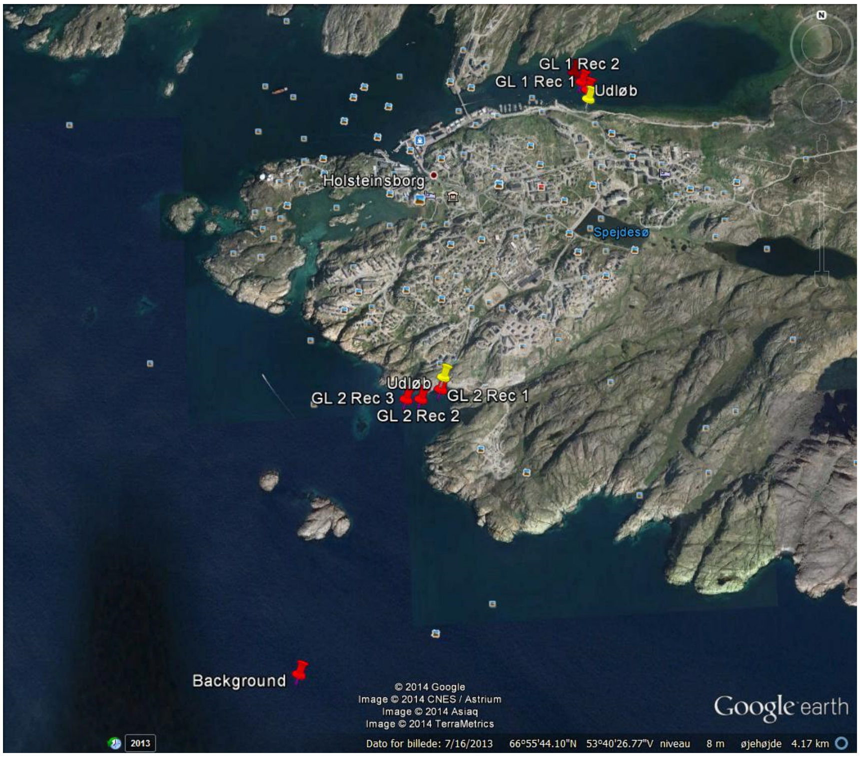


Figure 20: Sampling sites used in the third sampling round in Sisimiut, in Ulkebugten. The site of discharge, Udløb, is marked with a yellow pin

Figure 21: Sampling sites used in the third sampling round in Sisimiut, at the Natreno discharge site. The site of discharge, Udløb, is marked with a yellow pin

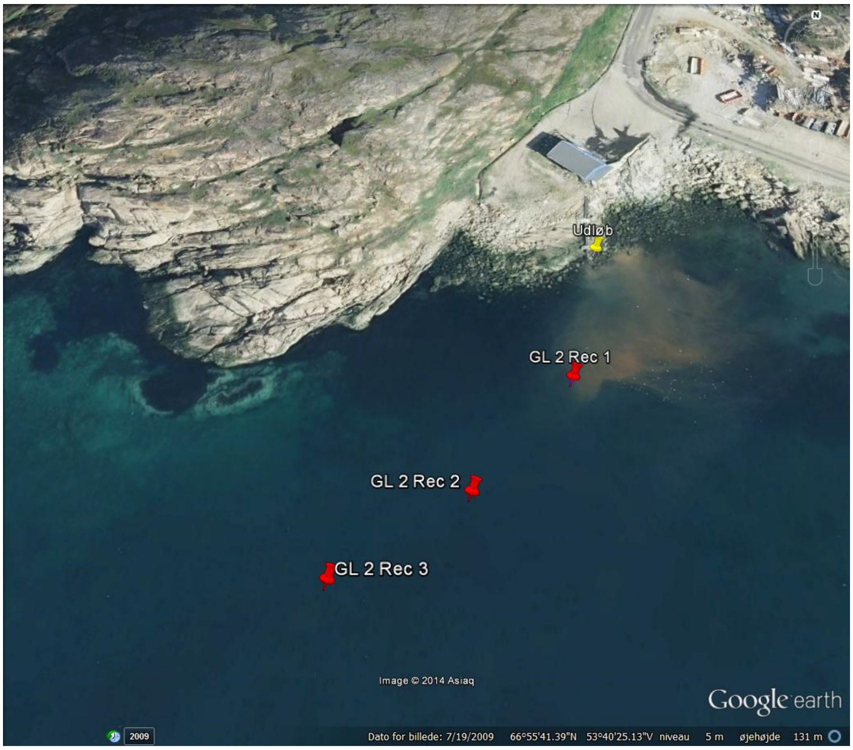
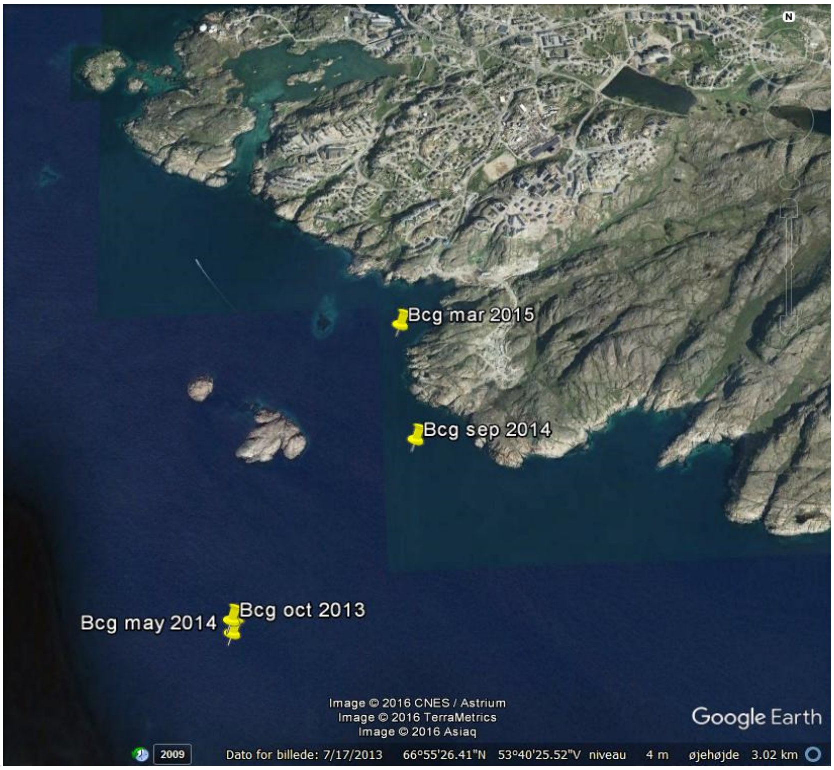


Figure 22: Sampling sites used in the fourth sampling round in Sisimiut, in Ulkebugten. The site of discharge is marked GL 1 Udløb

Figure 23: Sampling sites used in the fourth sampling round in Sisimiut, at the Natreno discharge site. The background sample site is in the lower left corner

Figure 24: Background samples off Sisimiut were taken as shown on map (round 1= oct 2013; round 2=may 2014; round 3=sep 2014; round 4=mar 2015)



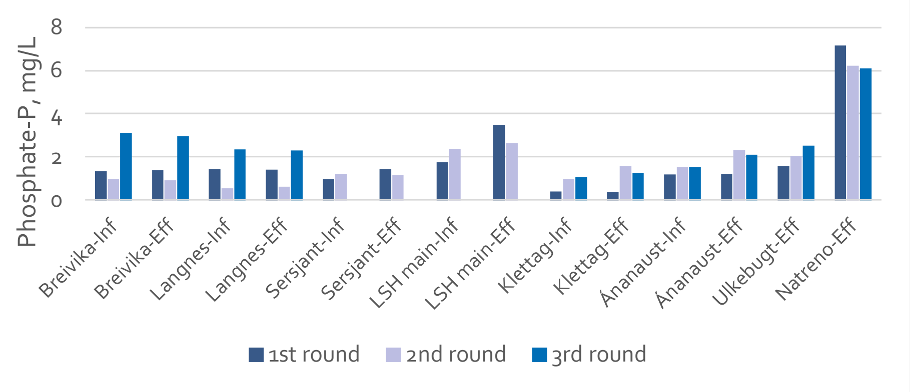
5. Results – By contaminants and with focus on wastewater

A complete listing of analytical data are provided in Appendix tables.

5.1 Phosphates

The concentration of phosphates (as orthophosphate) in influents and effluents of WWTPs were normally around 1–2 mg P/L, but in some cases also around 3 mg P/L, as in the August/September 2014 sampling in Breivika and the LSH Main hospital WWTP in Tórshavn. The same level of phosphate (1–2 mg P/L) was found in discharge from the Ulkebugt sewage line in the three instances when it was analysed. In the Natreno sewage line discharge, the concentration of phosphate was higher, at 6–7 mg P/L (Figure 25).

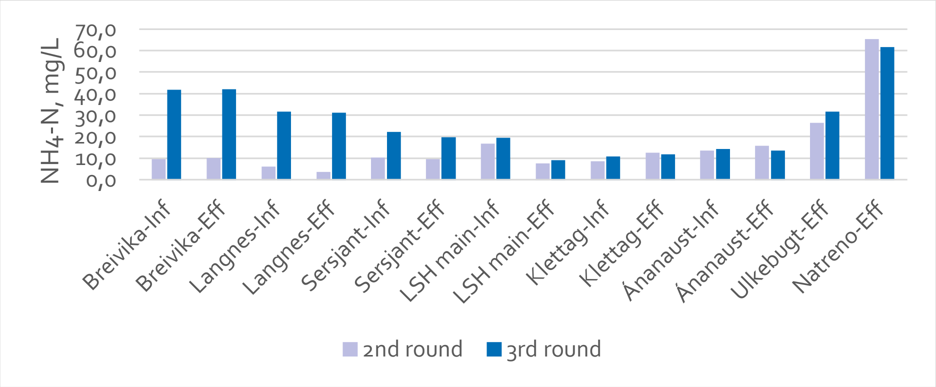
Figure 25: Phosphate concentration as measured in influent and effluents of the WWTPs /sewage lines



5.2 Ammonium, NH_4^+

The concentration of ammonium (NH_4^+) followed overall the concentration of TOC (Figure 26, Figure 28) with levels in the range 3–15 mg N/L in effluents samples from WWTPs (Sisimiut excluded) in the 2nd round, with markedly higher concentrations in Tromsø WWTPs in the following round. Overall, the concentration of ammonium did not change much from influent to effluent in WWTP samples, except in the LSH samples, where the ammonium concentration in effluents where half of that which was detected in influents. The samples are however not directly comparable, as the sampling was done as grab sampling on influent side thus the difference may stem from variability in composition in the water fluxes rather than actual decrease in concentration following passage through the WWTP. The highest levels were found in discharge from the Natreno sewage lines in Sisimiut.

Figure 26: Ammonium (NH_4-N) in influent and effluent samples from the various WWTPs/sewage lines



An overview of the measured concentrations of nutrients in the wastewater streams is given Table 10.

Table 10: The flow of ammonium and phosphate in and out of the WWTPs, in the 1st^{A}, 2nd^{B} and 3rd^{C} analyses rounds. Units mg/L N and P.

WWTP	Sample	NH_4-N	NH_4-N	Phosp-P^{A}*	Phosp-P^{B}	Phosp-P^{C}
Breivika	influent	41.5	9.3	1.29	0.91	3.06
Breivika	effluent	41.7	9.6	1.32	0.87	2.92
Langnes	influent	31.3	5.6	1.37	0.50	2.31
Langnes	effluent	30.8	3.2	1.35	0.57	2.26
Sersjantvíkin	influent	21.9	9.9	0.90	1.15	na
Sersjantvíkin	effluent	19.4	9.2	1.38	1.10	na
LSH-Main hosp	influent	19.1*	16.3*	1.7	2.3*	na
LSH-Main hosp	effluent	8.7	7.1	3.4	2.60	na
Klettagarðar*	influent	10.5	8.0	0.35	0.91	1.02
Klettagarðar*	effluent	11.3	12.1	0.32	1.52	1.20
Ánanaust*	influent	13.8	13.1	1.14	1.49	1.48
Ánanaust*	effluent	13.2	15.3	1.2	2.28	2.06
Ulkebugt	effluent	31.3	26*	1.5	2.0*	2.48
Natreno	effluent	61.2	65*	7.1	6.2*	6.07

Note: * Grab samples; every sample in 1 round, and every Klettagarðar and Ánanaust samples.

5.3 Total Organic Carbon- TOC

TOC was detected in influents and effluents to WWTPs but not in recipient samples at concentrations above 1.5 mg/L, which was the detection limit in most samples. As with ammonium, there were quite large differences in TOC between the two analyses rounds, especially in the Tromsø samples. The concentration of TOC and ammonium in wastewater co-varied as shown in Figure 28. The highest TOC was found in samples from sewage lines in Sisimiut (Figure 27), at concentrations up to 81 mg/L.

Figure 27: Total organic carbon, TOC, in influent and effluent samples from the various WWTPs/sewage lines

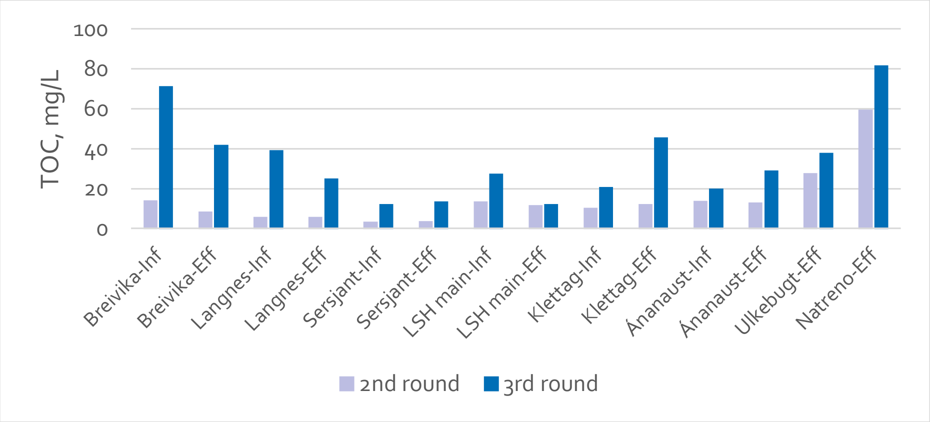
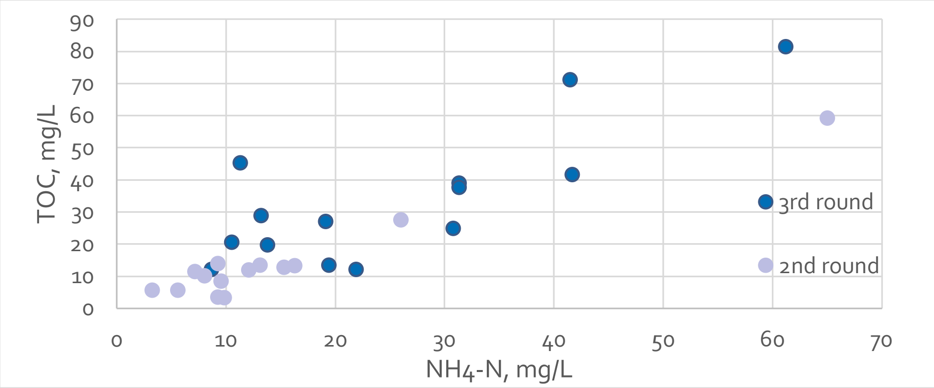


Figure 28: The concentration of TOC and NH4-N in influent and effluent samples



5.4 LAS

A summary of the LAS results are given below, in Figure 29 and details on findings from the various sampling sites are presented in following separate sections, one for each area, and in Appendix Tables 26, 28 and 29.

In Figure 29 all LAS concentrations as sums of the individually quantified LAS are given for effluent and influent samples taken in the Tromsø, Tórshavn, Reykjavík and Sisimiut.

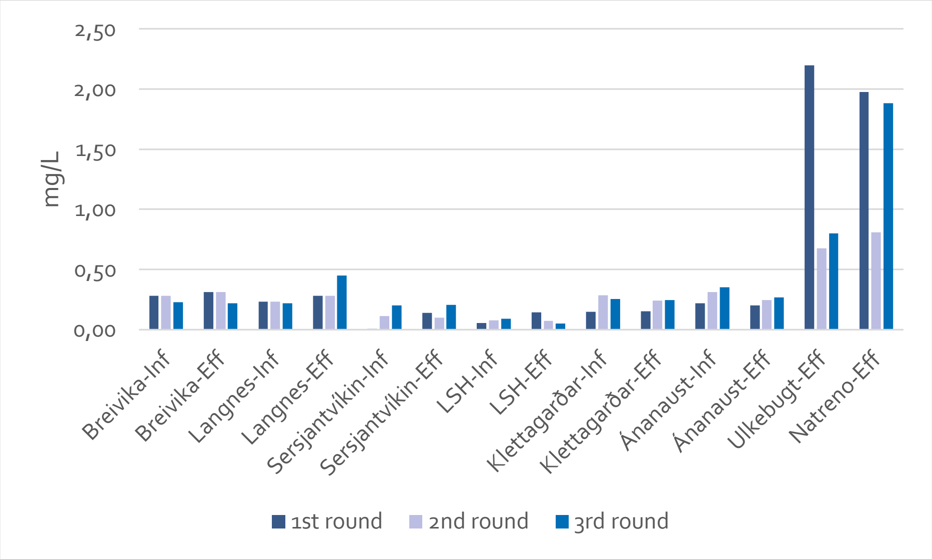
There are certain observations which may be commented upon. The first, is the high concentration of LAS in the Sisimiut samples which are markedly higher than in the other areas, and this could be due to the fact that wastewater is less diluted when discharged to the recipient in Sisimiut than in the other study sites- due to the separate treatment of sewage and water from sinks and washtubs. Another observation is that the concentration in wastewater before and after the WWTP were generally similar (Figure 29), and in some instances the LAS concentration appeared to be higher in effluents than in influents. This apparent increase during the passage of the WWTPs is seen in several WWTPs and is likely a result of the relatively low residence time of the wastewater in the WWTP in comparison to the degradation rate of LAS. In addition, the grab-sample sampling technique partially applied also influence the results, as may increased inflow to the WWTP in the event of rainfall during the sampling period. The assessment of the precise operational efficiency within the various WWTPs were not possible within the frames of the present study, where the focus was to assess the efficiency of the wastewater treatment in relation to the environmental risk posed by the wastewater discharge to the recipient.

The highest concentration of LAS in effluents were invariably measured in the Greenland samples, at Sum LAS on average 1.4 mg/L, and the lowest in the Faroese, at Sum LAS on average 0.10 mg/L across influent and effluent samples in the three sampling rounds. Arranging the countries in decreasing order based on the ratio between the Sum LAS concentrations calculated across influent and effluent, for the sampling rounds and the two sampling areas in each countries combined, would yield GL:NO:IS:FO, with the 14:3:2:1 as the corresponding ratio between Sum LAS concentrations.

The variability was overall highest in the Faroe Islands (0.10±0.06 (58%) mg/L) and in Greenland (1.39±0.70 (50%) mg/L), and least in Iceland (0.24±0.06 (24%) mg/L) and in Norway (0.28±0.08 (28%) mg/L).

Between the various locations, the relative distribution of LAS components in wastewater were quite similar, with the overall distribution (average of the three analyses rounds) such that C11 contributed 42–46%, C12 with 19–26%, C10 with 22–26% and C13 with 7–10%, and the smallest contribution from C14 with less than 1%. The only sample which did not fit into this description was the "FO-2-influent" sample which was taken in the sewage line of the hospital in Tórshavn, where the contribution of the various LAS homologues varied more than in the other wastewater lines between the sampling rounds. This can be exemplified with the proportion of LAS homologues in influents in the first vs the third round, where C10:C11:C12:C13:C14 were in the order 1:41:33:24:<1 and 70:11:11:8:<1 respectively. This is a reflection of activities taking place at the time of sampling, as the influent samples to the LSH main hospital WWTP were invariably grab samples.

Figure 29: Concentration of Sum C10-14 LAS in influent and effluent samples from Tromsø, Tórshavn and Reykjavík and in effluents in Sisimiut



5.5 Alkylphenols and alkylphenol ethoxylates

The samples taken in the fourth quarter of 2013 were analysed for octyl- and nonylphenols and ethoxylates of these. The detailed analyses results are given in Appendix Table 27. One or more of these substances were detected in every influent sample, and in most effluent samples. Comparisons between cities are difficult because different detection limits were provided for the samples delivered from the various areas, thus direct comparisons in the lower end of the concentration range is not possible. However, in the higher end, it is apparent that the highest concentration of nonylphenol monoethoxylate, 3.6 µg/L, was present in discharge from the sewage line at the Natreno site, and next highest in influent and effluent samples from Breivika WWTP, where concentrations of approx. two µg/L were found (Figure 31). Octylphenol and its ethoxylates were found in lower concentrations, with the highest concentration of octylphenol ethoxylate in effluents from the LSH main hospital WWTP in Tórshavn, at 0.84 µg/L of OP2EO and 0.45 µg/L of OP1EO. The highest concentration of OP (4-tertOP) was in effluents from Langnes WWTP (Figure 30).

Figure 30: Octylphenol and octylphenol ethoxylates in influent and effluent samples

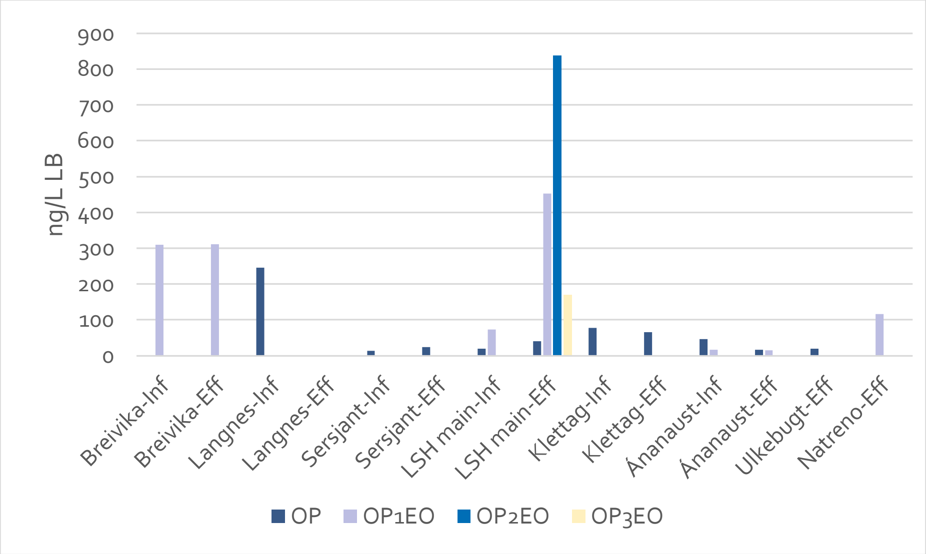
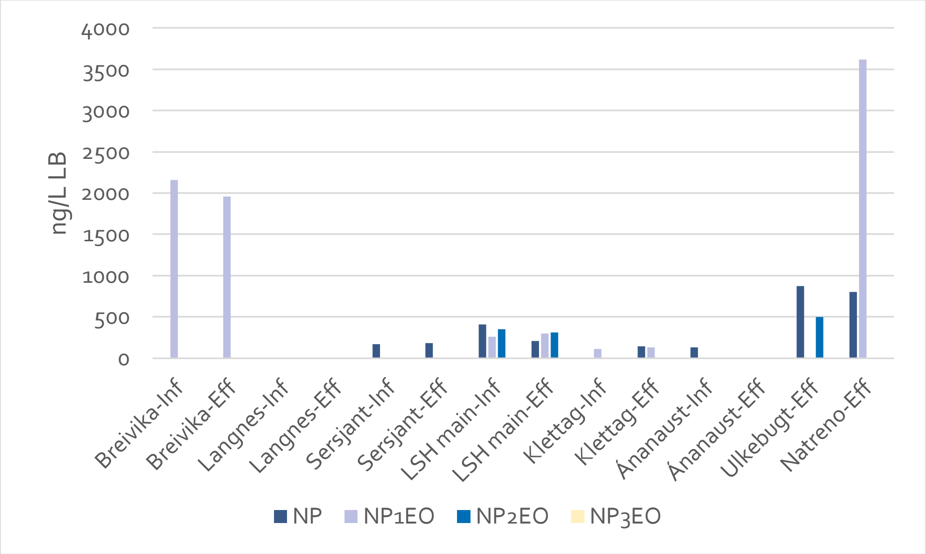


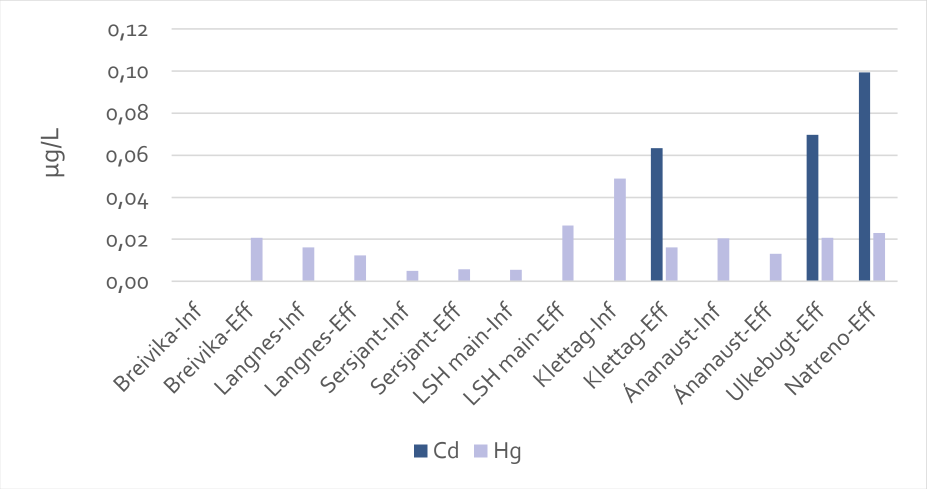
Figure 31: Nonylphenols and nonylphenol ethoxylates in influent and effluent samples



5.6 Cadmium

The concentration of cadmium was analysed in influent and effluent as well as in recipient samples taken in the first analyses round in the present project. Cadmium was detected in three wastewater samples only, in effluents from Klettagarðar WWTP and in effluents in the Sisimiut sewage lines (Figure 32). Cadmium effluent concentrations were in the range 0.06 to 0.10 µg/L.

Figure 32: Concentration of cadmium, Cd, and mercury, Hg, in influent and effluent i.e. as discharged to the recipient. Samples analysed for Cd where taken in October 2013, and for Hg in August/September 2014. Cd DL= 0.05 µg/L, and Hg DL=0.002 µg/L



5.7 Mercury, Hg

Mercury was analysed in samples from autumn 2014 (Appendix Table 29; Figure 32). The concentration of Hg in effluents were highest in the Tórshavn main hospital effluents (0.027 µg/L), followed by the Natreno effluents in Sisimiut (0.023 µg/L) and the Breivika WWTP in Tromsø (0.021 µg/L). The lowest mercury concentration in effluents were measured in the Sersjantvíkin WWTP Tórshavn, and Langnes WWT in Tromsø. In Reykjavík, the mercury effluent concentrations were 0.016 and 0.013 µg/L at the Klettagarðar and Ánanaust WWTPs, respectively, and particularly at the Klettagarðar WWTP this was markedly lower than in the influents. No sample contained mercury at concentrations of MAC EQS of 0.07 µg/L which is identified in the EU directive 2013/39 for surface waters.

5.8 PAH

In these analyses, the differences in population and city sizes were apparent. An overview of the detection frequencies of PAHs in wastewater from the various locations are shown in Table 11, and it is obvious that the frequency of PAH detection was markedly higher in the larger cities Tromsø and Reykjavík, than in the smaller Tórshavn and Sisimiut.

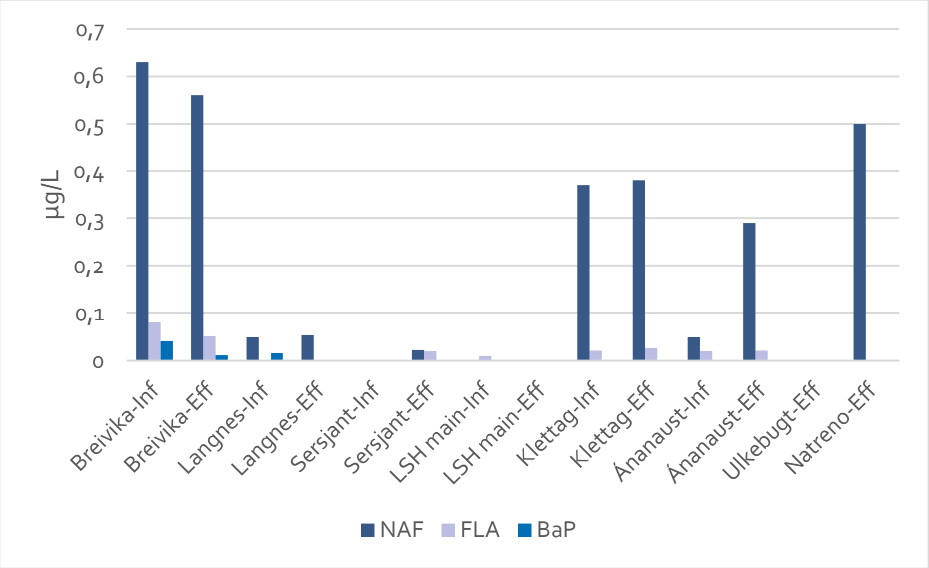
The carcinogenic PAHs, i.e. the lower eight PAHs listed in Table 11 from benz(a)anthracene to indeno(123cd)pyrene, were only detected in the samples from Tromsø. The highest concentrations of these carcinogenic PAHs were found in influents from the Breivika WWTP, where benz(a)anthracene, chrysene and benz(a)pyrene were detected at 0.5 µg/L or less (Figure 33). Only three PAHs were detected in all countries; naphthalene, fluorene and phenanthrene.

Surprisingly high concentration of fluorene and phenanthrene were detected in effluents in Sisimiut, at 93 and 57 μg/L, whereas these compounds occurred at more similar concentrations in the Tórshavn, Reykjavík and Tromsø samples, at 0.03 and 0.04 μg/L, respectively. Also, the Ánanaust WWTP in Reykjavík, acenaphthene influent concentration at 12 μg/L was elevated in comparison to the other study locations. The lowest concentration of naphthalene was found in the Tórshavn samples (0.01 μg/L). For Sum PAHs, the mean concentrations decreased in the following order GL:IS:NO:FO with ratios 940:45:7:1 (for the calculation, the NDs where replaced by the value 0.5*DL). The driver for the high ratios in GL and IS were the abovementioned elevated concentrations of fluorene/phenanthrene and acenaphthalene, respectively.

Table 11: Summary table of positive detection of PAHs. Bold types are used on PAHs listed as priority substances in the EU water framework directive, and those marked with an * are listed as priority hazardous substances. The DL was <0.010 μg/L except in the GL effluent samples where it was <0.050 μg/L

PAH	Frequency of detection of PAHs in wastewater, %.					Max value
	All cities	FO	IS	NO	GL	Country μg/L
Naphthalene	71	25	100	100	50	NO 0.63
Acenaphtylene	14	0	50	0	0	IS 1
Acenaphtene	50	25	100	50	0	IS 12
Fluorene	71	25	100	100	50	GL 93
Phenanthrene	86	75	100	100	50	GL 57
*Anthracene**	7	0	25	0	0	IS 0.16
Fluoranthene	57	50	100	50	0	NO 0.081
Pyrene	57	0	100	100	0	NO 0.067
Benz(a)anthracene	29	0	0	100	0	NO 0.049
Chrysene	14	0	0	50	0	NO 0.035
*Benz(b)fluoranthene**	7	0	0	25	0	NO 0.031
*Benz(k)fluoranthene**	7	0	0	25	0	NO 0.022
*Benz(a)pyrene**	21	0	0	75	0	NO 0.042
Dibenzo(ah)anthracene	0	0	0	0	0	-
*Benzo(ghi)perylene**	0	0	0	0	0	-
*Indeno(123cd)pyrene**	0	0	0	0	0	-

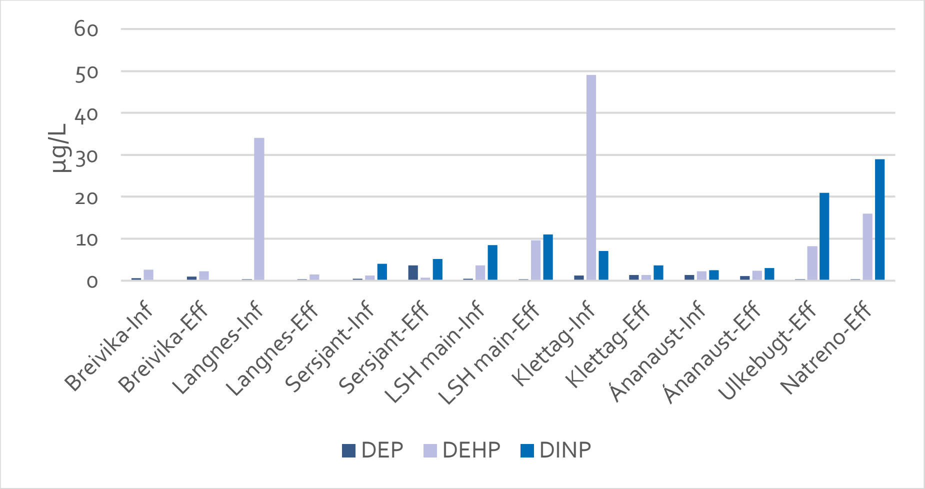
Figure 33: The concentration of three selected PAHs in wastewater. NAF= naphthalene; FLA=fluoranthene; BaP= Benz(a)pyrene



5.9 Phthalates

Of the 12 phthalates analysed, four were not detected at 0.3 µg/L in any influent or effluent sample, these were DMP, DPP, DPeP and BBP. On the other end, DEHP and DINP were detected in every effluent and influent sample (Figure 34). DEHP and DINP were detected in every wastewater sample analysed, and DEP in 70% of these. The other phthalates, DBP, DIBP, DOP, DCHP and DIDP, were encountered in 7–36% of the wastewater samples. The highest frequency of detectable phthalate concentrations were found in Sisimiut (42%) and the lowest in Tromsø (18%), with intermediate frequency in Tórshavn and Reykjavík at 30%. The reason for the low frequency of detection in the Tromsø samples stems in part from the lower number of phthalates analysed in these samples; the Tromsø samples were analysed for 10 phthalates whereas samples from the other areas were analysed for 12. There were high variability in DEHP concentration between wastewater lines, also from the same area, and thus no geographical difference could be discerned. However, the very marked decrease in DEHP in the Langnes and Klettagarðar WWTPs is worth noting; such efficiency of contaminants removal were not seen for other compounds and WWTPs.

Figure 34: Concentrations of selected phthalates in influent and effluent samples from the WWTPs and sewage lines. LB data. DINP were not analysed in Tromsø samples



5.10 Quaternary alkyl compounds, QAS

Quaternary alkyl compounds of the type C10–C18 DDAC, C12–C18 BAC and C12–C22 ATAC were analysed in a limited number of samples, consisting of effluent samples, two recipient sites from each discharge site, and a background recipient sample from each city. Only effluent samples from Tromsø and Sisimiut was analysed as part of the present study, as effluent samples from Tórshavn and Reykjavík had recently been analysed in connection with the Joint Nordic Screening study (Kaj et al. 2014).

ATAC was detected in every effluent samples, and with ATAC-C22 the most common in all but the Sisimiut samples, where ATAC-C16 was most prominent (Figure 36). ATAC was not detected in recipient samples from Tromsø and Sisimiut, but were detected in one Tórshavn recipient sample, and two Reykjavík recipient samples. ATAC was not detected in any bacground sample. DDAC was detected in every effluent sample (Figure 36), but as ATAC, it was not in any recipient sample from Tromsø and Sisimuit. DDAC was detected in two recipient samples from Tórshavn and three from Reykjavík. DDAC was like ATAC not retected in any background sample. BAC was detected in moresamples than ATAC and DDAC, which is also apparent from the number of bars in the figure (Figure 37). BAC was detected in every effluent sample, and it was detected in recipient samples from Tórshavn, Reykjavík and Sisimiut, but not from Tromsø. BAC was even detected in the background sample from Tórshavn, though at very low concentration.

The QAS occurring in highest concentration varied between areas (Figure 38), such that ATACs were the dominant QAS in the Tromsø effluent samples (Figure 35), DDAC was the dominant in the Reykjavík effluents (Figure 36) and BAC were the dominant group in the Sisimiut wastewater (Figure 37). The BAC C-12 was by far the most common BAC in the effluents (Figure 37).

Figure 35: C12– C22 ATAC in effluent, recipient and background samples. Samples in which no ATAC was detected is not shown

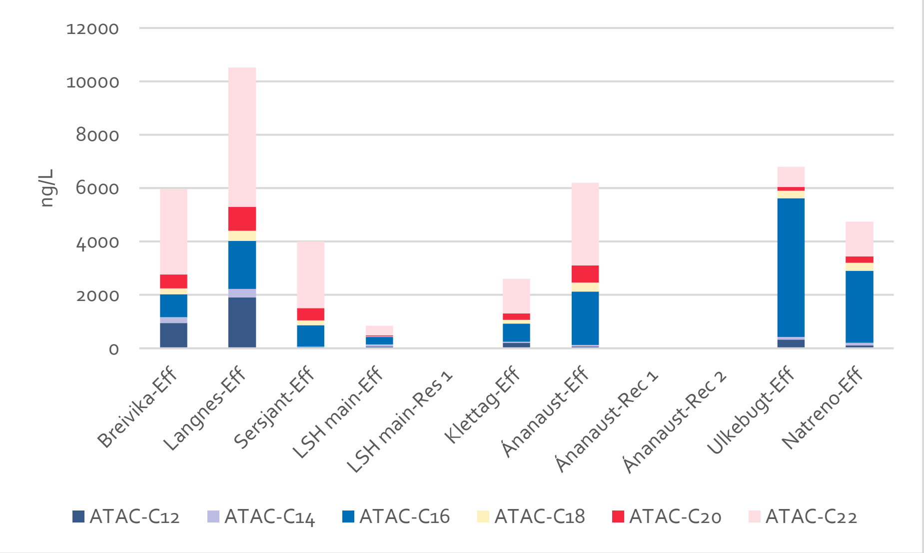


Figure 36: C10–C18 DDAC in effluent, recipient and background samples. Samples in which no DDAC was detected is ommitted from the figure

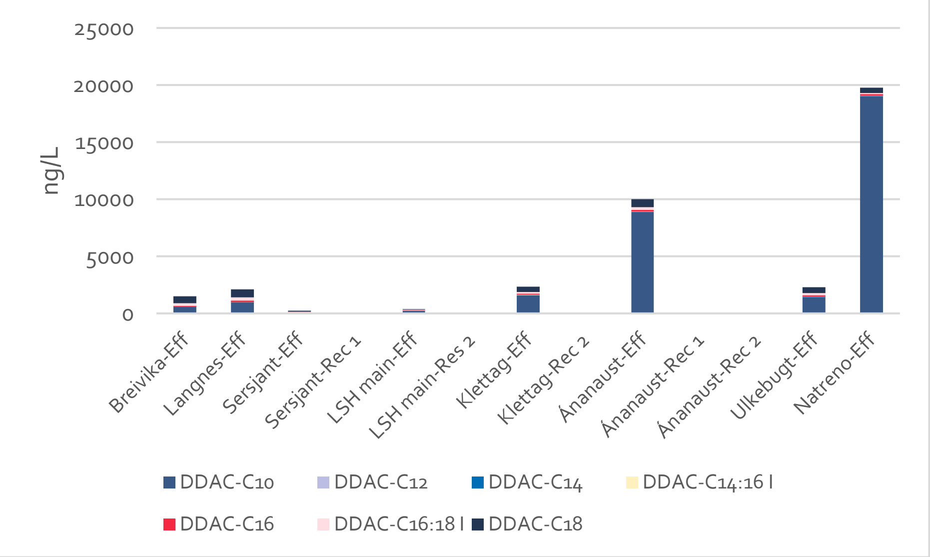


Figure 37: The BAC C12– C18 in effluent, recipient and background samples in which BAC was detected are shown

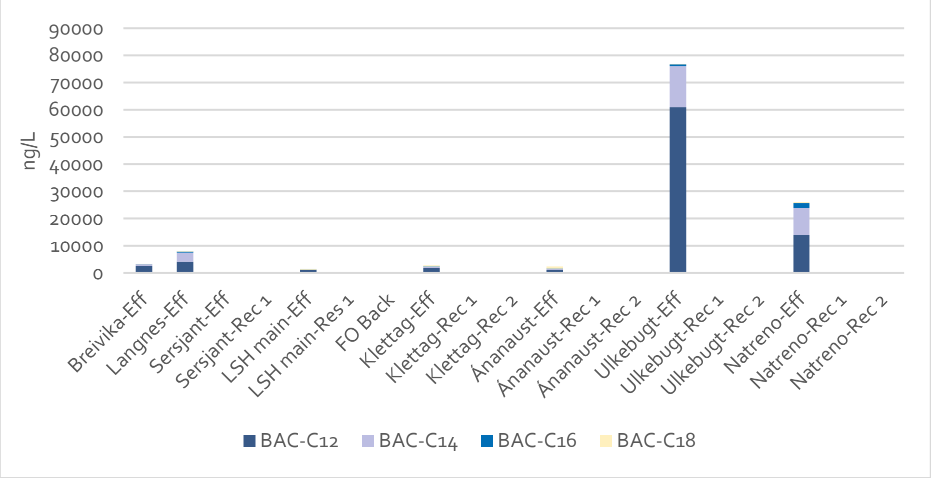
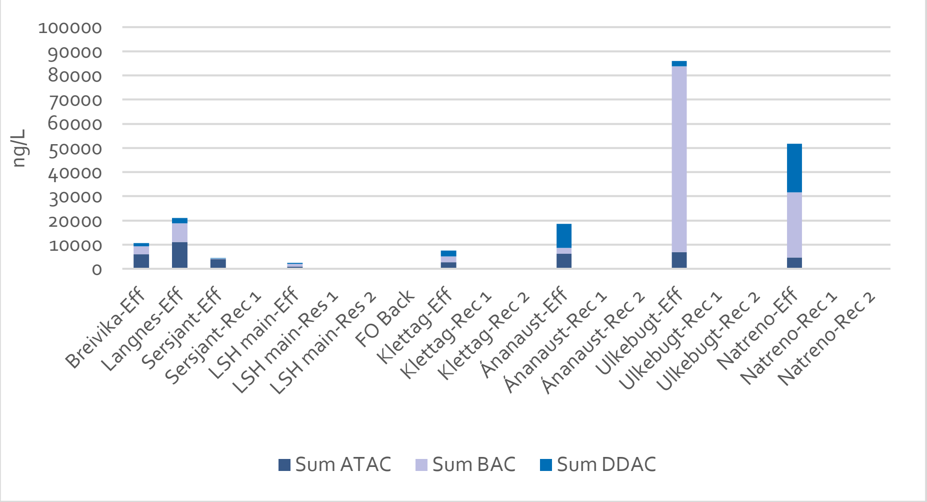


Figure 38: The summed concentration of QAS groups analysed are shown for every sample in which one or more of the QASs coumpounds were detected



5.11 Per- and polyfluoroalkyl

The perfluoroalkyl sulfonates with 4, 5, 6, 7, 8, 9 and 10 carbons were analysed, among these the 8-carbon perfluoroalkyl sulfonate mainly known as PFOS. In Figure 39 and Figure 40, the concentration of PFAS are shown in influents and effluents samples, whereas concentrations in recipients are shown in Figure 42. The perfluoroalkyl compound in highest concentrations was PFOS, and the highest concentrations were found in influent and effluent samples from Klettagarðar WWTP. The somewhat higher PFOS in the Klettagarðar samples may be linked to the fact that Reykjavík airport feeds into this sewage line. Among the possible sources of PFAS from the Reykjavík airport is surface water runoff from the firefighting training area, as PFAS has been used in firefighting foams and in the hydraulic oils which are used with permit on this site.

The perfluoroalkyl carboxylic acids with 4 to 14 carbon atoms were analysed, however PFBA could not be analysed in any of the recipient samples with good quality and in the effluent or influent samples were it could, the concentration were <DL at 1.6 ng/Kg, and PFTA were not detected in any sample at 0.05 ng/Kg. The concentrations of C6 to C12 perfluoroalkyl carboxylic acids in influents and effluents are shown in Figure 40. PFPeA and PFTrDA were detected in one sample each, Ulkebugten effluents and Sersjantvíkin influents respectively, and are not presented in the figure. The highest concentrations were found in an effluent sample from the LSH main hospital of the Faroe Islands. This sample was taken as a composite sample via an automatic sampling device whereas the sample from the influent at this WWTP was taken as a grab-sample only. To find out whether the elevated concentration in this LSH main hospital effluent sample could stem from the sampling device, a set of parallel samples were taken where one composite samples was drawn manually and one via the automatic sampler in August 2015 (Figure 39, Figure 40, Samples ID DL15-011:53 and :54 in Appendix Table 32), and it was found that the automated sampling device did not add PFAS to the sample. However, the results also revealed that the concentration of PFAS, in particularly PFHxA and PFOA, in effluents in the repeated sampling done in August 2015 was very much lower than in the February 2015 sampling, a factor 10 lower concentrations in the summer than in the winter samples. One possible explanation for this could be that the larger likelihood of all-weather proof outdoor clothing being used in February than in August.

Perfluorooctyl sulfonamide, PFOSA, was detected in influent and effluent samples from the two Faroese WWTPs only, and then at concentrations of max. 0.05 ng/kg.

Also polyfluoroalkyl compounds, the 4–2, 6–2 and 8–2 polyfluoroalkyl telomeres (PFTs) were analysed. Of these, 4–2 PFT was not detected in any sample (of influents and effluents), whereas 6–2 PFT was only detected in effluent samples from Reykjavík WWTPs, and 8—2 PFT was detected in one influent sample from Tórshavn, and in a recipient sample and a sewage line sample from Greenland, in these cases in low concentrations (at 0.07 ng/kg and less). The highest 6–2PTF concentration, 6.62 ng/kg was found in an effluent sample from Klettagarðar WWTP.

Overall, PFHxA, PFOA and PFOS were the PFAS compounds found in highest median concentrations in influent and effluent samples and in five of the six WWTP analysed, the concentration of these PFAS were not reduced by passage of the WWTP, only at the Langnes WWTP were the concentration of PFAS going out somewhat lower than in the waste water going in (mainly observed for PFHxA, PFHpA and PFHxS).

In recipient samples, the concentrations of PFAS were generally dominated by the perfluoroalkyl carboxylic acids (Figure 42), and the concentrations were highest in the Breivika recipient in Tromsø. In more of the Tromsø recipient samples, the concentration of PFOS was above the EQS, and that was also the case with the Ánanaust and one Natreno recipient sample (Figure 41).

Figure 39: Perfluoroalkyl sulfonates in influents and effluents to/from sewage treatment plant/ sewage lines are shown. For LSH main hospital effluents, results from sampling in February (4.0) and August (4.1) are shown

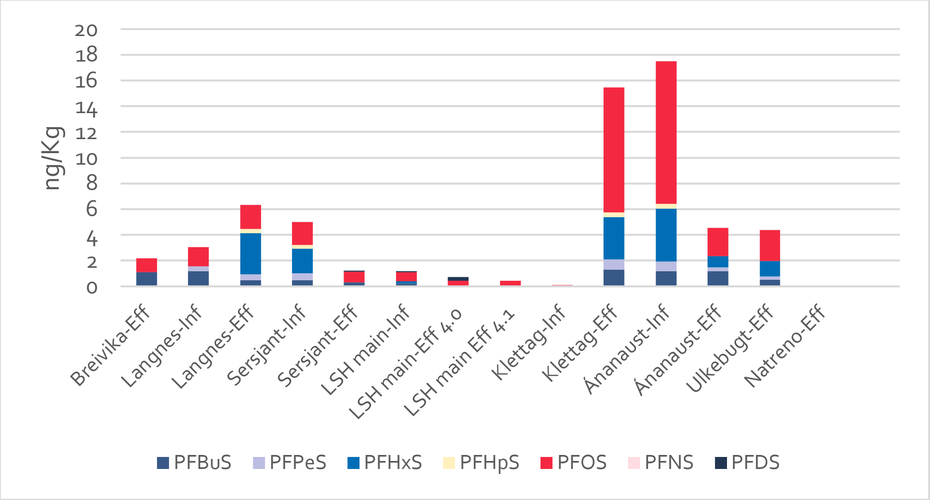


Figure 40: Perfluoroalkyl carboxylic acids (C6 to C12) in influents and effluents to/from sewage treatment plant/ sewage lines are shown. For LSH main hospital effluents, results from sampling in February (4.0) and August (4.1) are shown

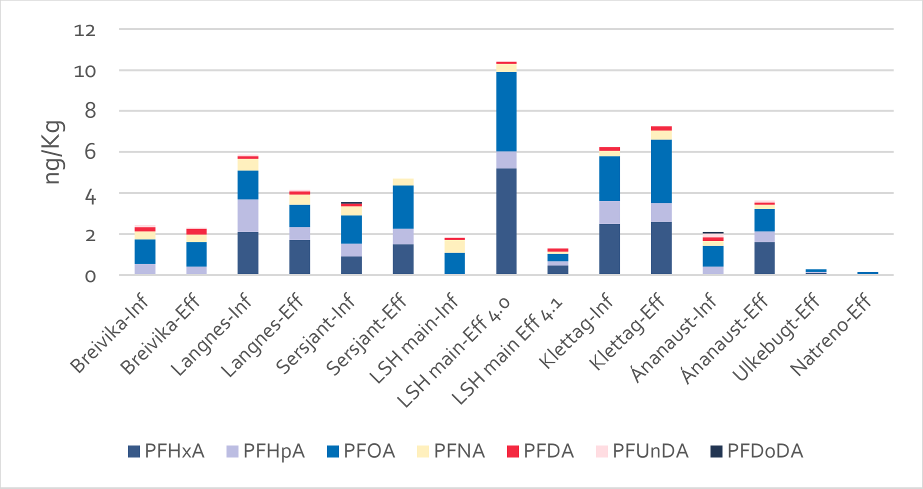


Figure 41: PFOS concentrations in recipient water samples are shown with EQS

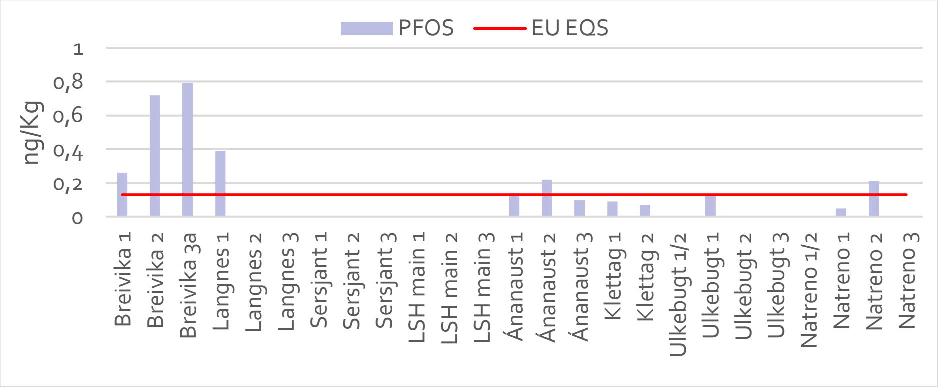
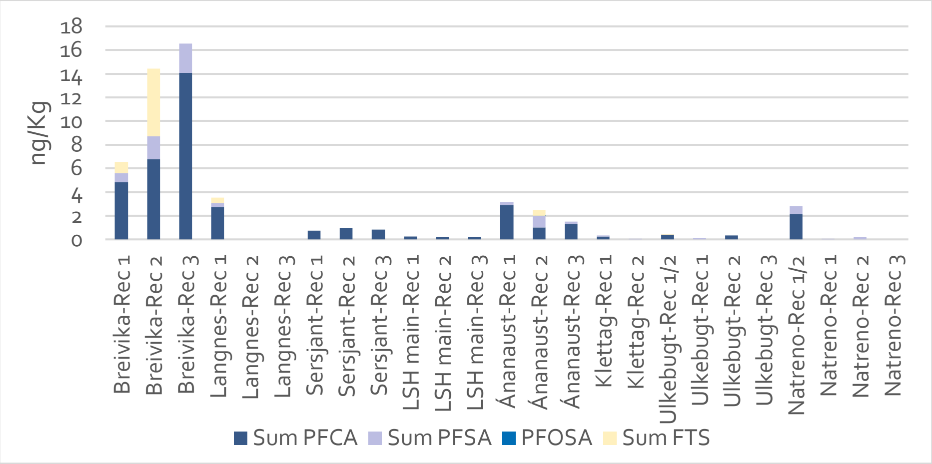


Figure 42: Sum of perfluoroalkyl carboxylic acids (PFCA), ditto sulfonic acids (PFSA) and perfluoroalkyl telomers (FTS) as well as PFOSA concentrations are shown in recipient samples



5.12 Contaminants flow to and from WWTPs

The contaminant load to the sewage treatment plants are described by the concentration in influents, and the contaminant load to the recipient is described by the concentration of these in the effluents from the WWTP. The degree of purification in the WWTP is the difference in contaminants in effluents versus that of the influents. The degree of purification may be assessed provided that it is possible to follow one volume of wastewater through the WWTP; thus the residence time in the WWTP needs to be known if grab samples are taken, or alternatively a time-integrated sample of influents must be taken. Such time-integrated samples are easily acquired with automated sampling equipment which is installed in newer WWTPs, but are more work intensive in plants where manual sampling is required.

A closer look at the LAS analyses in the influent and effluent samples taken simultaneously at the WWTPs, indicate that the concentration of LAS in effluents were in five out of 16 cases actually higher than in influents. Conversely, the concentration of

LAS in influents were positively larger than in effluents in six out of 16 cases, and in 10 cases the concentration of LAS were equal to or smaller than what went out of the WWTP (effluents) (Table 12). A truer picture of WWTP efficiency may be had from the sampling events where both influent and effluent samples were composite samples representing most of the 24 hours of a day and night. Such samples were taken in 2 and 3 rounds at the Breivika and Langnes WWTPs in Tromsø and at the Sersjantvíkin WWTP in Tórshavn (Table 5). In these four cases, the effluent LAS concentrations was higher than in the influent in one case, and in three of the four cases, the concentration of LAS in effluents were equal to or somewhat lower than in influents. Overall, the passage of wastewater through the WWTP had a close to negligible effect on the LAS concentration.

The last sampling and analyses round included PFAS and QAS. The samples were taken simultaneously, but a larger number of samples was analysed for PFAS than QAS. Thus, QAS was analysed in outgoing wastewater and recipients whereas PFAS was analysed also in wastewater going into the WWTP as well as in more recipient samples. Using PFHxA, PFOA and PFOS and as PFAS representatives, the analyses showed that in five of six cases did PFOS and PFOA not decrease on passage through the WWTP, whereas PFHxA did not decrease in three of the four cases where the assessment was possible, i.e. where PFHxA was detected in either one or both influent and effluent. In the three WWTPs where sampling was done as composite samples representing the flow through the WWTP for most of a day and a night, (Langnes, Breivika and Sersjantvíkin) the situation was most clear at the Sersjantvíkin WWTP that no purification took place. In the Langnes WWTP a small removal of PFAS upon passage of the purification plant was observed, whereas the effect of the Breivika WWTP in this respect appears to be small to negligible.

The fate of the contaminants in these three WWTPs were composite sampling allows such assessment (Table 13) indicates that LAS in not the only contaminant passing more or less unscaled through the WWTPs. Mercury increased upon passage through WWTP, as did phthalates and PAHs and even TOC in the Sersjantvíkin WWTP in the 3. sampling round (Table 13). The situation looked better at the Breivika and Langnes WWTPs, though in neither of these were the concentration of the pollutants always lowered upon passing the WWTP (Table 13). Overall thus one may conclude that the WWTPs in Tromsø and Tórshavn are not well suited to remove pollutants like LAS, mercury, PAH and PFAS. The nutrients and organic material, phosphate, NH4 and TOC, were removed to a larger extent, though not invariably, and the Langnes and Breivika WWTPs removed phthalates, in one instance with up to 94% efficiency (Table 13).

Table 12: The change in concentration in LAS upon passing through the WWTPs is shown. The symbols << means that the concentration in effluents were much higher than in influents, < mean the concentration in effluents were higher than in influents, ≥ means that the concentration in effluents were similar to but rather smaller than in influents. The abbreviation n.d. means that LAS was not detected in these samples, where the analyses were done with LoD at 0.5 mg/L compared to 0.0005 mg/L which normally was used

Land	WWTP	1. round.* Infl. vs. Effl.	2. round. Infl. vs. Effl.	3. round Infl. vs. Effl.
NO 1	Breivika	≤	n.d.	=
NO 2	Langnes	≤	n.d.	<
FO 1	Sersjantvíkin	<<	≥	=
FO 2	LSH main hospital*	<	≥	>
IS 1	Klettagarðar*	=	≥	=
IS 2	Ánanaust*	=	>	>

Note: * One or both of the pair of effluent/influent samples were grab samples.

Table 13: Reduction in contaminant concentration in the Breivika, Langnes and Sersjantvíkin WWTPs. The reduction, in %, was calculated as 100* (C_{infl}-C_{eff})/C_{infl}, where C denotes the concentration of a given pollutant or pollutant group. A negative reduction implies that the concentration in effluents were higher than in influents. Samples are described in Table 5. na= not analysed, nd= not detected in neither influent nor effluent

WWTP	Round no.	Phosphate	NH_4	TOC	LAS	Phthalates	Mercury	PAH
NO-1 Breivika	2.	4%	-3%	40%	nd	11%	na	na
	3.	5%	-0.5%	42%	4%	na	-940%	25%
NO-2 Langnes	2.	-15%	43%	0.2%	nd	94%	na	na
	3.	2%	2%	36%	-105%	na	nd	18%
FO-1 Sersjntv.	2.	4%	6%	-6%	9%	-54%	na	na
	3.	na	11%	-11%	-2%	na	-14%	-2,082%

5.13 Contaminants carried by effluents

The concentration of nutrients and contaminants discharged to recipient in the study sites are shown in Table 14 and Table 15. The concentration of nutrients and most contaminant groups are highest in the Natreno sewage line samples (GL-2-Eff). The few exceptions to this general observation are mercury and PFAS, represented with PFOA and PFOS in Table 15. Mercury was somewhat higher in the LSH main hospital effluents in Tórshavn than in the Sisimiut and Tromsø Breivika effluents. PFOS was markedly higher in the Klettagarðar effluents than at the other sites, whereas PFOA was marginally elevated in the LSH main hospital effluents compared to that of the Klettagarðar.

Table 14: The concentration of pollutants groups in effluent samples

Site	Sample	Phos-P mg/L^{A}	Phos-P mg/L^{B}	Phos-P mg/L^{C}	NH4-N, mg/L^{B}	NH4-N, mg/L^{C}	TOC, mg/L^{B}	TOC, mg/L^{C}	Cd, µg/L^{A}	Hg, µg/L^{C}
Breivika	NO-1-Eff	1.32	*0.867*	*2.92*	*9.56*	*41.7*	*8.28*	*41.5*	<0.05	*0.021*
Langnes	NO-2-Eff	1.35	*0.572*	*2.26*	*3.22*	*30.8*	*5.47*	*24.8*	<0.05	*0.012*
Sersjantvíkin	FO-1-Eff	1.38	*1.1*	*na*	*9.24*	*19.4*	*3.38*	*13.3*	<0.05	*0.006*
LSH M hosp	FO-2-Eff	3.44	*2.6*	*na*	*7.13*	*8.66*	*11.3*	*12*	<0.05	*0.027*
Klettagarðar	IS-1-Eff	0.32	1.52	1.2	12.1	11.3	11.8	45.2	0.063	0.016
Ánanaust	IS-2-Eff	1.17	2.28	2.06	15.3	13.2	12.6	28.8	<0.05	0.013
Ulkebugt	GL-1-Eff	1.54	2	*2.48*	26	*31.3*	27.5	*37.5*	0.070	*0.021*
Natreno	GL-2-Eff	7.14	6.2	*6.07*	65	*61.2*	59.1	*81.4*	0.099	*0.023*

Note: $^{A, B, C}$ Shade indicates results from 1st, 2nd and 3rd analyses rounds respectively. Composite samples representing approx. 24 hrs are indicated in italic numbers

Table 15: The concentration of nutrients and other pollutants as measured in effluent samples

Site	Sample	Sum AP & APEO, ng/L^{A}	Sum LAS LB, mg/L^{A}	Sum LAS LB, mg/L^{B}	Sum LAS LB, mg/L^{C}	Sum Phthalates, µg/L^{B}	PAH, summa 16 µg/L^{C}	Sum QAS, ng/L	PFOA, ng/Kg	PFOS, ng/Kg
Breivika	NO-1-Eff	2271	0.31	*<2.50*	*0.22*	*3.24*	*0.82*	*11 000*	*1.2*	*1.5*
Langnes	NO-2-Eff	<4400*	0.28	*<2.50*	*0.45*	*1.5*	*0.14*	*21 000*	*1.1*	*1.8*
Sersjantvíkin	FO-1-Eff	208	0.14	*0.10*	*0.20*	*9.65*	*0.24*	*4 500*	*2.1*	*0.74*
LSH M hosp	FO-2-Eff	2324	0.14	*0.07*	*0.05*	*20.96*	*<0.080*	*2 400*	*3.9*	*0.42*
Klettagarðar	IS-1-Eff	341	0.15	0.24	0.25	6.3	0.51	7 600	3.1	11.1
Ánanaust	IS-2-Eff	31	0.20	0.25	0.27	6.5	0.46	19 000	1.1	2.4
Ulkebugt	GL-1-Eff	1396	2.20	*0.68*	*0.80*	*33.02*	<0.40	86 000	0.12	<0.01
Natreno	GL-2-Eff	4537	1.98	*0.81*	*1.88*	*51.06*	150	52 000	0.11	<0.01

Note: $^{A, B, C}$ shade indicates results from 1st, 2nd and 3rd analyses round respectively, and no shade indicates 4th round results. Composite samples representing approx. 24 hrs are indicated in italic numbers.

* The Tromsø samples were analysed at DL higher than the other sites, so the data are not directly comparable. No OP or OPEO were detected at 100 ng/L, and no NP or NPEO at 1000 ng/L.

6. Results – Contaminants in recipients for wastewater

In the following, the pollutants found in the water bodies acting as recipients for the wastewater originating from the four study areas are in focus. The assessment of environmental risk was based on comparisons to reference values like Environmental Quality Standards, EQS, such that environmental risk is the ratio of measured pollutant concentration divided by the EQS. A ratio close to or higher than unity indicated environmental risk. For calculations of risk based on pollutants concentrations measured in wastewater directly from the output side of sewage treatment plants, i.e. effluent samples, the standard, but quite conservative, practise of assuming a 10 times dilution in the recipient has been adhered to. For pollutants concentrations in recipient samples, the risk ratio is based on the concentration as measured, or as in case on this being below the DL, by the DL. The environmental risk are shown graphically for all contaminants except QAS, which is presented in Table 16.

6.1 QAS in receiving water

QAS were not detected in any recipient (including the background site) sample from Tromsø, Norway, at DL varying between 0.08 and 10 ng/L (Appendix Table 31). QAS were detected in four of the five recipient samples from Tórshavn, herein the background sample, in three of the five recipient samples from Reykjavík and in four of the five recipient samples (but not in the background sample) from Sisimiut (Figure 35 to Figure 38). The concentrations measured in the recipient samples were however very low, and did not pose any risk to the coastal environment (Table 16). QAS compounds were treated in groups of ATAC, BAC and DDAC (Table 16). The risk ratios presented in bracket represent calculations where the compound in question was not detected, in these cases the risks were calculated assuming the concentration of the QAS in question was equal to the DL! This method was chosen so as not to ignore a potential risk for a chemical that could not be quantified. The backside is that this method potentially magnifies the risk above all reasonable levels. The potential exaggeration of risk is directly related to the detection limit, and the magnitude of this relative to the EQS. In the case of ATAC, these to levels are close, and thus a sample where nothing has been detected still was assigned a risk of 0.33. This is questionable, but not totally unreasonable given that the risk calculated for three of the 16 recipient samples in which ATAC was positively detected results in a similar risk quotient.

Apart from these considerations, the results allows some conclusions, where the first one is that the risk ratios calculated from effluent concentrations invariably results in a higher risk than the concentrations measured in the receiving waters does, i.e. this way of assessing risk provides a conservative estimate. Next, no QAS was detected in the waters around Tromsø, and in no recipient or background sample was the concentration of any QAS at a level where environmental risk was imminent.

Tabel 16: The concentration of QAS in effluent and recipient samples are shown along with the risk ratios (see text). The risk calculated from upper bound values, are shown in brackets

Location	Distance from outlet, m	Sum ATAC, ng/L	Sum BAC, ng/L	Sum DDAC, ng/L	ATAC[1] Risk ratio	BAC[2] Risk ratio	DDAC[3] Risk ratio
NO- Breivika eff	0	6,000	3,200	1,500	10.34	0.77	0.07
Breivika rec	148	nd	nd	nd	(0.33)	(0.01)	(0.00)
Breivika rec	216	nd	nd	nd	(0.32)	(0.01)	(0.00)
NO- Langnes eff	0	11,000	7,900	2,100	18.97	1.90	0.09
Langnes rec	218	nd	nd	nd	(0.32)	(0.01)	(0.00)
Langnes rec	229	nd	nd	nd	(0.36)	(0.02)	(0.00)
Background NO	8,052	nd	nd	nd	(0.33)	(0.01)	(0.00)
FO- Sersjantv. eff*	0	4,000	280	230	6.90	0.07	0.01
Sersjantvíkin rec	30	nd	5.9	2.0	(0.36)	0.02	0.00
Sersjantvíkin rec	570	nd	nd	nd	(0.38)	(0.02)	(0.00)
FO- LSH eff*	0	860	1,200	380	1.48	0.29	0.02
LSH rec	35	1.8	5.9	nd	0.37	0.02	0.00
LSH rec	320	nd	nd	11	(0.39)	(0.02)	0.01
Background FO	1,450	nd	7.6	nd	(0.42)	0.02	(0.00)
IS- Klettagarðar eff*	0	2,600	2,600	2,300	4.48	0.63	0.10
Klettagarðar rec	30	nd	0.5	nd	(0.33)	0.01	(0.00)
Klettagarðar rec	260	nd	4.9	1.8	(0.36)	0.02	0.00
IS- Ánanaust eff*	0	6,200	2,400	10,000	10.69	0.58	0.43
Ánanaust rec	25	1.3	18	14	0.36	0.04	0.01
Ánanaust rec	255	1.0	22	12	0.39	0.05	0.01
Background IS	7,000	nd	nd	nd	(0.36)	(0.01)	(0.00)
GL- Ulkebugt eff	0	6,800	77,000	2300	11.72	18.55	0.10
Ulkebugt rec	45	nd	16	nd	(0.33)	0.04	(0.00)
Ulkebugt rec	58	nd	21	nd	(0.33)	0.05	(0.00)
GL- Natreno eff	0	4,700	27,000	20,000	8.10	6.51	0.87
Natreno rec	30	nd	17	nd	(0.35)	0.04	(0.00)
Natreno rec	60	nd	17	nd	(0.35)	0.04	(0.00)
Background GL	800	nd	nd	nd	(0.35)	(0.01)	(0.00)

Note: * From Kaj et al., 2014.

[1] The PNEC for ATAC was based analyses of EC50 for Daphnia and trout by Sandbacka et al. (2000), as the lowest EC50 of 58 µg/L and an assessment factor, AF, of 1000.

[2] The PNEC for BAC were based on Perez et al. 2009 and US EPA 2006, with EC50 for natural ass. marine phytoplankton at 0.036 mg/L, and NOAC Daphnia at 4.2 µg/L and an AF of 10.

[3] The PNEC was based on a NOAEC of 0.23 mg/L for fathead minnow in river water and an AF of 100 (Lewis and Wee, 1983 and Lewis 1991).

6.2 Tromsø

In Tromsø, the concentration of *phosphate* was less than 0.010 mg/L in the background sample in the three sampling rounds and this is regarded as the upper limit of the natural phosphate background in this area. Phosphate was detected (at DL 0.010 mg/L) at recipient sampling sites 1 and/or 2, but only at recipient site 1 for the Breivika WWTP in concentrations that clearly are above 1.5 times the winter phosphate level. The highest phosphate concentration, 0.086 mg/L was measured 160 m away from the discharge point in August/September 2014 (Figure 43).

Ammonium was detected in all samples, in recipient samples in the range 0.05 to 0.13 mgNH4-N/L and in effluents at 3–10 mgNH4-N/L. *TOC* was not detected at detection limits of 1.5 mg/L in recipients of Tromsø wastewater. The concentration of TOC in effluents were from 5.5 to 8.3 mg/L, in the May 2014 samples.

LAS was found to be present at concentrations above PNEC in recipient samples taken 300–500 m from the sites of discharge in two of the three sampling rounds (Figure 44). In the analyses of the May 2014 samples, LAS was not detected at concentrations at 0.5 mg/L. Sum of *nonylphenol* and *nonyl ethoxylates* were below EQS in samples from the Tromsø recipient, but sum of *octylphenol* and *octylphenol ethoxylates* were above the EQS in 10 times diluted effluent from the Breivika WWTP site (Figure 45 and Figure 46). *Cadmium* was not detected in any sample from Tromsø at detection limit 0.05 µg/L, neither in influent nor effluent to/from the Breivika or Langnes WWTPs, nor in samples from the recipient (Figure 47). *Mercury* was detected in the influent sample to Langnes WWTP, at 0.016 µg/L and in effluents from both this and the Breivika WWTP at concentrations 0.012 and 0.021 µg/L, respectively. Only a maximum allowable EQS has been defined for mercury in the EU regulations, and the measured concentrations were well below this MAC EQS at 0.07 µg/L (EU 2013/39/EU).

Of the ten *phthalates* analysed in the Tromsø May 2014 samples, only two were detected in any sample. *DEHP* (Figure 48) was present in influent samples at the Langnes WWTP at 34 µg/L, whereas the concentration in influents to the Breivik WWTP was 2.6 µg/L. In effluents, the concentration of DEHP was between 1.5 and 5.3 µg/L. The EQS for DEHP at 1.3 µg/L in surface waters (EU 2013/39/EU) was thus not exceeded in the recipient, and may not be assumed to be exceeded in the near-outlet recipient either. *DIBP* was detected in two recipient samples at concentrations of 0.44 and 1.6 µg/L (Appendix table 28).

Among the cationic surfactants (*QAS*) neither ATAC, BAC nor DDAC were detected in recipient water samples (Table 16). In the immediate vicinity of the discharge sites of the Breivika and Langnes WWTPs the concentration of ATAC in particular may pose a risk to the local ecosystem, as risk quotients in the range 10–20 where found for effluents from the two WWTPs, respectively. Similarly, the risk quotient calculated from effluent concentrations of BAC from the Langnes WWTPS exceeded the PNEC with a factor 2, and were close to unity in the effluents from Breivika WWTP. Thus environmental risk from ATAC and to a certain extent BAC cannot be excluded. On the other hand, the concentration of DDAC were lower than the former two groups of QAS and the risk quotients calculated were below 0.1.

The concentration of PFAS was detectable in influent and effluent samples and in recipient samples with Sum PFAS less than 20 ng/kg, but with the higher concentrations in occasional recipient samples than in the WWTP influent and effluent samples (Figure 49). The PFAS occurring in highest concentration was PFOA – albeit the concentration of this was less than 10 ng/kg in every sample. When PFOS was detected in a recipient sample, its concentration exceeded the EQS for this compound (EU 2013/39/EU) at $1.3\ 10^{-4}$ µg/L (Figure 50).

Summing up: In the recipient around Tromsø, it appears that PFOS, LAS and phosphate are the most critical compounds in terms of potential environmental harm. The survey indicate that the PFOS exceed the AA-EQS in recipient samples, and that LAS PNEC and phosphate winter background concentration are exceeded approx. 300 to 500 m away from the sites of discharge. If the PFOS concentrations measured were compared to PNEC of 1.1 µg/L for marine environment organisms, as calculated by for instance Mhadhbi et al., (2012), then the apparent environmental risk (MEC/PNEC ≤ 0.001) would be negligible compared to *e.g.* that which arises from LAS.

Figure 43: Transects showing decreasing concentration of phosphate-P in the recipient around WWTPs in Tromsø. Lower bound data

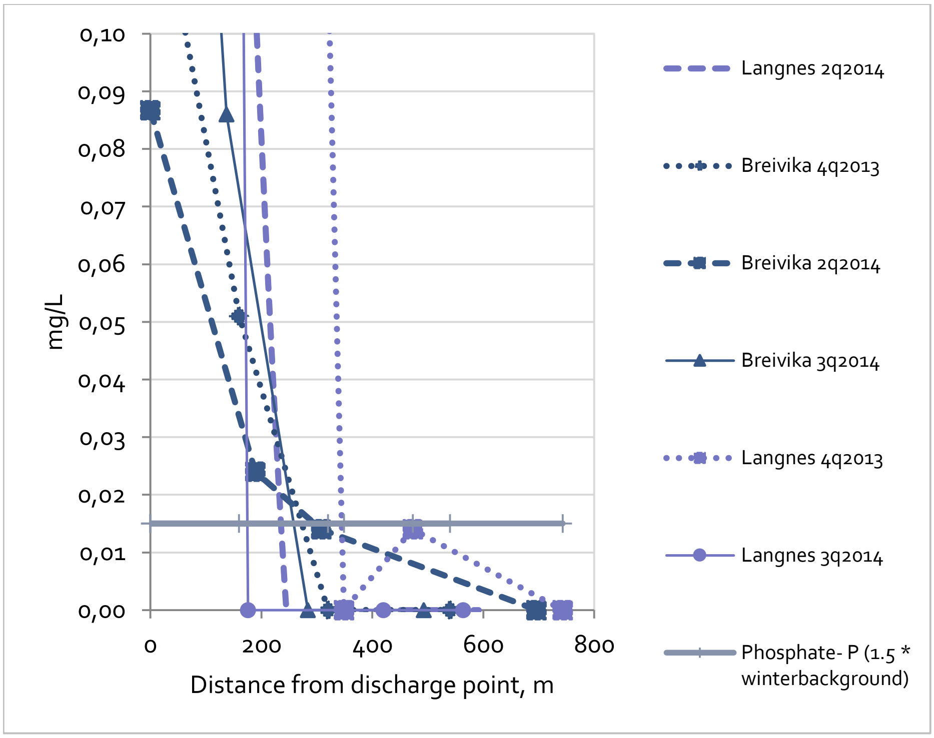


Figure 44: Transects depicting decreases in Sum C10–C14 LAS in the recipient around WWTPs in Tromsø are shown along with an ad hoc PNEC value. Lower bound data

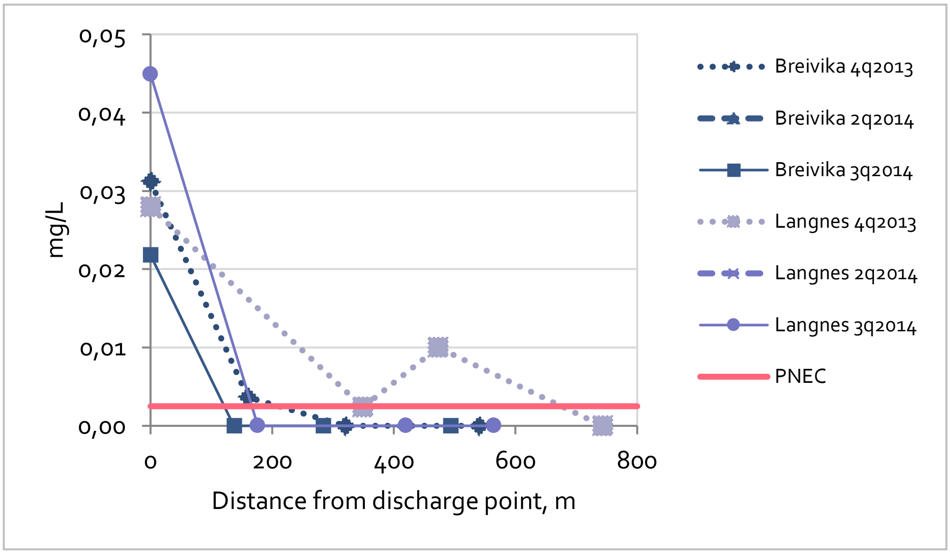


Figure 45: Transects depicting decreases in Sum OP in the recipient around WWTPs in Tromsø are shown along with the EQS value (red solid line). Lower bound data

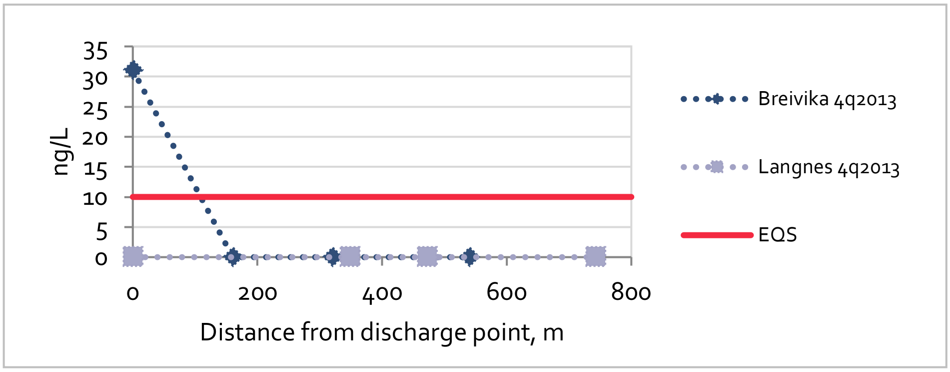


Figure 46: Transects depicting decreases in Sum NP in the recipient around WWTPs in Tromsø are shown along with the EQS value (red solid line). Lower bound data

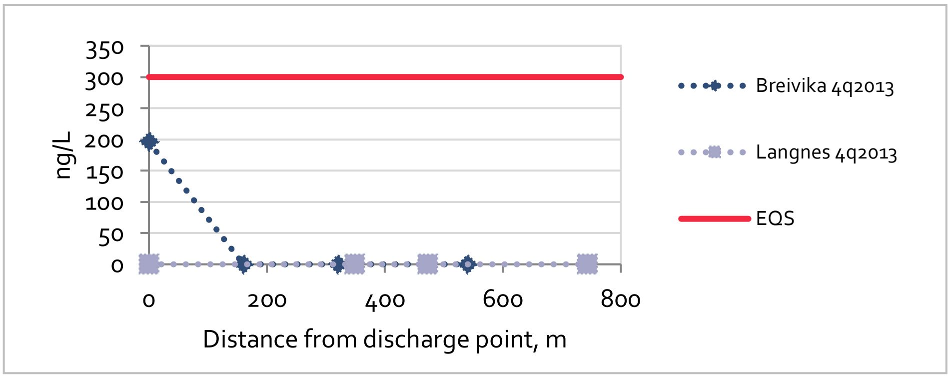


Figure 47: Transects depicting decreases in Cd in the recipient around WWTPs in Tromsø are shown along with the EQS value (yellow solid line). Lower bound data

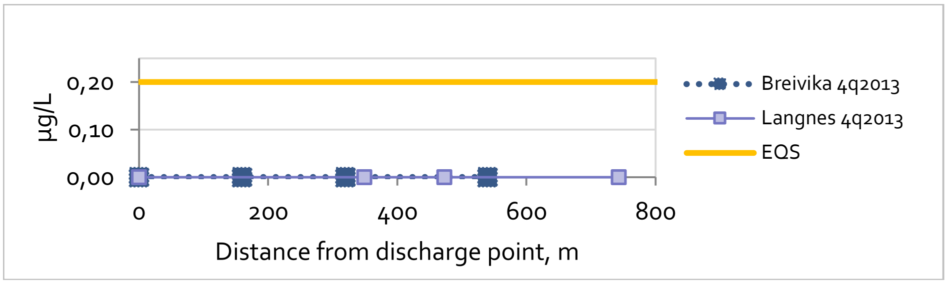


Figure 48: Transects showing decreasing DEHP in the recipient around WWTPs in Tromsø along with the EQS value (grey solid line). Lower bound data

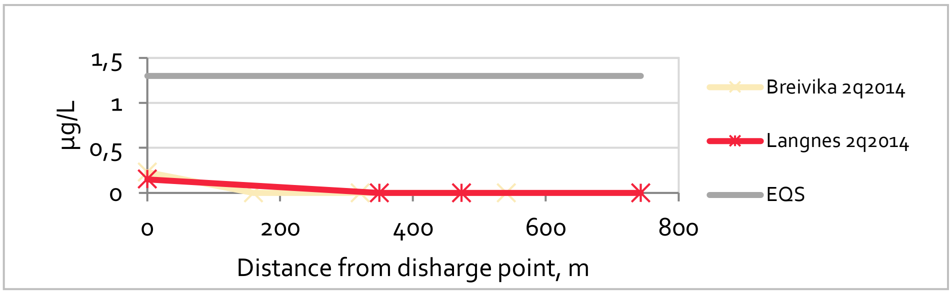


Figure 49: Transects showing Sum PFAS in the recipient around WWTPs in Tromsø. (Effluent concentration not divided by ten). Lower bound data

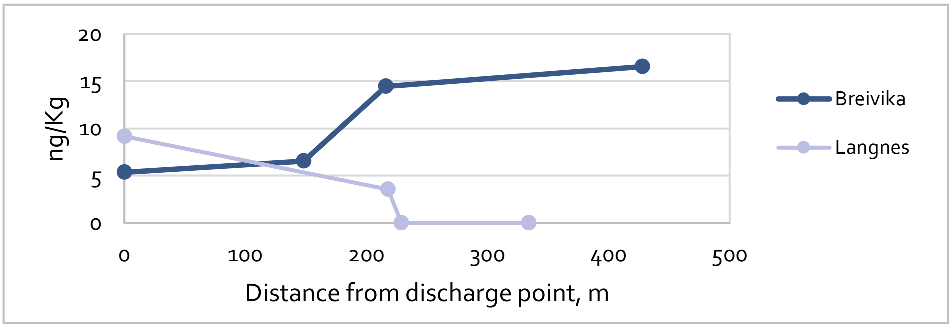
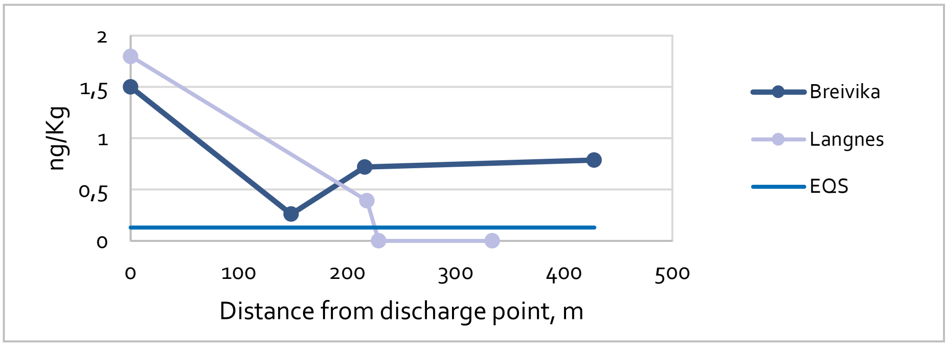


Figure 50: Transects showing PFOS in the recipient around WWTPs in Tromsø along with the EQS value (grey solid line). (Effluent concentration not divided by ten). Lower bound data



6.3 Tórshavn

In the recipient around Tórshavn, *phosphate* concentrations were generally lower than a local Environmental Quality Standard which may be defined as 1.5 times the winter background phosphate concentration. However, in samples from areas closer than approx. 200 m from the discharge points, the phosphate concentration was above this local EQS (Figure 51). *Ammonium* concentrations in recipient samples were 0.19 mg/L NH_4N or less. In influent samples to the WWTPs the ammonium concentrations were around 20 mg/L and in effluent samples, the concentration were either similar, as in the Sersjantvíkin WWTP, or less.

The highest *TOC* concentration was found in the influent samples to the LSH (Main hospital) WWTP, at 27 mg/L. The concentration of TOC in effluents were similar to or lower than that of the influent. At one recipient site, the concentration of TOC were higher than measured in the Sersjantvíkin effluent and influent samples. This is likely due to the closeness of the recipient sampling site to another wastewater discharge site in Tórshavn, the outlet known as UA22 which is near Argir marina.

The concentration of *LAS* in influent and effluent samples to the Sersjantvíkin WWTP were generally quite similar, and in the range 0.1–0.2 mg/L. In the LSH WWTP influent and effluent samples, the concentration of LAS were generally somewhat lower, overall less than 0.1 mg/L. LAS was generally not detected in recipient samples, at 0.0005 mg/L, and LAS was lower than PNEC in every recipient sample but one (Figure 52). *Octylphenol* and *nonylphenol* in recipient samples were lower than EQS (Figure 53 and Figure 54) and the respective *alkyl ethoxylates* could not be detected in any recipient sample, at detection limit 10 ng/L and 100 ng/L for octyl 1–3 ethoxylates and nonyl 1–3 ethoxylates, respectively. *Cadmium* was detected in three recipient samples from the Tórshavn area at concentrations between 0.06 and 0.09 µg/L, at sites corresponding to outside Sjósavnið, in the Sersjantvíkin bay and in Hoyvíkin bay (Figure 55). The concentration of cadmium was less than the EQS, at 0.2 µg/L in all samples. *Mercury* was not detected in any recipient sample at a limit of detection equal to 0.002 µg/L, compared to an MAC-EQS (EU Directive 39/2013) at 0.07 µg/L.

PAH was not detected in any recipient sample at detection limit 0.01 µg/L for BaP, and 0.080 µg/L for Sum PAH-16. The EQS (EU) for BaP is 0.00017 µg/L and thus an assessment based on the annual average EQS for BaP is not possible. However, compared to the MAC-EQS at 0.27 µg/L, it may be concluded that the concentration of BaP must have been well below this maximum limit. *Phthalates* were not detected in recipient samples, but were detected in wastewater samples (Appendix table 28). The phthalate occurring in the highest concentrations were DINP, DEHP and DEP, with the former two in approx. twice as high concentration in the LSH main hospital wastewater as in the Sersjantvíkin domestic wastewater line.

QAS was analysed in in all five recipient samples including the background sample. BAC was detected in three recipient samples, DDAC in two and ATAC in one. The concentrations found in the recipient samples were very low compared to the predicted no-effect levels and the environmental risk stemming from QAS were thus very low (Table 16) .

Of the 21 *PFAS* analysed, two could be detected in recipient samples: PFHxA was detected in three of six recipient samples, at concentrations approx. 0.8 ng/L, and PFOA was detected in four out of six recipient samples, at concentrations approx. 0.2 ng/L. The Sum PFAS concentations in recipients were 1 ng/L or less (Figure 57). PFOS was not detected in any recipient sample from Tórshavn.

Summing up: In the recipient around Tórshavn it appears that the nutrients and LAS would be the pollutants to prioritise for closer assessment.

Figure 51: Transects showing decreasing concentration of phosphate-P in the recipient around WWTPs in Tórshavn. Lower bound data

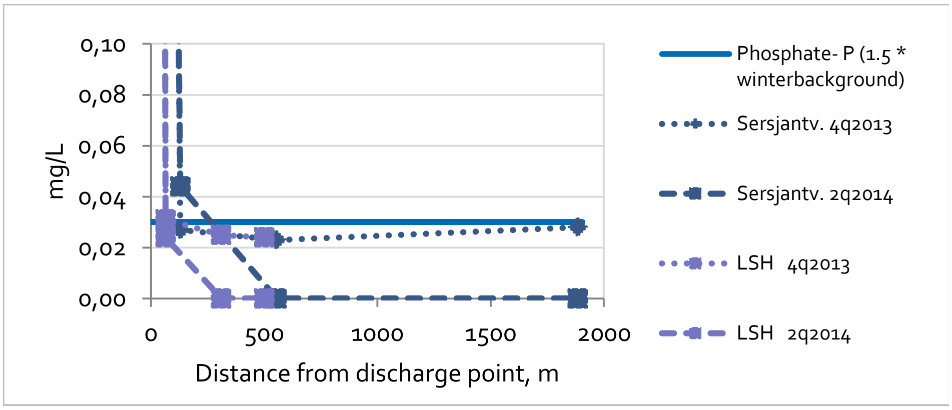


Figure 52: Transects depicting decreases in Sum C10–C14 LAS in the recipient around WWTPs in Tórshavn are shown along with an ad hoc PNEC value (orange solid line). Lower bound data

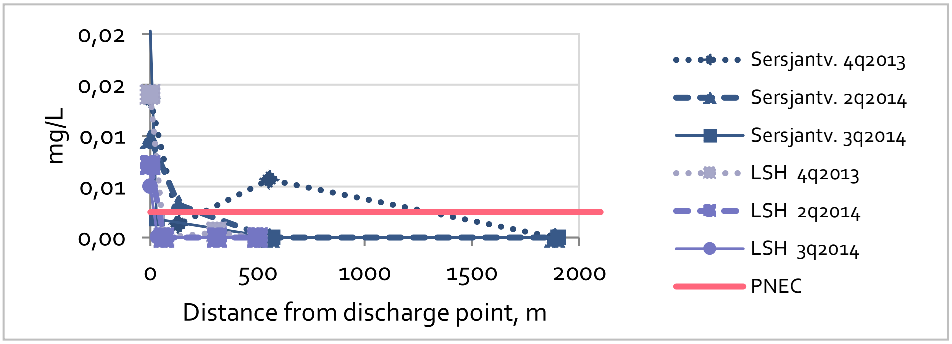


Figure 53: Transects depicting decreases in Sum OP in the recipient around WWTPs in Tórshavn are shown along with the EQS value (orange solid line). Lower bound data

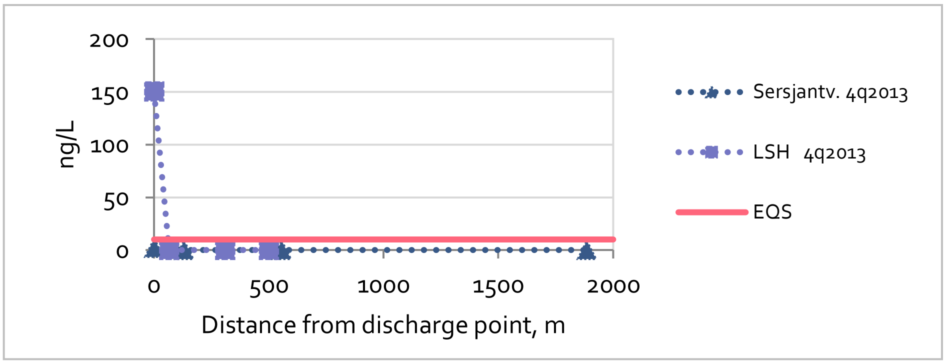


Figure 54: Transects depicting decreases in Sum NP in the recipient around WWTPs in Tórshavn are shown along with the EQS value (orange solid line). Lower bound data

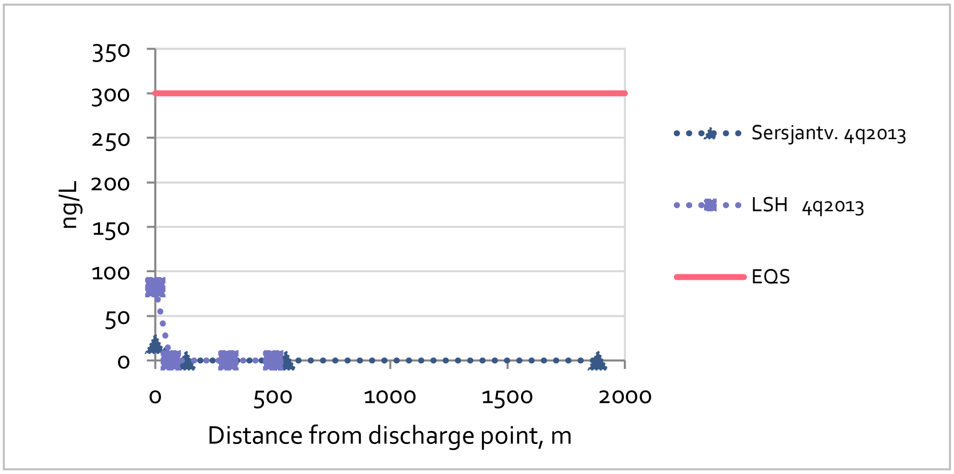


Figure 55: Transects depicting decreases in cadmium in the recipient around WWTPs in Tórshavn are shown along with the EQS value (yellow solid line). Lower bound data

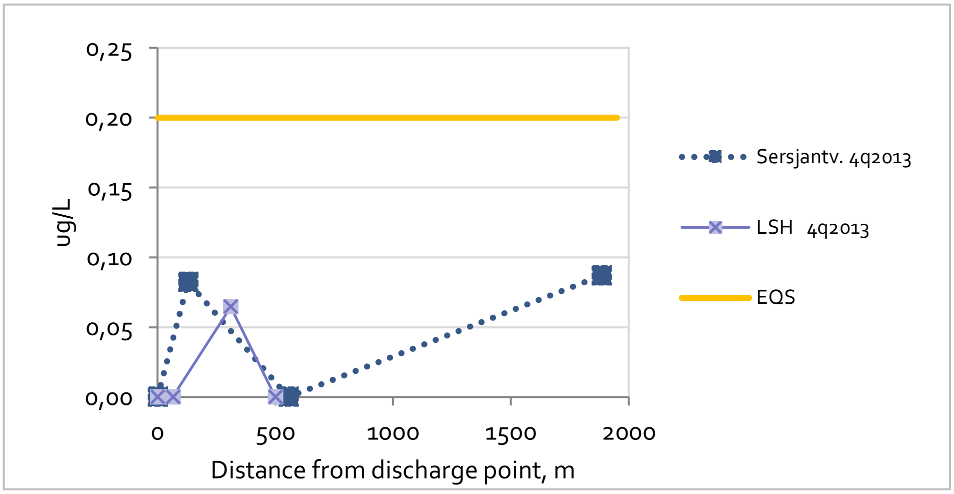


Figure 56: Transects depicting decreases in DEHP in the recipient around WWTPs in Tórshavn are shown along with the EQS value (grey solid line). Lower bound data

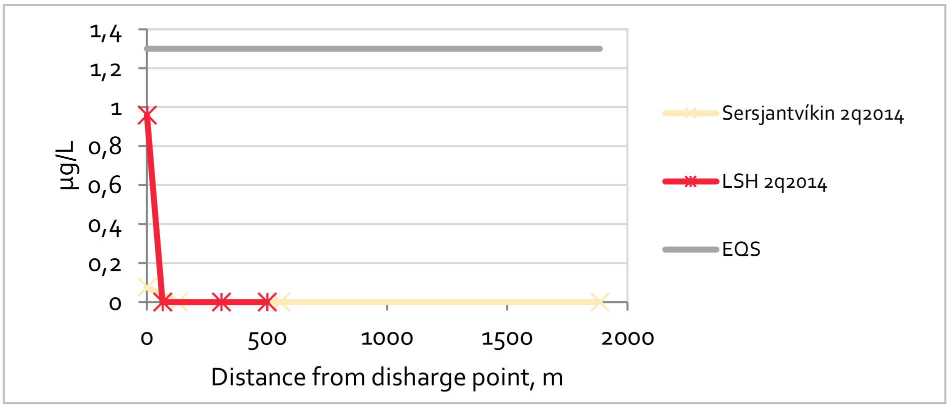
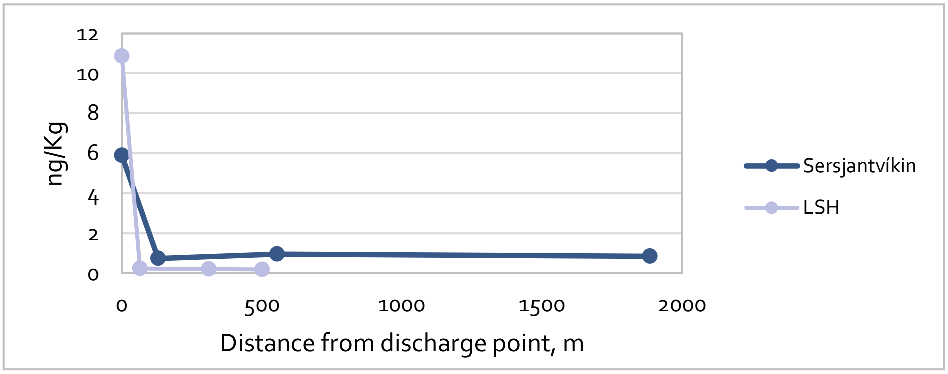


Figure 57: Transects depicting Sum PFAS in the recipient around WWTPs in Tórshavn. (Effluent concentration not divided by ten). Lower bound data



6.4 Reykjavík

In Reykjavík, the *phosphate* concentration in influent and effluent waters to the Klettagarðar WWTP were both close to 1 mg/L phosphate-P, and at the Ánanaust WWTP the influent and effluent concentrations were a little higher, at 1.5 and 2 mg/L respectively (Figure 58). In the recipient samples the concentration of phosphate was very similar to the background concentration at 0.015 mg/L, and phosphate was at most found in slightly elevated concentrations as in the October 2013 Ánanaust WWT recipient samples. The highest background phosphate concentration in the Reykjavík samples was 0.017 mg/L as measured in the October sample, and the phosphate concentration in recipient samples overall was within 50% of this background level.

Ammonium followed quite closely these phosphate concentrations in influent and effluent, although approx. at ten times higher concentrations, at around 10–14 mg/L as NH_4-N. Except in the Ánanaust effluents where the concentration of phosphate was somewhat higher relatively speaking with a ratio between ammonium-N and phosphate of approx. 6. As with phosphate, ammonium from the Ánanaust recipient samples were close to the background level, at 0.04 mg/L as NH4-N or less. The recipient samples from the Klettagarðar WWTP were somewhat elevated, in the range 0.06 to 0.09 mg/L as NH_4-N, and thus well below 1.5 mg/L (see also Ammonium in the Methods section). *TOC* was detected in influent and effluent samples only, at approx. 20 mg/L in influent and 29–45 mg/L in effluent samples.

The concentration of *LAS* was rather stable at the Klettagarðar WWTP in terms of influent and effluent concentrations, which seemed to follow each other quite closely, in the range 0.15 to 0.29 mg/L (Figure 59). At the Ánanaust WWTP the concentration of LAS was somewhat higher, in the range 0.20 to 0.35 mg/L, also in terms of influents as compared to effluents, with a tendency of decreasing concentrations in the WWTP. LAS was generally not detected in recipient samples, at DL 0.0005 mg/L, except in two samples from the 1st sampling round in October 2013, where the concentrations were 0.002 and 0.0008 mg/L.

Nonylphenol and *octylphenol* and their *ethoxylates* were not detected (DL 100 ng/L and 10 ng/L for NP/NPEO and OP/OPEO respectively) in any recipient samples from Reykjavík Figure 60 and Figure 61).

Cadmium was detected in recipient samples from Reykjavík in higher concentration than in effluents from the WWTPs, although at concentrations well below the EQS at 0.2 µg/L (Figure 62). The cadmium concentration at the background site however, was not detected at 0.05 µg/L, Thus, the recipient concentrations at 0.09 µg/L cannot be assumed to represent background, but is probably not very much elevated compared to this.

Mercury was not detected in recipient samples from Reykjavík at 0.002 µg/L, and the concentration in effluents were around 0.015 µg/L, and thus well below the MAC-EQS at 0.07 µg/L.

PAH was not detected in recipient samples in Reykjavík, at Sum PAH 16 DL at 0.08 µg/L. PAHs could only be detected in influent and effluent samples, and then at Sum PAH 16 concentrations at 0.5 µg/L, in three samples and 13 µg/L in the Ánanaust influent sample. The elevated Sum PAH concentration was mainly due to acenaphthene which alone accounted for 12 µg/L. The carcinogeneous PAHs were however not detected in any sample, at DL 0.035 µg/L.

Phthalates were detected in influent and effluent samples, but not in recipient samples, at DL 0.3 µg/L for most phthalates. The phthalate concentration was 6 µg/L in the two effluent samples, and the influent sample at the Ánanaust WWTP. At the Klettagarðar WWTP, the influent phthalate concentration was 59 µg/L, which was the highest concentration measured in the present study. The larger part of this sum was constituted by DEHP at 49 µg/L, and DINP at 7 µg/L, and small contributions from DEP and DIDP. Overall, DEHP was the phthalate most commonly detected in any sample in the present study, where it was detected in 14 out of 41 samples. DINP and DEP were detected in 25% of the samples and DIBP in 20%. DEHP in recipient samples off Reykajvík are shown in Figure 63.

Cationic surfactants, *QAS*, were analysed in a lower number of samples than the other potential environmental pollutants, since influent samples were not analysed, nor were the two most remote recipient sites samples. QAS were detected in effluent samples at Reykjavík WWTPs. The class of QAS occurring in highest concentration was DDAC, at 10,000 ng/L of Sum DDAC in effluents from Ánanaust WWTP, and 2,300 ng/L at the Klettagarðar WWTP. Sum ATAC in effluents were 6,200 and 2,600 ng/L in Ánanaust and Klettagarðar effluents, and Sum BACs were 2,400 and 2,600 ng/L respectively. Only very low concentrations, at Sum BAC of 22 ng/L or less, and lower still for Sum DDAC and Sum ATAC were detected in recipient samples. Though, if the environmental risk in the very vicinity of the effluent outlet sites is assessed based on a ten times dilution of effluents and the PNEC found in the literature, at 58 ng/L for Sum ATAC (Sandbacka et al., 2000), the possibility for environmental risk due to ATAC may not be excluded.

PFAS was detected in every sample, both influents and effluents at the two WWTPs and in the five recipient samples which were analysed successfully. The concentration of PFAS was highest at the Klettagarðar WWTP, with influent Sum PFAS at 21.7 ng/L and effluent concentration 29.4 ng/L. At the Ánanaust WWTP, the influent and effluent Sum PFAS concentrations were 6.6 and 8.5 ng/L, respectively. The main PFAS contributor at the WWTP sites was PFOS. The PFAS concentrations in one recipient sample was 4.8 ng/L, and 6:2 FTOH and PFOA were the major contributors to this. The concentration in the other recipient samples were lower (Figure 64). The PFOS concentration in recipient samples were equal to or higher than the EQS in two of the five samples (Figure 65). A high blank PFOS concentration indicates that there are some uncertainties in the representativity of the results, and this means that optimally, the PFAS analyses should have been repeated.

Summing up: In the recipient around Reykjavík it thus appears that the PFAS group of pollutants are the ones that should be looked closer into.

Figure 58: Transects showing decreasing concentration of phosphate-P in the recipient for WWTPs in Reykjavik. Lower bound data

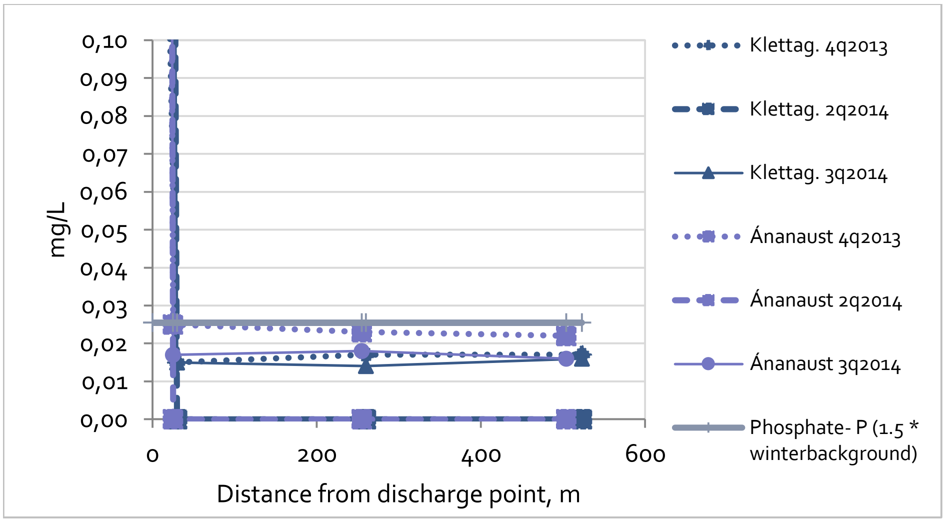


Figure 59: Transects depicting decreases in Sum of C10–C14 LAS in the recipient for WWTPs in Reykjavík are shown along with an ad hoc PNEC value (orange solid line). Lower bound data

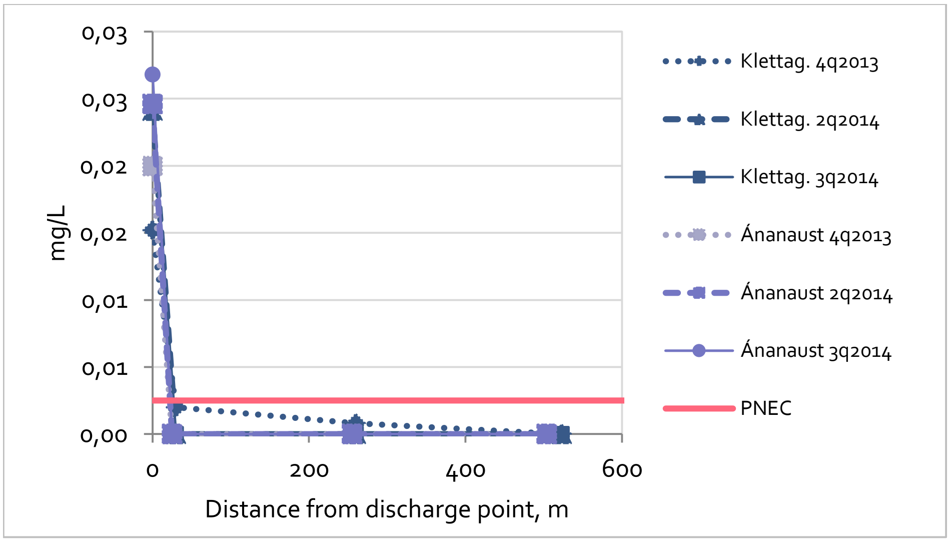


Figure 60: Transects depicting decreases in Sum of OP in the recipient for WWTPs in Reykjavík are shown along with the EQS value (orange solid line). Lower bound data

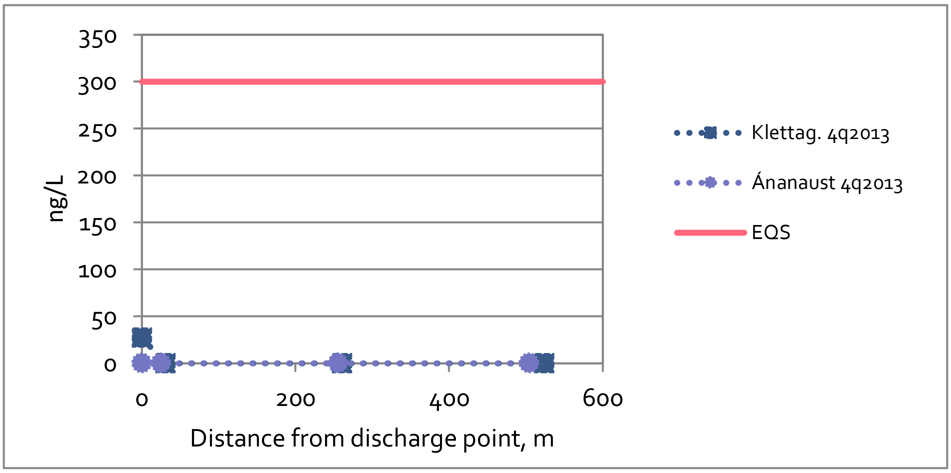


Figure 61: Transects depicting decreases in Sum of NP in the recipient for WWTPs in Reykjavík are shown along with the EQS value (orange solid line). Lower bound data

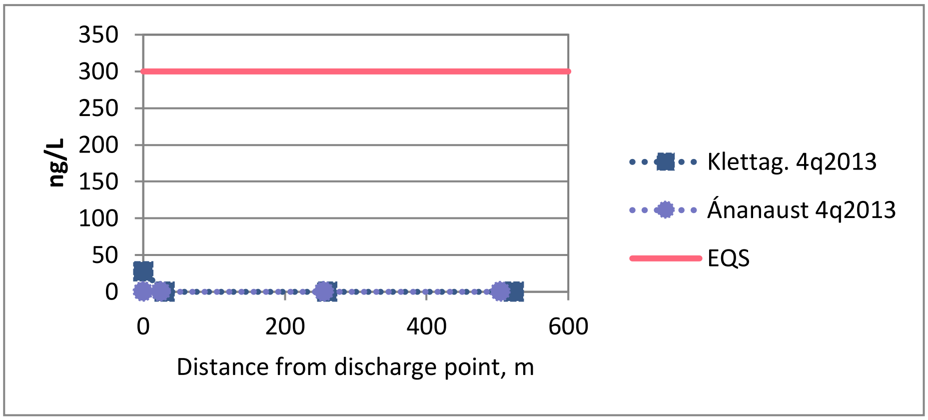


Figure 62: Transects depicting decreases in cadmium in the recipient for WWTPs in Reykjavík are shown along with the EQS value (yellow solid line). Lower bound data

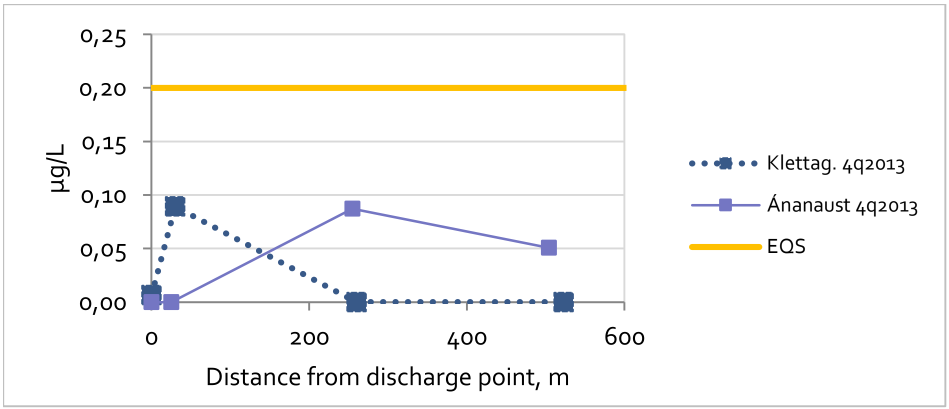


Figure 63: Transects depicting decreases in DEHP in the recipient off Reykjavík are shown along with the EQS value (grey solid line). Lower bound data

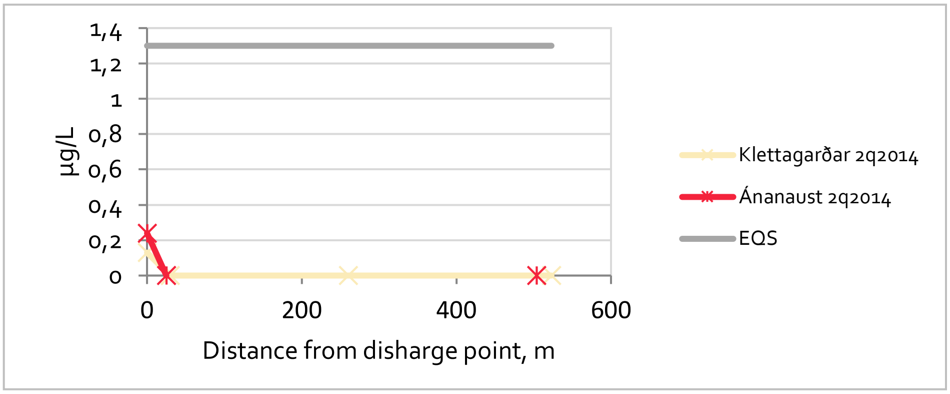


Figure 64: Sum PFAS in recipient water around Reykjavík. (Effluent concentration not divided by ten). Lower bound data

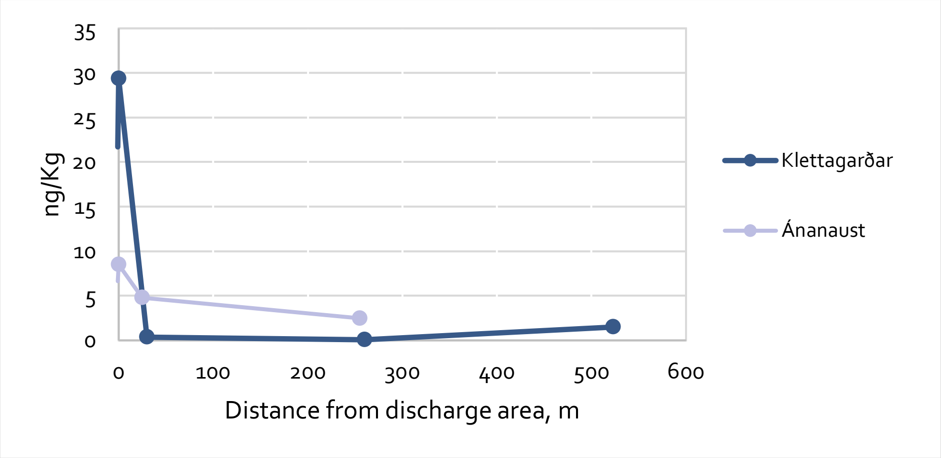
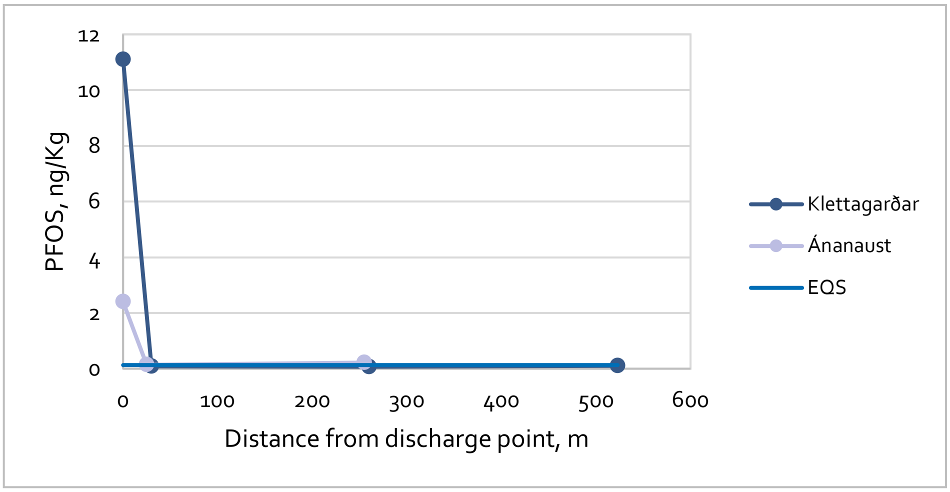


Figure 65: PFOS in recipient water around Reykjavík are shown along with the EQS value (solid green line). (Effluent concentration not divided by ten). Lower bound data



6.5 Sisimiut

The *phosphate* concentrations in the Natreno effluent samples were the highest recorded in the study, with 6–7 mg/L phosphate-P. The Ulkebugt effluent concentration was lower, at approx. 2 mg/L. In recipient samples concentrations of phosphate above the local EQS (1.5 times the background level at<0.01 mg/L phosphate-P) were found in the Ulkebugt area at all three sites in the April/May samples, and at two of three sites near the Natreno discharge site in the same round (Figure 66). Otherwise, elevated levels were noted in recipient samples also at the other two sampling rounds, though not as markedly as in the former mentioned. At the background site, the phosphate concentration was at most 0.016 mg/L, and this was in April/May 2014 sample. In the recipient samples from the Ulkebugten discharge site, the phosphate concentration was less than 0.010 mg/L in all but one sample taken in October 2013 and August/September 2014, but in the recipient 1 samples, taken approx. 50 m from the discharge site, the concentration of phosphate was 0.144 mg/L, or nine times the background concentration. Also the recipient samples taken further approx. 60 m away had phosphate concentrations that was clearly elevated and more than 1.5 times the background concentration. Phosphate was detected in the recipient samples closest to the Natreno discharge site on the three sampling campaigns. Though only in the April/May sample taken approx. 70 m from the discharge site was the concentration, 0.067 mg/L, clearly elevated above the background.

As with phosphate, *ammonium concentrations* in the Natreno effluents were the highest recorded, with 61.2 mg/L of NH_4N (Appendix Tables 28 and 29). The ratio between phosphate and ammonium in effluents from the two sites were 10 at the Natreno site and 12.6 at the Ulkebugten site. These are within the ratios found in effluents from the other study areas in the present work. *TOC* was similarly found in highest concentrations at the Natreno site, at 81.4 mg/L (Appendix Tables 28 and 29). At the Ulkebugt site, the effluent TOC concentration of 37.5 mg/L was within the range of similar samples in the study.

Also *LAS* was found in highest concentrations in the present study in the effluent samples from the Natreno outlet site, with concentrations at 0.8 to 2.9 mg/L in the three sampling occasions (Figure 67).

Nonylphenol and *octylphenol* and their ethoxylates where not detected (DL 100 ng/L and 10 ng/L for NP/NPEO and OP/OPEO respectively) in any recipient samples from Sisimiut (Figure 68 and Figure 69).

Cadmium was not detected in the recipient samples in Sisimiut (DL 0.05 µg/L; Figure 70). The effluent concentrations at the Natreno and Ulkebugten sites were 0.099 and 0.070 respectively. The former of these was thus the highest recorded in this survey but was not much higher than in the other samples, whether compared to effluents or recipient samples from other areas. *Mercury* was detected in effluent samples only, and then at concentrations of 0.021 and 0.023 µg/L, i.e. barely above the LD at 0.02 µg/L (Figure 32).

PAH was detected in the Natreno effluent sample at concentration of 150 µg/L for Sum PAH 16, which was way higher than in any other sample whether from Sisimiut or any other area in the present study (Appendix Table 30). The elevated concentration in the Natreno sample originates from fluorene, 93 µg/L, and phenanthrene, 57 µg/L, and a very small part naphthalene at 0.5 µg/L. Carcinogeneous PAHs were however not detected in any sample, at DL 0.035 and 0.18 µg/L in recipient and effluent samples respectively.

Phthalates were detected in effluent samples only, at concentrations 33 µg/L and 51 µg/L at the Ulkebugten and Natreno sites respectively. The phthalates contributing to the sum were DINP (21 to 29 µg/L), DEHP (8 to 16 µg/L) and smaller amounts, 4.4 µg/L or less, of DIDP, DIBP and DEP. The environmental risk from DEHP in the vicinity of the Natreno outlet may be non-negligible as the ten times diluted effluent at the Natreno site may exceed the EQS of 1.3 µg/L (Figure 71).

Cationic surfactants, *QAS*, were found at the highest concentrations in the present study in effluents from the Ulkebugt and Natreno site (Figure 38), where concentrations of Sum BAC were 77,000 and 27,000 ng/L respectively (i.e. highest at the Ulkebugt site; Figure 37) and Sum DDAC correspondingly 2,300 and 20,000 ng/L (Figure 36). Sum ATAC were found in lower concentrations, at 6,800 and 4,700 ng/L at the Ulkebugt and Natreno sites, respectively (Figure 35). In the four recipient samples analysed, BAC could also be detected, albeit at low concentrations, at 21 ng/L or less at the recipient sites up to 60 meter downstream the outlet sites. This BAC concentration is however well below the PNEC for BAC, at 415 ng/L (Perez et al., 2009).

The concentration of *PFAS* as the sum of perfluoroalkyl sulfonates and carboxylates in wastewater as discharged to the sea was lower in the Natreno wastewater line than in any of the other wastewater lines studied (Figure3 and Figure 40), though the concentration of sum perfluoroalkyl sulfonates in Ulkebugten effluents were not particularly low compared to the other wastewater lines analysed. The concentration of PFAS was detected in six of the seven recipient water samples analysed (not counting the background sample; Figure 72). The concentrations of PFOS was higher than the EQS in one of the eight samples, whereas in two, the DL was higher than the EQS, so the comparison is not possible (Figure 73). It appears strange that the samples taken closest to the point of discharge or even of the effluent are not the ones with the highest PFAS concentrations, however, given that the background sample from Sisimiut did not contain detectable levels of PFAS it is not unlikely that the measured concentrations in recipients represents the true situation.

Summing up: In the recipient around Sisimiut, the nutrients and PFAS group of compounds are probably the one to prioritise for future assessments.

Figure 66: Transects showing decreasing concentration of phosphate-P in the recipient for sewage lines in Sisimiut. The results are lower bound i.e. concentrations less than the detection limit has been assumed equal to zero

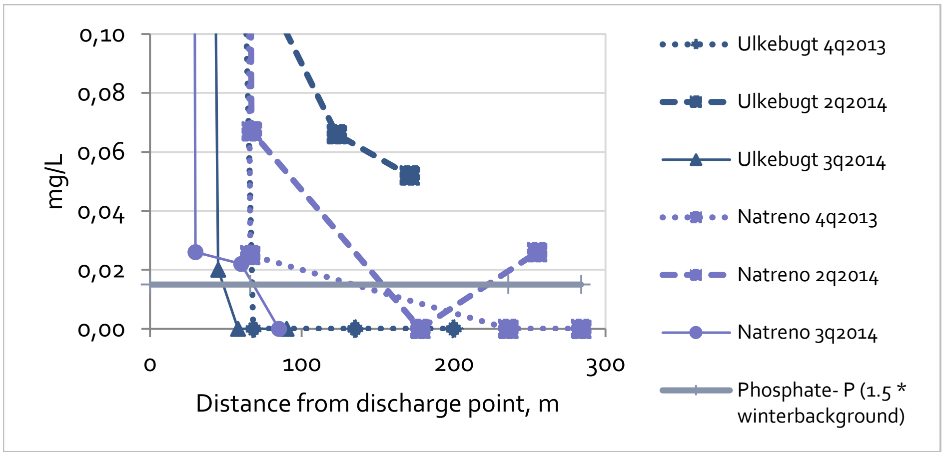


Figure 67: Transects depicting decreases in Sum of C10–C14 LAS in the recipient for sewage lines in Sisimiut is shown along with an ad hoc PNEC value (orange solid line). Lower bound data

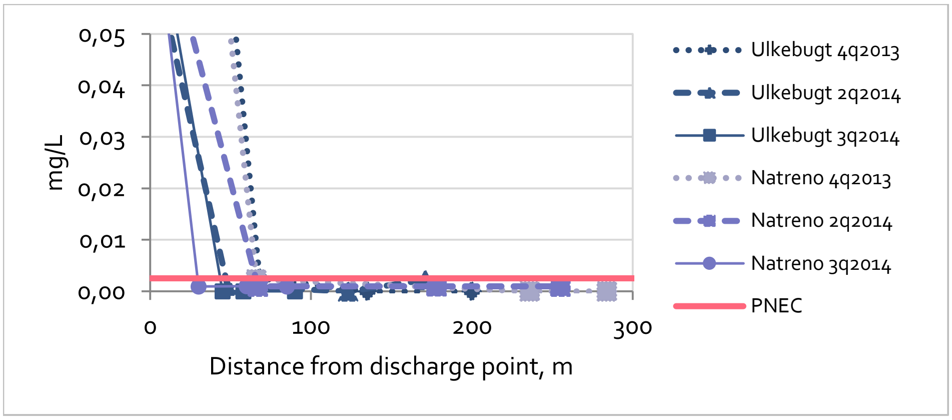


Figure 68: Transects depicting decreases in Sum of OP in the recipient for sewage lines in Sisimiut is shown along with the EQS value (orange solid line). Lower bound data

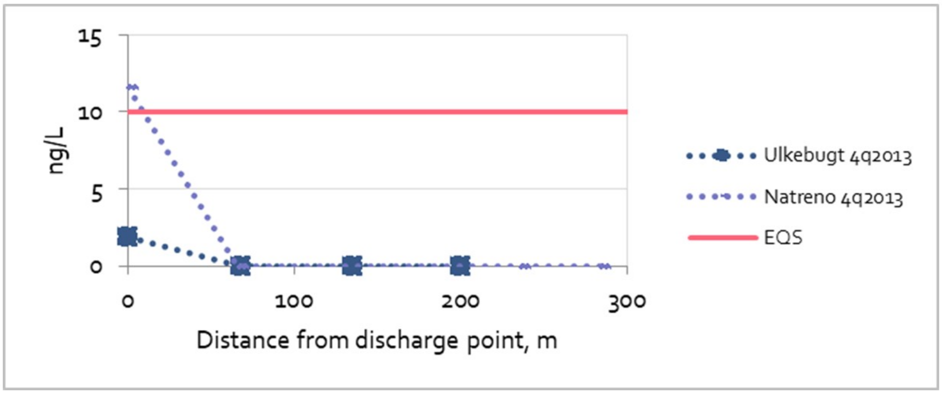


Figure 69: Transects depicting decreases in Sum of NP in the recipient for sewage lines in Sisimiut is show along with the EQS value (orange solid line). Lower bound data

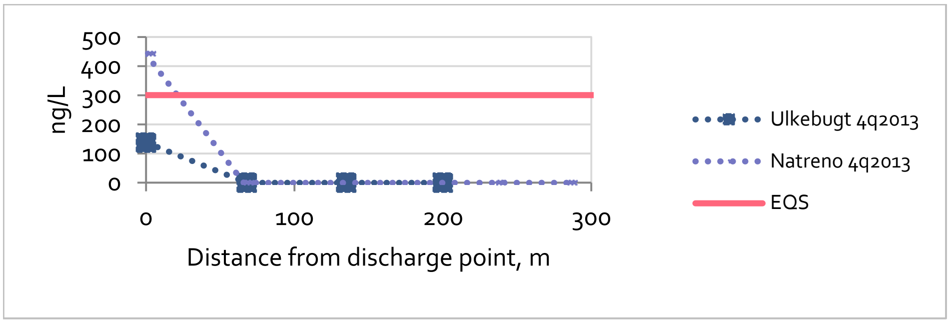


Figure 70: Transects depicting decreases in cadmium in the recipient for sewage lines in Sisimiut is shown along with the EQS value (yellow solid line). Lower bound data

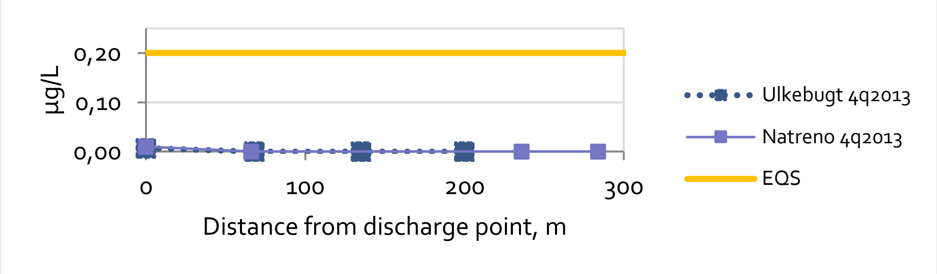


Figure 71: Transects depicting decreases in DEHP in the recipient for sewage lines in Sisimiut is shown along with the EQS value (grey solid line). (Effluent concentration not divided by ten). Lower bound data

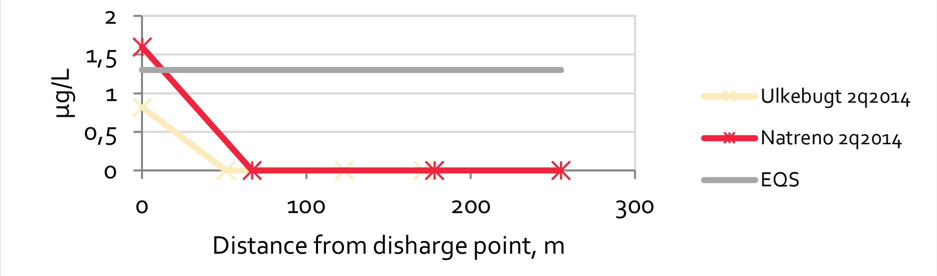


Figure 72: Sum PFAS in recipient samples from Sisimiut, Greenland, as analysed in samples from 2015. (Effluent concentration not divided by ten)

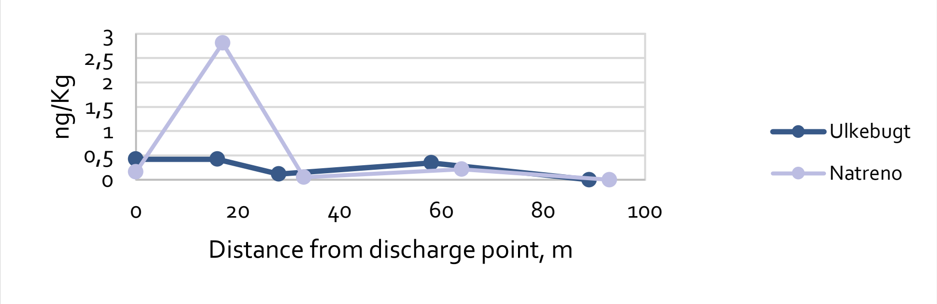
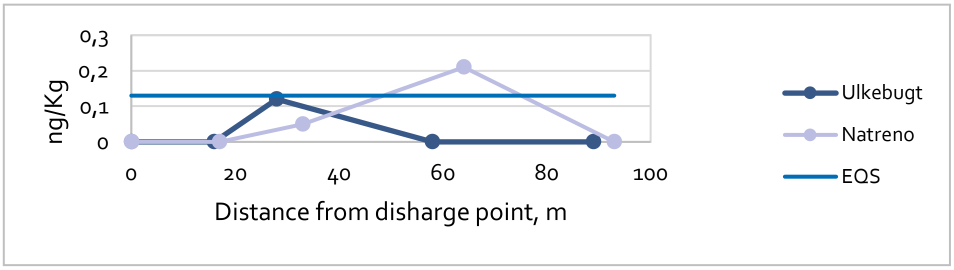


Figure 73: PFOS in recipient samples from Sisimiut, Greenland, as analysed in samples from 2015. (Effluent concentration not divided by ten)



6.6 The wastewater impact

The above has presented the analytical results for the four cities taking part in the study. In the following a short summary of results for these areas are presented for each contaminant/group of contaminants with focus on the environmental status of the recipients.

Phosphate was found at concentrations exceeding the local EQS in Tromsø, Tórshavn and Sisimiut, but not in the receiving waters for discharge from Reykjavík. The increased nutrient concentration in the recipient in relation to that of the natural, local background is shown in Table 17 as the ratio between the nutrient concentrations measured at the recipient site (Rec 1) closes to the point of discharge to that measured in the background sample. There are two wastewater discharge sites that stand out among the others in a negative way with regard to phosphates; Breivika and Ulkebugten. In Langnes, the other Tromsø WWTP, no phosphate was detected in the recipient, but as the table also shows, this may be a results of the large distance between the site of sampling of this Rec 1 sample and the point of discharge. As is seen, the distance between the first Langnes recipient sample to the effluent discharge site was minimum 176 m. The distance in meters of course is only part of the parameters that influence the dilution and assimilation of nutrients in the recipient, the exposure to water masses exchange is another. Such differences in the recipient qualities may be part of the explanation for the high concentration in the Breivika samples compared to that of Langnes, as the phosphate in effluents were not that much higher in the former (Table 14). And similarly, the effluent phosphate and ammonium concentration at the Ulkebugten site is half that of the Natreno site or less, and the distance from the effluent site similar, but the impact is rather similar. *Ammonium* was analysed in two rounds, in April/May 2014 and in September 2014. The highest median recipient concentrations in Reykjavík and Tórshavn were detected in the April/May samples, whereas in Tromsø and Sisimiut the highest overall recipient concentrations were found in the September samples. There were marked gradients of decreasing ammonium concentration going away from the outlets sites, as seen by inspecting the ratio of ammonium in the recipient sample taken closest to the outlet compared to that of the background samples (Table 17). There were no particular difference in the overall level of these ratios between the two seasons, but there were local variations. The highest ratios between recipient and background ammonium concentrations were found at the Natreno site in Sisimiut and the Breivika site in Tromsø, where levels of ammonium were increased by a factor of 7 and 6 respectively in the recipient site closest to the outlet compared to the local background level. The maximum ammonium concentration at 0.9 mg/L was found in a Breivika WWTP recipient sample taken approx. 130 m from the point of effluent discharge. No sample had ammonium concentration at or above 1.5 mg/L.

Table 17: The ratio between nutrients measured in the recipient 1 sample, i.e. closest to the outlet, to that measured in the reference (background)

WWTP	Phos-P^A	Phos-P^B	Phos-P^C	NH_4-N	NH_4-N	Distance, m	Distance, m	Distance, m
Breivika	*5.1*	*2.4*	*8.6*	1.7	6.1	160	as 1st	137
Langnes	nd	nd	nd	0.6	1.0	349	as 1st	176
Sersjantvíkin	1.4	*4.4*	na	5.1	*3.8*	130	as 1st	130
LSH	1.6	*2.4*	na	2.0	*1.1*	65	as 1st	65
Klettagarðar	0.9	nd	na	0.7	2.1	30	as 1st	30
Ánanaust	1.5	nd	na	0.9	0.9	25	as 1st	25
Ulkebugt	nd	9.0	*2.0*	5.7	2.7	68	51	47
Natreno	*2.5*	4.2	*2.6*	7.0	4.5	66	67	30

Note: $^{A, B, C}$ Analyses rounds.
Units mg/L N and P. Numbers in italic indicate a minimum ratio based on a background concentration <DL at 0.01 mg/L. nd denotes <DL in the recipient sample. na=not analysed.

LAS was analysed on three occasions, though in Tromsø one of these was done at such high limits of detection that these analyses are not comparable to the rest. The highest concentration of LAS (Sum of C10–C14 homologues) measured in a recipient sample was 0.01 mg/L which was found in a Langnes recipient sample. Of the in all four samples where LAS was higher than the *ad hoc* PNEC of 0.0025 mg/L two were from Tromsø and two from Tórshavn.

Alkylphenols, nonylphenol and octylphenol and their 1- 3 ethoxylates, were not detected in any recipient sample at DL 10 ng/L for OP and OPEO and 100 ng/L for NP and NPEO, respectively. Given the EQSs at 10 ng/L and 300 ng/L for these groups of compounds respectively, it is concluded that octyl- and nonylphenol and their ethoxylates do not appear to be present in concentrations likely to pose environmental harm. One could challenge this conclusion with respect to this being drawn on the basis of one sampling round only, but it is supported by the fact that the LAS concentrations measured in this round was higher rather than lower than in other rounds. Thus, there is no reason to assume that this was a chance low observation.

Cadmium was detected in recipient waters in Tórshavn and Reykjavík. The concentrations were elevated above background in half of the samples from these places, but did not exceed 0.1 µg/L and was thus below the EQS at 0.2 µg/L. Mercury was not detected in any recipient sample at 0.002 µg/L and thus was well below the MAC EQS at 0.07 µg/L.

PAH was not detected in any recipient samples at detection limits of 0.01 µg/L for each compound. An assessment of this finding in relation to possible environmental risk is however hampered by this detection limit being 50 times the EQS of EU for B(a)P.

Phthalates were not detected in any recipient sample at detection limits ranging from 0.3 to 0.5 µg/L. As this interval is below EU's EQS for DEHP of 1.3 µg/L, it is concluded that phthalates do not appear to be an environmental risk in these areas.

QAS was analysed in 16 recipient samples, and was detected in 10 of these at concentration levels up to 35 ng/L as sum of the three groups BAC, ATAC and DDAC. BAC was found in 10 recipient samples, mainly the C12 BAC, and to a lesser degree C14 and C18 analogues. DDAC was detected in five of the 16 recipient samples, and then mainly C10, and with equal frequency of C12, C14 and C14:16 analogues. ATAC was detected in three samples, and then only as C12 ATAC. The highest number and highest concentration of QAS was detected in the Ánanaust recipient samples. BAC was detected in four out of four samples from Sisimiut and Reykjavík at similar concentration, whereas in two of four samples from Tórshavn. The concentrations were however at most approx. 5% of the PNEC. QAS was not detected in the Tromsø recipient samples. The detection limits were very similar across the samples, and direct comparison is possible.

PFAS was analysed in 24 recipient water samples, and was detected in all but four of these; two in Tromsø and two in Sisimiut. PFOS concentration higher than EQS at 0.00013 µg/L was found in seven of the samples, whereas in two samples from Sisimiut recipient waters the comparison to EQS was hindered by the detection limit being higher than this. However, in four samples in Tromsø, two in Reykjavík and one in Sisimiut did the concentration of PFOS exceed the EQS. PFAS appears thus to be a group of contaminants that warrant closer scrutiny.

7. Discussion

Comparing measured environmental concentrations to EQS and PNEC values have been done interchangeably, depending on the availability of EQS values as these have been the preferred choice when available. The EQSs applied have been those intended to be protect the environment under constant exposure situations, i.e. are valid for annual average concentrations (AA-EQS). One might argue that for the purpose of assessing environmental status based on instantaneous concentrations of contaminants in samples of transient nature like water in a recipient body, one may also choose to use the EQS defined as maximum allowable concentration (MAC-EQS). The rationale for choosing the AA-EQS is that the sampling took place at a time with no particular peak discharge event, and the sample may therefore be regarded as a random one indicative of the environmental status at a time with relatively calm weather.

7.1 Eutrophication agents- nitrogen and phosphate

The assessment of environmental effects of wastewater discharge to the recipients were mainly based on analyses of pollutants for which the sources unquestionably were activities of or by man and human societies. Also, the assessment were to be based on pollutants who's nature left little room for uncertainty whether their presence could inflict environmental harm or not. Thus, nutrients which also have major natural sources as well as anthropogenic, were not targeted as indicators of sewage influence. However, these nutrients are well-established parameters for wastewater assessment and could contribute supporting information for instance in assessing wastewater dilution. The assessment of the measured nutrients concentrations in the recipient was based on the OSPAR guidelines (OSPAR Commission, 2002; Heslenfeld and Enserink, 2008), and locally derived quality criteria based on surface water measurements. For the assessment, the guidelines were interpreted as defining the EQSs for nitrogen and phosphor to be within 50% above the average winter natural background mean for the water body in question. Overall, the background phosphate level in Tórshavn, Reykjavík and Sisimiut appeared to be in the range 0.016 to 0.02 mg/L, with the level off Tromsø somewhat less than this. The maximum phosphate concentration encountered in the recipient waters was found in Ulkebugten, and the next highest near Breivika WWTP.

7.2 Metals and organic contaminants

Cadmium was not detected above the detection limit of 0.05 µg/L in any of the samples taken in Tromsø, neither in the WWTPs nor in the recipient Tromsøsound. Cadmium was detected in three recipient samples from Tórshavn, at concentrations between 0.06 and 0.09 µg/L. Similarly, concentrations of cadmium in the range 0.05 to 0.09 µg/L were recorded in the recipient of wastewater off Reykjavík as well as in effluents from the Klettagarðar WWTP. Cadmium was not detected at any background station, thus the natural background concentration of Cd in the water masses analysed was less than 0.05 µg/L. The AA EQS identified in the EU directive 2013/39 for surface waters, 0.2 µg/L, was not exceeded in any sample. The concentration of Hg were below the detection limit in all recipient samples (<0.002 µg/L). LAS was analysed in three rounds and was as such the best indicator on variability between analysis rounds. In the first round, October 2013, LAS was detected in every second recipient sample, and twice as often in the Tromsø and Tórshavn samples as in the Reykjavík and Sisimiut samples. Of the in all four samples where LAS was higher than the *ad hoc* PNEC of 0.0025 mg/L two were from Tromsø and two from Tórshavn.

LAS was the only group of contaminants which was analysed on three occasions. In retrospect, one could argue that it would have increased the possibility of making comparison between the various analyses campaigns if more compounds had been analysed repetitively. The rationale for choosing the strategy applied was that the focus was on recipient more than the efficiency of the single WWTPs. Thus increasing the number of potential pollutants was deemed more important to meet the overall goal of the project. However, in future work, one may want to focus on assessing the purification efficiency of selected WWTPs.

Phthalates were detected in three of the 24 recipient samples only, with DIBP being the only phthalate detected in recipients, and then at concentration of 1.6 µg/L or less. DEHP was detected in every influent and effluent sample, but generally not at concentrations that would be expected to pose a threat to the environment in the receiving water body, except in the effluents from the Natreno discharge site in Sisimiut where a 10 times dilution of effluent would render the DEHP concentrations above the EQS for DEHP of 1.3 µg/L. Important to note in this instance, was that the effluent samples for the phthalate analyses from Sisimiut consisted of composite samples collected over a day and a night, thus the phthalate results represent not merely a glimpse in time, but represents the discharge over 24 hours in May 2014.

The concentration of DEHP in wastewater was high in some influent samples, but there was quite some variability between samples in a given area and no particular trend could be discerned. Also DINP was detected in every influent/effluent sample analysed, and the concentrations were comparable to that of DEHP. Diethyl phthalate likewise was detected in the majority of the wastewater samples. Dimethyl phthalate, di-n-propyl phthalate, di-pentyl phthalate and butylbenzyl phthalate were not detected in any sample, at DL of 0.3 or 0.5 µg/L. the other phthalates (di-n-butyl- , di-isobutyl-, di-n-octyl-, di-cyclohexyl and di-isodecyl phthalate) were detected in 7–36% of the waste water samples. The highest concentration of phthalates was detected in wastewater in Sisimiut and the lowest in Tromsø with intermediate concentrations in Reykjavík and Tórshavn. The reason for the relatively low sum phthalate concentration in Tromsø samples is probably that these were not analysed for DINP which otherwise occurred at levels comparable to DEHP at the other sites.

The QAS included in the present study were DDAC, BAC and ATAC. Of these were BAC detected in 10 of the 16 recipient samples analysed, DDAC was found in five and ATAC in three. The assessment of the environmental risk posed by QAS was not straightforward due to a lack of standard quality criteria for these compounds. The concentrations were however low in most cases, although based on the concentrations measured in effluents, one would expect local negative impacts especially from the ATAC group, but in Sisimiut also from the BAC group of compounds.

PFOS was detected in water samples from the coastal waters around Tromsø at levels exceeding the EQS (EU 2013/39/EU). Due to analytical issued with some samples, the PFAS sampling was done in two rounds, in winter 2015 and in summer/autumn 2015. Two samples were sampled and analysed successfully in both rounds; a background sample from Tromsø and samples from the LSH main hospital WWTP effluents in Tórshavn. The results were in both cases that the concentrations were higher in the winter samples. This amounted to not less than a factor 10 in the PFHxA, PFOA and PFOS concentrations which were the compounds generally found in highest concentrations. Albeit the concentrations were low, they were still higher than the EQS in recipient coastal water samples. PFOS concentrations above EQS were found in 4 Tromsø coastal area samples (whereof 3 at the Breivika WWTP side), one sample in the Sisimiut near shore area and one in the Reykjavík Ánanaust WWTP recipient waters.

7.3 High concentrations of contaminants in Sisimiut effluents

The wastewater discharged to sea in Sisimiut, or as is the case with the Ulkebugten line, to estuary, were in many cases more concentrated in contaminants than wastewater discharged to recipients in the other cities of the study. This was seen for instance with phosphate, ammonium, TOC, cadmium, as it was seen for the sum of octyl and nonylphenols and their ethoxylates, LAS, phthalates, PAH and QAS. Actually only two pollutants were not in highest concentration in the Sisimiut effluent samples; mercury and PFAS. Especially the Natreno effluents were higher in pollutants than other effluent lines. Part of the explanation for these high concentrations is that wastewater are not purified before it is released to the recipient. This is in contrast to the other sites included in this study, where all wastewater is subject to some sort of purification before discharge. This is however not the only difference between the Sisimiut wastewater lines and the ones in Tromsø, Tórshavn and Reykjavík. The main reason for the higher concentration of contaminants in the Sisimiut effluents is likely that surface runoff do not enter the wastewater lines here, as it does to varying degrees in the studied wastewater lines in Tromsø, Tórshavn and Reykjavík. The limited part (approx. 15%) of grey wastewater which are discharged directly to terrain in Sisimiut (Figure 74), does not influence the sewage line effluent samples in the present study.

Figure 74: An estimated approx. 15% of total grey wastewater Sisimiut is discharged to terrain

7.4 In some cases concentrations in recipients followed a linear trend

The measured concentrations of pollutants from the wastewater discharge areas do not always appear to be declining linearly away from the discharge sites as would be the natural trend. There may be several reasons for this; in Tórshavn for instance, there is an array of wastewater outlet points so the sampling site apparently farthest from the WWTP studied is actually close to another discharge point (in Hoyvíkin). Thus; the apparent transect is not a true one in Tórshavn. In Reykjavík, the discharge from the wastewater treatment plants are taking place over a long distance, and the plumes and currents in the area will play a large role in distributing the discharge once it is released from the diffuser at approx. 20–35 meter below sea surface.

7.5 Efficiency of the sewage treatment plant

The efficiency, or degree of removal of pollutants, in the sewage treatment plants as seen from a recipient water perspective is a description of how well the WWTP holds back and/or degrades pollutants before the purified water is discharged to the recipient. The degree of purification in the WWTP may be assessed by the difference in contaminants in effluents versus that of the influents provided that it is possible to follow one volume of wastewater through the WWTP; thus the residence time in the WWTP needs to be known or alternatively the time-integrated concentrations of pollutant in effluent and influent must be known for a period which is comparable to the residence time. Such analyses were overall not possible to do within the present project, but sampling intended to meet these demands were performed in some sites as well as it could be done amidst regards also to all the other requirements and restrictions.

Some of the findings were, for LAS: No significant effects of treatment could be seen (primary treatment, septic tanks and biological treatment), meaning that there were no differences in concentrations before and after the WWTP. PAH: No effect of treatment in the WWTPs were seen for the PAHs. Phenols: No reduction was observed in the WWTPs. Phthalates on the other hand, was different. Only DEHP was found in all wastewater samples above DL. DINP probably would also have been, but the Langnes and Breivika samples were not analysed for this, so it can only be surmised. Treatment in the WWTPs had large effect on the levels of DEHP in the Langnes WWTP where more than 90% were withheld, and apparently also the Klettagarðar WWTP reduced the DEHP markedly. Sersjantvíkin WWTP also reduced DEHP in wastewater, though not the sum of phthalates as such.

Overall, it appears reasonable to conclude that the passage of wastewater through wastewater treatment facilities does little to reduce the concentration of water-soluble nutrients and pollutants, like LAS, alkylphenols and their ethoxylates and even some of the PAHs.. For some sites, like the LSH main hospital WWTP, and the Reykjavík WWTPs, part of the explanation is in the sampling which overall did not allow a thorough assessment of WWTP efficacy. However, recent studies of pharmaceuticals in WWTP indicate that even in situations where the study design allows efficiency analyses, the volume of pharmaceuticals exiting the WWTP is no less than the volume going in, and this finding was not restricted to a WWTP based solely of primary treatment, like the Breivika WWTP, but was also seen in WWTP utilizing both biological and chemical purification (Thomas et al., 2016).

8. Conclusion

Overall, the concentration of pollutants in the near-shore waters in the studied areas were low and compatible with good environmental status for the majority of the compounds assessed. However, if one uses the criteria that no pollutant must be present at concentrations above the EQS, then there are challenges with PFOS. PFOS did occur in concentrations above the EQS in recipient samples in Tromsø (four samples), Reykjavík (two samples) and Sisimiut (one sample)

The results also indicate that the concentration of the contaminants did not necessarily decrease on passage through the WWTP. The anionic detergents LAS did not decrease noteworthy in the WWTPs, nor did mercury, PAH and PFAS. No reduction in the concentration of octyl- and nonylphenols and their ethoxylates was found to take place in the WWTPs. Nutrients phosphate, ammonium, likewise appeared to go out of the wastewater treatment plant in the same concentration as it went in. Phthalates were generally not detected except DEHP and to a lesser degree DEP. DEHP was however detected in every influent and effluent sample, and these measurements showed a significant decrease of more than 90% of DEHP in passage through the Langnes WWTP. Similar decreases were seen also for the Klettagarðar WWTP where the influent DEHP concentration was the highest measured in the present study, 49 µg/L, whereas the concentration of DEHP in effluents was a mere 1.3 µg/L. A difference indeed, but as these were grab samples they are unsuited to assessment of the WWTP efficiacy. The Sersjantvíkin WWTP did catch part of the DEHP in wastewater, although not as efficiently as the others. This leaves organic material, TOC, and the contaminants that stick strongly to this, like phthalates, as the parameters which generally decreased upon passage of the WWTP, in addition to the retention of PFAS in the Tromsø Langnes WWTPs.

Thus, there is little evidence in the present study that water-soluble compounds were retained in the WWTPs.

Is the present wastewater treatment sufficient? Let's start by suggesting that merely channelling or hauling wastewater for someone else to do the purification can only with some stretch of the term be regarded as treatment. Still, that aside, the recipients appear to be overall of good environmental status when assessed with respect to contaminants. So, the answer to the question on whether the present wastewater treatment is sufficient is dependent on the criteria for what is good enough; if the aim is to protect biota of the coastal zone and maintain this environment for human recreational and harvesting purposes, then the conclusion is that for selected pollutants the purification of wastewater is questionable in the sewage lines analysed. Then remains the question of contaminants that were not included in the study- like the more visible pollution. At this point, we direct the attention to pictures taken from Google Earth of the Sisimiut coastal area (Figure 18 and Figure 21) which shows where sewage is discharged to sea, and leaves it to the discretion of the reader to decide whether this is appears to be sufficient treatment of wastewater.

For the other areas included in the present study, were wastewater treatment understood as purification is installed, the results still indicate that water-soluble stuff pass through to the recipient. In this study, we have not found that this exceeds the capacity of the recipients. Whether one chooses to target the water-soluble pollutants, as for instance by stepping up the wastewater purification or reducing the release of the pollutants to the wastewater stream, will depend on local priority.

8.1 Co-operation; transfer of knowledge and skills

A sewage treatment plant is part of the logistics of the modern society which most people are blissfully ignorant of. Even to people which has a professional interest and obligation to know- the exact function and efficiency of the WWTPs may be known only in vague outline. The experts, like those who designed the WWTP, may not be at hand nor may the oversight be close enough to allow a thorough insight in the purification achieved. This is the backdrop for some of the partners involved in the present project, and this may serve as an explanation for why the project was necessary and useful, and also for the development and adjustment in method which has taken place in the project period.

The project has included quite unequal partner cities in terms of population size, climate and access to sampling equipment and logistics. It has involved quite steep learning curves for some while all have encountered unexpected events which have arisen from the attempt to co-ordinate a study not only once but four times in areas so far apart and with all samples going into the same analysis process. That, at least was the plan, but with laboratories these days being international businesses, securing that the samples are indeed analysed at the same laboratories and with the same method may require additional alertness. That, learnt by doing, resulted in some patches in the results sheets, and even the occasional data being inapplicable for comparisons, but the majority of the analyses were successful and useful.

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Part II

Options for improved wastewater purification in selected areas

10. Introduction

10.1 Considerations around the wastewater handling issue with particular reference to Sisimiut

In the first part of the project we have assessed whether there were some substances or contaminants groups among those we have analysed that require particular attention. We have noted that there could be elevated concentrations of one or more of the compounds or groups of compounds phosphate, PFAS and LAS in recipient samples from Tromsø, Tórshavn, Reykjavík and Sisimiut. With the term elevated in this particular respect is meant that the concentration of a given compound exceeded the annual average Environmental Quality Standards, AA-EQS, which have been defined by EU in the context of priority substances in water policy, or, as is the case for phosphate, above a locally defined EQS. In Tromsø, exceedances of EQS were noted for phosphate as for the two group of compounds LAS and PFAS. In Tórshavn, recipient samples contained phosphate and one of these also LAS above the EQS. In Sisimiut exceedances were seen for phosphate and PFAS, whereas in Reykjavík only PFAS exceeded the AA-EQS. One might question the use of an AA-EQS for analyses that in some cases only represent one sample only- i.e. that the assumption that this should represent an annual average may be somewhat grand. Whether the assumption is rather bold may be assessed from the LAS and phosphate analyses which were done in three occasions. Unfortunately though, the analyses were done with high detection limits in more cases, and therefore an approximate annual average is not really accessible from these data. They do however, indicate that the concentrations that represents an exceedance of AA-EQS may not be representative of an all year average. Still, despite the finding of some pollutants in recipient waters that could be considered to be a potential environmental risk, there were also several compounds for which virtually no measurements demonstrated potential negative impacts on the recipients analysed – when assessed with reference AA-EQS. And this is despite the fact that we found concentrations exceeding the acceptable levels significantly in the discharged wastewater. Basically, this may be interpreted as we are diluting us out of trouble. This works apparently because the volume and the exchange of water in the recipient ensures rapid mixing of the wastewater. Thus, the contaminants released are not measurable at approx. 30–50 m from the coast. But is the bottom line then that there is no problem? What about the pollutants that we have not yet analysed for, as for instance the microfibers? Can we conclude that there is no problem just because we have not had the relevant analyses done yet? Maybe from an ordinary perception of wastewater treatment, but perhaps there are other ways of looking at it?

10.1.1 Reflections on the visual impact on the environment

An important aspect of wastewater treatment is the visuals. Must it be accepted that in our immediate environment various foreign elements float around that do not pose a greater danger for biology, but still represents a visual pollution, in particular to the cotton swabs, wipes, etc. which could be easily removed in a coarse filtration?

And then we have the issue with the visual effect of the discharge of black wastewater as offloaded by the tanker or in the emptying of bags from the "bag-toilets" which is done directly to the seashore. This can be seen daily in Sisimiut at least as floating brown patches on the sea surface around the coast. Looking at the discharge from prawn processing plant and the fish factory in Sisimiut, it will also be obvious that this require some treatment, at least a filtering before discharged to sea. As we have previously discussed, this is also a matter of dealing with a waste product that also represents a potential commercial value.

Although we were just routing organic materials taken from the sea back to the sea where it can enter the food web again, it is done in a very concentrated way and in a restricted area, which can by no means digest the large amounts of added material. This leads to the occasional bottom reversal, so the wastes becomes visible on the surface, not to speak of the situation of the bottom dwelling wildlife.

We should also consider whether it is important to remove microfiber, plastic and similar from wastewater. The fibres are so crushed or finely divided that they rarely are visible as individual parts in the marine environment – but that does not preclude the possibility that they do harm for instance in the fish's stomach. The removal can be done with a very fine-mesh filter cloth.

We must consider the following options:

- Compliance with international regulations; Compliance with EU Directives should be brought into play when we talk about pollutants transported over long distances with air masses or ocean currents, etc. as one generally would in cases related to international impact.
- Economy. The parameter I think we should have in mind should be the relationship between the cost of wastewater treatment in conjunction with what we have and what we will achieve; to me that belongs in the realm of local priorities.
- The visual impact of wastewater and wastewater removal. This should be an issue of local priorities, with due regard to the following comments:
  - It is hardly possible to stop contamination of the harbour environment from one day to the next, as this is affected by the international shipping rules.
  - Impacts from production of fish and other industry – here a holistic view should be taken so as to link an unspoilt environment to our commitment to sell the products we harvest from this. The wastewater should as a minimum be cleaned of visible organic particles.

- Impacts of wastewater (grey and black) should be dealt with if there is a visible impact in the local environment.
- It would be wonderful if we could afford to fish in the urban environment confidently and with clean conscience invite guests to share a fishmeal from this.

11. Description of test sites

In the present study, the possibilities for optimization of the current wastewater treatment plants (WWTPs) were investigated for selected cities and towns in Iceland, Greenland, Norway, and the Faroe Islands. The following sections provides a short description of the sites, including the current wastewater treatment facilities and the problems that arise in the recipient in relation to these. Table 18 gives a brief description of the sites, and which issues that should be addressed for each of these.

Table 18: Description of the sites treated in the present study

Country	Site	Coordinates	Person equivalents	Current treatment	Focus contaminants
Iceland	Klettagarðar and Hafnafjördur		97,000 PE 26,000 PE	Mechanical (settling + 3mm grid)	No/limited removal of microplastics from effluent
Greenland	Ulkebugten, Sisimiut	66°56’34.9”N 53°39’10.9”W	1,560 PE (domestic+ hospital)	None	Introducing primary treatment; aesthetics, TOC, nutrients, TSS
Norway	Breivika, Tromsø	69°40’30.9”N 18°58’43.4”E	18,000 PE (domestic, hospital & university)	Primary treatment, (settling + grease removal)	Nutrients (primarily phosphorous), Painkillers (paracetamol) and micropollutants in general, Microplastics (microbeads)
Faroe Islands	Sersjantvíkin, Tórshavn	62°00’29.2”N 6°45’42.7”W	11,000 PE (domestic)	Primary treatment, (Septic tank)	Nutrients (primarily phosphorous), Painkillers (paracetamol and acetylsalicylic acid), Phthalates, Hormones (natural and synthetic), Detergents, and Pathogens.

11.1 Klettagarðar and Hafnafjördur (Iceland)

The wastewater treatment in Reykjavik, the capital in Iceland, is done in two WWTPs; Ánanaust and Klettagarðar (Part I of the present report). These WWTPs are of similar capacity and design, and thus for the present discussion where options for microplastics removal are treated, the focus is one of these, Klettagarðar (200,000 PE). In addition, the discussion will include a WWTP serving a smaller city, Hafnafjördur (26,000 PE). The Klettagarðar and Hafnafjördur WWTPs are both mechanical treatment plants utilizing 3 mm screens followed by grit chambers and fat flotation.

The rationale for focusing on these two Icelandic WWTPs is that these have been subject to a previous study of the removal efficiency of microplastics in the WWTPs

(Magnusson et al., 2016). The results from the analyses were that the removal of microplastic particles (MP) in both WWTPs were completely inefficient or at least very limited, and the effluent MP concentrations are therefore high. In the study, the concentration of particles ≥300 µm in effluents from Klettagarðar was 6.3 millions MP/h and in Hafnafjördur it was 2.2 millions MP/h (Magnusson et al., 2016). Since removal of microplastics from WWTPs is still very much an area of research, this study aims at summarizing the recent research in the area. This may improve the understanding of the removal of microplastics in WWTPs and the potential options for improving the current treatment.

11.2 Ulkebugten, Sisimiut (Greenland) (GL-1)

Sisimiut is the second largest city in Greenland having approximately 5,600 inhabitants distributed into 2,240 households. Currently, all wastewater is discharged directly and untreated into the marine and estuarine waters around the city. The sewage line discharging to Ulkebugten receives hospital wastewater (about 30 beds) and domestic wastewater from 1,560 PE. Surface runoff and grey wastewater are not discharged to the sewer, but are usually discharged at the individual households and are not included in the discharge to Ulkebugten.

Ulkebugten is an estuary situated in a bay which at its deepest is 30 meters, and it is separated from the coastal area with a sill. Outside of the sill there is another wastewater line carrying discharge from the fishing industry. A number of previous investigations have shown that the rate of renewal of the waters inside the estuary is low, which allows for sedimentation in the bay of components in the carried in the wastewater. The currents inside Ulkebugten are not sufficiently strong to resuspend the sedimented material and thus a buildup of organic rich sediments takes place (Thomsen et al., 2003; Chawes et al., 2004). Whether the fishing industry wastewater discharge just outside Ulkebugten has adverse effects on the water quality in the bay is not clear (Chawes, Nielsen, & Nielsen, 2004). The results of the analyses conducted in phase 1 of this project showed that the recipient Ulkebugten has a high content of nutrients and organic matter. Previous studies conducted in Ulkebugten have shown similar results as well as problems with heavy metals in both water and sediment, indications of fecal contamination and elevated concentrations of antibiotic-resistant bacteria (Thomsen et al., 2003; Pedersen, 2008; Pedersen & Vilsgaard, 2010; Klupsch, 2014).

11.3 Breivika, Tromsø (Norway) (NO-1)

Tromsø is a city in northern Norway with around 70,000 inhabitants. Currently, the wastewater discharged from the city is treated by primary treatment. Brevika WWTP is located on the eastern part of the island Tromsøya, from where the treated wastewater is discharged into Tromsøysundet. The WWTP receives wastewater from approximately 18,000 PE, mainly households but also from the University Hospital of Northern-Norway and the campus of the Tromsø University. Breivika WWTP is a primary treatment plant consisting of a mechanical treatment step. This includes a sand filter (of the type langsandfilter Meva) from which the sewage distributes to four parallel sieving units (of the type SF6000 Salsnesfilters) each with a capacity of 45 L/s and thus a total hydraulic capacity of 180 L/s. A one-step sieving on a 350 micrometer mesh is applied. The effluent is discharged to sea at approx. 15 meters below the sea surface.

The results of phase 1 of this project showed that the recipient Tromsøysundet is generally not adversely affected by the discharge from the WWTP, apart from phosphate which was found in elevated concentrations compared to the background concentration. In addition there is a general concern of the outlet of emerging contaminants such as micropollutants (i.e. contaminants of negative environmental effect at low concentrations) and microplastics.

11.4 Sersjantvíkin, Tórshavn (Faroe Islands) (FO-1)

The Sersjantvikin WWTP is located in Tórshavn, Faroe Islands (62°00'29.2"N 6°45'42.7"W). The WWTP receives domestic wastewater from 820 PE. The WWTP involves a primary treatment step consisting of a septic tank with a volume of 129 m^3 which is emptied once a year. The hydraulic residence time (HRT) is approximately 10 hours during dry weather conditions, and can be considerable lower (about 1–2 hours) during precipitation events. The municipality of Tórshavn is planning to implement a separate sewer system, due to the high amount of precipitation in the Faroe Islands, which will increase the HRT in the septic tank. The effluent of Sersjantvikin WWTP joins with an effluent stream from another sewage line just before it is discharged to sea. The second effluent stream contributes with domestic wastewater from of approximately 10,000 PE. The main part of this wastewater has been treated in septic tanks at the individual households. The combined effluent are released about 5 meters below sea surface at a distance of about 5 meters from the shoreline.

The area around the Sersjantvikin outlet in Tórshavn is used for recreational purposes and food production (fish farming) takes place within few kilometers. Maintaining a high quality marine environment is therefore of great concern. The results of the analyses conducted in phase 1 of this project showed that the recipient of the Sersjantvikin WWTP is not adversely affected by the discharge of the investigated contaminants. Phosphate was the only contaminant that was found in the recipient at concentrations higher than the reference value which was 1.5 times the background concentration. However, previous investigations in the same area have shown high concentrations of detergents (LAS, DDAC, and BAC). Furthermore, there is interest in investigating the possible removal other emerging contaminants such as pharmaceuticals (as painkillers paracetamol and acetylsalicylic acid), hormones (both natural and synthetic), and phthalates. In addition to this, there is a focus on pathogen removal.

12. Wastewater treatment and pollutants

Wastewater can stem from a number of different sources including domestic wastewater/sewage, industrial wastewater, surface runoff and infiltration and the source origin can be very influential to the wastewater characteristics. The characteristics and the required quality of the effluent are crucial for the choice of treatment. Treatment technologies include physical, chemical, and biological processes that reduce or remove impurities from the wastewater.

12.1 WWTP treatment

The countries involved aim to meet the regulation set by the EU directive on urban wastewater treatment (Council directive of 21st May 1991 91/271/EEC, last amended in 2008) (European Council, 1991). The EU directive defines the purification steps mainly in terms of the degree of reduction of parameters like suspended solids, biological and chemical oxygen demand as well as total phosphorous and nitrogen:

> "'primary treatment' means treatment of urban wastewater by a physical and/or chemical process involving settlement of suspended solids, or other processes in which the BOD5 of the incoming wastewater is reduced by at least 20 % before discharge and the total suspended solids of the incoming wastewater are reduced by at least 50 %;" (European Council, 1991)
>
> and "'secondary treatment' means treatment of urban wastewater by a process generally involving biological treatment with a secondary settlement or other process in which the requirements established in the [directive] are respected" (European Council, 1991). "The directive also uses phrases like 'appropriate treatment' by which is meant "treatment of urban wastewater by any process and/or disposal system which after discharge allows the receiving waters to meet the relevant quality objectives and the relevant provisions of this and other Community Directives" (European Council, 1991);

The directive further dictates that for all discharges from agglomerations of between 10,000 and 15,000 p.e., and for discharges to fresh-water and estuaries from agglomerations of between 2,000 and 10,000 p.e. the requirements shall be met at the latest by 31st December 2005. These requirements relates to the degree of purification in terms of actual concentrations and relative reductions in concentrations in parameters like BOD_5, COD, total suspended solids, and for sensitive recipients where eutrophication may occur, also phosphorus and nitrogen. The directive are of course only legally binding for member states and states which have specific agreements with EU, but the criteria has been defined so as to protect the environment and those are likely to be protective of environments also outside the legal reaches of the directive.

These functional aims may be reached by a variety of processes that can be can be applied at a WWTP: preliminary, primary, secondary, and tertiary treatment. The purification frequently consists of a tiered approach, but there is no strict order of sequence of the WWT treatment steps, but a suitable combination is selected based on the local requirements and restraints.

12.1.1 *Preliminary treatment*

The main purpose of the preliminary treatment is to protect the operation of the WWTP which is done by removing constituents from the influent wastewater which potentially can clog or cause damage to the subsequent treatment processes. The treatment devices, often a grid, are designed to remove or reduce the size of large, entrained, suspended or floating solids, such as wood, glass, cloths, plastics and fecal matter. Alternatively or additionally, the pretreatment can include a sand channel, where sand and gravel settle.

12.1.2 *Primary treatment*

The purpose of the primary treatment is to settle and remove the suspended and generally organic matter from the wastewater. In the primary treatment step the wastewater flows through a primary sedimentation tank/clarifier e.g. a septic tank, where heavier solids settle to the bottom of the tank, while grease and oil floats to the surface and are skimmed of if this step is not included in the preliminary treatment.

12.1.3 *Secondary treatment*

The main purpose of secondary treatment is to reduce the colloidal and soluble organic matter as well as reduce the concentration of nutrients in the wastewater. The secondary treatment step is biological process, where micro-organisms utilize the soluble organic matter in their metabolism and bind some of the colloidal matter in flocs. The nutrient nitrogen can be removed by nitrification (requires an aerobic environment) and subsequent denitrification (requires an anoxic environment). The nutrient phosphor can also be removed biologically (in aerobic conditions) or be chemically precipitated. Secondary treatment systems are often classified as either fixed-film/attached growth systems, such as biofilters, or suspended growth systems e.g. activated sludge systems. These systems also include a secondary clarifier where the biologically suspended particles are settled.

12.1.4 *Tertiary treatment*

The main purpose of tertiary or advanced treatment is to further improve the water quality of the effluent from the secondary treatment process. The motives for this can be that the preceding treatment processes are unable to reduce the contaminant concentrations in the effluent to a satisfactory level. This can either be due to the composition and characteristics of the influent wastewater (which can contain high concentrations of certain contaminants e.g. pathogens and pharmaceuticals not removed in the primary and secondary treatment processes), or because the effluent is released into a sensitive recipient or used for purposes (such as irrigation) which requires a higher degree of purification. Examples of tertiary treatment are disinfection, filtration, advanced oxidation processes (such as ozonation, and hydrogen peroxide), activated carbon, and reverse osmosis.

The sewage sludge, which is a by-product of wastewater primary, secondary and tertiary treatment, is often also treated at the WWTP. The treated sludge can sometimes be reused for composting or land applications or be incinerated.

12.2 Pollutants

12.2.1 Nutrients: phosphorus and nitrogen

Nutrient pollution, also referred to as eutrophication, is a vast problem in aquatic environments in relation to the discharge of wastewaters around the world. Eutrophication or nutrient pollution may occur when high loads of nutrients, primarily nitrogen and phosphorus, are added to a water body by either a natural source or an anthropogenic source such as a wastewater outlet. In a water body nutrients act as fertilizers which can cause algal bloom, and eventually hypoxia or oxygen depletion. Due to the problems related to nutrient pollution, the concentrations of total nitrogen and total phosphorus from WWTP outlets are regulated by the European Urban Waste Water Directive (European Council, 1991). Nitrogen can be removed from wastewater by biological or physico-chemical processes. The biological processes are commonly applied to the treatment of both household and industrial wastewaters. This is usually done in the secondary treatment by means of nitrification and denitrification. Phosphorus removal can, like nitrogen removal, be achieved by either biological or physico-chemical processes. Biological removal can achieved by means of phosphate accumulating organisms in the primary sedimentation tank, often in combination with sludge fermentation. The performance of this removal strategy is very site specific and dependent on the wastewater characteristics. The removal of phosphorus is mostly achieved by chemical precipitation with iron or aluminum salts rather than biologically.

12.3 Micropollutants

In addition to the main components of in sewage, i.e. natural organic matter with nutrients, fats and solids, the wastewater will almost invariably also contain contaminants often of industrial origin which may be toxic in the natural environment. Examples of such are heavy metals and synthetic manmade compounds like pesticides, pharmaceuticals, various industrial chemicals as well as polymers. These pollutants may be referred to with the common term micropollutants, which reflects the facts that these occur in low concentration compared to the main components in domestic wastewater. Generally, there are four different ways of improving the removal of micropollutants from wastewater: 1; Optimizing existing treatment operation and technologies, 2; upgrading existing treatment plants, 3; applying source separation methods, and 4; introducing source control measures. In the frame of this study it will be relevant to consider the first two possibilities; optimizing or upgrading WWTPs.

Since the present WWTPs for municipal wastewaters are not designed to eliminate micropollutants, these substances are often insufficiently removed in the WWTPs. In order to improve the removal of micropollutants in WWTP effluents there are two major factors to consider; the internal and the external factors.

The internal factors are the biodegradability and the physiochemical and properties related to the micropollutants including the sorption capacity, the acidity, the compound structure and size, and the volatilization rate (Eggen & Vogelsang, 2015; Luo et al., 2014a). In order to reduce the discharge of micropollutants from a WWTP it is therefore important to know the wastewater characteristics and how target compounds can be eliminated in the treatment processes. Source separation and source control measures can also be effective measures to reduce the effluent concentrations of micropollutants. This can e.g. be achieved by identifying point sources (e.g. industries and hospitals) and implementing on-site treatment facilities, or by reducing the use of micropollutants that are not removed in WWTPs. The latter is for instance attempted in Sweden, where pharmaceuticals have been classified based on their environmental hazard characteristics (persistence, potential for bioaccumulation and toxicity) and their environmental risk profile (includes predicted or measured environmental concentration relative to toxicity data of predicted no effect concentration, PEC/PNEC) (Janusinfo, 2016). Thereby, the environmental effects can be taken into consideration when pharmaceuticals are prescribed.

The external factors that may be adjusted to remove the micropollutants are the factors related to the operation and conditions in the WWTP, which is what primarily will be addressed here. The external factors includes e.g. the sludge retention time (SRT), hydraulic retention time (HRT), redox conditions, temperature, pH and organic loading (Eggen & Vogelsang, 2015; Luo et al., 2014a). Studies show that the degree of removal of micropollutants in the primary treatment processes are highly depended on the sorption capacity of micropollutants, and this step is therefore ineffective in the removal of many highly water soluble micropollutants. The removal of micropollutants in conventional secondary treatment increases compared to primary treatment due to biotransformation/degradation and increased sorption (Luo et al., 2014a). Generally, favorable conditions for the removal of micropollutants are high SRT (promoting the growth of slow growing nitrifying bacteria that are believed to co-metabolize a number of micropollutants), high HRT (increasing both biodegradation and sorption of micropollutants), aerobic conditions, warmer temperatures (which promote microbial activities). These rules of thumb are however not always valid, as some studies have shown that extended SRT does not have any effects on the removal of micropollutants, and that anoxic conditions are favorable for the removal of some micropollutants (Luo et al., 2014a).

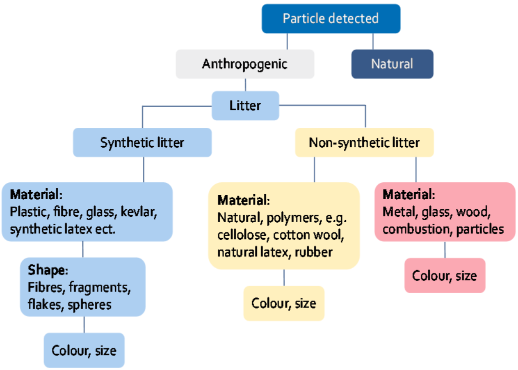
Secondary treatment has proven insufficient for some micropollutants that are persistent and not sorped to the sludge. The removal of micropollutants can be further improved by means of tertiary treatment, including advanced oxidation processes (AOPs), membrane filtration, and adsorption. These methods are however often very energy consuming, can cause undesired byproducts and are affected by both internal and external factors (Eggen & Vogelsang, 2015; Luo et al., 2014a).

13. Purification options for Klettagarðar and Hafnafjördur (Iceland): Microplastics

13.1 Microplastics definition

Marine litter has been subject to increasing concern during the last years and that marine littering should be considered a "common concern of humankind" (UNEP, 2016). Marine litter is defined by Magnusson et al. (2016) as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment". By this definition marine litter consists of e.g. plastics, wood, metals, glass, rubber, clothing, paper. Inputs to sea may be from normal operations, accidental losses or deliberate discarding. No international standards have been set for the classification of marine litter, however Magnusson et al. (2016) have made a suggestion for a classification, which is presented in Figure 75. In this work only microscopic synthetic litter made from plastic, i.e. microplastics, have been investigated.

Figure 75: Purification options for Klettagarðar and Hafnafjördur (Iceland): Microplastics



Microplastics may be defined as plastics that are less than 5 mm in size and is separated into two different types based on the source of the plastics; primary and secondary microplastic. Primary microplastics are the plastics that are intentionally manufactured to be microscopic in size e.g. in personal care products such as tooth paste and cosmetics as in facial scrubs. Secondary microplastics are the plastics that are formed when larger pieces of plastics are eroded and fragmented by environmental stressors such as wind, water or photo degradation. It can also be formed by abrasion of plastic- or painted surfaces and wear and tear of e.g. clothes (Murphy, Ciaran, Frederic, & Quinn, 2016; Lassen *et al*., 2015). The microplastics are often also classified according to shape, color, size, etc., see Figure 75. In recent studies conducted in the Nordic countries (Sweden, Norway, Finland and Iceland) microplastics have been subdivided into fibres, fragments, and flakes (Magnusson et al., 2016; Magnusson, 2014; Magnusson & Wahlberg, 2014; Magnusson & Norén, 2014).

13.2 Microplastics in the environment

Microplastics have been observed in the marine environment since the 1970s. However, it is only in the past decade that the scale and importance of the problem has received much attention. As a consequence hereof, only relatively few studies have been conducted of the sources, pathways, and adverse effects of microplastic in the marine environment (Lassen et al., 2015; DHI, 2015; Magnusson et al., 2016; UNEP, 2016). Most studies however, suggest that secondary microplastic is the main source of microplastics in the oceans and that the most prominent emission sources are road wear and the abrasion of tires as in Sweden, Norway and Denmark (Sundt *et al*., 2014; Lassen *et al*., 2015; Magnusson *et al*., 2016). However, it is uncertain how many of these particles that are transported to water recipients and how many that are permanently deposited in the ground near the road surfaces (Magnusson et al., 2016).

Microplastics can potentially cause adverse effects in the marine environment due to the physical presence effects of the intake of these on species and the possible toxic effects that may accompany the release of hazardous substances on or in the plastic, e.g. bisphenol A, phthalates, biocides, nonylphenol etc. (Lassen *et al*., 2015). In addition to this, hazardous PBT-substances (persistent, bioaccumulative and toxic) can be adsorped to either the microplastics or the biofilm surrounding the microplastic, which can potentially cause problems if released (Lassen *et al*., 2015; Sundt, Schulze, & Syversen, 2014). UNEP (2016) concluded that there is enough evidence to suggest that marine plastics and microplastics have a negative impact to invoke the Precautionary Approach, which means that society should start reducing plastic inputs to the ocean now, and not wait until the magnitude of impact has been quantified.

13.3 Microplastics in WWTPs

WWTPs are not designed for the removal microplastics and other microlitter, and any retention of these particles in a conventional wastewater treatment process is an unintentional but positive side-effect (Magnusson et al., 2016). The discharge of microplastics from WWTPs is a fairly new area of research. However, there are strong indications that WWTP discharge contributes significantly to the outlet of microplastics; several studies have shown elevated concentrations of microplastics in the recipient at and downstream of the outlets of WWTPs compared to background measurements (DHI, 2015; Magnusson *et al.*, 2016; Magnusson & Norén, Screening of microplastic particles in and down-stream a wastewater treatment plant (NUMBER C 55), 2014). The relative magnitude of WWTP-effluents as source of microlitter compared to other sources is however still unclear due to the scarcity of data in this area (Lassen et al., 2015; Magnusson & Norén, 2014).

13.3.1 Microplastics in effluents from WWTP

The outlet levels and/or removal efficiencies of WWTPs have been investigated for a number of primary, secondary and tertiary treatment plants. The removal efficiency and effluent levels of microplastic for a number of these have been summarized in Table 19. Furthermore, a few studies have measured the removal of microplastics in the various stages of the treatment process; Table 20 summarizes the removal after each treatment step in a Norwegian secondary WWTP and a Scottish secondary WWTP in Glasgow. It should be noted that direct comparisons between the studies presented in Table 19 and Table 20 are not warranted because a common standard method for quantifying microplastics has not been determined at this point in time and the findings of the different studies are therefore not necessarily directly comparable. Several other studies have measured the final effluent levels of outlet from the WWTPs in e.g. Germany; however as these studies do not contain data on the influent levels of microplastics it is not possible to determine the removal efficiencies of the treatments.

The overall results from Norwegian, Swedish, and Finish studies showed that non-synthetic anthropogenic fibres (cf. Figure 75) are more efficiently removed in the WWTPs than microplastics. Furthermore, larger microplastic particles (>300 µm) are retained in the WWTPs to a larger extent than smaller particles (>20 µm) (Magnusson & Wahlberg, 2014; Magnusson et al., 2016; Magnusson 2014).

13.3.2 Preliminary and Primary treatment

Mechanical treatment as sieving seems to be ineffective in the retention of microplastics (Magnusson et al., 2016; Murphy et al., 2016). In the two Icelandic mechanical WWTPs, both consisting of settlement pools followed by sieving on a 3 mm mesh filter, there were no significant difference between the influent and effluent levels of microplastics. The small differences observed were most likely caused by sampling method. Hence, no or very limited retention of microplastics occurs during this kind of primary mechanical treatment processes (Magnusson et al., 2016).

Chemical treatment, where phosphorus is precipitated with ferric or aluminum salts followed by addition of polymers and settling, appears to improve the retention of microplastics considerably compared to mechanical sieving treatment. The two Norwegian chemical WWTPS Tönsberg and Fuglevik had removal efficiencies of 97% and 99% respectively for microplastics ≥300 µm. In both WWTPs particles in the influent ≥300 µm were dominated by plastic fibres whereas the effluent contained greater amounts of plastic fragments (Magnusson, 2014). The removal efficiencies of particles ≥20 µm were 88% Tönsberg and 91% for Fuglevik (Magnusson, 2014). A study in the Glasgow WWTP investigated the removal for particles ≥11 µm, and this showed that post-primary treatment (screening, grit and grease removal, addition of ferric and a polymer followed by a settling tank) the level of microplastic was reduced by 78%. The study also showed that the infamous microbeads which amounted to only 3% of the total inlet microplastic, were removed during the grease removal in the preliminary treatment step and where not detected in the outlet (Murphy et al., 2016). These findings indicate that chemical treatment improves the retention of microplastics and that it appears to be more efficient for the removal of larger particles than of smaller ones (Magnusson et al., 2016).

13.3.3 Secondary and Tertiary treatment

Several studies have been conducted on the removal efficiencies of microplastics from secondary and tertiary WWTPs, cf. Table 19. These studies indicate that there is an effective removal of microplastics in both types of WWTPs (Carr, Liu, & Tesoro, 2016; DHI, 2015; Murphy, Ciaran, Frederic, & Quinn, 2016; Magnusson *et al*., 2016). However, even though only a small fraction of the microplastic passes through the treatment system and enters into the receiving water body, the effluent level of microplastics can still be high because the influent level of microplastic is often high, cf. Table 19. Like in the primary WWTPs, the dominant form of microplastics in the influent was fibres, whereas the effluent contained a larger fraction of plastic fragments (Magnusson, 2014; Magnusson et al., 2016). Hence, the removal efficiency of microplastics appears to be affected by the shape of the particles, since plastic fibres were retained to a higher extent than plastic fragments in all the investigated Nordic WWTPs.

The *secondary* WWTPs generally showed excellent removal efficiencies; >99% for particles ≥300 µm in Långevik, Kalteva and VEAS (Magnusson, 2014; Magnusson et al., 2016). The removal of particles ≥20 µm were 87% and 97% for Långevik and VEAS respectively. The results from VEAS showed that the concentration of particles ≥300 µm were reduced by a factor 10 in the biological treatment compared to the chemical treatment step whereas the particles ≥20 µm were only reduced by a factor 1.3 compared to the chemical treatment step, cf. Table 20 (Magnusson, 2014). However, the Scottish WTTP, that was screened for microplastics ≥11 µm, showed effective removal in the secondary treatment step (aeration basin, addition of polymer, clarification and outfall); the level of microplastic was reduced by 98% after the secondary treatment, corresponding to a reduction of a factor 14 better than the chemical treatment, Table 20 (Murphy et al. 2016).

The tertiary WWTPs generally showed removal efficiencies similar to those of secondary WWTPs, cf. Table 19. In the Finish studies, the secondary WTTP Kalteva had a better removal efficiency and a lower level of microplastics in the effluent (per PE), than Viikinmäki WWTP, that utilize tertiary biological filtration (Magnusson et al., 2016). However, tertiary treatment in Viikinmäki improved both the removal of fibres and synthetic particles in the effluent compared to the previous treatment steps (Talvitie et al., 2015). In the Swedish WWTP, Henriksdal, there was observed no additional reduction in the number of microparticles after the wastewater had passed through the tertiary sand filter. However, in Rya WWTP that utilize a 15 µm disc filter in the tertiary treatment step, the effluent number of particles with a size >300 µm were considerably lower than in the other two Swedish WWTPs. However, there were no such difference for particles >20 µm (Magnusson & Wahlberg, 2014). Furthermore, the effluent from Henriksdal WTTP was also passed through another tertiary treatment step; a membrane bioreactor (MBR) at a test plant at Hammarby Sjöstadsverket. This treatment step reduced the number of particles >20 µm to about ten percent of what was found in effluent water from the other Swedish WWTPs (Magnusson & Wahlberg, 2014).

Generally, the knowledge of the effects of tertiary treatment on removal efficiency of microplastics is still limited. It appears that some treatment methods (biological filtering, MBR, 15 µm disc filter) decrease the effluent levels of microplastic, while other methods (sand filtration) have shown limited effects compared to secondary treatment. In a recent report from Sundt et al. (2016) regarding measures and reduction potentials of microplastics in Norway, improving wastewater treatment and optimising existing technologies were considered effective measures for reducing microplastic in the environment. It was suggested that suspended solids can act as a surrogate parameter for microplastics and a link could thereby be made between technologies for particle removal in general and removal of microplastic particles. A number of different technologies utilizing microfiltration as an add-on polishing step after conventional biological/chemical treatment was suggested. These were based on Norwegian conditions but included sand filters, drumfilters with micro filter disks (from 10 µm) and MBRs (pore size in the filters is normally lower than 0.5 µm). MBRs was considered the most suitable for new treatment plants or existing plants with only mechanical treatment, and is also the method providing the lowest effluent of suspended solids (Sundt et al., 2016). According to Sundt et al. (2016), an effective filtering system can give an additional retention of 90% for particles in general, and they assumed the removal of microplastic could be equally effective. Whether this high retention will be observed in an actual situation may be questioned, since several of the studies in the Nordic countries (Magnusson et al., 2016; Magnusson & Wahlberg, 2014; Magnusson, 2014) have shown that retention of non-synthetic particles is generally higher than that of microplastics in WWTPs.

13.3.4 *Microplastics in sludge*

Studies of WWTPs show that most of the microplastic in the influent water is retained in the sludge. Sludge is often used as a fertilizer, and as a consequence hereof, there is a risk of this being a pathway for microplastics into the environment. Currently, no data is available on the degradation of microplastic in the wastewater treatment steps, but Lassen et al. (2015) expect that mineralisation of microplastics in WTTP treatment is insignificant, which is supported by studies of (Zubris & Richards, 2005). Therefore, it should also be considered how microplastics could be separated from the sludge used for fertilizer (Sundt et al., 2016).

13.3.5 Further considerations

During events of storm water overflows from combined sewer systems, wastewater is led past the WWTP with no or limited treatment, which will lead to a temporarily higher discharge of microplastics (DHI, 2015; Magnusson et al., 2016; Sundt et al., 2014). One method of reducing or eliminating the effects of heavy rain fall in the context of conventional wastewater treatment has been to construct separate sewer systems which are designed to convey sewage and storm water in different systems. Storm water that is discharged into the marine environment without treatment will also be a source of microplastic pollution, as emissions from road wear and the abrasion of tires is suspected of being the most substantial source of microplastics. The effects of overflows can be avoided/reduced by construction of e.g. retention basins which can reduce the load to the WWTP (DHI, 2015; Sundt et al., 2016).

Other measures to reduce the discharge of microplastics from WWTPs into the environment include measures to reduce the influent level of microplastics to WWTPs. This can be achieved by for instance source control (e.g. via legislation), better technologies for production, onsite treatment (e.g. like installing filters in washing machine effluent outlets) or other measures to similar effect.

Table 19: The removal of microplastics in WWTPs applying different treatment types. It should be noted that the results are not directly comparable since no standard method exists for the measurement of microplastics. The results do however give an indication of the magnitude of the removal of microplastics in WWTPs. (n.d. = no data available, MP = microplastics in number of particles)

Site	Person eq. [PE]	Treatment type	Removal efficiency [%] ≥300 µm ≥20 µm	Additional comments	Effluent [MP/(h*PE)] ≥300 µm ≥20 µm	Effluent [MP/h] ≥300 µm ≥20 µm	Ref.
Sweden							
Henriksdal Rya Långevik	750,000 740,000 14,000	Tertiary: Mechanical, chemical, biological, filtration, MBR Tertiary: Mechanical, chemical, biological, filtration Secondary: Mechanical, chemical & biological	98.9±0.30 90.3±2.6 99.9±0.11 69.9±16.1 99.5±0.20 87.0±4.1		1.2 35 0.16±0.14 90 0.65±0.06 69	120,100 66,600,000* 9,100 966,000*	[1,2] [1,2] [1,2]
Finland							
Viikinmäki Kalteva	800,000 40,000	Tertiary: Mechanical, chemical & biological, filtration Secondary: Mechanical, chemical & biological	99.93 n.d. 99.97 n.d.		0.41±0.41 n.d. 0.29±0.29 n.d.	468,400 n.d. 11,700 n.d.	[1] [1]
Norway							
VEAS Tönsberg Fuglevik	700,000 185,000 85,000	Secondary: Chemical & Biological Primary: Chemical Primary: Chemical	99.90 97.00 97.33 87.62 99.36 90.69		0.5 10 1.75 189 0.3 41	350,000* 7,000,000* 232,750* 34,965,000* 25,500* 3,485,000*	[3] [3] [3]
Iceland							
Klettagarðar Hafnafjördur	97,000 26,000	Primary: Mechanical Primary: Mechanical	≥100 µm (-118.23 %) (50.17 %)	Likely limited or no removal	≥100 µm 65.2 10.9±5.7	≥100 µm 6,348,800 2,232,000	 [1] [1]
Scotland							
Glasgow	650,000	Secondary: Mechanical, chemical & biological	≥11 µm 98.41		≥11 µm 4.18**	≥11 µm ~2,718,000**	[4]

Note: * calculated based on Person equivalents and Effluent [MP/(h*PE)].

** calculated based on numbers from Table 1 in [4] and Person eq.

References: [1] (Magnusson et al., 2016), [2] (Magnusson & Wahlberg, 2014), [3] (Magnusson, 2014), [4] (Murphy et al., 2016).

Table 20: The removal efficiency of microplastics after each treatment step in a Norwegian secondary WWTP, VEAS, and in a Scottish secondary WWTP in Glasgow. (MP = microplastics in number of particles)

Site	Treatment steps	Removal efficiency [%]	Microplastics [MP/m3]	Ref
Norway				
VEAS	Influent	≥300 µm* ≥20 µm*	≥300 µm* ≥20 µm*	[1]
	Chemical	99.1 94.3	23,1(±1.1)$\cdot 10^3$ 47,3(±4,7)$\cdot 10^3$	
	Biological	99.9 95.6	204(±174) 2,69$\cdot 10^3$	
			22.6(±3,5) 2.10(±0.17)$\cdot 10^3$	
Scotland				
Glasgow	Influent (after 19 mm coarse screening)	≥11 µm	≥11 µm	[2]
	Preliminary (grit and grease effluent)	0	15.70 (±5.23) $\cdot 10^3$	
	Chemical	44.59	8.70 (±1.56) $\cdot 10^3$	
	Biological	78.34	3.40 (±0.28) $\cdot 10^3$	
		98.41	0.25 (±0.04) $\cdot 10^3$	

Note: *calculated as based on the average influent and post treatment measurements in table 5 in Magnusson & Miljöinstitutet (2014).

References: [1] (Magnusson, 2014), [2] (Murphy et al., 2016)

14. Purification options for Ulkebugten, Sisimiut (Greenland)

The near shore marine environment in Greenland is generally not threatened by the discharge of pollutants such as nutrients and organic matter from domestic and industrial wastewaters (Miljøstyrelsen, 2005). The extent of the adverse effects of hazardous substances discharged with Greenlandic wastewaters are unclear. However, it is suspected that the majority of environmentally hazardous contaminants in the Greenland marine environment originates from discharge in other countries which have been transported by currents and winds to the Arctic. On a local scale there have been detected pollution near residential areas which should be addressed (Miljøstyrelsen, 2005; Naalakkersuisut, 2015). Especially, coves and bays with a low rate of water exchange have been emphasized as sensitive areas with potential problems like oxygen depletion, elevated concentrations of heavy metals, pathogens etc. which can have adverse effects on marine plants and animals as well as human health. In addition to this, aesthetical problems of discolored water and floating objects have been highlighted, because it acts against the image Greenland wish to portray to the outside world as a land of pure and untouched nature. Furthermore, the tourist and food production industries have an interest in a clean marine environment (Miljøstyrelsen, 2005).

Eutrophication, heavy metals, pharmaceuticals, pathogenic bacteria and aesthetical problems have all been identified as problems in the wastewater and/or sediments in the recipient Ulkebugten (Klupsch, 2014; Pedersen & Vilsgaard, 2010; Thomsen et al., 2003). An option could be to accept the current impact and continue to discharge the wastewater untreated. This option of continuing the discharge of untreated wastewater is no longer considered an acceptable solution, due to the identified local effects of the discharge in Ulkebugten. In general the following solutions to the problems could be considered: 1) Redirect the wastewater to a different outlet where the water exchange and dilution would reduce the impacts, or 2) Establish WWTPs either decentralized or centralized for wastewater treatment and continue to discharge those places. In the context of this study it will be relevant to consider either to redirect the wastewater to a different outlet or to establish a WWTP, or a combination of the two options.

14.1 Redirecting the wastewater to another outlet

The incentive of redirecting the wastewater from the outlet in Ulkebugten to a different site would be to reduce the problems in Ulkebugten which is categorized as a sensitive recipient. An alternative discharge point was suggested by Petersen et al. (2004). Based on studies of the tidal currents outside Ulkebugten it was suggested that the discharge point could be redirected to the westside on Teleøen in Sisimiut. The study showed that the flow rates west of Teleøen are sufficient for transporting wastewater with a certain content of larger particles (Petersen et al., 2004). The solution would require that the discharge point is moved about 1.5 km (Petersen et al., 2004), which would require a pumping station and a pressure pipe. The cost of construction for a pumping station was estimated to be around DKK 400,000 and the yearly operation costs estimated to DKK 30,000 (Miljøstyrelsen, 2005). The cost of construction for a pressure pipe was estimated to be in the same magnitude as the pumping station (Poulsen, 2016) and electricity costs would amount to about DKK 25 per meter per year (corresponding to 9W per meter). This solution will of course not reduce the amount of compounds discharged with the wastewater, they will merely be diluted. Furthermore, there have been problems with the discharge of fresh water in the cold sea water; frequently, part of the drain, which is below the sea level during high tide, must be removed because the wastewater carried in them would freeze instantaneously when meeting the colder, marine water. However, if these issues can be resolved this solution can be an option, since it has been suggested that the wastewaters are generally not of concern.

14.2 Establishing primary treatment

The option of establishing centralized or decentralized wastewater treatment can be addressed in a number of ways. With consideration of the Greenlandic conditions it was concluded that establishing a centralized secondary WWTP would not be a valid option. The solution is too expensive and too difficult to construct and operate (Miljøstyrelsen, 2005). It has also been suggested to establish decentralized biological wastewater treatment either as composting toilets or low flush toilets at the individual households, which would also increase the potential for biological degradation of micropollutants (Gunnarsdottir et al., 2010). Both of these options have been tested in Sisimiut, with a bioblock system and a mini-treatment-facility of the type Kongsted. Both of these treatment options proved ineffective due to operational problems and the mishandling of the systems (Ahmad, 2009). The aforementioned report was inconclusive, but it emphasizes the many difficulties that can be related to establishing and operating the decentralized treatment systems in Sisimiut. Based on these considerations, it is considered a more realistic option to introduce a primary treatment step for the outlet at Ulkebugten. Introducing centralized primary treatment in Sisimiut would remedy a number of the main pollution problems; including the reduction of visible waste (toilet paper, cotton swabs, feces), and some nutrients etc. which are bound to the sludge. However, primary treatment can only reduce the pollution from wastewaters to a certain extent and the treatment is generally not efficient in the removal of highly water soluble micropollutants.

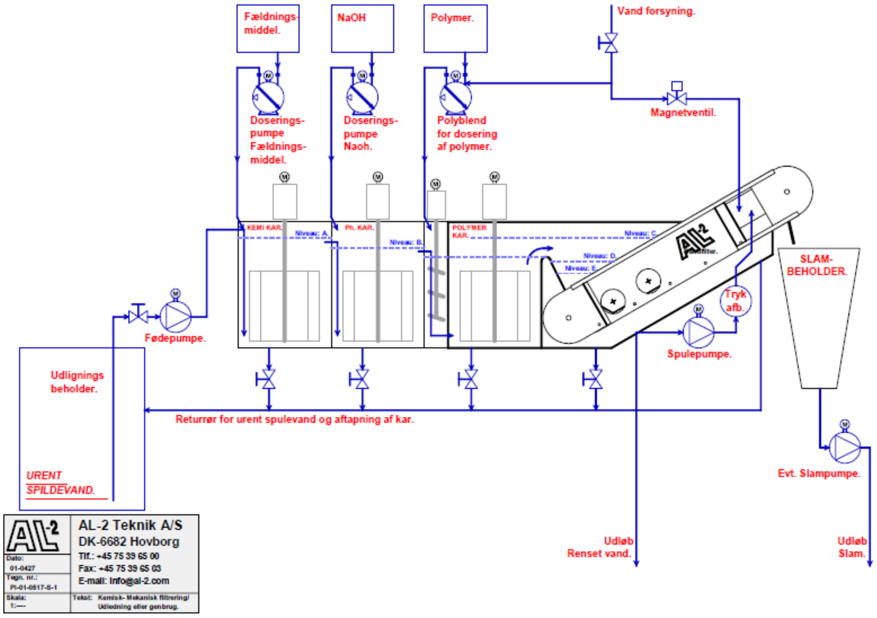
14.2.1 Mechanical treatment

A mechanical treatment step can be implemented in a number of different ways. The simplest and cheapest solution is to construct a grid with a grid size of 10x10mm to remove visible waste such as cotton swabs, sanitary pads etc. Another option would be to implement a finer grid and/or sand filtration. However, under the EU discharge requirements (European Council, 1991) it is assumed that purely mechanical purification would not to be sufficient to treat the wastewater which presently are discharged in Ulkebugten, as this a sensitive recipient according to the same directive and as strongly supported by the environmental observations from the area. Thus, for discharge to this recipient, a combination of mechanical and chemical treatment as in the Al-2 treatment plant could be an option (Thomsen et al., 2003; Chawes et al., 2004; Gunnlaugsdottir & Wraae, 2010).

14.2.2 Al-2 treatment plant (mechanical-chemical treatment)

In Sisimiut there have been conducted a number of tests to determine the treatment efficiency of an Al-2 WWTP with the intention of establishing one or more of the treatment plants in the town. The Al-2 WWTP is a primary treatment plant which utilizes a chemical-mechanical method for separation of wastewater (Al-2, 2016). The method is primarily developed for the removal of phosphates in wastewater from fish farms and agriculture. The Al-2 treatment plant includes a three-step purification process; coagulation, flocculation and subsequent filtration where water and sludge are separated. A conceptual drawing of the treatment facility is shown in Figure 76.

Figure 76: Conceptual drawing of the Al-2 treatment plant (Al-2, 2016)



The WWTP has shown successful removal of COD, phosphorus and to some extent nitrogen, heavy metals, LAS, PAHs, DEPHs and NPEs (Riger-Kusk, 2014; Drastrup & Petersen, 2013). The investigation did however not include an analysis of the pathogens etc., which could cause hygienic issues. The produced sludge was also examined for the purpose of reuse; and the results were that only the concentration of LAS was higher than the limit defined in the regulation "Slambekendtgørelsen" for reuse of sludge for agricultural purposes in Denmark. Lowering of LAS in the sludge could be achieved by composting or source regulation of detergents sold in the city (Riger-Kusk, 2014). In order for sludge to be reused the sludge must be sanitized as for instance in a digester tank. In Sisimiut there have been conducted investigations of the potential of using sludge for biogas production (Alberola & Vasilaki, 2013). It has also been suggested that sanitized sludge could be used as plant growth medium or as biocover on landfill or on hillslopes along roads etc. to give a "greener" look, similar to what has suggested for kitchen waste (Nielsen & Skadborg, 2015). Alternatively, the sludge could be incinerated if the necessary dewatering and drying systems were installed. The work done in the report by Riger-Kusk (2014) estimate that construction costs for establishing a treatment plant for 2000 PE would be DKK 1.8 mill and the yearly operation costs would amount to DKK 0.5 mill. For 4000 PE, the construction costs would be DKK 7.7 mill and the yearly operation costs would amount to DKK 0.9 mill. It has been suggested that construction costs of dewatering and drying system for the sludge would be in the range of DKK 3.5 mill – however this estimate is uncertain (Miljøstyrelsen, 2005). In a Greenlandic perspective the option of implementing primary treatment in the form of an AL-2 WWTP could be viable, as the operation of the WWTP is relatively simple and spare parts are easy to replace (Riger-Kusk, 2014).

14.3 Redirecting the wastewater and establishing primary treatment

The incentive for choosing the Al-2 treatment based option is that Ulkebugten is a sensitive recipient and hazardous substances are shown to accumulate in the waters and sediments in the fiord (Thomsen et al., 2003; Chawes et al., 2004; Pedersen & Vilsgaard, 2010; Pedersen, 2008; Klupsch, 2014). Even if a primary treatment step is established at the wastewater outlet, the effluent wastewater will still contain hazardous substances and micropollutants (e.g. from the hospital wastewater line) which will not be removed during the treatment. Furthermore, the efficiency of nitrogen removal in primary treatment is low, and this can pose a problem in Ulkebugten if nitrogen is the limiting factor as this will lead to continued eutrophication. A solution could therefore be to redirect the wastewater to a different outlet and implement the primary treatment there. This solution was also suggested by Gunnlaugsdottir and Wraae (2010), who conducted an assessment of the costs of establishing various solutions for wastewater treatment in Sisimiut, with a special focus on Ulkebugten as a sensitive recipient. This study showed that with a lifespan of 30 years, the most economically advantageous solution would be to construct a WWTP with mechanical treatment at Natreno (outlet C, at

"Chokoladefabrikken", Figure 77) with a pump-supported sewage line from Ulkebugten to this site (Gunnlaugsdottir & Wraae, 2010). It was suggested that mechanical treatment would be sufficient in this scenario provided that the recipient at the Natreno site can be considered less sensitive. In their study, Gunnlaugsdottir and Wraae (2010) assessed the costs of different paths for sewage lines and treatment methods, where the overall conclusion indicated that combining the sewage lines into one single WWTP could be the optimal solution in a cost-benefit perspective.

Figure 77: The existing and planned sewer system in Sisimiut. The green line shows the existing sewage lines, whereas the yellow lines indicates the planned ones. The capital letters indicate sewage outlet points. The plan is, that outlet points indicated in yellow letters shall be removed, whereas the green ones will be maintained. Ulkebugten outlet is "A" and the recommend alternative outlet site is the Natreno outlet "C", and then with a sewage treatment plant installed here

15. Breivika, Tromsø (Norway)

The main recipients of the wastewater outlets in Tromsø city are monitored regularly, and generally the environmental conditions in these recipients may be described as good due to high water exchange in the area (Norconsult, 2014). However, in order to reduce the organic fractions in the final effluent it has been suggested to redirect the wastewater from Breivika and several other WWTPs in the city to a centralized secondary treatment plant (Norconsult, 2014). The primary purpose of this, would be for the effluent to meet the Norwegian discharge criteria for BOD (70% reduction and max 25 mg/L O_2 in the outlet) and COD (75% reduction and max 125 mg/L O_2 in the outlet). Currently, Tromsø is not required to meet the Norwegian effluent criteria for nutrients, but it is likely that the wastewater discharge of the city may be subject to the effluent quality criteria for phosphorus in the future (Norconsult, 2014). This is supported by the findings in phase 1 of this report, which found elevated concentrations of phosphorus in the recipient of the Breivika, Tromsøysundet, compared to the background concentration.

In a future scenario with a centralized secondary WWTP in Tromsø, Breivika would not be recommended as a discharge point (Norconsult, 2014). In an analysis by Akvaplan-niva AS (as cited in Norconsult 2014) it was concluded that discharge to the shallower parts of Tromsøysundet and Sandnes Sundet would be undesirable. Generally, the deeper areas of the north-Tromsøya would be a more suitable recipient for a discharge from a future secondary WWTP, Figure 78.

Figure 78: Possible discharge points from a future secondary WWTP in Tromsø. Based on an analysis of the flow directions and velocities as well as potential for entrapment and dilution, it was recommended that one or more future discharge points should be located north of Nordspissen on the Island Tromsøya. However, to determine a more exact discharge point, further investigations of the recipient should be conducted (Norconsult, 2014). Modified from Google Maps, 2016

The recommendations for the location of one or two future secondary WWTP in Tromsø was based on a number of requirements that the plants should fulfill, including; lowest possible costs (including utilization of existing infrastructure to the maximum extent possible), finding locations that are acceptable on the basis of expected future land use and urban development, appropriate positioning in relation to logistics and traffic systems, and access to an adequate recipient (Norconsult, 2014). Based on these considerations it has been recommended that a secondary WWTP should be located in either in the Langnes area (in the western part of Tromsøya) or north-Tromsøya. In both cases the wastewater should be pumped from Breivika WWTP and other primary treatment plants to the centralized secondary treatment plant. If the secondary treatment plant where to be located in the Langnes area, the effluent wastewater where to be pumped to the northern part of the island to the aforementioned discharge site. With a WWTP in north-Tromsøya, the effluent could be directed directly into the discharge lines.

Norconsult (2014) have proposed a number of different solutions for a centralized secondary treatment step. The proposed secondary treatment solutions include conventional activated sludge (AS) processes, sequencing batch reactor (SBR) processes, moving bed biofilm reactors (MMBR), and integrated fixed-film activated sludge (IFAS) processes. These purification methods can be designed for different purposes (BOD/COD removal, nitrification/denitrification and enhanced biological phosphorus removal) but was in the context of the Norconsult report primarily thought only to reduce BOD/COD from the effluent (Norconsult, 2014). In the context of this study the removal of phosphorus, micropollutants such as pharmaceuticals, and microplastics are considered within the frame of the above-mentioned suggested solutions.

In the Norconsult (2014) report it was suggested that phosphorus should be removed by chemically precipitation, which would reduce the effluent concentration to a level that would meet the guideline. As described in the previous section (on microplastic), mechanical treatment appears to be ineffective in the removal of microplastics and micropollutants in general. Chemical precipitation of phosphorus can however reduce the effluent concentration of microplastic particles >300 µm very efficiently (>97% in two Norwegian plants as analysed by Magnusson 2014), whereas the removal of microplastics particles >20µm in the same study was somewhat less effective (~90%). On the other hand, chemical precipitation processes in general yield ineffective elimination of most micropollutants (Luo et al., 2014a).

Upgrading to a secondary WWTP will increase the removal of microplastic particles >300 µm but may not have any significant effects on the removal of the smaller microplastic particles. As the amount of data on removal efficiencies of microplastics in secondary WWTPs is still very limited, it is not possible to say which of the four different secondary treatment types, that will result in the best effluent. However, since Sundt et al. (2016) suggested that suspended solids potentially can act as a surrogate parameter for microplastic particles, removal rates of these may act as an indicator for the removal of microplastics. The removal efficiency for micropollutants is both dependent on micropollutant-related factors and WWTP specific factors (Luo et al., 2014a). Hence, differences in removal effciency can occur in different secondary treatment processes.

15.1 Activated Sludge (AS)

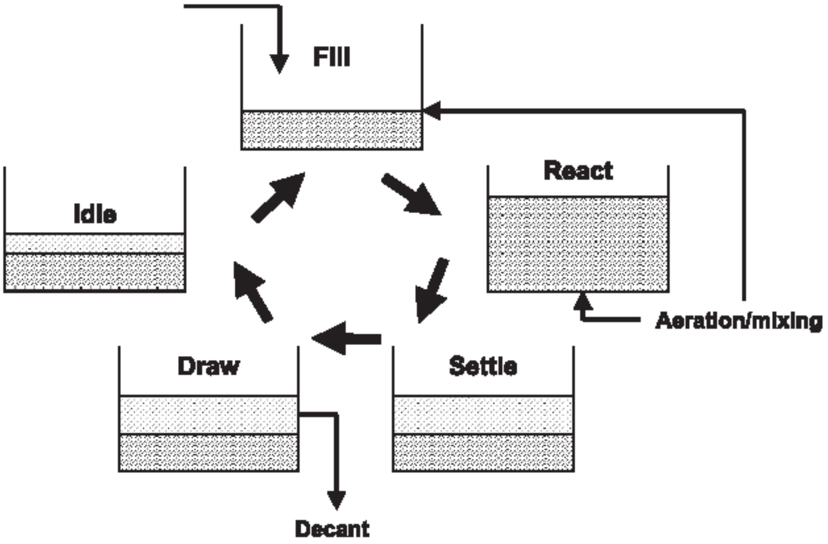
The conventional activated sludge (AS) process is a type of aerobic biological treatment that is primarily intended for reducing dissolved organic matter. The AS process is a suspended growth process, where microorganisms are kept in suspension within an aerated tank/basin. After the secondary settlement, a portion of the microorganisms are recycled back into the aerated tank to increase the biomass and thereby increase the removal efficiency of soluble dissolved organic matter. The removal of micropollutants from secondary WWTPs, are depend on both the type of micropollutants that are dominant in effluent and the operating conditions of the WWTP. Improving the removal of micropollutants could be achieved by an increased SRT, extended HRT, good aeration and keeping warm temperatures. In practice this would require an increased plant size in an indoor environment, thereby increasing costs.

15.2 Sequencing Batch Reactor (SBR)

A Sequencing Batch Reactor (SBRs) is a draw-and-fill variation of the conventional AS process, where all processes are carried out in a single reactor. The SBR is hence time rather than space orientated; equalization, metabolic reactions and sedimentation is happening in a time sequence rather than in the conventional space sequence of continuous-flow system, Figure 79. The advantage of this relative to the conventional AS system is that it can work with variable influent volumes, the operation control is easier, the space requirements are reduced compared to conventional AS and the capital costs are lower (USEPA, 1999; Stricker & Béland, 2006).

The performance of SBRs is comparable to that of a conventional AS and depends on system design and wastewater characteristics (USEPA, 1999). However, due to the greater possibilities of system control, such as SRT and HRT control (Stricker & Béland, 2006), it could be easier to optimize the conditions for biodegradation of micropollutants.

Figure 79: The principle of a SBR; a variation of the activated sludge treatment (USEPA, Sequencing Batch Reactor Systems, 2016), Treatment sequence: 1. Idle, 2. Fill, 3. React, 4. Settle, and 5. Draw.



15.3 Moving Bed Biofilm Reactor (MBBR)

The moving bed biofilm reactor (MBBR) process is an attached growth system which is highly suited for BOD/COD removal as well as total nitrogen removal (Odegaard, 2006). The idea behind the MBBR is to combine the best part of the activated sludge and biofilm processes; utilizing the entire tank volume and no sludge recirculation (Odegaard, 2006). Odegaard (2006) claims that by doing so, it is possible to achieve low capital, operational, maintenance and replacement cost, all within one single reliable and robust operation procedure.

In the MBBR process polyethylene biofilm carriers are retained in the biological reactor**.** Each carrier increases the productivity by having a protected surface area that can support the growth of heterotrophic bacteria (bacteria that grow on organic carbon, e.g. denitrifiers) and autotrophic bacteria (produces complex organic compounds e.g. nitrifiers). It is the high-density population of bacteria that results in a high-rate biodegradation in the system (Odegaard, 2006). The MBBR can be used for aerobic, anoxic or anaerobic processes. However, in the case of Tromsø only BOD/COD removal in an aerated reactor are considered (Norconsult, 2014) with possible chemical precipitation of phosphorous. Biological phosphorous removal using enhanced biological phosphorus removal is also a possibility if the MBBR system was extended with anaerobic treatment; though this is a process usually being carried out in an activated sludge processes.

Based on the findings of the present study, there have not been conducted any investigations of the removal efficiencies of micropollutants (pharmaceuticals etc.) for MBBR systems that are only intended for COD/BOD removal. However, studies of MBBRs that include denitrification/nitrification have shown positive results for micropollutant removal; the removal of bisphenol A, oseltamivir and atrazine was enhanced by the addition of biofilm carriers (Accinelli, Saccà, Mencarelli, & Vicari, 2012) and in a study where polyurethane sponge was used as attached-growth carrier there was effective removal of ibuprofen, metronidazole, naproxen, primidone, triclosan, estrone, 17-a ethinylestradiol, 4-n-nonylphenol, 4-tert-octylphenol and fenoprop and moderate removal (50–70%) of toprofen, acetaminophen (paracetamol), metronidazole, and gemifibrozil (Luo et al., 2014b). Similar results were found in an experiment with staged MBBRs for the biodegradation of pharmaceuticals in hospital wastewater (Escola Casas *et al*., 2015). Although, MBBRs have not been used widely for micropollutant removal, results appears that attached growth treatment processes, such as MBBRs, are promising methods for reducing discharges of micropollutants (Luo et al., 2014a). The biofilm carriers means that an increased microbial community can be maintained in the system, which is beneficial for the growth of slow-growing microorganisms that can biologically degrade micropollutants (Luo et al., 2014a).

15.4 Integrated fixed-film activated sludge (IFAS)

The IFAS process combines the conventional activated sludge technology and biofilm systems. An IFAS configuration is similar to that of an activated sludge system, but includes the biomass carriers of an MBBR system. An advantage of doing this is that the anaerobic, aerobic, and anoxic zones can be integrated in the same step ; thereby increasing the BOD and nitrogen removal compared to a conventional activated sludge system and reducing the space requirements without increasing the costs. Enhanced biological phosphorous removal (EBPR) is not necessarily an integrated part of an IFAS system, but it is possible to include it. However, since both EBPR and denitrification consume organic substrate, including EBPR would affect the performances of the nitrogen removal (Sriwiriyarat & Randall, 2005). This would however not pose a problem if nitrogen effluent guidelines for wastewaters are not to be upheld in Tromsø.

The removal of micropollutants appears to be more efficient in the IFAS process than in a conventional activated sludge process. In a study investigating the removal efficiency of estrogenic activities in IFAS systems, the estrogenic activities in the effluent from the IFAS system were 70 % lower than those of the conventional activated sludge system, which suggested a high estrogen removal by IFAS (Kim *et al.*, 2009) as cited in (Luo et al., 2014a). Also pharmaceutical removal have shown great potential in IFAS systems, compared to conventional activated sludge systems (Falås et al., 2012). It appeared that the presence of biofilm carriers could increase the biological degradation of some compounds which were not eliminated in the activated sludge systems (Falås et al., 2012).

15.5 Further considerations

Great concern exists about the presence and effects of micropollutants in the aquatic environment. In this context, it could be relevant to identify particular wastewater sources in a given sewage line – such as industrial and hospital wastewaters – and to implement specific on-site treatment solutions. Breivika WWTP receives wastewaters from the university and hospital. The characteristics of these can differ considerably from domestic wastewaters, and this can have adverse effects of the treatment processes in a biological treatment plant. Hospitals generally discharge considerable amounts of chemicals and microbial agents in their wastewaters. Chemicals from hospitals include different groups, such as antibiotics, X-ray contrast agents, disinfectants and pharmaceuticals, many of which are also found in regular wastewater but are found in higher concentrations in the discharge from hospitals. Multi-resistant microbial agents can potentially contribute to the spreading of antibiotic resistance (Beier et el., 2010). It could therefore be relevant to consider a pre-treatment of discharge from the hospital and university before these are mixed with the municipal wastewaters (Beier et al., 2010; Filtration and Separation, 2015).

16. Sersjantvíkin, Tórshavn (Faroe Islands)

In addition to being an important harbour for freight, ferry and fishing vessels, the waters in and around Tórshavn is used for recreational purposes as well as food production (fish farming) and the quality of the marine environment is therefore a matter of concern. The main concerns of the recipient for the Sersjantvikin WWTP discharge are nutrients, primarily phosphorous, and micropollutants, both groups of potential pollutants which are not efficiently removed during primary treatment.

Phosphorus removal can be achieved be means of chemical precipitation with either iron or aluminum salts. However, in order to address the removal of micropollutants, additional measures must be taken. As described above, the municipality of Tórshavn is planning to implement a separate sewer system, where the surface run-off will be separated from domestic wastewaters. This initiative will increase the hydraulic retention time of the domestic wastewaters in the WWTP, which have been shown to have a positive effect on the degradation of some micropollutants. In the context of this study and the focus of improving the wastewater treatment it will be relevant to consider optimizing the existing treatment in the household septic tanks and the Sersjantvikin WWTP, or establishing either a secondary or tertiary treatment WWTP at the junction of the outlets downstream of the Sersjantvikin WWTP, where the Sersjantvikin effluents meets the larger part of effluents from the UA11 discharge area, as described in the next section.

16.1 Optimizing the septic tank solutions

The outlet UA11 in the Sersjantvikin combines two wastewater effluent streams both of mainly household origin. One stream carries effluents from the Sersjantvikin WWTP, which basically is one large septic tank collecting wastewaters from 820 PE, and the other stream are wastewaters from approximately 10,000 PE. The stream from the 10,000 PE has already passed through septic tanks which in most instances have been installed for and serves one household each. The possibilities for improving the effluent qualities of septic tanks have been examined in a number of studies. Although the exact mechanism by which many pharmaceuticals and chemicals in personal care products, PCPPs, are removed is still unclear, evidence suggests that aerobic conditions in the treatment are favorable for their removal (Kupferschmidt, 2010; Margot et al., 2016). The environment in septic tanks are anaerobic and a number of different possibilities of improving the effluent quality have been suggested. In a study by Wilcox et al. (2009) a number of different contaminants including paracetamol and estrogens which are good exampels of

PPCP that may pass through primary treatment to the recipient, where detected in the effluent of household septic tanks. By improving the treatment with sand filtration or aerobic treatment, the effluent concentrations where significantly lowered. The study indicated that by upgrading the septic tanks it was possible to obtain a treated effluent with similar concentrations as municipal WWTP (Wilcox et al., 2009). A similar result was obtained in another study that found excellent removal rates of nonylphenols and and total estrogenic activity (estrone (E1), 17β- estradiol (E2), estriol (E3), and 17α-ethinylestradiol (EE2)) by implementing a pretreatment aerobic filter (Stanford & Weinberg, 2010) as exemplified with a KLARO One sequencing batch reactor.

16.1.1 KLARO One (Sequencing Batch Reactor)

One way of introducing aerobic conditions and thereby enhancing the potential for biodegradation in the septic tanks could be to upgrade the individual septic tanks to aerobic treatment. One option of upgrading could be KLARO One (KLARO, 2015). In this type of system different types of septic tanks (concrete, plastic, fiberglass, etc.) can fairly simple be retro-fitted to sequencing batch reactors (SBRs) (KLARO, 2015), where the SBR-cycle consists of: 1. An aeration phase, 2. A settle phase and 3. a discharge phase. Implementing this type of solution would reduce the effluent of organic matter, nutrient and micropollutants. Another advantage of upgrading to the aerobic treatment is that pathogen removal is increased (Wilcox et al., 2009). However, in order to achieve a more effective removal of micropollutants, tertiary treatment would be necessary.

16.2 Upgrading to a secondary treatment step

A second option is to introduce a centralized secondary treatment step at junction of the outlets from the households and the Sersjantvikin WWTP. As above mentioned, introducing secondary treatment to the treatment process can be an endpoint in itself, as several studies have shown that biological treatment is effective for removal of paracetamol (acetaminophen), estrogens (natural and synthetic), salicylic acid (metabolite of acetylsalicylic acid), and pathogens. However, the efficiency of the removal processes are dependent on both wastewater characteristics and WWTP operations, and removal efficiencies of micropollutants have shown to vary between WWTPs. A Swizz study showed that about 50% of micropollutants were removed by secondary treatment plants and other studies have shown similar results (Margot et al., 2013).

Another option is to introduce secondary treatment as a mean to improve the water quality in terms of reducing readily biodegradable organics. By doing so, the water quality can be improved and tertiary treatment can be implemented.

16.2.1 Sequencing Batch Reactor

Similar to upgrading septic tanks, it would be possible to improve the removal of micropollutants by introducing a centralized secondary treatment step in the form of a sequencing batch reactor (SBR). A sequencing batch reactor is often used for smaller WWTPs and has the advantage of having a small physical footprint compared to a conventional activated sludge system, as all processes occur in the same reactor. This could be an advantage at the Sersjantvikin outlet due to the relatively limited space available for a treatment plant between the present plant and the outlet at the coast-line.

A relatively new type of SBR is the granular SBR. Aerobic granular SBRs are considered a promising technology for municipal wastewater treatment due to their small physical footprint, their ability to biologically remove nitrogen and phosphorous at the same time, their reduced energy and chemical consumption, low costs, and flexibility of operation compared to conventional activated sludge processes (RoyalHaskoningDHV, 2016; Margot et al., 2016). The concept behind this is that aerobic granules have aerobic conditions on the outside and anoxic/anaerobic in the inside, which means that the biological removal processes known from conventional wastewater treatment processes can occur simultaneously. An example of the granular SBR is the one utilizing the Dutch Nereda technology. The Nereda technology was invented by the Delft University of technology and further developed in public-private partnership between the University, the Dutch Foundation for Applied Water Research (STOWA), the Dutch Water Authorities and Royal HaskoningDVH. This type of SBR has proved effective even during low temperatures (<10 degrees) and appears very effective in the removal of 'conventional' contaminants (nutrients, suspended solids etc.). However, the potential removal of micropollutants for a granular SBR is still a new research area. In a study by Margot et al. (2016) the removal efficiency of micropollutants in an aerobic granular SBR was investigated; the study showed that some micropollutants were removed efficiently, including paracetamol, ibuprofen, and the natural estrogens estrone (E1) and estriol (E3). However, the total removal of the 36 investigated micropollutants was only 42%. Since hydraulic retention time is often emphasized as a potential important factor for the biodegradation of micropollutants this could be a setback for this treatment method; the granules cause a faster settling time and thereby a shorter hydraulic retention time. Though, it should be noted that Margot et al. (2016) utilised a different granular technique than the Nereda technology, which may affected the outcome. Thus, if secondary treatment only is to be implemted, a "normal" SBR but with longer hydraulic retention time, may possibly be more efficient for this purpose. The granular SBR could provide a high quality effluent, with respect to conventional pollutants, which is advantageous if advanced/tertiary treatment is to be applied.

16.2.2 Aerobic Membrane bioreactor (MBR)

An alternative biological treatment step would be a membrane bioreactor. MBR systems use microorganisms for degradation of organic pollutants and requires aeration similar to those of the conventional activated sludge process. The MBR is a wastewater treatment system that combines biological wastewater treatment with membrane separation for clarification and purification of biologically treated wastewater.

MBRs have gained significant popularity as an advanced wastewater treatment technology as it has a reduced footprint and a sludge production compared to conventional activated sludge processes.

Generally, MBRs are shown to give high quality effluents for "conventional" pollutants and show good results for the removal of micropollutants (Radjenovic et al., 2006). A study of the fate 99 pharmaceuticals and personal care products (including paracetamol) in a MBR showed a removal rate of more than 90% for many of the compounds. However, as observed in other secondary WWTPs the removal efficiency of the different compounds varied significantly with removal rates ranging from -34% to >99% (Kim et al., 2014).

16.3 Upgrading to a tertiary treatment step

Conventional wastewater treatment, with primary and secondary treatment steps, is not designed for the purpose of removing micropollutants from the effluent. Therefore, in order to get the most effective removal of micropollutants, it could be considered to upgrade the treatment with both secondary and tertiary treatment steps. Several different tertiary treatment processes have proven efficient in the removal of micropollutants where the most promising are advanced oxidation processes and activated carbon (Altmann et al., 2014; Margot et al., 2013; Eggen et al., 2014) which are mostly followed by some type of filtration, e.g. ultrafiltration or sand filtration.

Generally, studies with different types of advanced oxidation processes have proven efficient in the removal of a broad spectra of micropollutants. E.g. ozonation is a process which have shown to have a high removal efficiency (up to 98% removal of pharmaceutical residues), the technology is advancing and it is therefore getting more cost-efficient to implement this solution (Primozone 2016; Ozonia 2012). Primozone (2016) estimates an additional costs of 20–50% compared to conventional treatment for small-scale WWTPs, and in addition there is a risk of toxic by-products. Activated carbon (AC) is another effective method for removing micropollutants (up to 98% removal of pharmaceutical residues). However, AC primarily works by adsorption of micropollutants, which means that further treatment of the contaminants need to be addressed as well as the regeneration of the AC.

In this context of evaluating suitable tertiary treatment options, it may also be relevant to know more about the wastewater characteristics; the fate of micropollutants in a WWTP is not only dependent on the operational conditions in the WWTP (temperature, pH etc.) but also of the composition of the wastewater. Also, the characteristics of the various micropollutants (e.g. hydrophobicity, biodegradability, and volatility) are of relevance to removal processes. In a large scale study comparing the efficiency of ozonation and activated carbon (both reaching an efficiency of 80% removal compared to the raw wastewater), ozonation was more effective in the removal of some specific substances whereas powdered AC removed a wider range of pollutants (Margot et al., 2013).

In addition to this, it is important to consider that there are also environmental costs of implementing advanced treatment in the form of increased energy consumption, nutrient enrichment, and acidification. Wenzel et al. (2008) conducted a Life Cycle Analysis (LCA) in which secondary treatment was compared with tertiary treatment in terms of environmental benefits and costs. The study included the contaminants cadmium, lead, nickel, 17b-estradiol (E2), 17a-ethinylestradiol (EE2), PAH, DEHP, nonylphenol, and LAS – whereof several contaminants coincide with the focus contaminants of this study. The conclusion of the LCA was that only sand filtration had a net positive environmental effect (Wenzel et al., 2008). However, inclusion of other contaminants and/or concentrations in the analysis could have changed the outcome; possibly in either direction, as an inclusion of more contaminants would enhance the environmental benefits but also increase the energy consumption needed for the treatment. By extension, it might also be relevant to consider the ongoing process in Switzerland. From 1st January 2016 a new and more ambitious water protection law has been adopted in Switzerland (Eawag, 2015), which means that 100 WWTPs in the country must be upgraded to advanced wastewater treatment. However, based on the load expected from the outlet, and the sensitivity of the recipient, the Sersjantvikin outlet would not fall into the category of WWTPs that should be upgraded with advanced treatment according to the new Swiss legislation (Eggen et al., 2014).

16.4 Further considerations

It may be worthwhile to include considerations of biodegradability of micropollutants in the environment; although micropollutants are known to be ubiquitous in inland waters the effects of micropollutants on complex aquatic ecosystems is poorly understood. Determining the effects of these are challenging as this is influenced by a number of factors. First of all there are potentially thousands of pollutants and these are present in mixtures that could have combination effects (addition, antagonism or synergism) which should be considered when evaluating ecotoxicological impact (Eggen et al., 2014).

In addition, source control measures is also something which should be taken seriously (Janusinfo, 2016; Pedersen & Nielsen, 2007; Eggen et al., 2014). In Sweden, pharmaceuticals have been classified based on hazard and risk to the environment; a strategy that aims to reduce the adverse effects on the environment without compromising the health of the public (Janusinfo, 2016).

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Sammenfatning

Byene som undersøkelsen omfatter, Tromsø, Tórshavn, Reykjavík og Sisimiut, har mange likhetstrekk, for eksempel ved at de er i områder som er sterkt økonomisk avhengig av havets ressurser. Disse samfunnene har også i stor grad samme bakgrunn i form av samfunnsstruktur og -utfordringer, og de kan også beskrives som en del av det nordiske arktiske området. Det er imidlertid en gradient mellom disse områdene både i klimamessig, fra et oseanografiske temperert klima i Tórshavn på 620 N til arktisk klima i Tromsø på 69.70N, og ikke minst i befolkningstall, fra mindre enn 6000 innbyggere i Sisimiut til nærmere 120 000 i Reykjavík.

De fire nordiske arktiske byene er forskjellige, og langt fra hverandre, men avløpsvannet fra disse er likt i forhold til forurensninger. Avløpsvannsbehandlingen varierer ganske mye, fra screening på finmasket nett, via septiktank basert renseløsninger, til ingen rensing i det hele tatt, som i Sisimiut. Bortsett fra renseanlegget ved LSH landssykehuset og det septiktank-lignende renseanlegget i Sersjantvíkin, begge to i Tórshavn, er den biologisk nedbrytning av de vannløselige elementene i avløpsvannet på Færøyene stort sett overlatt til mottakeren- recipienten. Den biologiske behandlingen i Sersjantvíkin renseanlegget er avhengig av aktiviteten av det mikrobielle fellesskap som til enhver tid er tilstede i kloakkbehandlingstanken, og dette er i liten grad kontrollert. I ca. 15 % av husholdningene i Sisimiut slippes grått avløpsvann direkte til terreng, mens kloakken samles på ulike måter for senere å slippes urenset i fjæra. Den største delen, ca. 75%, av husholdningene i Sisimiut er tilknyttet kloakkledningsnettet, som leder grått og sort avløpsvann, men lite eller intet overflatevann. Kloakkledningsnettet leder ned i fjæra hvor det finnes et fåtall utslippspunkter, og herværende undersøkelse er gjort ved to av disse, Ulkebugten og Natreno. I Sisimiut er utfordningen ikke bare knyttet til de usynlige miljøforurensende stoffene i avløpsvannet, men også den synlig og uhygieniske tilgrisingen av de kystnære områdene som dette medfører- slik at utslippsstedene langs kysten fremstår som veldig synlige beviser på den manglende rensingen.

Denne studien omfatter to av disse utslippsområdene i Sisimiut, Ulkebugten og Natreno, hvor utfordringene ikke bare skyldes miljøgifter som stort sett er usynlige for det blotte øye, men også innebærer mer skjemmende og uhygienisk forurensning av det kystnære miljøet.

I løpet av prosjektperioden, har en rekke av de forurensende stoffer som er identifisert som prioriterte farlige stoffer i vannpolitikk innen EU (direktiv 2013/39 / EU) blitt analysert, både i avløpsvannet så vel som i de vannforekomster som fungerer som recipient for dette. De prioriterte miljøgiftene som ble analysert var: kadmium og kvikksølv, polysykliske aromatiske hydrokarboner, PAH, inkludert naftalen, samt di(2-etylheksyl) ftalat, nonylfenol og perfluoroktansulfonat og andre perfluoroalkyl forbindelser, PFAS. I tillegg omfattet studien analyser av forbindelser som brukes daglig i alle moderne husholdning feks. i vaskemiddel produkter, som lineære alkylbenzensulfonater, LAS. Også kjemikalier som benyttes til mer spesialiserte vaske- og renseformål ble analysert, som oktylfenol og nonylfenol og deres ethoxylates, samt kationisk overflateaktive forbindelser av typen kvaternære ammonium forbindelser, QAS, som anvendes i en rekke desinfiserende produkter så vel som i tøymyknere. I tillegg ble mer vanlige avløpsvannsparametere som fosfat, ammonium og totalt organisk karbon analysert, i tillegg til klorid som indikasjon på saltholdighet. Disse sistnevnte parametrene kan anvendes til kalibreringsformål når det gjelder å vurdere det relative bidraget av de syntetiske forurensende stoffer i forhold til de som er utskilt av mennesker, og til en generell beskrivelsen av fysisk-kjemisk status for vannforekomsten. Konsentrasjonen av forurensninger ble målt i avløpsvanns-strømmen før og etter passering av renseanlegg for sammenligning. Når en slik prøvetaking er riktig utformet vil analysene kunne fortelle om hvor effektiv avløpsvannsrensingen har vært. En omfattende vurderinger av rensningsgraden for de enkelte renseanleggene var ikke innenfor rammen av prosjektet, men kombi-prøver som representerte avløpsvanns flyten i bortimot et døgn ble tatt i de renseanleggene hvor det var mulig å få til, uten nyinstallasjoner. Dette ble kombinert med gjentatt omganger av prøvetaking/analyser for et utvalg av forbindelser, for å støtte opp under en vurderingen av representativiteten til prøvene. Slike kombi-prøver (døgnprøver) av influent og effluent (avløp til recipient) ble arrangert i Breivika, Langnes og Sersjantvíkin renseanlegg. Totalt sett viste det seg, at konsentrasjonen av forurensningene ikke nødvendigvis ble minsket ved passering gjennom renseanlegget. Det anioniske vaskemiddelet LAS ble ikke redusert nevneverdig i renseanlegget, og heller ikke kvikksølv, PAH og PFAS. Det ble heller ikke funnet at renseverket medføret nevneverdig reduksjon i konsentrasjonen av oktyl- og nonylfenol og deres etoksylater i avløpsvannet. Heller ikke næringsstoffer som fosfat og ammonium ble nødvendigvis redusert i renseanlegget, på den annen side ble organisk materiale, TOC, generelt redusert i renseanleggene. Det ble også påvist betydelig lavere kvikksølv i avløpsvannet som gikk ut fra Klettagarðar renseanlegg enn i det som gikk inn, og dessuten var det antydning til at noe PFAS ble fjernet i Langnes renseanlegget i Tromsø.

Den viktigste suksesshistorien synes imidlertid å være reduksjonen av ftalat, DEHP, i Langnes renseanlegget, hvor mer enn 90 % av DEHP holdes tilbake. Like effektivt som Langnes syntes renseanlegget Klettagarðar å fjerne DEHP fra avløpsvannet, men i Klettagaðar anlegget ble det bare tatt stikkprøver, så denne konklusjonen er mer usikker. Mer beskjedne reduksjoner i DEHP ble funnet i Sersjantvíkin renseanlegget.den. Mer beskjedent, men allikevel reduksjoner av DEHP, ble sett i Sersjantvíkin renseanlegget. De andre renseanleggene hadde mindre og mer blandet effekt på ftalatkonsentrasjonen, men der var heller ikke DEHP konsentrasjonen i avløpsvannet så høye som i Langnes og Klettagarðar renseanleggene.

Konsentrasjonene av forurensninger målt i avløpsvann kan brukes til å estimere utslipp av forurensende stoffer til resipienten. Dette krever at prøvene kan antas å være representative og i praksis betyr det at disse bør være tatt over lengre tid, i praksis vil det typisk bety sammensatte prøver, feks døgnprøver. De renseanleggene som inngikk i studien hadde ikke utstyr på plass for slik prøvetaking, men gjennom ekstra innsats ble det tatt ut et mindre antall slike kombi-prøver i utvalgte avløpsvannlinjer, b.la. de som ble nevnt ovenfor samt i Sisimiut, i prøvetakingsrundene 2 til 4.

Konsentrasjonene av miljøgifter i mottaker-vannforekomstene ble analysert, og resultatene evaluert med hensyn til miljørisiko. Risikoen ble vurdert ved å sammenligne målte verider med EU's miljøkvalitetskriterier, EQS, i de tilfellene der slike fantes (direktiv 2013/39 / EU).

Fosfat ble funnet i konsentrasjoner som overstiger 1,5 ganger den lokale vinter-bakgrunnskonsentrasjonen, i Tromsø, Tórshavn og Sisimiut. Ammonium ble analysert i to omganger, i april/mai 2014 og i september 2013. Konsentrasjonen av ammonium minket med økende avstand fra utslipps områdene, slik som konsekvent observert for Sisimiut området. Forholdet mellom konsentrasjonen av ammonium i resipientsprøver i forholdet til den som ble målt på referansestasjonene var forhøyet, spesielt i Natreno områder, mens det ble funnet noe lavere forholdstall i Ulkebugten resipienten og i resipienten til Sersjantvíkin renseanlegg i Tórshavn. I resipienten rundt Breivika renseanlegg var det også forhøyet ammoniumkonsentrasjon, men det var store variasjoner mellom de to prøvetakingsrundene. Forhøyet ammonium ble ikke observert i resipienten i Reykjavík. LAS ble analysert i tre runder, og er som sådan den beste indikatoren på variasjonen mellom analyseomgangene. I den første runden, oktober 2013, ble LAS påvist i halvparten av alle resipient prøvene, og dobbelt så ofte i Tromsø og Tórshavn som i Reykjavík og Sisimiut. Av de i alt fire resipientprøvene hvor LAS var høyere enn ad hoc PNEC på 0,0025 mg/l var to fra Tromsø og to fra Tórshavn.

QAS er en gruppe av kationiske tensider som har noen egenskaper og bruksområder tilfelles med LAS vaskemidler. De QAS som var inkludert i undersøkelsen var DDAC, BAC og ATAC. Av disse, ble BAC påvist i 10 av de 16 resipientprøvene som ble analysert, DDAC ble funnet i fem og ATAC i tre. Konsentrasjonene av disse var imidlertid lave og utgjorde max. 5 % av EQS. PFAS, som omfatter lite nedbrytbare fluorforbindelser som til overflatebehandling av bla. papir og tekstil, ble analysert i 24 resipientprøver, og ble påvist i alle unntatt fire av disse; to i Tromsø og to i Sisimiut. I fire prøver i Tromsø, to i Reykjavík og en i Sisimiut, overskred konsentrasjonen av PFOS EUs miljøkvalitetskriteriet på 0,00013 mg/l. PFAS fremstår dermed som en representant for en gruppe miljøgifter som tilsier at avløpsvannproblematikken bør granskes nærmere.

Samlet sett var imidlertid konsentrasjoner av miljøgifter i mottakervannmassene lave; ftalater og PAH ble ikke påvist i resipientene, ved konsentrasjoner under EQS for antracen og benzo(a)pyren, hvor sistnevnte bare vurderes i forhold til maximalt tillatte konsentrasjon (MAC-EQS) på grunn av begrensninger i analytisk følsomhet. Oktyl- og nonylfenol og etoksylatene av disse ble ikke påvist i resipientene ved deteksjonsgrenser på henholdsvis 10 og 100 ng/l, noe som også betyr at indholdet av disse var under EQS. Kvikksølv ble ikke påvist i noen resipientprøver, ved deteksjonsgrensen 0,002 mg/l, og var dermed også under EQS. Kadmium ble funnet i resipientprøver i Tórshavn og Reykjavik, men max. halparten av EQS-verdien.

Å lage en status oppsummering med hensyn til fire byene med utgangspunkt i miljøkvalitetskriterier krever som det første at det finnes slike hvilket ikke altid var tilfellet. Men med dette som bakgrunn, så ser det ut som det er fosfat, PFAS og LAS som er de forurensningsstoffene som utgjør den største miljørisikoen i de områdene som ble undersøkt. I Tromsø ble overskridelser av EQS observert for alle tre forbindelser, i Tórshavn var det overskridelser for fosfat og LAS, i Sisimiut ble det sett overskridelser for fosfat og PFAS og i Reykjavík oversteg konsentrasjonen av PFOS i resipienten EUs EQS.

Del II av prosjektet var dedikert til å vurdere måter til å forbedre avløpsrensing på utvalge avløpsanlegg i de fire byene. For å konkretisere vurderingen ble deltakerne fra de ulike områdene bedt om å identifisere hvilken gruppe av forureninger som skulle prioriteres for rensing i de utvalgte avløpssystemene. Denne metoden ble valgt, siden del I av prosjektet bare omfattet en begrenset vurdering av miljøtilstanden i resipienten, både med hensyn til bredde av miljøgifter og utstrekning av undersøkelsen i tid og rom. Siden foreløpige undersøkelser i renseanlegg i bl.a. Reykjavík har antydet at mikroplast i avløpsvann passerte renseanlegget mer eller mindre upåvirket, ønsket den islandske representasjonen at vurderingen av forbedringstiltak for deres del skulle fokusere på mikroplast. I Sisimiut er problemet at det mangler rensningsanlegg for avløpsvann, og således var fokus for dette området å få et forslag som ville bestå hovedsakelig av primær behandling, det vil si å behandle den visuelle forurensningen samt næringsstoffer og organisk materiale i kloakken. Det rensealegget i Tromsø som er inkludert i studien er basert på mekanisk filtrering av kloakken, lignende den som er i de store renseanleggene i Reykjavík, men med mere finmasket sil. På grunn av lokale miljøutfordringer med forhøyet indhold av næringsstoffer, samt den velkjente svakheten ved slike rensemetoder til å håndtere vannløselige legemidler og frykten for økende miljøproblemer fra mikroforurensninger inkludert plast, som slippes ut med avløpsvann, ønsket Tromsøs representasjon i prosjektet at vurderingen skulle fokusere på økt renseeffektivitet for disse komponentene. I Tórshavn har det i tidligere undersøkelser vært påvist utfordringer på avløpsvannssiden med rensning av legemidler, ftalater og vaskemidler, slik at ønsket fra denne siden var et forslag til hvordan avløpsrensingen kunne forbedres for et nokså bredt spekter av potensielle miljøgifter.

Løsningene som diskuteres for å bedre avløpsrensingen var basert på litteraturstudier, både av fagfellevurderte publikasjoner, statlige og sektorforskningsinstitutter publikasjoner, kommersielle produktbeskrivelser samt lærebøker på området avløpsvann og resipientforurensning. Diskusjonen av rensemetodikk og krav til rensningsgrad ble gjort med utgangspunkt i EUs direktiv om urban avløpsrensing (21. Mai 1991, 91/271 / EØF). Løsninger til forbedret rensing for de ulike prioriterte miljøgifter (mikroplast, legemidler, næringssalter m.m.) ble diskutert i forhold til effektiviteten av de ulike behandlingstrinn som er beskrevet i litteraturen. Diskusjonen av rensingalternativer sum ble foreslått for de utvalgte avløpsnettene ble gjort på basis av renseprinsippenes egnethet for de enkelte stedene. Formålet med disse er at de skal kunne brukes som grunnlag for utforming av konkrete renseanleggutbedringer i de utvalgte område samt i andre lignende anlegg.

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Tromsø

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Tórshavn

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Reykjavík

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Sisimiut

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Appendices

Method description PFAS analyses

A protocol for water sampling (see below) and 2L PE bottles were sent out to the project participators. Water samples were stored at 4 °C until analysis and filtered through glass microfiber filters (GF/B, Whatman) before extraction using Oasis WAX (6cc/150 mg, Milford, MA, USA) according to standard method ISO 25101. Sea water samples were pre-treated prior filtration with sodium thiosulfate pentahydrate to reduce the risk of chlorine ions interfering in the extraction procedure. The SPE cartridges were conditioned with 4 mL of methanol and 4 mL water. Internal standards 13C4PFBA, 13C2PFHxA, 13C4PFOA, 13C5PFNA, 13C2PFDA, 13C2PFUnDA, 13C2PFDoA, 18O2PFHxS, 13C4PFOS, 13C26:2FTS, and 13C8PFOSA, were added to the water samples, before vacuum was used to run through the water at a flow rate of approximately 1 drop per second. The bottles used to store water samples were rinsed with 20 ml methanol that was added to the water sample to prevent losses to the surface during storage, mainly of the more hydrophobic PFAS. Between 200 and 2000 mL water was used in the extraction procedure. Sodium acetate buffer (4 mL, 0.025 M) was used after the sample load to wash out water soluble interferences, and the eluate was discarded. After drying the cartridges 4 mL methanol was added to elute neutral PFAS and the ionic analytes were then eluted with 4 mL of 0.1 % NH4OH/methanol solution. The eluates were collected, filtrated and evaporated to suitable volume with a gentle stream of nitrogen gas. Performance standards 13C3PFBA, 13C8PFOA, 13C9PFNA, 13C6PFDA, 13C7PFUnDA, 13C3PFHxS, 13C8PFOS were added prior injection. All standards used are from Wellington Laboratories (Guelph, Canada). The equivalent volume of 2mM NH4Ac in H2O was added to LC extracts which were injected (10 µL) on an Acquity UPLC Xevo TQ-S tandem mass spectrometer (Waters Corporation, Milford, USA) with an atmospheric electrospray interface operating in negative ion mode. The analytes were separated on an Acquity BEH C18 column (2.1 x 100 mm, 1.7 µm), with flow rate 300 µL/min using a gradient program delivering mobile phases consisted of 2 mM NH4Ac in MeOH, and 2 mM NH4Ac in H2O. An extra guard column (PFC isolator, Waters Corporation, Midford, US) was inserted between the pump and injector to remove any PFAS originating from the LC system. Capillary voltage was set to 0.6 kV, source and desolvation gas (N2, 950L/hr) temperatures were 150 and 450 °C. Cone voltages and collision energies were optimized for each transition. Multiple reaction monitoring was used monitoring two product ions. Samples were quantified using solvent calibration curves and isotope dilution. A minimum of five-point calibration curve was used. The internal standard closest in retention time was used for those compounds that did not have a corresponding labeled internal standard. It should be noted that only the linear isomer of target compounds were quantified if other structures were present. Qualifier ions were monitored for each compound if possible to verify the identity of the quantified peaks according to EU Council Directive 96/23/EC. The ratio between the two product ions in the samples were calculated and compared to an authentic standard, and did not exceed 50%. Blank methanol/water injections were carried out repeatedly during the analysis to monitor possible contamination from the instrument. Extraction blanks, using ultra-pure water, were also monitored. The limit of detection (DL) was set to the average signal found in the extraction blanks plus three standard deviations. The target analytes that did not fulfill the quality criteria's (ratios, internal standard recoveries) are not reported and left blank in the result tables.

Protocol for water sampling for PFAS analysis

General Avoid fluorinated materials such as PTFE in materials, clothes, etc. Any sampler used should be cleaned with high purity methanol (LC-MS grade). Also clean the plastic bottles (2L, PE/PP) with a small volume of methanol prior sampling.

Sampling Rinse the sampler several times with the water. Fill up the bottle with water and discard it. Take a fresh new sample and this time fill the bottle, seal it and label it. Please label the bottles in a non-erasable way of your choice. Please indicate if the bottle contains sea water or fresh water.Take one bottle and open the lid. Keep it open for a short while and then close it. Label the bottle as "Field blank" and include it together with the other samples.

Storage and shipment Store all bottles cold, but not frozen, in a fridge (+4 °C). Keep the samples cold during shipment with ice-packs. If sending the samples by courier; notify the contact person in advance and supply us with the courier name and tracking number after dispatch.

Table 21: Sampling event 1 in Tromsø

					LAT WGS84			LONG WGS84		
Matrix	Sample ident.	Location	Site	Sampling date	Deg	Decimal min	N	Deg	Decimal min	W/E
Influent	NO-1-Infl	Breivika RA	Innløp	29.10.13						
Effluent	NO-1-Eff	Breivika RA	Utløp	29.10.13						
Recipient	NO-1-Rec1	Breivika RA	Tromsøysundet	29.10.13		0421830	N		7730758	W
Recipient	NO-1-Rec2	Breivika RA	Tromsøysundet	29.10.13		0421921	N		7730626	W
Recipient	NO-1-Rec3	Breivika RA	Tromsøysundet	29.10.13		0421994	N		7730413	W
Influent	NO-2-Infl	Langnes RA	Innløp	29.10.13						
Effluent	NO-2-Eff	Langnes RA	Utløp	29.10.13						
Recipient	NO-2-Rec1	Langnes RA	Sandnessundet	29.10.13		0418254	N		7731980	W
Recipient	NO-2-Rec2	Langnes RA	Sandnessundet	29.10.13		0418106	N		7731865	W
Recipient	NO-2-Rec3	Langnes RA	Sandnessundet	29.10.13		0417873	N		7731626	W
Background	NO-Back	Tisnes	Referanse	29.10.13		0416277	N		7722091	W

Table 22: Sampling event 1 in Tórshavn

Matrix	Sample ident.	Location	Sampling date	Deg	Decimal min	N	Deg	Decimal min	W/E
Influent	FO-1-Infl	Sersjantv. WWTP	22-10-2013	62	0.495	N	006	45.714	W
Effluent	FO-1-Eff	Sersjantv. WWTP	22-10-2013	62	0.495	N	006	45.714	W
Recipient	FO-1-Rec1	Sersjantvíkin	22-10-2013	62	00'511	N	006	45'538	W
Recipient	FO-1-Rec2	Válgaravík	22-10-2013	62	00'738	N	006	45'371	W
Recipient	FO-1-Rec3	Boðanes	22-10-2013	62	01'471	N	006	45'335	W
Influent	FO-2-Infl	LSH WWTP	22-10-2013	62	0.6	N	6	46	W
Effluent	FO-2-Eff	LSH WWTP	22-10-2013	62	0.6	N	6	46	W
Recipient	FO-2-Rec1	LSH	22-10-2013	61	00'131	N	006	46'351	W
Recipient	FO-2-Rec2	Sjósavnið	22-10-2013	61	59'963	N	006	46'481	W
Recipient	FO-2-Rec3	Bátahyl Argir	22-10-2013	61	59'869	N	006	46'273	W
Background	FO-Back	Referansa	22-10-2013	61	59'952	N	006	44'861	W

Table 23: Sampling event 1 in Reykjavík

Matrix	Sample ident.	Sampling date	XUTM	YUTM	Lat.	Long.
Influent	IS1-Infl-K	13-11-2013			64°09.376'	21°52.334'
Effluent	IS1-Eff-K	13-11-2013				
Recipient	IS1-Rec-K-1	31-10-2013	455211	7118782	64°11.5458'	21°55.3244'
Recipient	IS1-Rec-K-2	31-10-2013	455445	7118868	64°11.5940'	21°55.0370'
Recipient	IS1-Rec-K-3	31-10-2013	455680	7118953	64°11.6415'	21°54.7482'
Influent	IS2-Infl-A	13-11-2013			64°09.205'	21°57.326'
Effluent	IS2-Eff-A	13-11-2013				
Recipient	IS1-Rec-A-1	31-10-2013	451859	7117562	64°10.8619'	21°59.4407'
Recipient	IS1-Rec-A-2	31-10-2013	452093	7117647	64°10.9097'	21°59.1535'
Recipient	IS1-Rec-A-3	31-10-2013	452328	7117733	64°10.9580'	21°58.8650'
Background	IS1-Rec-Back	31-10-2013	448236	7116948	64°10.5000'	22°03.9000'

Table 24: Sampling event 1 in Sisimiut

Matrix	Sample ident.	Location	Sampling date	Deg Min	decimal min	N/S	Deg Min	decimal min	W/E
Effluent	GL-1-Eff	Ulkebugt syd	21.10.2013	66 56	34.80	N	53 39	10.87	W
Recipient	GL-1-Rec1	Ulkebugt syd	21.10.2013	66 56'	60 97	N	53 39'	23 51	W
Recipient	GL-1-Rec2	Ulkebugt syd	21.10.2013	66 56'	63 51	N	53 39'	30 25	W
Recipient	GL-1-Rec3	Ulkebugt syd	21.10.2013	66 56'	66 26	N	53 39'	35 94	W
Effluent	GL-2-Eff	Natreno-bugt	21.10.2013	66 55	42.36	N	53 40	22.35	W
Recipient	GL-2-Rec1	Natreno-bugt	21.10.2013	66 55'	67 21	N	53 40'	40 10	W
Recipient	GL-2-Rec2	Natreno-bugt	21.10.2013	66 55'	61 62	N	53 40'	60 00	W
Recipient	GL-2-Rec3	Natreno-bugt	21.10.2013	66 55'	63 68	N	53 40'	72 00	W
Background	GL-Back	VSV for Sisimiut	21.10.2013	66 54'	86 19	N	53 41'	48 80	W

Note: The positions for effluent are given in decimal minutes and seconds.

Table 25: Sampling event 2 in Sisimiut

Matrix	Sample ident.	Location	Sampling date	Deg Min	decimal min	N/S	Deg Min	decimal min	W/E
Effluent	GL-1-Eff	Ulkebugt syd	26-05-2014*	66 56	34.80	N	53 39	10.87	W
Recipient	GL-1-Rec1	Ulkebugt syd	26-05-2014	66 56'	36 53	N	53 39'	11 17	W
Recipient	GL-1-Rec2	Ulkebugt syd	26-05-2014	66 56'	38 08	N	53 39'	13 88	W
Recipient	GL-1-Rec3	Ulkebugt syd	26-05-2014	66 56'	39 85	N	53 39'	17 45	W
Effluent	GL-2-Eff	Natreno-bugt	26-05-2014*	66 55	42.36	N	53 40	22.35	W
Recipient	GL-2-Rec1	Natreno-bugt	26-05-2014	66 55'	40 14	N	53 40'	23 56	W
Recipient	GL-2-Rec2	Natreno-bugt	26-05-2014	66 55'	38 36	N	53 40'	32 89	W
Recipient	GL-2-Rec3	Natreno-bugt	26-05-2014	66 55'	38 36	N	53 40'	39 72	W
Background	GL-Back	VSV for Sisimiut	26-05-2014	66 54'	49 99	N	53 41	28 87	W

Note: The positions for effluent samples are given in decimal minutes and seconds.
* Samples analysed for phthalates are 24-hrs mixed samples (sampling every 2. hrs starting Monday at 10 hrs ending Tuesday at 8 hrs mixed). Samples analysed for other parameters are taken at aorund 17 hrs on 26/5/2014.

Table 26: Results of the 1 analysis round; cadmium (Cd), phosphate and Linear alkyl benzene sulphonates (LAS)

Sample ID	Cd µg/l	Phosphate-P mg/l	C10 LAS mg/l	C11 LAS mg/l	C12 LAS mg/l	C13 LAS mg/l	C 14LAS mg/l	10-14 LAS µg/l UB
NO-1-infl 2013-10-29	<0.05	1.29	0.069	0.12	0.063	0.025	0.00084	0.278
NO-1-eff 2013-10-29	<0.05	1.32	0.078	0.13	0.071	0.032	0.00096	0.312
NO-1-rec1 2013-10-29	<0.05	0.051	0.00058	0.0013	0.001	0.00075	<0.0005	0.004
NO-1-rec2 2013-10-29	<0.05	<0.010	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
NO-1-rec3 2013-10-29	<0.05	<0.010	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
NO-2-infl 2013-10-29	<0.05	1.37	0.052	0.1	0.057	0.022	0.00068	0.232
NO-2-eff 2013-10-29	<0.05	1.35	0.057	0.12	0.07	0.031	0.0013	0.279
NO-2-rec1 2013-10-29	<0.05	<0.010	<0.0005	0.00094	0.00083	0.00056	<0.0005	0.003
NO-2-rec2 2013-10-29	<0.05	0.014	0.0017	0.0039	0.0027	0.0017	<0.0005	0.011
NO-2-rec3 2013-10-29	<0.05	<0.010	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
NO-back 2013-10-29	<0.05	<0.010	<0.0005	<0.0005	0.0005	<0.0005	<0.0005	0.003
FO-1-Infl 2013-10-22	<0.05	0.902	0.00076	0.0015	<0.0005	<0.0005	<0.0005	0.004
FO-1-Eff 2013-10-22	<0.05	1.38	0.025	0.053	0.038	0.019	0.0011	0.136
FO-1-Rec1 2013-10-22	0.0825	0.027	0.00071	0.00055	<0.0005	<0.0005	<0.0005	0.003
FO-1-Rec2 2013-10-22	<0.05	0.023	<0.0005	0.0021	0.0018	0.0018	<0.0005	0.007
FO-1-Rec3 2013-10-22	0.087	0.028	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
FO-2-Infl 2013-10-22	<0.05	1.7	0.00074	0.022	0.018	0.013	<0.0005	0.054
FO-2-Eff 2013-10-22	<0.05	3.44	0.018	0.044	0.043	0.034	0.0012	0.140
FO-2-Rec1 2013-10-22	<0.05	0.031	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
FO-2-Rec2 2013-10-22	0.0645	0.025	<0.0005	0.00052	<0.0005	<0.0005	<0.0005	0.003
FO-2-Rec3 2013-10-22	<0.05	0.024	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
FO-Back 2013-10-22	<0.05	0.02	<0.0005	0.0017	0.0017	0.0016	<0.0005	0.006
IS-1-Infl-K 2013-11-13	<0.05	0.345	0.034	0.06	0.036	0.018	0.0005	0.149
IS-1-Eff-K 2013-11-13	0.0633	0.32	0.034	0.063	0.038	0.017	<0.0005	0.153
IS-1-Rec-K1 2013-11-24	0.0892	0.015	<0.0005	0.0007	0.0008	0.0005	<0.0005	0.003
IS-1-Rec-K2 2013-11-24	<0.05	0.017	<0.0005	0.0008	<0.0005	<0.0005	<0.0005	0.003
IS-1-Rec-K3 2013-11-24	<0.05	0.017	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
IS-1-Infl-A 2013-11-13	<0.05	1.14	0.057	0.093	0.049	0.019	0.0008	0.219
IS-1-Eff-A 2013-11-13	<0.05	1.17	0.049	0.087	0.047	0.016	0.0008	0.200
IS-1-Rec-A1 2013-11-24	<0.05	0.025	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
IS-1-Rec-A2 2013-11-24	0.0871	0.023	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
IS-1-Rec-A3 2013-11-24	0.0507	0.022	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
IS-1-Rec-Back 2013-11-24	<0.05	0.017	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
GL-1-Eff 2013-10-21	0.0696	1.54	0.5	0.91	0.54	0.24	0.0068	2.197
GL-1-Rec1 2013-10-21	<0.05	<0.010	<0.0005	0.00055	<0.0005	<0.0005	<0.0005	0.003
GL-1-Rec2 2013-10-21	<0.05	<0.010	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
GL-1-Rec3 2013-10-21	<0.05	<0.010	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
GL-2-Eff 2013-10-21	0.0994	7.14	0.49	0.83	0.44	0.21	0.0059	1.976
GL-2-Rec1 2013-10-21	<0.05	0.025	<0.0005	0.00084	0.00071	0.00076	<0.0005	0.003
GL-2-Rec2 2013-10-21	<0.05	<0.010	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
GL-2-Rec3 2013-10-21	<0.05	<0.010	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003
GL-Back 2013-10-21	<0.05	<0.010	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.003

Note: The prefixes C10 to C14 indicated the number of carbon atoms in the alkyl-chain. UB = upper bound (meaning that concentrations reported as less than the detection limit has been set equal to the detection limit in calculation of sums.

Table 27: Results of the 1 analysis round. OF = octylphenol, NF= nonylphenol

Sample ID	4-tert-octyl-phenol	4-tert-OF-monoetoxy-late	4-tert-OF-dietoxy-late	4-tert-OF-trietoxy-late	4-nonyl-phenoler (techn. mix.)	4-NF-monoetoxy-late	4-NF-dietoxy-late	4-NF-trietoxy-late
NO-1-infl 2013-10-29	<100	310	<100	<100	<1000	2160	<1000	<1200
NO-1-eff 2013-10-29	<100	311	<100	<100	<1000	1960	<1000	<1000
NO-1-rec1 2013-10-29	<10	<10	<10	<10	<100	<100	<100	<100
NO-1-rec2 2013-10-29	<10	<10	<10	<10	<100	<100	<100	<100
NO-1-rec3 2013-10-29	<10	<10	<10	<10	<100	<100	<100	<100
NO-2-infl 2013-10-29	246	<100	<100	<100	<1000	<1000	<1000	<1200
NO-2-eff 2013-10-29	<100	<100	<100	<100	<1000	<1000	<1000	<1000
NO-2-rec1 2013-10-29	<10	<10	<10	<10	<100	<100	<100	<100
NO-2-rec2 2013-10-29	<10	<10	<10	<10	<100	<100	<100	<100
NO-2-rec3 2013-10-29	<10	<10	<10	<10	<100	<100	<100	<100
NO-back 2013-10-29	<10	<10	<10	<10	<100	<100	<100	<100
FO-1-Infl 2013-10-22	13	<10	<10	<10	169	<100	<100	<100
FO-1-Eff 2013-10-22	24	<10	<10	<10	184	<100	<100	<100
FO-1-Rec1 2013-10-22	<10	<10	<10	<10	<100	<100	<100	<100
FO-1-Rec2 2013-10-22	<10	<10	<10	<10	<100	<100	<100	<100
FO-1-Rec3 2013-10-22	<10	<10	<10	<10	<100	<100	<100	<100
FO-2-Infl 2013-10-22	20	73	<80	<140	411	259	348	<200
FO-2-Eff 2013-10-22	41	453	838	170	210	299	313	<500
FO-2-Rec1 2013-10-22	<10	<10	<10	<10	<100	<100	<100	<100
FO-2-Rec2 2013-10-22	<10	<10	<10	<10	<100	<100	<100	<100
FO-2-Rec3 2013-10-22	<10	<10	<10	<10	<100	<100	<100	<100
FO-Back 2013-10-22	<10	<10	<10	<10	<100	<100	<100	<100
IS-1-Infl-K 2013-11-13	78	<10	<20	<10	<250	113	<200	<400
IS-1-Eff-K 2013-11-13	66	<10	<15	<10	144	131	<350	<900
IS-1-Rec-K1 2013-11-24	<10	<10	<10	<10	<100	<100	<100	<100
IS-1-Rec-K2 2013-11-24	<10	<10	<10	<10	<100	<100	<100	<100
IS-1-Rec-K3 2013-11-24	<10	<10	<10	<10	<100	<100	<100	<100
IS-1-Infl-A 2013-11-13	46	16	<15	<10	129	<100	<110	<1100
IS-1-Eff-A 2013-11-13	16	15	<15	<15	<100	<100	<500	<300
IS-1-Rec-A1 2013-11-24	<10	<10	<10	<10	<100	<100	<100	<100
IS-1-Rec-A2 2013-11-24	<10	<10	<10	<10	<100	<100	<100	<100
IS-1-Rec-A3 2013-11-24	<10	<10	<10	<10	<100	<100	<100	<100
IS-1-Rec-Back 2013-11-24	<10	<10	<10	<10	<100	<100	<100	<100
GL-1-Eff 2013-10-21	19	<10	<10	<20	876	<500	501	<2200
GL-1-Rec1 2013-10-21	<10	<10	<10	<10	<100	<100	<100	<100
GL-1-Rec2 2013-10-21	<10	<10	<10	<10	<100	<100	<100	<100
GL-1-Rec3 2013-10-21	<10	<10	<10	<10	<100	<100	<100	<100
GL-2-Eff 2013-10-21	<30	116	<10	<15	801	3620	<150	<500
GL-2-Rec1 2013-10-21	<10	<10	<10	<10	<100	<100	<100	<100
GL-2-Rec2 2013-10-21	<10	<10	<10	<10	<100	<100	<100	<100
GL-2-Rec3 2013-10-21	<10	<10	<10	<10	<100	<100	<100	<100
GL-Back 2013-10-21	<10	<10	<10	<10	<100	<100	<100	<100

Table 28: Results of the 2 analyses round April/May 2014

ELEMENT	Phosphate-P	salinity	NH_4-N	TOC	DMP	DEP	DPP	DBP	DIBP	DPeP	DOP	DEHP	BBP	DCHP	DIDP	DINP	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS UB
SAMPLE	mg/l	o/oo	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
NO-1-Infl 28-29.04.14	0.906	0.6	9.25	13.8	<0.30	0.65	<0.30	<0.30	<0.40	<0.30	<0.30	2.6	<0.30	0.33			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-1-Eff 28-29.04.14	0.867	0.5	9.56	8.28	<0.30	0.94	<0.30	<0.30	<0.40	<0.30	<0.30	2.3	<0.30	<0.30			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-1-Rec1 28.04.14	0.024	33.4	0.126	<1.50	<0.30	<0.30	<0.30	<0.30	1.6	<0.30	<0.30	<0.40	<0.30	<0.30			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-1-Rec2 28.04.14	0.014	33.6	0.077	<1.50	<0.30	<0.30	<0.30	<0.30	<0.40	<0.30	<0.30	<0.40	<0.30	<0.30			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-1-Rec3 28.04.14	<0.01	33.7	0.053	<1.50	<0.30	<0.30	<0.30	<0.30	<0.40	<0.30	<0.30	<0.40	<0.30	<0.30			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-2-Infl 28-29.04.14	0.497	0.1	5.6	5.48	<0.30	<0.30	<0.30	<0.30	<0.40	<0.30	<0.30	34	<0.30	<0.30			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-2-Eff 28-29.04.14	0.572	0.1	3.22	5.47	<0.3	<0.3	<0.3	<0.3	<0.4	<0.3	<0.3	1.5	<0.3	<0.3			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-2-Rec1 28.04.14	<0.01	33.9	0.047	<1.50	<0.3	<0.3	<0.3	<0.3	<0.4	<0.3	<0.3	<0.4	<0.3	<0.3			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-2-Rec2 28.04.14	<0.01	34	0.099	<1.50	<0.3	<0.3	<0.3	<0.3	0.44	<0.3	<0.3	<0.4	<0.3	<0.3			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-2-Rec3 28.04.14	<0.01	34.1	0.066	<1.50	<0.3	<0.3	<0.3	<0.3	<0.4	<0.3	<0.3	<0.4	<0.3	<0.3			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
NO-Back 28.04.14	<0.01	33.9	0.074	<1.50	<0.3	<0.3	<0.3	<0.3	<0.4	<0.3	<0.3	<0.4	<0.3	<0.3			<0.50	<0.50	<0.50	<0.50	<0.50	2.5
FO-1-Infl 2014-04-29	1.15	0.1	9.86	3.18	<0.30	0.44	<0.30	<0.30	0.64	<0.30	<0.30	1.2	<0.30	<0.30	<1.0	4	0.028	0.047	0.026	0.012	<0.0005	0.1135
FO-1-Eff 2014-04-29	1.1	0.1	9.24	3.38	<0.30	3.7	<0.30	<0.30	<0.50	<0.30	<0.30	0.75	<0.30	<0.30	<1.0	5.2	0.022	0.04	0.023	0.012	<0.0005	0.0975
FO-1-Rec 1 2014-04-29	0.044	29.8	0.319	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	0.0008	0.00092	<0.0005	0.0015	<0.0005	0.00422
FO-1-Rec 2 2014-04-29	<0.01	30.4	0.089	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
FO-1-Rec 3 2014-04-29	<0.01	28.4	0.06	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025

ELEMENT	Phosphate-P	salinity	NH_4-N	TOC	DMP	DEP	DPP	DBP	DIBP	DPeP	DOP	DEHP	BBP	DCHP	DIDP	DINP	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS UB
SAMPLE	mg/l	o/oo	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
FO-2-Rec 1 2014-04-29	0.024	34.5	0.127	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
FO-2-Rec 2 2014-04-29	<0.01	37.6	0.048	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
FO-2-Rec 3 2014-04-29	<0.01	36.1	0.083	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
FO-Back 2014-04-29	<0.01	31.6	0.063	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
FO-2-Eft BLANK 2014-04-29					<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0						
IS2-Infl-K 2014-05-15	0.905	1.4	8.04	10	<0.30	1.2	<0.30	<0.30	0.55	<0.30	<0.30	49	<0.30	<0.30	1.4	7.1	0.062	0.11	0.074	0.039	<0.0050	0.2900
IS2-Eff-K 2014-05-15	1.52	0.85	12.1	11.8	<0.30	1.3	<0.30	<0.30	<0.50	<0.30	<0.30	1.3	<0.30	<0.30	<1.0	3.7	0.052	0.091	0.064	0.034	<0.0050	0.2460
IS2-Rec-K-1 2014-05-15	<0.01	38	0.091	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.10	<0.50	<0.30	<0.10	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
IS2-Rec-K-2 2014-05-15	<0.01	35	0.207	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
IS2-Rec-K-3 2014-05-15	<0.01	39	0.131	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
IS2-Infl-A 2014-05-19	1.49	0.92	13.1	13.4	<0.30	1.3	<0.30	<0.30	<0.50	<0.30	<0.30	2.3	<0.30	<0.30	<1.0	2.5	0.065	0.13	0.082	0.035	<0.0050	0.3170
IS2-Eff-A 2014-05-19	2.28	2.4	15.3	12.6	<0.30	1.1	<0.30	<0.30	<0.50	<0.30	<0.30	2.4	<0.30	<0.30	<1.0	3	0.056	0.099	0.063	0.028	<0.0050	0.2510
IS2-Rec-A-1 2014-05-19	<0.01	39	0.123	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
IS2-Rec-A-3 2014-05-19	<0.01	39	0.152	<1.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
IS2-Rec-Back 2014-05-15	<0.01	39	0.13	<1.50	<0.30	<0.30	<0.30	<0.30	0.5	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025
GL-1 Eff Ulkebugt Syd* 2014-05-26	2	0.08	26	27.5	<0.30	<0.30	<0.30	<0.30	0.82	<0.30	<0.40	8.2	<0.30	<0.30	3	21	0.18	0.29	0.12	0.087	0.05	0.7270
GL-1 Rec1 Ulkebugt Syd 2014-05-26	0.144	21.7	0.291	1.33	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	0.0011	<0.0005	<0.0005	0.0031

ELEMENT	Phosphate-P	salinity	NH_4-N	TOC	DMP	DEP	DPP	DBP	DIBP	DPeP	DOP	DEHP	BBP	DCHP	DIDP	DINP	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS UB
SAMPLE	mg/l	o/oo	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
GL-2 Eff Natreno-bugt* 2014-05-26	6.2	0.11	65	59.1	<0.30	0.38	<0.30	0.34	0.94	<0.30	<0.50	16	<0.30	<0.40	4.4	29	0.25	0.36	0.12	0.08	0.05	0.8600
GL-2 Rec1 Natreno-bugt 2014-05-26	0.067	32.7	0.358	<0.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	0.00097	<0.0005	<0.0005	0.0030
GL-2 Rec2 Natreno-bugt 2014-05-26	<0.01	34.9	0.041	<0.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	0.00098	<0.0005	<0.0005	0.0030
GL-2 Rec3 Natreno-bugt 2014-05-26	0.026	33.6	0.042	<0.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	0.00097	<0.0005	<0.0005	0.0030
GL-Back VSV for Sisimiut 2014-05-26	0.016	33.6	0.051	<0.50	<0.30	<0.30	<0.30	<0.30	<0.50	<0.30	<0.30	<0.50	<0.30	<0.30	<1.0	<1.0	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0025

Note: *Phthalates were analysered in 24-hrs pooled sample.

Table 29: Results of the third analyses round – part a LAS, mercury (Hg), total organic carbon (TOC), chloride, salinity, ammonium-nitrogen and phosphate

ELEMENT SAMPLE	DeLAS mg/l	UnLAS mg/l	DoLAS mg/l	TriLAS mg/l	TeLAS mg/l	Chloride mg/l	salinity o/oo	ammonium-N mg/l	TOC mg/l	phosphate-P mg/l	Hg µg/l
NO-1-Infl Breivika Rense anlegg	0.066	0.098	0.044	0.018	<0.00050	1570	2.9	41.5	71	3.06	<0.002
NO-1-Eff Breivika Rense anlegg	0.055	0.1	0.046	0.017	<0.00050	1610	2.9	41.7	41.5	2.92	0.0208
NO-1-Rec1 Breivika Rense resipient	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19300	34.9	0.914	<2.50	0.086	<0.002
NO-1-Rec2 Breivika Rense resipient	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19600	35.4	0.209	<2.50	<0.010	<0.002
NO-1-Rec3 Breivika Rense resipient	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19200	34.7	0.18	<2.50	<0.010	<0.002
NO-2-Infl Langnes renseanlegg	0.052	0.096	0.052	0.018	<0.00050	80.8	0.18	31.3	38.8	2.31	0.0163
NO-2-Eff Langnes renseanlegg	0.11	0.21	0.11	0.019	<0.00050	64.6	0.15	30.8	24.8	2.26	0.0123
NO-2-Rec1 Langnes resipient	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	21600	39	0.156	<2.50	<0.010	<0.002
NO-2-Rec2 Langnes resipient	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19500	35.2	0.102	<2.50	<0.010	<0.002
NO-2-Rec3 Langnes resipient	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19800	35.8	0.116	<2.50	<0.010	<0.002
NO-Back Referanse	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19500	35.2	0.149	<2.50	<0.010	<0.002
FO-1-Influent	0.044	0.085	0.051	0.019	<0.00050	59.5	0.14	21.9	12		0.0051
FO-1-Effluent	0.047	0.085	0.05	0.021	<0.00050	55.7	0.13	19.4	13.3		0.00578
FO-1-Rec 1	<0.00050	0.0011	0.00072	<0.00050	<0.00050	25200	45.5	0.19	4.3		<0.002
FO-1-Rec 2	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	26800	48.4	0.075	3.63		<0.002
FO-1-Rec 3	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	24800	45	<0.050	3.67		<0.002
FO-2-Influent	0.064	0.0099	0.01	0.0071	<0.00050	45	0.11	19.1	27		0.00547
FO-2-Effluent	0.011	0.021	0.013	0.0046	<0.00050	79.2	0.17	8.66	12		0.0267
FO-2-Rec 1	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	27700	50	0.053	3.54		<0.002
FO-2-Rec 2	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19700	35.6	<0.050	2		<0.002
FO-2-Rec 3	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	24200	43.7	<0.050	15.1		<0.002
FO-Background	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	27100	49	<0.050	3.16		<0.002
FO-2-Eff 10-9-14	0.0093	0.018	0.012	0.0048	<0.00050						
IS3-Infl-K 2014-08-28;2014-09-02	0.057	0.11	0.065	0.021	<0.00050	514	0.96	10.5	20.4	1.02	0.0489
IS3-Eff-K 2014-08-28;2014-09-02	0.054	0.11	0.061	0.02	<0.00050	410	0.77	11.3	45.2	1.2	0.0161
IS3-Rec-K-1 2014-08-28;2014-09-02	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	21000	38	0.089	<2.50	0.015	<0.002
IS3-Rec-K-2 2014-08-28;2014-09-02	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19700	36	0.062	<2.50	0.014	<0.002
IS3-Rec-K-3 2014-08-28;2014-09-02	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	21300	38	0.063	<2.50	0.016	<0.002
IS3-Infl-A 2014-08-28;2014-09-02	0.074	0.15	0.097	0.031	<0.00050	425	0.8	13.8	19.7	1.48	0.0204
IS3-Eff-A 2014-08-28;2014-09-02	0.063	0.12	0.065	0.02	<0.00050	1530	2.8	13.2	28.8	2.06	0.0132
IS3-Rec-A-1 2014-08-28;2014-09-02	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	21500	39	0.04	<2.50	0.017	<0.002
IS3-Rec-A-2 2014-08-28;2014-09-02	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	30000	54	<0.040	<2.50	0.018	<0.002
IS3-Rec-A-3 2014-08-28;2014-09-02	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	34100	62	<0.040	<2.50	0.016	<0.002
IS3-Rec-Back 2014-08-28;2014-09-02	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	18400	33	0.043	<2.50	0.015	<0.002
GL1-EFF. degn 20140831-20140901	0.22	0.36	0.15	0.07	<0.00050	37.6	0.1	31.3	37.5	2.48	0.0207
GL1-rec1 20140831-20140901	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	17500	32	0.168	2.02	0.02	<0.002
GL1-rec2 20140831-20140901	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	17400	31	0.127	1.38	<0.010	<0.002
GL1-rec3 20140831-20140901	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	17300	31	0.078	<2.50	<0.010	<0.002
GL2-EFF. degn 20140831-20140901	0.46	0.87	0.37	0.18	0.00093	61.2	0.14	61.2	81.4	6.07	0.023
GL2-rec1 20140831-20140901	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	18900	34	0.283	<2.50	0.026	<0.002
GL2-rec2 20140831-20140901	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19800	36	0.19	<2.50	0.022	<0.002
GL2-rec3 20140831-20140901	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	20500	37	0.12	<2.50	<0.010	<0.002
GL Back 20140831-20140901	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	19200	35	0.063	<2.50	<0.010	<0.002

Note: DeLAS: decylbenzene sulfonate, UnLAS: undecylbenzene sulfonate, DoLAS: dodecylbenzene sulfonate, TriLAS: tridecylbenzene sulfonate and TeLAS: tetradecylbenzene sulfonate.

Table 30: Results of the third analyses round – part b PAH

ELEMENT	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Antracene	Fluoranthene	Pyrene	Benz (a) anthracene	chrysene	Benz (b) fluoranthene	Benz (k) fluoranthene	Benz (a) pyrene	Dibenzo (ah) - antracene	Benzo (ghi) perylene	Indeno (123cd) pyrene	PAH, Sum 16	PAH, sum carcinogens	PAH, sum others
SAMPLE	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
NO-1-Infl Breivika Rense anlegg	0.63	<0.010	0.02	0.041	0.1	<0.010	0.081	0.067	0.049	0.035	0.031	0.022	0.042	<0.077	<0.010	<0.010	1.1	0.18	0.94
NO-1-Eff Breivika Rense anlegg	0.56	<0.010	0.02	0.028	0.07	<0.010	0.052	0.047	0.022	0.015	<0.010	<0.010	0.011	<0.010	<0.010	<0.010	0.82	0.048	0.77
NO-1-Rec1 Breivika Rense resipient	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
NO-1-Rec2 Breivika Rense resipient	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
NO-1-Rec3 Breivika Rense resipient	<0.010	<0.010	<0.010	<0.010	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.01	<0.035	0.01
NO-2-Infl Langnes renseanlegg	0.049	<0.010	<0.010	0.018	0.04	<0.010	<0.034	0.03	0.012	<0.010	<0.010	<0.010	0.016	<0.010	<0.010	<0.010	0.17	0.028	0.14
NO-2-Eff Langnes renseanlegg	0.054	<0.010	<0.010	0.018	0.031	<0.010	<0.027	0.025	0.013	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.14	0.013	0.13
NO-2-Rec1 Langnes resipient	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
NO-2-Rec2 Langnes resipient	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
NO-2-Rec3 Langnes resipient	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
NO-Back Referanse	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.01	0.01	<0.045
FO-1-Influent	<0.010	<0.010	<0.010	<0.010	0.011	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.011	<0.035	0.011
FO-1-Effluent	0.023	<0.010	0.02	0.082	0.1	<0.010	0.02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.24	<0.035	0.24
FO-1-Rec 1	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
FO-1-Rec 2	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
FO-1-Rec 3	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
FO-2-Influent	<0.010	<0.010	<0.010	<0.010	0.019	<0.010	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.016	<0.010	<0.010	<0.010	0.029	<0.038	0.029
FO-2-Effluent	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
FO-2-Rec 1	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
FO-2-Rec 2	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
FO-2-Rec 3	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
FO-Background	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
IS3-Rec-K-1 2014-08-28; 2014-09-02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045

ELEMENT	Naphthal-ene	Ace-naphth-ylene	Ace-naphth-ene	Fluorene	Phenan-threne	Antra-cene	Fluor-anthene	Pyrene	Benz (a) anthra-cene	Chrysene	Benz (b) fluor-anthene	Benz (k) fluor-anthene	Benz (a) pyrene	Dibenzo (ah) - antra-cene	Benzo (ghi) perylene	Indeno (123cd) pyrene	PAH, Sum 16	PAH, sum carcino-gens	PAH, sum others
SAMPLE	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
IS3-Rec-K-2 2014-08-28; 2014-09-02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
IS3-Rec-K-3 2014-08-28; 2014-09-02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
IS3-Infl-A 2014-08-28; 2014-09-02	0.049	1	12	0.11	0.028	0.016	0.02	0.02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	13	<0.035	13
IS3-Eff-A 2014-08-28; 2014-09-02	0.29	<0.010	0.02	0.041	0.058	<0.010	0.021	0.03	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.46	<0.035	0.46
IS3-Rec-A-1 2014-08-28; 2014-09-02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
IS3-Rec-A-2 2014-08-28;2014-09-02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
IS3-Rec-A-3 2014-08-28; 2014-09-02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
IS3-Rec-Back 2014-08-28; 2014-09-02	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
GL1-EFF. degn 20140831–20140901	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.40	<0.18	<0.23
GL1-rec1 20140831–20140901	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
GL1-rec2 20140831–20140901	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
GL1-rec3 20140831–20140901	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
GL2-EFF. degn 20140831–20140901	0.5	<0.050	<0.050	93	57	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	150	<0.18	150
GL2-rec1 20140831–20140901	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
GL2-rec2 20140831–20140901	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
GL2-rec3 20140831–20140901	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045
GL Back 20140831–20140901	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.080	<0.035	<0.045

Table 31: QAS in ng/l, in samples taken in the fourth analysis round, i.e. in February and March 2015

Sample Name	DDAC-C10	DDAC-C12	DDAC-C14	DDAC-C14:16 I	DDAC-C16	DDAC-C16:18 I	DDAC-C18	BAC-C12	BAC-C14	BAC-C16	BAC-C18	ATAC-C12	ATAC-C14	ATAC-C16	ATAC-C18	ATAC-C20	ATAC-C22	Sum DDAC	Sum BAC	Sum ATAC
NO-1-Effl	550	6.3	2.3	9.0	110	220	580	2600	530	14	18	950	210	860	220	530	3200	1500	3200	6000
NO-2-Rec	<1.4	<0.25	<0.32	<0.074	<1.1	<1	<3.4	<4.2	<0.82	<0.37	<0.45	<0.69	<2.4	<3.4	<1.4	<1.4	<10			
NO-3-Rec	<1.3	<0.24	<0.31	<0.071	<1	<0.96	<3.3	<4.1	<0.79	<0.35	<0.43	<0.66	<2.3	<3.2	<1.3	<1.3	<10			
NO-4-Effl	980	9.1	3.0	11	130	250	740	4100	3300	490	59	1900	320	1800	380	910	5200	2100	7900	11000
NO-5-Rec	<1.3	<0.23	<0.3	<0.069	<0.99	<0.94	<3.2	<4	<0.77	<0.35	<0.42	<0.65	<2.3	<3.2	<1.3	<1.3	<9.8			
NO-6-Rec	<1.5	<0.27	<0.35	<0.081	<1.2	<1.1	<3.7	<4.6	<0.9	<0.4	<0.5	<0.76	<2.7	<3.7	<1.5	<1.5	<11			
NO-7-Bac	<1.4	<0.25	<0.32	<0.073	<1	<0.99	<3.4	<4.2	<0.81	<0.36	<0.45	<0.68	<2.4	<3.3	<1.3	<1.4	<10			
FO-2-Rec	2.0	<0.27	<0.35	<0.081	<1.2	<1.1	<3.7	5.9	<0.9	<0.4	<0.49	<0.75	<2.7	<3.7	<1.5	<1.5	<11	2.0	5.9	
FO-3-Rec	<1.5	<0.28	<0.36	<0.082	<1.2	<1.1	<3.8	<4.7	<0.91	<0.41	<0.5	<0.76	<2.7	<3.7	<1.5	<1.5	<12			
FO-5-Rec	<1.4	<0.26	<0.33	<0.076	<1.1	<1	<3.5	5.9	<0.84	<0.38	<0.46	1.8	<2.5	<3.4	<1.4	<1.4	<11		5.9	1.8
FO-6-Rec	11.0	<0.29	<0.37	<0.085	<1.2	<1.2	<3.9	<4.9	<0.95	<0.43	<0.52	<0.8	<2.8	<3.9	<1.6	<1.6	<12	11		
FO-7-Bac	<1.7	<0.3	<0.39	<0.089	<1.3	<1.2	<4.1	7.6	<0.99	<0.45	<0.55	<0.83	<2.9	<4.1	<1.6	<1.7	<13		7.6	
IS4-Rec-K1	<1.4	<0.25	<0.32	<0.072	<1	<0.99	<3.4	<4.2	<0.81	<0.36	0.5	<0.68	<2.4	<3.3	<1.3	<1.4	<10		0.5	
IS4-Rec-K2	1.8	<0.26	<0.34	<0.077	<1.1	<1	<3.6	4.9	<0.86	<0.38	<0.47	<0.72	<2.5	<3.5	<1.4	<1.5	<11	1.8	4.9	
IS4-Rec-A1	9.2	1.9	1.7	0.8	<1.1	<1	<3.5	16.0	1.7	<0.38	<0.47	1.3	<2.5	<3.5	<1.4	<1.4	<11	14	18	1.3
A2 IS4-Rec-A2	8.5	1.9	1.2	0.6	<1.2	<1.1	<3.8	18.0	3.5	<0.41	<0.5	1.0	<2.7	<3.7	<1.5	<1.5	<12	12	22	1.0
GR IS4-Back	<1.4	<0.26	<0.34	<0.077	<1.1	<1	<3.6	<4.4	<0.86	<0.38	<0.47	<0.72	<2.5	<3.5	<1.4	<1.5	<11			
GL 1 Effluent	1400	26	18	8	160	170	530	61000	15000	740	190	320	110	5200	270	140	760	2300	77000	6800
GL 1 Rec 1 Havvand	<1.4	<0.25	<0.32	<0.073	<1.1	<1	<3.4	17.0	<0.82	<0.37	<0.45	<0.69	<2.4	<3.3	<1.4	<1.4	<10		16	
GL 1 Rec 2 Havvand	<1.4	<0.25	<0.32	<0.074	<1.1	<1	<3.4	19.0	1.7	<0.37	<0.45	<0.69	<2.4	<3.3	<1.4	<1.4	<10		21	
GL Background Havvand	<1.4	<0.25	<0.33	<0.075	<1.1	<1	<3.5	<4.3	<0.83	<0.37	<0.46	<0.7	<2.5	<3.4	<1.4	<1.4	<11			
GL 2 Effluent, Spildevand, kloak	19000	31	48	3	110	120	440	14000	10000	1700	470	110	90	2700	310	230	1300	20000	27000	4700
GL 2 Rec1 Havvand	<1.4	<0.25	<0.32	<0.074	<1.1	<1	<3.4	15.0	1.7	<0.37	<0.46	<0.7	<2.4	<3.4	<1.4	<1.4	<11		17	
GL 2 Rec2 Havvand	<1.4	<0.25	<0.32	<0.074	<1.1	<1	<3.4	15.0	1.7	<0.37	<0.46	<0.7	<2.4	<3.4	<1.4	<1.4	<11		17	

Table 32: polyfluoroalkyl substances in ng/kg, in samples taken in the fourth analysis round, i.e. in February and March 2015. The analyses were done on fil-tered water samples. Detection limits, DL, are defined in the lower rows. Lab ID refers to journal nr. DL15-011

Round	Lab ID	ID	Sample type	Sum PFAS	PFBA[1]	PFPeA	PFBuS	PFHxA	PFHpA	PFPeS	PFHxS	PFHpS	PFOA	PFNA	PFOSA	PFOS	PFDA	PFUnDA	PFNS	PFDS	PFDoDA	PFTrDA	PFTDA	6:2 FTS	8:2 FTS
4.0	:01	NO-1-INFL	Influent	4.63			1.1	<DL	0.53	<DL	<DL	<DL	1.2	0.4		1.1	0.21	0.09	<DL						
4.0	:02	NO-1-EFF	Effluent	5.36			1.2	<DL	0.41	0.34	<DL	<DL	1.2	0.35		1.5	0.29	0.07	<DL		<DL	<DL	<DL		
4.0	:03	NO-1-Rec1	Recipient	6.5		0.41	0.38	1.2	0.4	<DL	0.13		2.3	0.17		0.26	0.36							0.77	0.15
4.0	:04a	NO-1-Rec2 A	Recipient	14.4		0.73	0.87	2.1	0.89	0.08	0.29		2.1	0.36		0.72	0.59	<0.30	<DL	<DL				5.7	
4.0	:04b	NO-1-Rec2 B	Recipient	1.5							0.68					0.8									
4.0	:05a	NO-1-Rec3"A	Recipient	16.6		1.3	1.1	3.1	1.1	0.08	0.39	0.1	7.1	0.68		0.79	0.81								
4.0	:05b	NO-1-Rec3"B	Recipient	12.8				3.4	1.2	0.04	0.38	0.11	6.2	0.77		0.73									
4.0	:06	NO-2-INFL	Influent	12.23			0.46	2.1	1.6	0.47	3.2	0.32	1.4	0.56		1.9	0.15	0.07	<DL						
4.0	:07	NO-2-EFF	Effluent	9.17			0.49	1.7	0.63	0.54	1.9	0.28	1.1	0.49		1.8	0.16	0.08	<DL						
4.0	:08	NO-2-Rec 1	Recipient	3.6									2.7	<0.30		0.39								0.46	
4.0	:11	NO Back	Background	3.35	<DL	0.39	0.42	0.47	0.3	<DL	0.14	<DL	1.1	0.13	<DL	0.26	0.14	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:12	NO Blank	Blank	0	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:13	IS4-EFF-K	Effluent	29.37			1.2	2.6	0.9	0.73	4.1	0.38	3.1	0.44		11.1	0.22		<DL		<DL	<DL		4.6	
4.0	:15	IS4-INFL-A	Influent	6.65			1.2	<DL	0.42	0.26	0.88	<DL	1	0.25		2.2	0.18	0.17	<DL		0.09	<DL	<DL		
4.0	:16	IS4-EFF-A	Effluent	8.5			0.51	1.6	0.52	0.26	1.2	<DL	1.1	0.2		2.4	0.12	0.1	<DL		<DL	<DL		0.49	
4.0	:17	IS4-INFL-K	Influent	21.71			1.3	2.5	1.1	0.78	3.3	0.38	2.2	0.25		9.7	0.2	<DL	<DL		<DL	<DL			
4.0	:18	IS4-Rec3	Recipient	1.49		<0.10	<DL	0.53	0.15	<DL	<DL	0.11	0.49	<DL	<DL	0.1	0.11	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:20	IS4-RecA1	Recipient	4.77		<DL	<DL	0.85	0.19	<DL	0.15	<DL	1.5	0.11	<DL	0.14	0.23	<DL	<DL	<DL	<DL	<DL	<0.10	1.6	<DL
4.0	:21	FO-1-EFF1	Effluent	5.89			0.23	1.5	0.76	<DL	0.15	<DL	2.1	0.34	<DL	0.74	<DL	<DL	<DL	0.07	<DL	<DL	<DL		
4.0	:22	FO-2-INFL	Influent	2.54			<DL			<DL	<DL	<DL	1.1	0.6	<DL	0.42	0.12	<DL	0.02	0.28		<DL			
4.0	:23	FO-2-EFF LSH	Effluent	10.87			<DL	5.2	0.82	<DL	<DL	<DL	3.9	0.38	0.05	0.42	0.1	<DL	<DL	<DL		<DL	<DL		
4.0	:24	FO-1-INF STP	Influent	4.9	<DL		0.31	0.9	0.62	<DL	<DL	<DL	1.4	0.43	<DL	0.85	0.12	<DL	<DL	0.05	0.08	0.07	<DL		0.07
4.0	:29	GL-1-REC 1/2	Recipient	0.42	<DL	0.09	<DL	0.11	0.05	0.01	<DL	<DL	0.12	<DL	<DL	<DL	<DL		<DL	<DL					0.04
4.0	:30	GL-1-EFF	Effluent	0.42	<DL	0.09	<DL	0.11	0.05	0.01	<DL	<DL	0.12	<DL	<DL	<DL	<DL		<DL	<DL					0.04
4.0	:32R	GL 1-Rec1	Recipient	0.35			<DL	<0.35	<0.27	<DL	<DL	<DL	0.35	<0.12		<0.15	<0.15	<0.30						<0.50	<DL
4.0	:33R	GL 1-Rec2	Recipient	0.00			<0.30			<0.10	<0.14					<0.30									
4.0	:34	GL-2-REC 1/2	Recipient	2.81			0.24			0.13	0.08	<DL	1.7	0.34	<DL	<DL			0.23	<DL		0.09	<DL		
4.0	:35	GL-2-EFF	Effluent	0.16	<DL	<DL	<DL	<DL	0.05	<DL	<DL	<DL	0.11	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL		<DL
4.0	:38	GL 2 Rec3	Recipient	0.00		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL		<DL
4.0	:39	GL Back	Background	0	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:40	IS4-RecK1	Recipient	0.34		<DL	<DL	0.17	0.08	<DL	<DL	<DL	<DL	<DL	<DL	0.09	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:41	IS4-RecK2	Recipient	0.07		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL		<DL	0.07	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL

Round	Lab ID	ID	Sample type	Sum PFAS	PFBA[1]	PFPeA	PFBuS	PFHxA	PFHpA	PFPeS	PFHxS	PFHpS	PFOA	PFNA	PFOSA	PFOS	PFDA	PFUnDA	PFNS	PFDS	PFDoDA	PFTrDA	PFTDA	6:2 FTS	8:2 FTS
4.0	:42	IS4-RecA2	Recipient	2.48		<0.20	0.51	0.35	0.19		0.14	0.14	0.38	0.08	0.01	0.22	<DL	<DL	<DL	<DL				0.46	
4.0	:43	IS Blank	Blank	1.8	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	1.8	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:44	GL Blank	Blank	0	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:45	FO1-Rec1	Recipient	0.7		<DL	<DL	0.73	<DL	<DL	<DL	<DL	<DL		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL		<DL
4.0	:46	FO1-Rec2	Recipient	1.0		<DL	<DL	0.81	<DL	<DL	<DL	<DL	0.15		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL		<DL
4.0	:47	FO1-Rec3	Recipient	0.9		<DL	<DL	0.85	<DL	<DL	<DL	<DL	<DL		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL		<DL
4.0	:48	FO2-Rec1	Recipient	0.2		<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.23	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:49	FO2-Rec2	Recipient	0.2		<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.19	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:50	FO2-Rec3	Recipient	0.2		<DL	<DL	<DL	<DL	<DL	<DL		0.18	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:51	FO Back	Background	0	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	:52	FO Blank	Blank	0	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.1	:53	FO Eff LSH m[2]	Effluent	1.73	<DL	<DL	<DL	0.45	0.2	<DL	<DL	<DL	0.37	0.12	na	0.23	0.1	<DL	<DL	<DL				0.2	0.06
4.1	:54	FO Eff LSH a[2]	Effluent	1.7	<DL	<DL	<DL	0.47	0.21	<DL	<DL	<DL	0.36	0.11	na	0.12	0.14	<DL	<DL	<DL				0.23	0.06
4.1	:55	NO-2-Rec 2	Recipient	0.0			<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.1	:56	NO-2-Rec 3	Recipient	0.0			<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.1	:57	NO-back	Background	0			<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.1	:58	GL 1 Rec1	Recipient	0.12			<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.12	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.1	:59	GL 2 Rec1	Recipient	0.05			<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.05	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.1	:60	GL 2 Rec2	Recipient	0.21			<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.21	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
4.0	Det. Limit	Backgr and Blank[3]	DL	2.86	1.6	0.01	0.2	0.1	0.05	0.05	0.07	0.01	0.09	0.02	0.01	0.01	0.01	0.05	0.01	0.01	0.04	0.04	0.05	0.41	0.02
4.0, 4.1	Det. Limit	Recipients	DL	1.51		0.05	0.2	0.1	0.05	0.05	0.07	0.01	0.1	0.02	0.01	0.01	0.1	0.05	0.03	0.1	0.04	0.04	0.05	0.41	0.02
4.0	Det. Limit	In&effluents[4]	DL	2.353	1.6	0.01-0.03	0.2	0.1	0.02	0.005	0.07	0.01	0.09	0.02	0.01	0.01	0.01	0.04	0.008	0.01	0.04	0.04	0.05	0.2-0.4	0.02
4.0, 4.1	Det. Limit	In &effluents	DL	2.773	1.6	0.01	0.2	0.1	0.02	0.005	0.07	0.01	0.09	0.02	0.01	0.01	0.01	0.04	0.008	0.01	0.04	0.04	0.05	0.41	0.02

Note:

[1] PFBA could not be analyzed in any of the recipient samples with good quality.

[2] M= manual sampling; A= automated sampling.

[3] Samples: 11,12,39,43, 44, 51 and 52.

[4] Samples:21-:24 and :53 and :54.

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Micropollutants in wastewater in four arctic cities –
is the treatment sufficient?

The four Nordic cities included in the present study form a gradient both in climate, from oceanographic temperate in Tórshavn at 620 N to arctic in Tromsø at 69.70N, and in population, from less than 6000 inhabitants in Sisimiut to close to 120 000 in Reykjavík. The cities are different and far apart but products from the sea has been mainstay to the economy and societal development. Thus, the management of sewage from the municipalities must maintain a clean and healthy marine environment. The wastewater treatment varies, from screening on fine mesh, via septic tank based purification solutions, to no purification at all. We measured the contaminants in wastewater streams and in recipient samples, and with that in hand assessed whether the wastewater treatment appeared sufficient, and if not, which mitigating solutions could be relevant for wastewater purification optimisation.

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