NTNU
Norwegian University of
Science and Technology

Mapping and study of contamination in sediment and water column in the area used for snow dumping in the Trondheimsfjord.

Hilde Alida Hammer

Environmental Toxicology and Chemistry
Submission date: June 2016
Supervisor: Øyvind Mikkelsen, IKJ
Co-supervisor: Silje Salomonsen, Trondheim Kommune

Norwegian University of Science and Technology
Department of Chemistry

Forord

Da var tiden inne for å levere, endelig! Det har vært lærerikt, men samtidig godt å bli ferdig. Jeg vil først og fremst takke veilederen min Øyvind Mikkelsen for å ha vært behjelpelig og hatt tid til en prat alle gangene jeg har kommet innom kontoret med masse spørsmål.

Jeg vil også takke medveilederen min Silje Salomonsen ved Miljøenheten i Trondheim Kommune for gode råd og for at du tok deg tid til å gå gjennom oppgaven med meg, selv om du har mye å gjøre.

Takk NGI, for at dere har støttet med en sedimentfelle til oppgaven, og særlig vil jeg takke Anita Nybakk for at du har vært med å sette ut og ta opp sedimentfellene, men også fordi du tok deg tid til å hjelpe meg med grafer og diskutere resultater resultatene. Det satt jeg veldig stor pris på.

Jeg vil takke Miljøringen for at jeg fikk studentstipendet høsten 2015, og Trondheim Havn, Renere Havn og Miljøenheten for støtte til oppgaven, tusen takk.

Takk til min bror som var med å hjalp meg med DGT'ene da det var iskaldt ute bak piren, og for at du har korrekturlest. Jeg vil også takke Hanna og Mari for å ha lest over deler av oppgaven. Og spesielt Per Ivar, du har vært så behjelpelig, rene leksikonet! Takk!

Også takk til Syverin Lierhagen for å ha tatt imot alle prøvene mine og analysert de, i tillegg til at du har tatt deg tid til å forklare da jeg lurte på ting.

Og ikke minst min gode studievenn Tonje! - studietiden hadde ikke vært det samme uten deg, selv om vi nesten aldri fikk tid til å jobbe sammen.

Til sist må jeg takke værgudene som ga byen masse snø i vinter, oppgaven hadde heller ikke vært den samme uten dere.

Hilde Alida Hammer

Trondheim, 15.06.2016

Summary

In Trondheim most of the excess snow from the city and areas around are dumped directly into the fjord from piers in the harbour. Snow contain pollutants from sources in the city, and will therefore be polluted with compounds such as heavy metals and organic pollutants (PAHs and PCBs). How this contribution affects water and sediment quality in the areas used for snow dumping is not studied to a large degree, and was therefore studied in this thesis, on request from Trondheim Municipality.

The study area was pier 68, as this was the only area it was allowed to dump snow in the harbor during the winter of 2015 and 2016. A total of 16 sediment samples of the top layer 0-2 cm were taken at increasing distances from the pier in three different directions, as well as down in the sediment 0 ~ 16 cm in the sampling points in one of the directions. In addition, a core sample was taken 195 cm into the sediment at Østmarka, to represent background levels. The samples were decomposed in UltraClave and analysed for selected heavy metals in ICP-MS. Manual water samples (in total 39 samples) was taken in the surface water before, during and after the snow dumping at pier 68, and at Ringve as background levels. All the samples got filtered. In the water column DGTs were out during and after the snow dumping. Both the manual water samples and the DGTs were analysed for the selected heavy metals in ICP-MS. 3 sediment traps were out in the fjord at increasing distances (41 m, 89 m, and 136 m) from pier 68 in direction North East during almost the whole snow dumping period in 2016 and collected sedimenting material. The material was analysed for both selected heavy metals and PAHs. POMs were attached on the sediment traps to measure PAHs and PCBs in the water column. Snow samples from Trondheim center were also taken and both dissolved and particulate fraction were analysed for selected heavy metals on ICP-MS. The selected heavy metals were As, Pb, Cd, Cu, Cr, Hg, Ni and Zn for all the samples.

The results were compared with the Klifs guideline for metals and organic pollutants in coastal waters and marine sediments. The guideline specifies levels of pollution in the water and sediment and goes from level I to V, where level I is equivalent to background level and level V is highly polluted, and have increased risk of harm on water- and sediment-dwelling organisms. In addition, the deposition of fine and coarse particles in the sediment and were most of the sedimenting material deposit were studied.

The results showed that there was only a small impact in the water and sediment in the studied area. In the surface water only Pb and Cr were found in higher concentrations during snow dumping, and in the water column Cd, Cr and Zn were found higher during snow dumping. Pb, Cd and Cr were found to be higher in the surface water than in the water column. The concentrations of the metals in the surface water and the water column were low (level I and II) during snow dumping, except for Cu and Zn that had one or more concentrations in level III and IV. Cu was also high after the snow dumping (level III and IV). The highest increase of Cr and Pb in the surface water was unexpected out from the results from the snow samples, which showed highest concentrations of Zn, Cu and Ni in the dissolved phase. In the particulate material in the snow samples Zn, Cu and Cr were found in highest concentrations.

The PAHs was found in level II in the water column except for in POM2 where acenaphthene, phenanthrene and fluoranthene were found in level III and pyrene in level V. It is uncertain whether these high concentrations were due to the snow dumping as the concentrations differ significantly from the other two POMs and other sources may have affected. Any further investigation is proposed. For the PCBs, PCB-28 and PCB-52 were found in the water column.

The sedimenting material was found to have low concentrations (level I for the metals, and level I and II for the PAHs) and to be deposited in decreasing amounts with increasing distances from the pier, with most of the material sedimenting within around 100 m from the pier in direction North East. The amount of sedimenting material were significantly higher than the natural sedimentation (found in the harbour in other studies), and will increase the need for dredging in the area outside pier 68.

Also in the top layer (0-2 cm) in the sediment the condition seemed to be good, as all the concentrations were found in the level I and II. No large differences were seen in the concentrations in the various directions. The fine particles seemed to be concentrated around 50 m and 150 m from the pier in the direction North East, 100 m and 200 m in the direction North and 150 m in the direction North West. Coarse particles from the snow dumping was seen in sample point 250 m in the direction North East.

In the samples taken deeper down in the sediment, some higher concentrations of Cu (level IV) and Hg (level V) were found, but else level I and II dominated. The concentrations in these layer were also found to have higher concentrations than the background concentrations in the core sample from Østmarka. Except for Ni and Cr, which are naturally high in Trøndelag, this reflects inputs from anthropogenic sources outside pier 68.

Sammendrag

I Trondheim dumpes det meste av overskuddssnøen fra byen og omegn direkte i fjorden fra kaier i havna. Snø tar opp forurensninger fra kilder i byen, og vil dermed være forurenset med stoffer som bla. tungmetaller og organiske miljøgifter (PAH og PCB). Hvordan denne tilførselen av forurensninger påvirker vann og sediment kvalitet i området utenfor dumpestedet er ikke studert i noen stor grad tidligere, og ble derfor undersøkt i denne oppgaven, med ønske fra Trondheim Kommune.

Undersøkelsesområdet var pir 68, da dette var det eneste området det var lov til å dumpe snø i havna vinteren 2015 og 2016. Totalt 16 sedimentprøver av topplaget 0-2 cm ble tatt i økende avstand fra piren i tre ulike retninger, samt nedover i sedimentet 0~16 cm i prøvepunktene i en av retningene. I tillegg ble en kjerneprøve tatt 195 cm ned i sedimentet ved Østmarka, for å representere bakgrunnsnivåer. Prøvene ble dekomponert i UltraClave og analysert for utvalgte tungmetaller i ICP-MS. Manuelle vannprøver (totalt 39 prøver) ble tatt i vannoverflaten før, under og etter snødumpingen ved pir 68, samt ved Ringve som bakgrunnsnivåer. Alle prøvene ble filtrert. I vannkolonnen stod DGT'er ute under og etter snødumpingen. Både de manuelle vannprøvene og DGT'ene ble analysert for utvalgte tungmetaller i ICP-MS. 3 sedimentfeller stod ute i fjorden i økende avstand (41 m, 89 m, og 136 m) fra pir 68 i retning nord øst under omtrent hele snødumping-perioden 2016 og samlet opp sedimenterende materiale. Materialet ble analysert for både utvalgte tungmetaller og PAH'er. POM'er var festet på sedimentfellene for å måle PAH'er og PCB'er i vannkolonnen. Snøprøver fra Trondheim sentrum ble også tatt, og både løst (17 prøver) og partikulær fase (3 prøver) ble analysert for utvalgte tungmetaller i ICP-MS. De utvalgte tungmetallene for alle prøvene var As, Pb, Cd, Cu, Cr, Hg, Ni og Zn.

Resultatene ble sammenlignet med Klif's tilstandsklasser for metaller og organiske miljøgifter i kystvann og marint sediment. Tilstandsklassene angir forurensningsgraden i vann og sediment og går fra klasse I til V, hvor klasse I tilsvarer bakgrunnsnivå og klasse V er svært forurenset, og økt fare for risiko for vann- og sediment levende organismer. I tillegg ble det sett på hvor i sedimentet fine og grove partikler så ut til å avsettes og hvor mesteparten av det sedimenterende materialet avsettes.

Resultatene viste at det kun var en liten påvirkning i vannet og sediment i det undersøkte området. I vannoverflaten var det kun Pb og Cr som viste seg å være høyere under

snødumpingen, og i vannkolonnen ble Cd, Cr og Zn funnet høyere under snødumpingen. Pb, Cd og Cr ble funnet høyere i vannoverflaten enn i vannkolonnen. Konsentrasjonene av metallene i både vannoverflaten og i vannkolonnen var lave (i klasse I og II) under snødumpingen, unntatt for Cu og Zn som hadde en eller flere konsentrasjoner i klasse III og IV. Cu var høy også etter snødumpingen (klasse III og IV). Høyest økning av Cr og Pb i overflatevannet var uventet ut ifra resultatene fra snøprøvene, som viste høyest konsentrasjoner av Zn, Cu og Ni i løst fase. I partikulært materiale i snøprøvene ble Zn, Cu og Cr funnet i høyeste konsentrasjoner.

PAHene ble funnet i klasse II i vannkolonnen foruten om i POM2 hvor acenaften, fenantren og fluoranten ble funnet i klasse III og pyren i klasse V. Det er usikkert hvorvidt disse høye konsentrasjonene skyldes snødumpingen da verdiene skiller seg betydelig fra de to andre POM'ene, og andre kilder kan ha påvirket. Eventuell videre undersøkelse foreslås. For PCB'ene, ble PCB-28 og PCB-52 ble funnet i vannkolonnen.

Det sedimenterende materialet ble funnet til å være lite forurenset (klasse I for metallene, og klasse I og II for PAHene) og til å avsettes i avtagende mengder utover fra piren, med det meste av materialet innenfor omtrent 100 m fra piren i retning nord øst. Mengden sedimenterende materiale var betydelig høyere enn den naturlige sedimenteringen (funnet i havna i andre studier), og vil kunne øke behovet for mudring i området utenfor pir 68.

Også i topplaget (0-2 cm) i sedimentet så tilstanden ut til å være god, da alle konsentrasjonene ble funnet i klasse I og II. Ingen store forskjeller ble sett i konsentrasjonene i de ulike retningene. De fine partiklene så ut til å konsentrere seg i området rundt 50 m og 150 m fra piren i retning nord øst, 100 m og 200 m i retning nord og 150 m i retning nord vest. Grove partikler fra snødumpingen ble sett i prøvepunktet 250 m i retning nord øst.

I prøvene tatt lengre nede i sedimentet ble det funnet noen høyere konsentrasjoner av Cu (klasse IV) og Hg (klasse V), men ellers var også konsentrasjonene dominert av klasse I og II. Konsentrasjonene i dette laget ble også funnet til å ha noe høyere konsentrasjoner enn bakgrunnsverdien i kjerneprøven fra Østmarka. Utenom for Ni og Cr, som er naturlig høye i Trøndelag, gjenspeiler dette antropogen tilførsel utenfor pir 68.

Abbreviations

DGT	Diffuse Gradient in Thin films
DBL	Diffusive Boundary Layer
DL	Detection Limit
DW	Dry Weight
CI	Confidence Interval
GC-MS	Gas Chromatography-Mass Spectrometry
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IDL	Instrumental Detection Limit
ISO	International Organization for Standardization
Klif	The Norwegian Climate and Pollution Agency (now under NEA)
MS	Mass Spectrometer
m/z	mass to charge ratio
MQ	Milli –Q-water
MW	Molecular Weight
M.U.	Measurement uncertainty
NEA	the Norwegian Environment Agency
NGI	the Norwegian Geotechnical Institute
NTNU	the Norwegian University of Science and Technology
PAH	Polycyclic Aromatic Hydrocarbons
PCB	PolyChlorinated Biphenyl
POM	PolyOxyMethylene
PPM	Parts Per Million
PPT	Parts Per Trillion
PP-vials	PolyPropylene –vials (used for ICP-MS analysis)
RSD	Relative Standard Deviation
SFT	The Norwegian Pollution Control Authority (Now NEA)

Content

Figure list

Table list

1. Introduction

Cities receiving snow during the winter months must remove excess snow to maintain accessible roads and safety. Many cities have snow dumping sites on land while other dump their excess snow in the marine environment, such as rivers, lakes, or the ocean. In Trondheim, Norway, excess snow from the city and areas around are mainly dumped from the piers in the harbor and into the Trondheimsfjord. Urban snow contains pollutants such as heavy metals, PAH, PCB, and oil that will enter the fjord with the snow. In this way the snow dumping contributes with pollutants to the water and sediment.

In recent years there has been an increased focus on the pollution in water and sediment in coastal areas in Norway. The Norwegian Pollution Control Authority stated in 2000 that "polluted fjord areas is one of our biggest remaining local environmental concerns in Norway" (SFT, 2000). 17 coastal areas in Norway have been selected as priority areas by the Norwegian Environment Agency (Miljødirektoratet, 2013). Trondheim harbour was one of these. The reason was that the sediments were highly polluted in many areas in the harbour (NGI, 2011b). As a result, the project "Cleaner harbour" was initiated that aimed to clean up the polluted sediment in the harbour and identify active pollution sources. The City Council in Trondheim Municipality adopted some goals for the harbour basin, and one of the goals is read as follows: "Direct discharges to sea from businesses along the basin should if possible be stopped, or the emissions must be reduced to a level that does not provide an unacceptable environmental or health risk" (NGI, 2011b).

How the snow dumping contributes with pollutants to the water and sediment in the harbor has not been studied to a large degree, and the comprehensive action plan for Trondheim harbour basin states that the snow dumping should be studied further to evaluate the discharge of pollutants to the sediments (NGI, 2011b, DNV and NGI, 2011). In a previous study by GeoSubSea AS in 2007, on behalf of Trondheim Municipality, sediment sample were taken outside each pier used for snow dumping (see appendix A). In 2007, Trondheim Municipality took samples from trucks with snow that were to be dumped in the harbor (Støver et al., 2007), and sediment samples have further been taken outside the piers used for snow dumping in other contexts. These are very limited studies and doesn't say anything about the spread in the sediment or how the snow dumping affects the water column. The PAH concentrations are found in high concentrations in the sediment outside piers used for snow dumping, and for one of the piers it was assumed to originate from the snow dumping (NGI, 2011a) (see appendix A).

In other cities in Norway, where the contribution of pollutants from the snow dumping into rivers and fjords have been estimated, the conclusions have mostly been that the snow dumping only have marginal effect on water and sediment quality. It is despite this need to study the contribution at each location individually as the recipients are different. Trondheim Municipality have for a long time wanted a study on the contribution of pollutants from the snow dumping to the water and sediment outside piers used for snow dumping, especially now since there is a focus on a cleaner harbour.

1.1 Aim of the study

The aim of this thesis is to study the degree of contamination in sediment and water in the area used for snow dumping in Trondheim harbour. The study area will be pier 68.

The focus is mainly on the heavy metal(loid)s: arsenic (As), lead (Pb), chromium (Cr), copper (Cu), cadmium (Cd), nickel (Ni), sink (Zn), and mercury (Hg), but also selected PAHs (sum PAH-16) will be measured in some of the samples, and PCBs in the water column.

Samples will be taken during snow dumping to measure the concentrations of heavy metals, PAHs and PCBs in the water during dumping. Heavy metals will also be measured before and after the snow dumping. Sediment traps will be used to collect sedimenting material. Samples of the sediment will be taken to check the condition in the sediment in the area. In addition, samples in the sediment will be taken at increasing distances from the pier to study the spread of heavy metal(loid)s from the pier.

The following sampling and sampling methods will therefore be performed:

- Snow, sediment and surface water samples
- Sediment traps to collect sedimenting material
- DGTs to measure heavy metal(loid)s in the water column
- POMs to measure PAHs and PCBs in the water column

The results will be compared with Klif’s guideline to evaluate the contamination state in the water and the sediment. The thesis is in collaboration with Trondheim Municipality.

2. Theory

2.1 Marine pollution

Coastal areas, especially sheltered estuaries, fjords, bays and harbors, close to industrialized and urbanized areas around the world are highly polluted due to emissions from industry and other human activities (SFT, 2000). Coastal areas have for a long time been exposed to different pollution sources, and pollutants have accumulated in the sediment many places. However, the pollution from industrial point sources have been reduced during the last decades (Breedveld et al., 2010). But many of the Norwegian fjords are still polluted. Fjord areas are important feeding and growth areas for many marine organisms (SFT, 2000).

The elevated concentrations of pollutants can harm organisms and hence the marine ecosystem, with dramatic effects such as species loss, restriction of fishing and dietary restrictions on seafood as a consequence (SFT, 2000). Consumption of fish and shellfish from several places have been restricted due to high amounts of pollutants (SFT, 2000). Among the pollutants of concern in marine pollution are heavy metal(loid)s, petroleum hydrocarbons, pesticides and plastic (Zitko, 2000), and organic pollutants, such as PAH, PCB and TBT.

2.2 Snow dumping

Cities in the northern hemisphere can receive a lot of snow during the winter. The snow has to be removed from streets and be disposed somewhere (Viklander, 1997). Where to dispose the snow is a big issue in many cities, as there is often large amounts of snow and little available place inside the city. In addition there are issues regarding to costs, safety, noise, esthetics/public acceptance and effects on the recipient (Reinosdotter et al., 2003, Viklander, 1997). The snow disposal practices vary between different cities, but the most common practices are to dump it on land and/or in the marine environment, such as rivers, lakes or the ocean. For cities close to the ocean, lakes etc. it might be convenient to dump the snow in the water as it is close and no extra space to store snow are needed. The snow is most often dumped directly, without any treatment of the snow. With an increased focus on marine pollution, snow dumping in water is restricted many places. Dumping in the marine environment have declined over the last years and is not so widespread as before, due to environmental concern and public acceptance (CH2M, 2006).

In several of the Norwegian cities, excess snow is or have been dumped in fjords or rivers (Hansen, 2015, Ranneklev et al., 2013)(personal communication Ivar Kaski 16.04.04, Dag Ivar Andreassen 16.04.04). However different practices exist; in Tromsø all the excess snow is dumped in the harbor (personal communication Dag Ivar Andreassen 16.04.04), while in Harstad it is not allowed to dump snow that is more than 2 weeks old from areas with high traffic and 4 weeks old from areas with less traffic, it is not allowed to dump ice clumps, and not allowed to dump snow during daytime from the pier in the centre. In addition: all the snow has to be logged (where it is from, amount and how old the snow is) (Hansen, 2015). Oslo have a snow melting machine, that melts and clean the snow before it is released out in the fjord (NCC).

2.3 Heavy metals and metal(loid)s

Heavy metals are often referred to those metals with atomic mass above 5 g/cm^3, especially the transition metals such as lead (Pb), cadmium (Cd), and mercury (Hg). Metalloids, non-metals that have the appearance and/or some of the properties as metals, e.g., arsenic (As), are also often included in the term heavy metals. If metalloids are included the term is considered misleading and the term heavy metal(loid)s should be used (Duffus, 2002, Alloway, 2013).

The heavy metal(loid)s occur naturally in the environment in trace amounts (Alloway, 2013), but their concentrations have been elevated many places due to anthropogenic activity (SFT, 2000). The natural sources are volcanoes, and weathering of rocks and sediment. They cannot be degraded or metabolized (Sansalone and Buchberger, 1997), they can therefore accumulate in the environment.

The heavy metal(loid)s are known for their potential toxicity to organisms. However, some heavy metal(loid)s are cofactors or part of cofactors in enzymes and structural elements in proteins, and are thus needed in small amounts by plants, animals and humans for vital biological processes (Alloway, 2013).

The most environmentally important heavy metal(loid)s are As, Cd, chromium (Cr), cobalt (Co), copper (Cu), Hg, Pb, manganese (Mn), nickel (Ni), selenium (Se) and zinc (Zn) (Alloway, 2013).

2.4 Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a group of chlorinated organic compounds. PCBs have serious health effects (toxic and carcinogenic) even in low concentrations. They have been used in different products, but have been forbidden to use in Norway since 1980. They are however still found in the environment, leaking out from products and buildings (Miljødirektoratet, 2015).

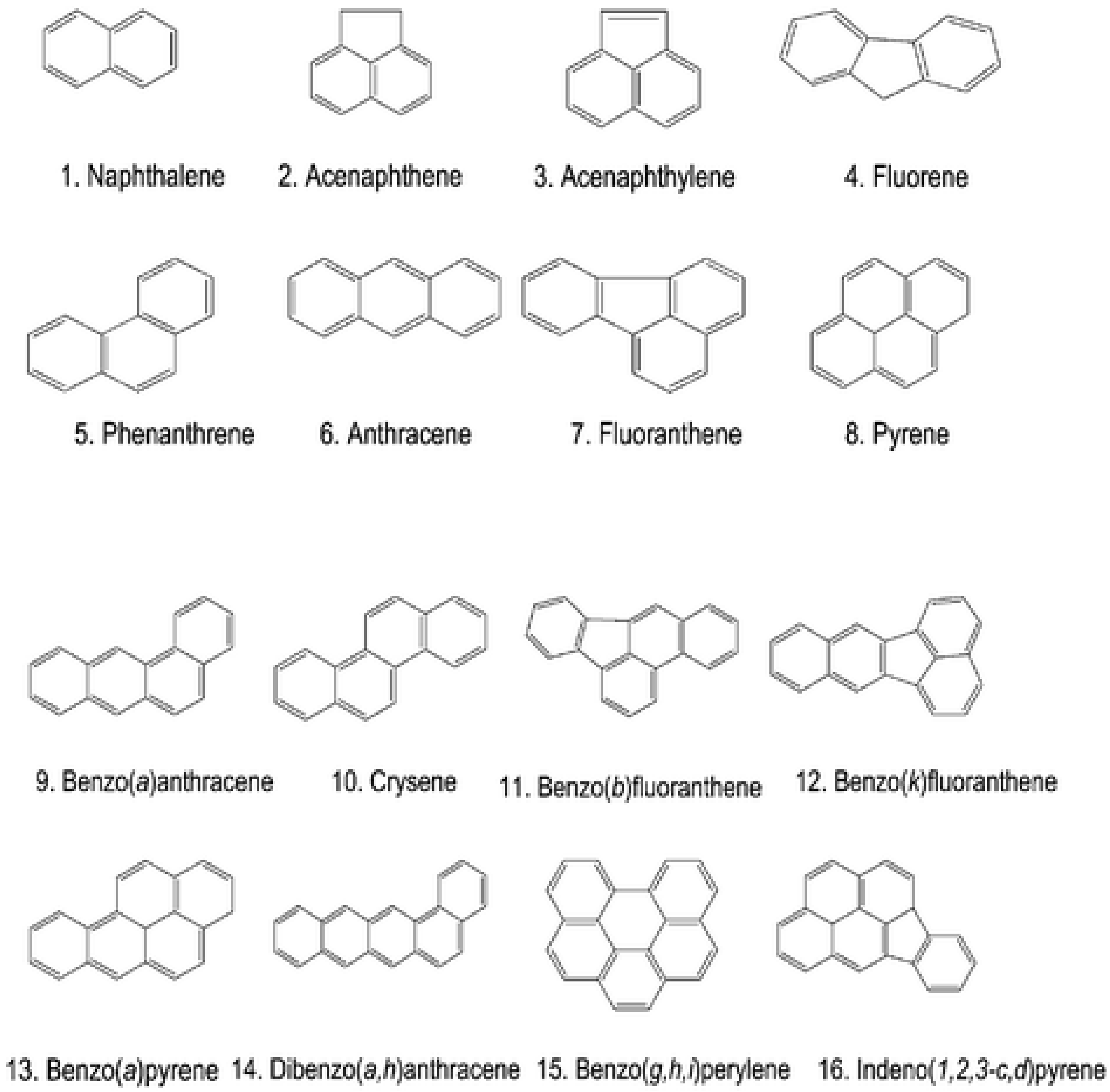
There exists over 200 different PCBs. 7 common PCBs to measure when studying PCBs in the environment are: PCB-28, PCB-52, PCB-101, PCB-118, PCB-153, PCB-138 and PCB-180, referred to as PCB7.

2.5 Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds consisting of two or more aromatic (benzene) rings fused together. There exist several hundred PAHs, with different molecular weights (MW) and arrangements. PAHs are naturally compartments in fossil fuels (*petrogenic* PAHs). They can also be formed during incomplete combustion of organic material, such as wood and fossil fuel (*pyrogenic* PAHs). It is common to divide the PAHs into low molecular weight PAHs (2 and 3 rings) and high molecular weight PAHs (more than 3 rings). The low molecular weight PAHs have a significant acute toxicity, while the carcinogenic PAHs are found among the high molecular weight PAHs. PAHs are degradable, but the degradation can be slow and they therefore tend to accumulate in organisms. The PAHs are usually found together in nature as a mixture of two or more (Viskari et al., 1997, Witt, 1995, Neff, 1979)

Sum PAH-16

Environmental studies usually focus on some of the PAHs. United States Environmental Protection Agency and World Health Organization have chosen 16 of the PAHs to be “priority pollutants”, termed sum PAH-16. These are chosen due to their toxicity and because they are common in the environment (Bruzzoniti et al., 2010). The 16 PAHs can be seen in *Figure 1.*



1. Naphthalene
2. Acenaphthene
3. Acenaphthylene
4. Fluorene
5. Phenanthrene
6. Anthracene
7. Fluoranthene
8. Pyrene
9. Benzo(*a*)anthracene
10. Crysene
11. Benzo(*b*)fluoranthene
12. Benzo(*k*)fluoranthene
13. Benzo(*a*)pyrene
14. Dibenzo(*a,h*)anthracene
15. Benzo(*g,h,i*)perylene
16. Indeno(*1,2,3-c,d*)pyrene

Figure 1. *The 16 PAHs chosen by US EPA and constitutes sum PAH-16 (Bruzzoniti et al., 2010).*

2.6 Urban snow

Urban snow has a porous structure and are therefore a trap for pollutants (Sansalone and Buchberger, 1996, Sansalone et al., 2003). The pollutants deposit in the snow through dry or wet deposition, or through gas adsorption. The sources can be local or long distance sources, and can be naturally or anthropogenic (Viklander, 1997). However, local anthropogenic sources are most important, even though snowflakes are effective scavengers of pollutants from the atmosphere (Sansalone and Glenn, 2002). Pollutants typically found in urban snow are heavy metal(loid)s, nitrogen, phosphorus, salt, organic compounds (PAH and PCB), oil and particles. In addition, snow can contain different types of litter, such as plastic, cigarette stumps etc. Snow will contain about 30-50 % water, depending on the density of the snow (Bækken, 1994).

Snow quality

Picture 1. Polluted urban snow in Trondheim Photo: Hilde A Hammer.

Pollutants will continuously deposit in the snow. The residence time of the snow is therefore important for the snow quality. Bækken (1994) found the new snow to be as polluted as the old snow after 1 week. Other factors that affect the snow quality are site specific sources (industry, heating sources etc.), meteorological conditions, amount of traffic and winter road maintenance practices (Viklander, 1997). The geographical position can also have an effect on the snow quality; higher atmospheric deposition rates are for example detected in southern Norway than in the middle and north of Norway (Aamot et al., 1996).

In the snow the pollutants are dissolved or particulate bound, and are highly heterogeneously distributed (Ranneklev et al., 2013, Bækken and Tjomsland, 2001). When the temperature rises above 0°C the dissolved fraction can leave the snowpack with the melt water, while the particulate bound fraction stays in the snow. Heavy snowfall can lead to a dilution of the concentrations (Viklander, 1997).

Traffic and winter road maintenance are the most important sources (Bækken, 1994, Bjørgaas, 2010). The highest amount of pollutants are therefore most often found in snow close to highly trafficated roads, and when salt and/or sand is used as a part of winter road maintenance.

2.6.1 Heavy metal(loid)s in urban snow

Many of the heavy metal(loid)s are found in urban snow. Fe, Zn, Cr, and Cu are most often found in highest concentrations (Larsen et al., 2003, Sandefjord, 2005, Bækken, 1994). The concentrations are usually significantly higher than the reference stations. Bækken (1994) found for instance Cu to be almost 700 times higher than the reference station.

The heavy metal(loid)s are mostly particulate bound in the snow (Sansalone et al., 2003). Viklander (1997) found that less than 1 % of the Pb, 10 % of the Cu and 18 % of the Zn were in the dissolved phase in snow samples. In new snow the dissolved fraction of metals tends to dominate, then over time when the particle content in the snow increases, the particulate bound fraction tends to dominate. Other factors that will affect the partitioning are redox, hardness, pH and alkalinity (Glenn and Sansalone, 2002, Sansalone and Buchberger, 1997).

2.6.2 PAHs in urban snow

All of the 16 PAHs in sum PAH-16 have been found in snow. The PAHs usually found in the highest concentrations in urban snow are pyrene, phenanthrene, fluoranthene, chrysene, and benzo(a)anthracene (Støver et al., 2007, Viskari et al., 1997, Larsen et al., 2003, Ranneklev et al., 2013, Bækken, 1994). Bækken (1994) found the concentration of PAHs in urban snow to be 1000 times higher than the reference sample. Average concentrations of the PAHs in sum PAH-16 found in a snow sample from Tromsø and from snow samples in Trondheim can be seen in **Table 1**. The sample in Tromsø was taken from a parking lot and the samples in Trondheim were taken from 17 trucks with snow that were going to be dumped in the harbour.

Table 1. Concentrations of PAHs in snow sample(s) from Tromsø and Trondheim (Larsen et al., 2003, Støver et al., 2007).

PAHs	**Unit**	**Sample Tromsø**	**Samples Trondheim**
Naphthalene	µg/L	< 0.13	0.32
Acenaphthylene	µg/L	1.1	0.11
Acenaphthene	µg/L	5.0	0.60
Fluorene	µg/L	3.1	0.69
Phenanthrene	µg/L	15	4,1
Anthracene	µg/L	3.3	0.90
Fluoranthene	µg/L	43	17
Pyrene	µg/L	130	17
Benz(a)anthracene	µg/L	6.9	4.1
Chrysene	µg/L	43	5.3
Benzo(b)fluoranthene	µg/L	-	1.7
Benzo(k)fluoranthene	µg/L	-	1.8
Benzo(a)pyrene	µg/L	-	2.2
Indeno(1,2,3-cd)pyrene	µg/L	7.1	0.60
Dibenzo(a,h)anthracene	µg/L	3.3	0.16
Benzo(ghi)perylene	µg/L	25	0.45
SumPAH-16	µg/L	290	57

2.6.3 Sources of heavy metal(loid)s and PAHs

Vehicles/traffic

Vehicles/traffic is an important source due to exhaust (see below), and wear of different compartments of vehicles. An overview over which heavy metal(loid)s that comes from different compartments of vehicles can be seen in Table 2. In tires the metals are found in the rubber and in the steel wires on the outside of the tire, and will wear of during driving. Especially Zn and Fe are dominant in tires (Håøya and Aabøe, 2004), Also PAHs are also found in tires. A prohibition against tires with high-aromatic oils with more than 20 mg PAH/kg have been set from 2010 (Ottesen et al., 2011).

The vehicle will also wear of particles from the asphalt, that can deposit in the snow, especially if studded tires are used. Asphalt contain both metals and PAHs (Amlo and Bakke, 2010). Støver et al., (2007) performed a factor analysis which showed that around 80 % of the PAH in their snow samples most likely came from asphalt and up to 15 % most likely came from tires and diffuse sources such as combustion of wood. Also others have ranked asphalt to be the main source (Sansalone and Buchberger, 1997, Bækken, 1994). Oil leakage from vehicles can also be a source of PAHs (Neff, 1979).

Use of salt as a part of winter road maintenance can increase the amount of metals in the snow due to increased corrosion of vehicles (Viklander, 1997).

***Table 2**. Compartments leading to heavy metal(loid)s and PAHs in snow (Håøya and Aabøe, 2004, Ottesen and Langedal, 2006, Davis et al., 2001, Sansalone and Buchberger, 1997).*

Compartment	**Source of:**
Tire	Zn, Fe, Cd, Cr, Co, Cu, Pb, Ni, As, Hg (only minor amounts), PAHs
Brake	Cr, Cu, Pb, Cd, Zn
Engine	Cr, Cu, Ni,
Frame	Cr, Fe, Zn, Fe

Incomplete combustion

Incomplete combustion in industry, heating, exhaust, fires and waste incineration are sources of metals and PAHs (Ottesen and Langedal, 2006). The metals and PAHs are emitted to the air as particles or vapour (Manahan, 2010). Which PAHs that forms during incomplete combustion depends among other factors on the composition of the fuel, temperature and the duration of the combustion (Neff, 1979). In general, high- temperature combustion mainly generates high molecular weight PAHs, while low molecular weight PAHs mainly derive from lower temperature combustion of fossil fuels (Fernandes et al., 1997). Removal of Pb in petrol have led to less emission of Pb close to roads (Alloway, 2013).

Buildings and structures

Paint can contain metals such as Zn, Cr, Pb and Cd that can wear off with time and deposit in the snow (Viklander, 1997, Ottesen and Langedal, 2006). In a study of outdoor paint on buildings in the city center of Trondheim, Ti, Pb, Zn and Fe were found most frequent and in highest concentrations (Andersen et al., 2009). Galvanized roofs and other structures can be a source of Zn and Cu (Alloway, 2013). PAHs have also been found in paint, and roofing membrane (Amlo and Bakke, 2010).

***Picture 2**. Important sources of heavy metal(loid)s and PAHs in the urban environment (Ottesen, not dated).*

2.6.4 Particles in urban snow

Particles have many of the same sources as heavy metal(loid)s and PAHs and can therefore be water soluble components, oil fractions, soot, rubber, stone dust and metal parts (Bækken and Tjomsland, 2001). Other sources of particles are construction work and the use of sand/gravel as a part of the winter road maintenance (Støver et al., 2007, Reinosdotter and Viklander, 2006).

The particles can be of different sizes and range from soluble to insoluble particles (Bækken and Tjomsland, 2001). Particles from combustion reactions are generally smaller than particles from for example asphalt. The combustion particles are usually less than 0.1 µm, but they can aggregate together to become larger (FHI, 2005, Qian et al., 2014).

Smaller particles have a larger relative surface area and are often found to contain the highest concentration of pollutants (Sansalone et al., 2003, Miler and Gosar, 2009, Viklander, 1997),

Concentration of particles in snow have been found between 0.01 – 7.8 g/L (Ranneklev et al., 2013, Bjørgaas, 2010, Bækken and Tjomsland, 2001) and up to 73 g/L (Bækken, 1994).

Since traffic is an important source of particles (and heavy metal(loid)s and PAHs) most of the pollutants deposit on or close to roads, and the amount are found to increase with traffic load (Bækken, 1994, Sansalone et al., 2003, Bækken and Tjomsland, 2001, Ranneklev et al., 2013). The amount and type of particles, will also be dependent on factors such as driving pattern (accelerating, stops, speeding), congestion, type and condition of the vehicle, use of studded tires, type of tires, and the durability of the asphalt (Snilsberg et al., 2008, Bækken, 1994).

2.6.5 PCB in snow

PCBs have been found in snow (Ranneklev et al., 2013, Bækken and Tjomsland, 2001). (Ranneklev et al., 2013) found between 9 – 10 ng/L in snow samples from 4 different locations in Drammen. The source(s) of PCBs in snow is a bit unclear. PCBs are not typically related to traffic, but Bækken (1994) found an association between amount of PCB and traffic. Larsen et., al (2003) concluded that PCB in the snow samples in Tromsø most likely came from long distance transport, rather than local sources.

2.7 Sea water

Sea water consist of major, minor and trace elements. The major ions, such as chloride (Cl^-), sodium (Na^+), sulfate (SO_4^{2-}), and magnesium (Mg^{2+}) constitute more than 99 % of the dissolved ions in sea water. These ions have a long residence time and relatively constant concentrations (conservative) in sea water. Minor and trace elements have a shorter residence time and hence much more variable concentrations in sea water (non-conservative). Their concentration varies from place to place due to differences in inputs (pollution) and reactivity of the elements. Heavy metal(loid)s and PAHs are among the minor and trace elements. They usually have concentrations in µg/L in sea water (Kennish, 2000).

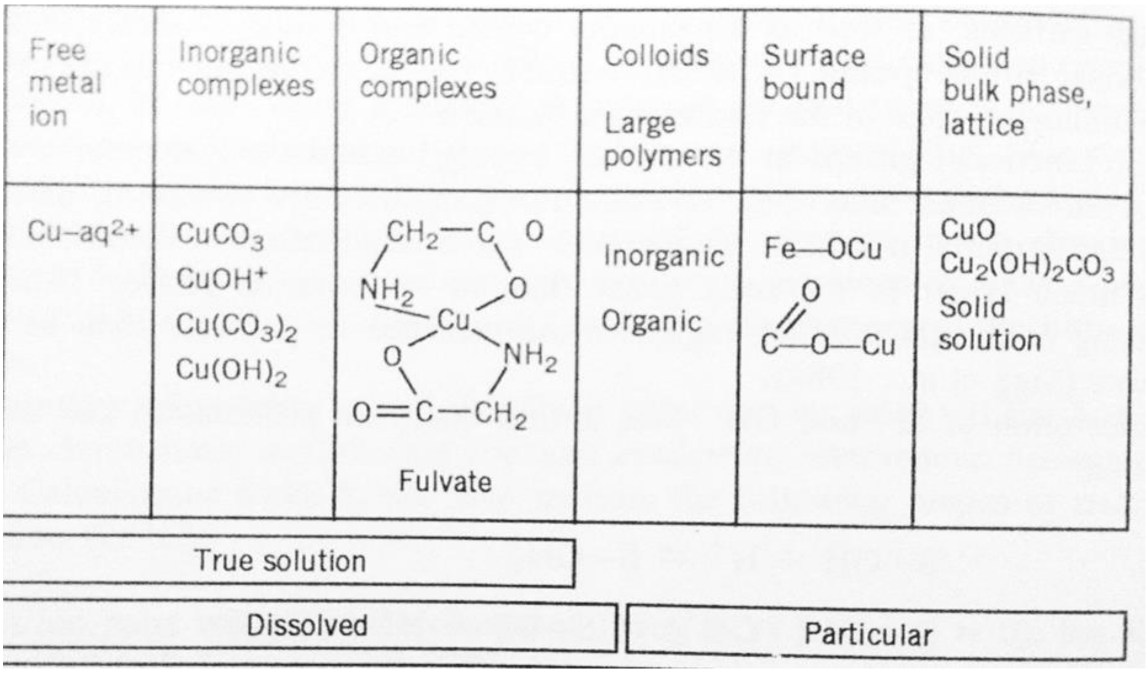
2.7.1 Heavy metal(loid)s in sea water

Sources

Anthropogenic sources of heavy metal(loid)s in sea water are river inflow, atmospheric deposition, antifouling paints from boats, urban runoff, wastewater from industry or municipality, sewage and other nonpoint sources (Kennish, 2000, Stumm and Morgan, 1996). Pb, Cu and Cr are often used in paint on boats, and Cu are also widely used as antifouling agent on boats and nets, which can leak out in the water (SFT, 2000, Jartun and Volden, 2005).

Speciation

In sea water the metals can exist in different forms (species), see *Figure 3***.** Metals bound to water molecules (free metal ions), or complexed with dissolved organic or inorganic ligands represent the *dissolved fraction*, while metals bound to suspended particles (colloids and solids) represents the *particulate fraction*. The particles can be colloids (0.001 – 1 µm in diameter) or larger particles (> 1 µm) in suspension (Manahan, 2010).



Free metal ion	Inorganic complexes	Organic complexes	Colloids Large polymers	Surface bound	Solid bulk phase, lattice
Cu–aq^{2+}	$CuCO_3$ $CuOH^+$ $Cu(CO_3)_2$ $Cu(OH)_2$	Fulvate	Inorganic Organic	Fe—OCu C—O—Cu	CuO $Cu_2(OH)_2CO_3$ Solid solution
True solution					
Dissolved				Particular	

Figure 2. Different types of speciation of metals in water (Stumm and Morgan, 1996).

Ligands are molecules or anions that contains free pairs of electrones (bases) where metal cations can bind. Examples of ligands are CO_3^{2-} and OH^-. Especially Cl^- is an important ligand in sea water. The binding of a ligand to a metal cation can generally as seen in equation 1.

$\text{Me(H}_2\text{O)}\frac{n+}{m} \cdot \text{L} \xrightarrow{k_{-w}} Me(H_2O)_{m-1}L^{n+} + H_2O$ (1) (Stumm and Morgan, 1996),

where Me is the metal cation and L is the ligand.

Particles contain functional groups, such as –OH, -SH and –COOH on their surface. These functional groups contain ligand atoms (similar as the dissolved ligands) and the mechanism for binding on the solid surface is therefore the same as for the complex formation in the dissolved phase, see equation 2 and 3 (Stumm and Morgan, 1996).

In solution: $RCOOH + Me^{2+} \leftrightarrow RCOOMe^+ + H^+$ (2)

On the surface: $=S\text{-}OH + Me^{2+} \leftrightarrow =S\text{-}OMe^+ + H^+$ (3)

Particles in water can be minerals (oxides, carbonates, sulfides), humic substances, macromolecules, biological debris, and biological surfaces (such as algae and bacteria) (Kennish, 2000, Stumm and Morgan, 1996, Manahan, 2010).

The speciation will have a big influence on the fate, transport and bioavailability of the metal (Manahan, 2010).

Bioavailability

The free metal ions are most bioavailable, i.e. easiest taken up by organisms, and hence more acute toxic to aquatic organisms (Florence et al., 1992). Complexed metals and particulate-bound heavy metal(loid)s are less bioavailable and pose a more long-term chronic toxicity impact (Sansalone and Buchberger, 1996). However, the uptake, storage, detoxification, and removal will vary between the organisms (Kennish, 2000).

Removal from water

Metal(loid)s are removed from the sea water by active uptake in organisms or passive when scavenged by living or non-living particulate material and deposited in the sediment (Bruland and Lohan, 2003).

2.7.2 PAHs in sea water

Sources

Anthropogenic sources of PAHs in sea water are oil spills, petroleum products from boats, domestic and industrial wastewater, riverine input, atmospheric deposition and urban runoff (Neff, 1979, Kennish, 2000). A common source of PAHs in the coastal marine environment is creosote which is used on wooden structures (Zitko, 2000, SFT, 2000).

Solubility

PAHs have a nonpolar hydrophobic nature and have therefore low solubility in water. The solubility will generally decrease with increasing number of rings, hence the high molecular weight PAHs are less soluble than the low molecular weight PAHs. The molecular arrangement will also affect the solubility. Angular arrangements will be more soluble than linear arrangement (Neff, 1979).

PAHs can solubilize by associating with the hydrophobic core of micelles, or with the polar surface of micelles, or both. Another way that PAHs can solubilize is by the introduction of organic compounds such as, humic and fulvic acids, and other degradative products of biological materials in the water (Neff, 1979).

Removal from sea water

Since the PAHs are hydrophobic they readily bind to particles. The high molecular weight PAHs are more associated with particles than the low molecular weight PAHs, and will to a higher degree sink to the sediment (Neff, 1979).

PAHs can be degraded in sea water, and low molecular weight PAHs are more easily degraded than the high molecular weight PAHs (Neff, 1979, Kennish, 2000). However, the degradation is slow, especially during the winter (Fernandes et al., 1997). The low molecular weight PAHs can also escape from the sea surface due to volatilization. Another way of removal is by uptake in organisms (Neff, 1979).

2.8 Snow melting in sea water

Snow is more similar to fresh water than sea water, and will hence float on the surface of the sea water, before it melts. The floating snow will spread with surface currents, where stronger currents and wind will lead to a more spread of the snow. With time the snow melts and the pollutants are distributed between the water column and the sediment (Bækken and Tjomsland, 2001, Ranneklev et al., 2013).

The distribution will depend on several factors such as: the type of pollutant, the movement in the water, how strong the currents are, whether the pollutants are particulate bound or dissolved, amount and type of particles/ligands present in the water and particle size. Generally, the particulate bound pollutants will sink to the sediment, while the dissolved pollutants (and the smallest particles) will stay in the water column. Pollutants not bound to particles in the snow can bind to particles in the water and deposit in the sediment. Especially high molecular weight PAHs will quickly adsorb to organic and inorganic particles in the water and sink to the sediment to escape from the water (Neff, 1979).

2.9 Sedimentation of particles

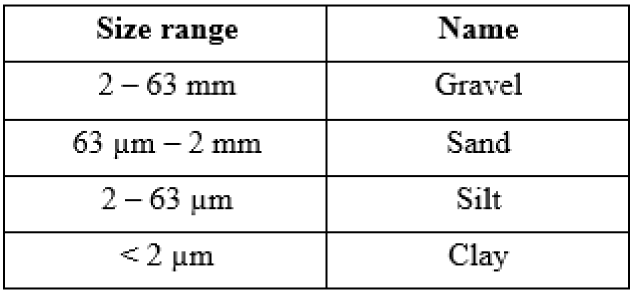
The sedimentation rate of particles depends on the size of the particle and the movement in the water (currents etc.). Larger particles tend to sink faster to the sediment than smaller particles. The smaller particles will be more affected by motion in the water and will be transported more horizontally than vertically in the water, and will hence be transported further away before they might sediment. For the smallest particles, the water has to be in order for them to settle. The smallest particles therefore tend to be suspended in the water column and drifts with currents (Schindl et al., 2005).

Suspended clay-sized particles can flocculate together and become larger aggregates, especially with increasing salinity. This increases the deposition rate (Neff, 1979).

2.10 Marine sediment

Sediment consist of minerals and inorganic particles of different sizes, ranging from clay < silt < sand < gravel. The diameter of the particle is commonly used to distinguish between different particle sizes, see **Table 3.** The finer particles (silt and clay) are usually more contaminated, due to their larger relative surface area, while sand and gravel usually have less contamination. However, porosity of the particle may confound this assumption that the relative surface area increase as the particle size decreases (White, 2005).

Table 3. Particle sizes according to ISO 14688-1:2002.



Size range	Name
2 – 63 mm	Gravel
63 µm – 2 mm	Sand
2 – 63 µm	Silt
< 2 µm	Clay

New sediment comes from sedimenting particles from the overlaying water. In fjords much of these particles comes from rivers and atmospheric deposition (Bakken, 2000), in addition to anthropogenic activity. The sediments are in this way a respiratory for particulate bound pollutants (Kennish, 2000). The pollutants can also be re-suspended into the water column again due to turbulent forces from waves, currents, propellers on boats, discharges into water, dredging or sediment dwelling organisms (bioturbation) (Schindl et al., 2005, Kennish, 2000)

As most of the pollutants will accumulate in the sediment, organisms living in or spend much time near the sediments are particularly exposed (Kennish, 2000). In the sediment the bioavailability is dependent on factors such as type of compound, organic matter in the sediment, particle sizes, redox conditions and more (Laugesen et al., 2003). PAHs tend to accumulate in sediment due to their hydrophobic character, and their slow degradation (SFT, 2000).

As new material builds up in the sediment over time the vertical profile of the sediment can show a historical trend (Ottesen, 2015).

2.11 Klifs guideline

The previous Norwegian Climate and Pollution Agency (Klif) (now under *Miljødirektoratet*) made guidelines for classification of metals and organic contaminants in sea water and marine sediments. The latest guideline is *"Guidelines on classification of environmental quality in fjords and coastal waters – A revision of the classification of water and sediments with respect to metals and organic contaminants TA-2229-2007"* (Bakke et al., 2007). The guideline provides limits for different levels of pollution and are meant to be a common tool for assessment of the environmental state of the water and sediment. The limits are based on ecological effects in form of risks of harm on living organisms in water and sediments.

In total there are five levels, and the risk of harm on organisms is expected to increase with increasing level. Level I represent the background level, but can however have loads from local sources. All the levels above I will therefore indicate that there are one or more point sources polluting the studied area. In this way the guideline can be used to identify if areas are affected by local pollution (Bakke et al., 2007).

In sea water, the guideline is meant for water where the salinity is above 5 and is based on non-filtered water samples. The guideline for metal(loid)s in sea water can be seen in Table **4**. For marine sediments the guideline is based on samples taken 0-10 cm down in the sediment.

Table 4. Klifs guideline for metal(loid)s in sea water (Bakke et al., 2007).

Level	I	II	III	IV	V
	Background	Good	Moderate	Polluted	Heavily polluted
Arsenic (µg As/L)	< 2	2 – 4.8	4.8 – 8.5	8.5 - 85	> 85
Lead (µg Pb/L)	< 0.05	0.05 – 2.2	2.2 – 2.9	2.9 - 28	> 28
Cadmium (µg Cd/L)	< 0.03	0.03 – 0.24	0.24 – 1.5	1.5 - 15	> 15
Copper (µg Cu/L)	< 0.3	0.3 - 0.64	0.64 – 0.8	0.8 – 7.7	> 7.7
Chromium (µg Cr/L	< 0.2	0.2 – 3.4	3.4 - 36	36 - 360	> 360
Mercury (µg Hg/L)	< 0.001	0.001 – 0.048	0.048 – 0.071	0.071 – 0.14	> 0.14
Nickel (µg Ni/L)	< 0.5	0.5 – 2.2	2.2 - 12	12 – 120	> 120
Zinc (µg Zn/L)	< 1.5	1.5 – 2.9	2.9 - 6	6 – 60	> 60

The classification only say something about the risk of harm on living organisms in sediment, and nothing about for example spread of the pollutants from the sediment or the bioavailability of the pollutants (Laugesen et al., 2003). The effect on the marine organisms from the pollutants are complex due to many factors affecting the bioavailability (SFT, 2000).

2.12 Total fraction, and separation of dissolved and particulate fraction

A common way to separate the dissolved fraction from the particulate fraction is to filter the solution through a 0.45 µm filter. The solution that goes through the filter is termed the dissolved fraction. However, the smallest colloids are small enough to pass though this filter and lead to that the solution termed “dissolved” can also contain small particles and are hence not the true dissolved fraction (Stumm and Morgan, 1996). A newer method is to use 0.2 µm filters to get a better separation (Bruland and Lohan, 2003). The concentration of the compound in the dissolved fraction and the particulate fraction constitutes the total concentration of the compound in the solution. Hence the total concentration doesn’t say anything about the speciation of the metal.

2.13 Diffuse gradient in thin films (DGT)

Diffuse gradient in thin films (DGT) quantitatively measures the average concentrations of dissolved labile species in an aqueous solution *in situ* over a time period (Zhang and Davison, 1995, Zhang and Davison, 1994). It can also be used in sediment and soil (Reasearch, 2015). The DGT technique was introduced in 1994 and have since then been widely used. The technique is applicable to any inorganic or organic diffusing species in a non-acid aqueous medium (Zhang and Davison, 1994).

The sampler consists of a filter, a layer of diffusion gel and an ion-exchange resin embedded in a plastic casing, see *Figure 3*. Outside the filter, there is an opening to the aqueous solution. The opening is 2.5 cm in diameter. The filter is 100 µm thick and have pore sizes of 0.45 µm (Zhang and Davison, 1994).

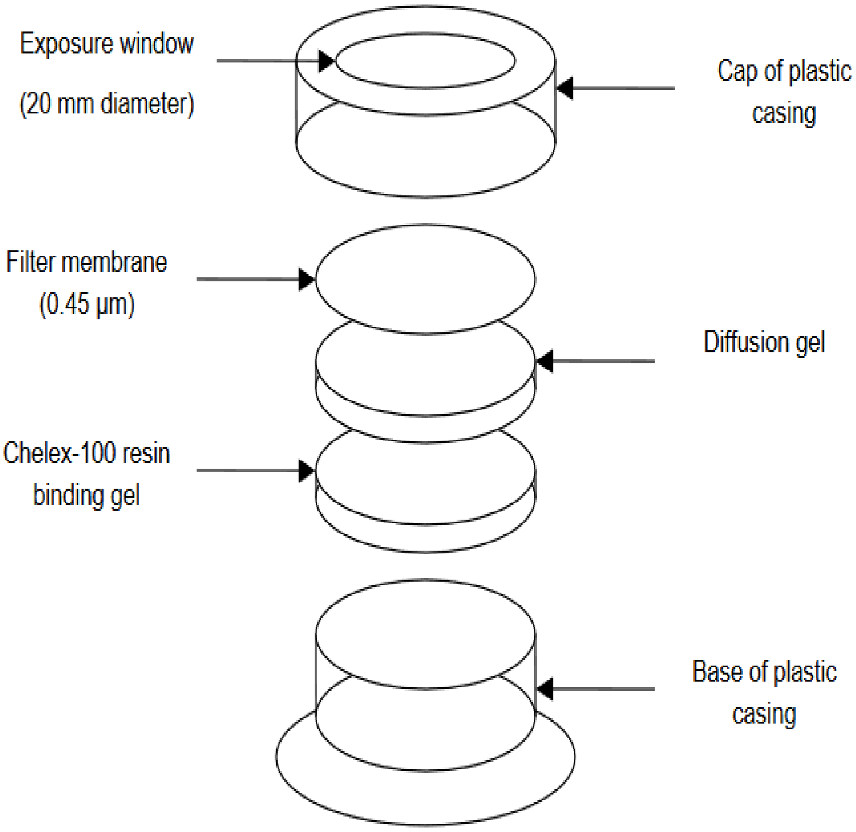


Figure 3. *Illustration of DGT assembly (Wagner, 2004).*

When the DGT is placed out in water, ion small enough to pass through the filter, will diffuse through the diffusion gel by molecular diffusion, and reach the ion-exchange resin. Here ions in the resin will be exchanged by the new ions. The ion-exchange resin therefore functions as a binding gel where the ions become permanently immobilized (Zhang and Davison, 1995, Zhang and Davison, 1994).

The mass transport of the ions in the diffusive gel needs to be controlled for the technique to provide quantitative measurements. The mass transport in the diffusive gel layer is controlled by using a gel of known thickness, Δg. This known gel thickness controls the overall rate of mass transport, meaning it will control over for instance hydrodynamics such as the velocity of water in the aqueous solution (Zhang and Davison, 1994).

Between the diffusive gel and the bulk solution (the aqueous solution), there is assumed to be a layer called diffusive boundary layer (DBL), see *Figure 4,* that has the thickness δ. Here the transport of ions are solely by molecular diffusion (Zhang and Davison, 1995)(Zhang and Davison, 1995)(Zhang and Davison, 1995)(Zhang and Davison, 1995)(Zhang and Davison, 1995)(Zhang and Davison, 1995)(Zhang and Davison, 1995). The thickness of the DBL can be neglected as it is assumed that the thickness of this layer is much smaller than the layer of the diffusive gel layer (Zhang and Davison, 1994).

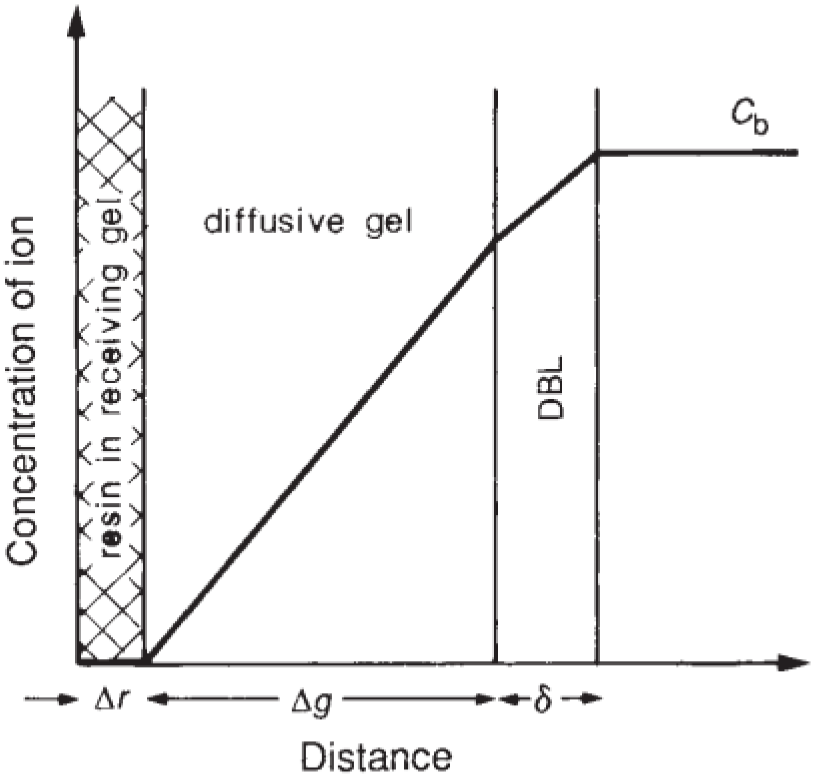


Figure 4. *Illustration of the diffusive boundary layer (DBL), diffusive gel layer and the resin in receiving gel (Zhang and Davison, 1995).*

When the mass (M) in the resin-gel is analysed, the concentration in the bulk solution (C_b) can be calculated by using the following equation 4.

$C_b = M\Delta g / DAt$ (4)

Where D is the molecular diffusion coefficient, A is the exposure surface area of the membrane and t is time (Zhang and Davison, 1995). The molecular diffusion coefficient is a well-defined factor specific for each metal and can be found in a Table.

The diffusion gel is usually a polyacrylamide hydrogel, which consists of 2-5 nm pores. The type of binding gel is dependent on what analyte is to be measured. When measuring trace metals, Chelex100 is often used as an ion-exchange resin. This resin is selective for trace metals and is normally around 150 µm thick (Zhang and Davison, 1994, Zhang and Davison, 1995).

The uptake and binding continues until the binding gel has reached full capacity (fully saturated), or the DGT is taken up from the water. The sampler can be out for about 3 months in contaminated coastal waters before it reaches saturation (Zhang and Davison, 1994).

Advantages

DGT can measure average concentrations over time, in contrast to single water samples where only the concentrations at the time of sampling are measured (Vrana et al., 2005). Use of DGT will also avoid the problem with distribution change of chemical species during sampling and storage and gives a more reliable measurement of trace species in water (Zhang and Davison, 1994).

Another advantage is that it measures the readable (labile) fraction that are able to transport across bio membranes, and are hence the most bioavailable fraction that can be taken up by organisms (Florence et al., 1992).

Disadvantages

Since DGT gives the average concentration over a time period it won’t be able to show how the concentrations varies during a period and episodic pollution events (Vrana et al., 2005).

The sampler can be subjected to biofouling, which can affect the area of the exposure window, leading to less ions being taken up (Zhang and Davison, 1994).

2.14 Polyoxymethylene (POM)

Polyoxymethylene (POM) is a plastic material used as a passive sampling method for organic pollutants, such as PAH and PCB. It can be used in water, air and sediment/soil, where it establishes equilibrium with the surroundings. When used in water, POM establishes equilibrium with the dissolved fraction of the organic pollutants, usually within 3-4 weeks. The concentrations measured in POM together with established coefficients, can be used to calculate the concentrations in the water. The concentrations represent the average concentrations in the water for the last 3-4 weeks of the sampling period. The detection limits are as low as 0.1 ng/L for PAH and 0.1 pg/L for PCB. Two types of POM exist; POM-76 (sheet) and POM-55 (strips, see picture 3) (wag solutions, not dated, NGI, 2010).

Picture 3. POM strips (wag solutions, not dated).

Advantages

POM can detect concentrations that are below detection limits in traditional water sampling (Pettersen and Breedveld, 2009). Traditional water sampling is also time consuming and requires a lot of water samples to be taken. Using POM is a much more efficient and time saving method (NGI, 2010).

Disadvantages

As POM shows the average concentration over a period, it won’t show how the concentration varies during time (Vrana et al., 2005).

2.14 Sediment traps

Sediment traps are passive samplers that collect sedimenting material in water. The sedimenting material can be taken out and analyzed. The values will represent a time integrated average (NGI, 2011a). The traps can have different designs; one of them are cylindrical tubes mounted on a tripod and placed vertically in the water column, see *Figure 5*. The tubes are open at the top and closed at the bottom, so that the sedimenting material is trapped inside the tube. The tripod is bound to a mooring at the bottom, to keep it in place, and to a buoyancy buoy at the top to make it stay upright in the water.

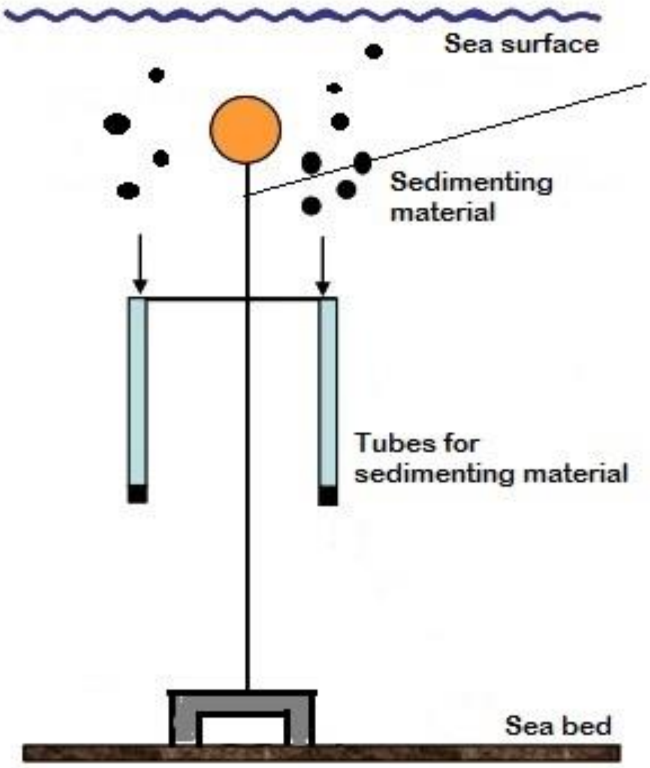


Figure 5. *Illustration of sediment trap, with two tubes, mooring in the bottom and buoyancy buoy in the top. Figure modified from (NGI, 2015).*

Advantages

The trap can collect both new material and/or material suspended from the bottom sediment, depending on where it is placed in the water column (NGI, 2011a). If it is placed higher up in the water column only new sedimenting material will be collected, and only the new supply of material can be studied. By placing the trap lower in the water column suspended material from the bottom sediment can sediment in the trap and i.e. the spread of the sediment can be studied. Compared with sediment samples, where the fine material can be lost during sampling, the sediment traps avoid this (Schindl et al., 2005). Even with low sedimentation, the material in the trap can be analysed. The method has therefore high sensitivity (Pettersen and Breedveld, 2009).

Disadvantages

Material from the sediment can be swirled up and deposit in the trap, is a disadvantage if only new material is the goal of the measure.

2.15 UltraClave

UltraClave is used to decompose samples. It is based on microwaves that heat and digest the samples within a chamber. Inert gas is used to pre-pressurize the chamber to avoid the samples from boiling. Closed chamber and sample tubes prevent the volatile compounds to escape. A temperature program can be applied to offer different temperatures during the digestion (Milestone, not dated).

The direct microwave heating in a high pressure reactor gives a very high performance. It is possible to decompose 40 samples at once, leading to same pressure and temperature on all the samples. Since the samples are decomposed inside the tubes, no cross-contamination occurs (Milestone, not dated).

2.16 GC-MS

In gas chromatography-mass spectrometry (GC-MS) the two separate techniques gas chromatography (GC) and mass spectrometry (MS) are combined. It can be used to determine molecular weights and elemental composition in complex mixtures, especially for qualitative and quantitative determination of volatile and semi-volatile organic compounds, such as PAHs. The GC separates the compounds, while the MS detect them Detection limit can be down in the sub-ng area. The GC-MS was developed in the mid 1950’s and is now a widely used technique around the world (Sneddon et al., 2007).

2.17 ICP-MS

Inductively coupled plasma mass spectrometry (ICP-MS) is an analytical method with very low detection limits, down in the sub parts per trillion (ppt) range and to the high parts per million (ppm) level, and is therefore a suiTable method for analyzing trace metals. The analysis is fast and it is possible to perform multi element analysis. ICP-MS is one of the fastest growing trace element techniques (Thomas, 2004).

Principle

The principle is to generate positively charged ions in a plasma, which then are separated by mass-to-charge ratio in a mass spectrometer and detected in an ion detector. The different components of the ICP-MS can be seen in *Figure 6.*

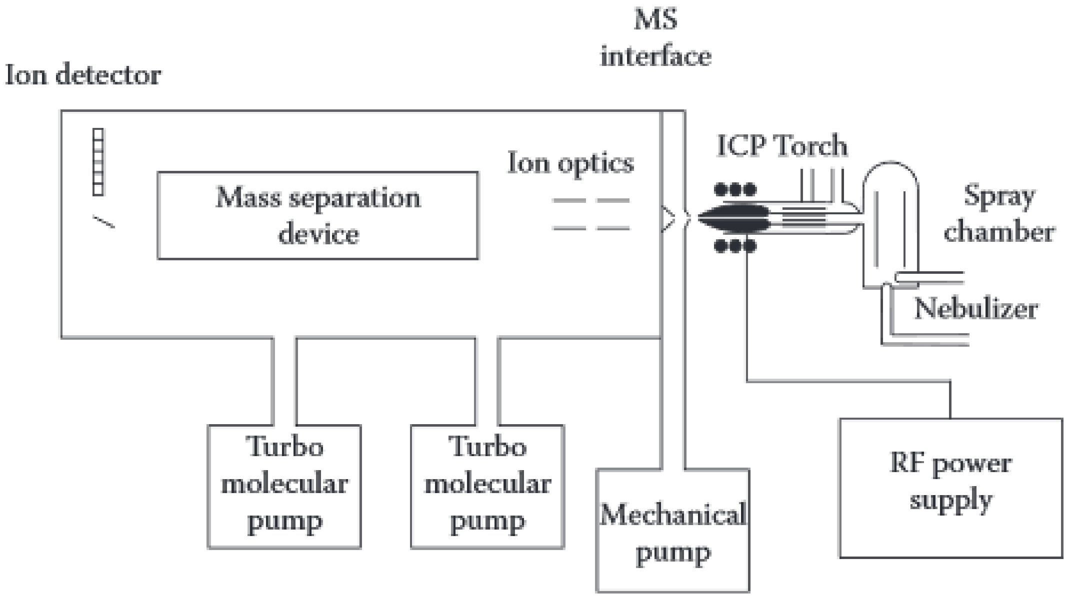


Figure 6*. The different components of ICP-MS (Thomas, 2004).*

The sample, normally in liquid form, is first pumped into the **nebulizer.** The pump is a peristaltic pump that ensure constant pumping, pressure and flow regardless of differences in viscosity between the samples, standards, and blanks and pump at a rate of 1 mL/min. In the nebulizer, a gas, usually argon gas, breaks the liquid into smaller droplets and creates a fine aerosol. After the aerosol generation, the largest droplets are separated from the smaller droplets. The amount of fine droplets depends on the matrix and the method of introduction of the sample, but constitute usually about 1-2 % of the sample. This separation occurs in the **spray chamber.** The spray chamber also smooths out nebulization pulses produced by the peristaltic pump (Thomas, 2004).

The fine aerosol then reaches the **plasma torch**, which usually is argon plasma. The aerosol leaves the spray chamber in such a velocity that it creates a hole horizontally through the center of the plasma. The argon plasma consists of highly energized argon ions, which can remove electrons from the atoms outer shells, and positively charged ions are created, see *Figure 7* (Thomas, 2004).

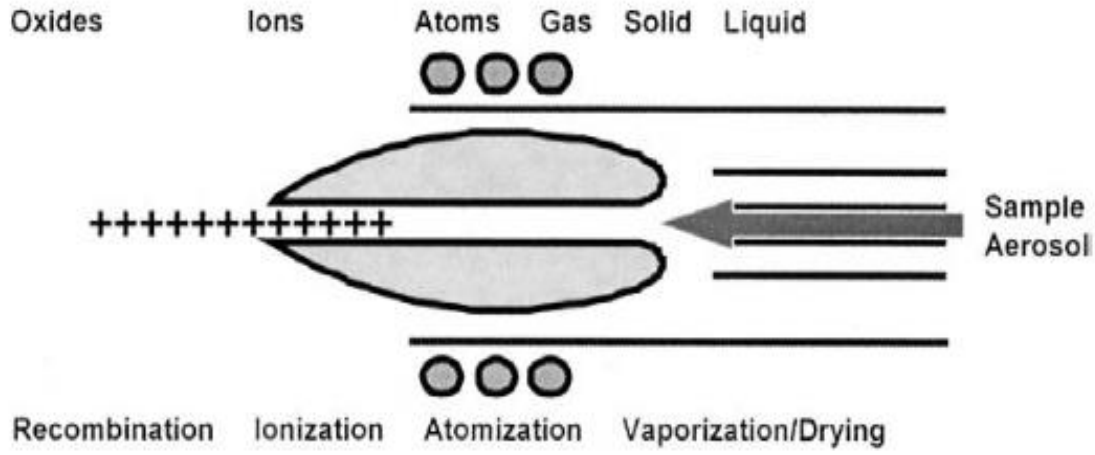


Figure 7. *The plasma has different heating zones and as a result the sample is dried, vaporized, atomized, and then ionized, and changes from liquid aerosol to solid particles, and then into gas (Thomas, 2004).*

The energy available in the argon plasma is around 15.8 eV and is high enough to ionize most of the elements in the periodic Table as most of the elements of the periodic Table have first ionization potential between 4 and 12 eV. It is this large production (and detection of these) ions that gives ICP-MS its characteristic low-ppt/ultra trace detection capability.

The ions then reach the **interface region** of the MS, where the ions are efficiently and consistently transported with electrical integrity from the plasma to the MS. The interface region is kept at a vacuum of 1-2 torr by a mechanical roughing pump and consists of two metallic cones; a sampler and a skimmer cone. The interface housing is cooled with water to reduce effects of the high-temperature plasma on the cones. From the interface region the ions reach the ion optics. The **ion optics** are a series of electrostatic lenses which focus the ion beam electrostatically towards the mass separation device; while photons, particulates, and neutral species are prevented from reaching the detector. Before the detector there is a **mass separation device.** There exist different types of mass separation devices, such as quadrupole, magnetic sector systems, and time-of-flight technology, but they all separate the ions according to their mass-to-charge (m/z) ratio and ensure that only analyte ions of particular m/z ratio is sent through to the detector (Thomas, 2004).

In the detector the ions generate electronic signals. The magnitude of the signal will correspond to the number of analyte ions present in the sample and can be converted into analyte concentration by using a data-handling system and ICP-MS calibration standards (Thomas, 2004).

Calibration

In quantitative analysis the ICP-MS has to be calibrated for each of the analytes of interest, to be able to find the concentrations of the analytes in the samples. One type of calibration is *external standardization*. During this type of calibration, a set of samples (called *calibration standards*) with known concentrations of the analytes of interest are analyzed to measure their intensity. Also a blank (sample with the same matrix, but without the analytes of interest) is used. The concentration range of the calibration standards represent the concentration range likely to be encountered in the unknown samples. The intensity found for each of the analytes in the calibration standards are plotted against the concentrations in a *calibration curve*. When the intensity in the unknown samples is measured, the concentration can be found from the curve.

Spectral interferences

Elements can occur naturally in several isotopes (same atomic number, but different atomic masses). When non-analytes have the same mass as the analytes they will give signal at the same mass and lead to spectral overlap. Spectral interferences are a serious type of interferences in ICP-MS. The most common type of spectral interferences is *polyatomic or* *molecular spectral interferences*. These occur when two or more atomic ions bind and the new compound have the same mass as one of the analytes. Argon ions in the plasma can for instance bind to other ions or species, i.e. from the sample or the acid used, and form new species with the same mass as the analytes. One example is the formation of $^{40}Ar^{35}Cl^{+}$, when hydrochloric acid is used. $^{40}Ar^{35}Cl^{+}$ interfere with the only isotope of arsenic at mass 75. Also ions from the matrix or solvent can combine and form new species that lead to spectral overlap. In analysis containing sea water, which have high concentration of sodium, Na-ion can combine with Ar-ion and form $^{40}Ar^{23}Na^{+}$ molecular ion. This molecule interferes with the most abundant isotope of Cu at mass 63. Many other polyatomic spectral interferences exist. Another type of spectral interference is *isobaric overlap*, which is when isotopes of different elements have the same mass, and hence give a signal at the same mass (Thomas, 2004).

Ways to reduce spectral interferences are mathematical corrections, use of cool plasma conditions, and use of a high-resolution mass analyzer (Thomas, 2004).

Non-spectral interferences

The matrix itself can suppress the signal of the analytes. It can influence the droplet formation in the nebulizer, droplet size selection in the spray chamber or it can affect the ionization condition in the plasma. The degree of suppression depends on the level of the components in the matrix. The matrix induced interferences can be corrected for by using internal standardization (Thomas, 2004).

2.18 Quality assurance

Quality assurance is a way to ensure that the quality of the samples and the analysis is good enough for the intended use (Harris, 2010a). Collecting representative and enough samples, make sure that the analyte(s) are preserved in the samples after sampling, reduce sources of errors, and use of suiTable sampling material are some factors in the *sampling process* which are important to increase the quality of the samples. In the analysis, use of acids and solvents which gives little interferences in the instrument can increase the quality of the analysis. Often

ISO standards are used/followed. The ISO standards are international documents providing guidelines regarding sampling, sample preservation and preparation, and analysis.

The quality of the analytical analysis (or to check if the method is accepTable for its intended use) can be checked by *method validation.* Important validation parameters are accuracy and precision (Harris, 2010a).

Accuracy is a measure of how close the measured value is from the true value. To test the accuracy of the analytical method, certified reference material can be used. Certified reference material is a material with known concentrations of the analyte(s). The result of the analysis of the certifies material should be acceptably close to the certified level to have sufficient accuracy of the method (Alloway, 2013, Harris, 2010a). If the analysed value is the same as in the reference material the accuracy is 100%, see equation 5, but most often the accuracy is considered good when it is between 85 – 115 %.

$$\text{Accuracy} = \frac{\text{measured value}}{\text{value in reference material}} \cdot 100\ \% \quad (5)$$

Precision is the spread of the measured values. If the samples are analysed under same conditions (by same person, same lab, same day etc.) the precision is a measure of the *repeatability* of the analysis. The repeatability is usually expressed as a *standard deviation,* which gives information about how close the values are around the mean. It is usually written as: mean value ± standard deviation. A low standard deviation therefore means that the precision is better and the measured values are closer to each other. The standard deviation is dependent on the confidence interval (CI) chosen. The confidence interval states how certain it is that the true value lies within the interval that the standard deviation gives. Often a 95 % CI is used, which represent 2 standard deviations and means that there is a 95 % chance that the true value is within the interval the standard deviation gives. If one standard deviation is chosen, the CI is around 67 %. (Harris, 2010b, Harris, 2010a, Alloway, 2013).

Standard deviation can also be expressed in % as relative standard deviation (RSD), see equation 6. σ is the standard deviation and $\bar{X}$ is the average measured value (Alloway, 2013). The RSD value should be as low as possible to have less spread in the results.

$$RSD = \frac{\sigma}{\bar{x}} \times 100 \qquad (6)$$

If the samples are analysed under different conditions (different person, lab, day etc.) the precision is referred to as *reproducibility*. The reference material can also be used to check the reproducibility (Harris, 2010a).

2.19 Errors and uncertainty

Error is the difference between the measured value and the “true value”. Many factors, referred to as sources of errors, can affect the analytical result leading to a different value than the true value. Examples of sources can be seen in Figure *8*. Known errors can be corrected for in the results, but most often the errors are of unknown values, leading to uncertainty in the results (Bell, 2001).

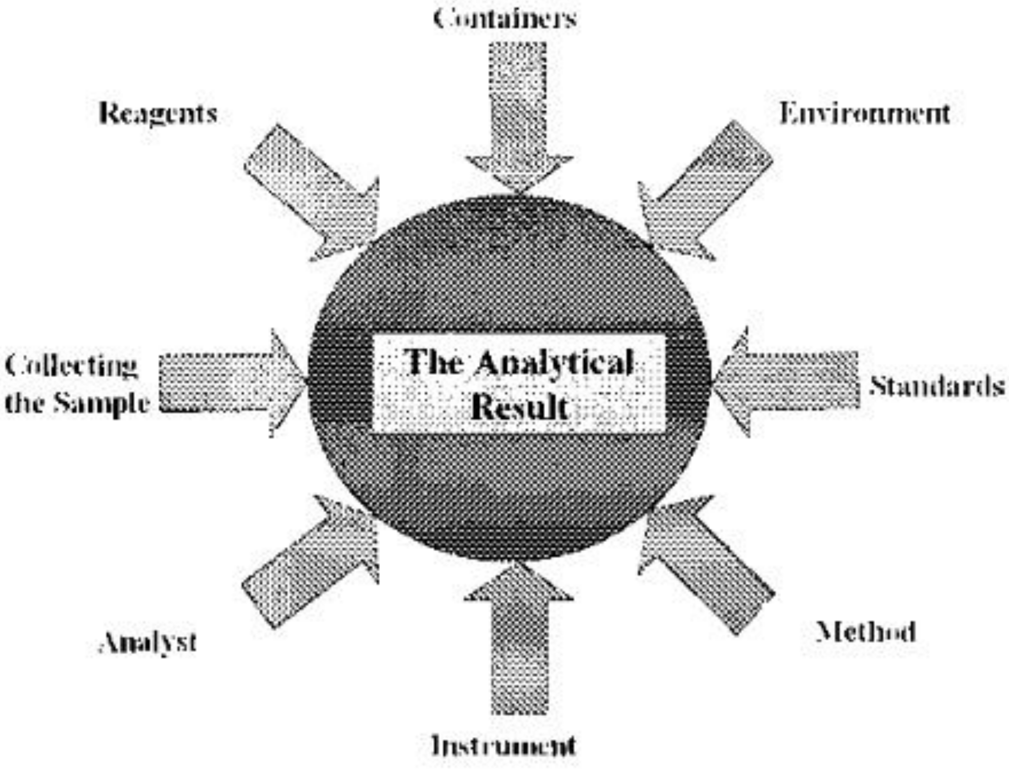


Figure 8. *Showing factors affecting the analytical result (Thomas, 2004).*

Blanks can correct for some of the errors. *Blanks* are samples of same or similar material/matrix as the samples and contain the same compounds as the real samples but do not contain the analyte(s). Blanks that have been through all the steps as the real samples from sampling to analysis are *field blanks*. Blanks that only have been through the same steps in the sample preparations are called *method blank* and blanks that has not been through the preparation steps are called a *reagent blank* (Harris, 2010a). The blanks are then analysed at the same time as the samples, and if there is any contamination or the analyte(s) are present in the matrix or the material this can be corrected for in the samples.

2.20 Detection limit

The lowest concentration that can be measured of a analyte and which is significantly different than the blank is referred to as the detection limit (also sometimes called lower limit of detection) (Harris, 2010a).

3. Previous studies

In this section previous studies of snow dumping are mentioned in **section 3.1** and previous studies at pier 68 in **section 3.3.**

3.1 Snow dumping

Analysis of snow samples to estimate the contribution of pollutants from snow dumping and the quality in water and sediment in areas used for snow dumping have been performed several places in Norway over the years. A short overview of some of them and what they concluded are seen below.

Bispevika, Oslo

The sediments in the area used for snow dumping in Bispevika in Oslo's inner harbour were severely polluted with heavy metals, PAH and PCB. It was assumed that the pollutants came from the snow dumping. Samples of snow were taken from 5 different roads in Oslo in 1994 to estimate the amount of pollutants from the snow. Together for the whole winter season of 1993/1994, which was a very snow rich winter, 43,000 loads/trucks with snow were dumped in Bispevika. The contribution of pollutants from snow were estimated to be 1000 tons' of particles, 60 kg zinc, 29 kg lead, 20 kg copper, 20 kg chromium, 5 kg nickel, 0.4 kg cadmium, 8.3 kg PAHs, 0.8 kg KPAH, 21 g PCB and 7.5 tons of oil. This contribution was low compared to the contribution from sewerage and watercourses during one year. The conclusion was therefore that the snow dumping did not contribute significantly to the pollution state in the sediment in Bispevika, but it does however contribute with particulate material so that the need of dredging increased. The amount of particles contributed the winter 1993/1994 would lead to an increase of the sediment of 1-1.5 cm (Bækken, 1994).

Drammen 2001

Snow samples were taken from 4 different roads in the center of Drammen and at a reference place and simulations were performed to check the impact on water and sediment quality in the river Drammenselva due to snow dumping. The model estimated the spread and gave distributions of concentrations in the river. The model took the speed of the water, turbulence and substance sedimentation into account, but assumed idealized conditions such as constant current, continuous emission and that the snow melted immediately after dumping. Different spreading patterns (high and low water flow, with and without sedimentation) with very contaminated snow (4 weeks old) were performed to check "worst case" scenario. The simulations showed that the concentrations of the different substances (metals, PAHs and PCBs) in river water was low outside the dumping site. The water quality was in level I and the concentrations in the sedimented material in snow samples corresponded to " negligible " or " moderate " contaminated sediments. The conclusion was therefore that it was unlikely that the snow dumping contributed substantially to contaminated sediments in the river Drammenselva and to the Drammensfjord. It was however pointed out that Cu and PAHs should be followed up due to that they had occasionally high concentrations that could cause elevated concentrations of "negligible polluted " or " moderately polluted " by SFTs sediment criteria if long term snow dumping continued and with little dispersion in the river (Bækken and Tjomsland, 2001).

Drammen 2013

A similar survey as in 2001 (see above) was conducted in Drammen in 2013. Snow samples were taken, and the spread and dilution in the river Drammenselva were modeled. Also here simulations with highly contaminated snow (4 weeks old) were performed and showed that the concentrations only increased marginally above the background level (level I and II) for metals at the dumping site. Furthermore, the simulations showed that the substances and the particles were well spread out over a large area. The conclusion was therefore that the snow dumping only had a marginal effect on water and sediment quality, for both metals and organic pollutants (Ranneklev et al., 2013).

3.2 Pier 68

Sediment samples have been taken outside pier 68 by NGI in 2009 (NGI, 2011b), GeoCore in 2000 (Ottesen et al., 2001) and GeoSubSea AS in 2007 (see appendix A). An overview of the sampling points can be seen in *Figure 9.*

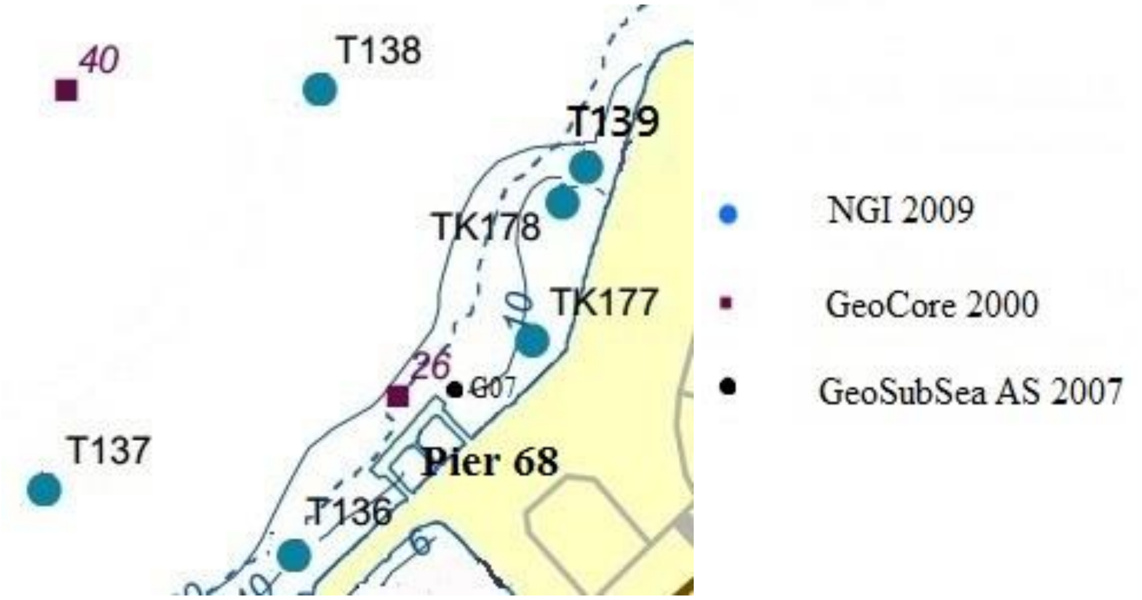


Figure 9. *Overview over previous sampling points in the sediment outside pier 68 (NGI, 2011b).*

In sample points 26 and 40 the top layer (0-2 cm) were analysed, while in the other sampling points the layer 0-10 cm were analysed. The samples from 2000 was re-analysed by NGI in 2009 and adjusted (NGI, 2011b).

The concentrations found in the samples are compared with Klifs guideline for marine sediment from 2007 (see appendix B) and can be seen in **Table 5**. The concentrations were mostly in level I and II for the metals, but PAHs have been found in high levels (level V) in some of the samples.

Table 5. Concentrations found in previous sediment samples taken at pier 68. Samples taken by NGI, GeoCore and GeoSubSea (Ottesen et al., 2001, NGI, 2011b)(appendix A).

Sampling point	**G07**	**26**	**40**	**T136**	**T138**	**TK177**	**TK178**	**T139**
Layer in the sediment (cm)	0 - 10	0 - 2	0 - 2	0 - 10	0 - 10	0 - 10	0 - 10	0 - 10
As	2.4	4	7	4	7.3	5.4	6	4.8
Pb	17.3	22	85	14	26	120	24	30
Cd	0.14	0.5	0.70	0.39	0.47	0.58	0.4	0.68
Cu	51.8	32	36	19	36	32	26	38
Cr	43.6	32	29	33	43	50	140	100
Hg	0.03	0.55	0.15	0.038	0.19	0.087	0.017	0.23
Ni	36.9	29	21	22	27	31	26	32
Zn	112	81	147	82	110	89	41	87
SumPAH-16	0.483	19	3.8	6.6	7.4	35	82	25
B(a)P	0.018	0.719	0.250	0.49	0.86	1.7	3.4	1.6

4. Snow removal and dumping in Trondheim

Different companies are in charge for snow removal in Trondheim. *Trondheim Bydrift* is in charge of the snow removal of the municipalities roads. The road network is around 805 km The removal from the main streets, pavements, bicycle lanes and residential streets starts when the snow reaches 5 cm (Trondheim Kommune, 2016). The snow removed from the roads is first stored in piles around in the city (*see picture 3),* before they are further removed.

Picture 4. Snow piles in Trondheim, winter 2016. Photos: Hilde A. Hammer.

There have previously been snow disposal sites on land (one at Iladalen and one at Heimdal), but these are no longer in use, and all the excess snow is dumped from piers in the harbour. Three piers have been used as snow dumping sites in the last years; pier 30 in Ila, pier 68 at Brattøra and pier 57 at Nyhavna, see *Figure 10***.** During the last two winters only pier 68 have been allowed for snow dumping. During the winter of 2013/2014 and 2014/2015 about 1000 m^3 snow were dumped per year (personal communication Rolf Magne Brødreskift 16.04.14).

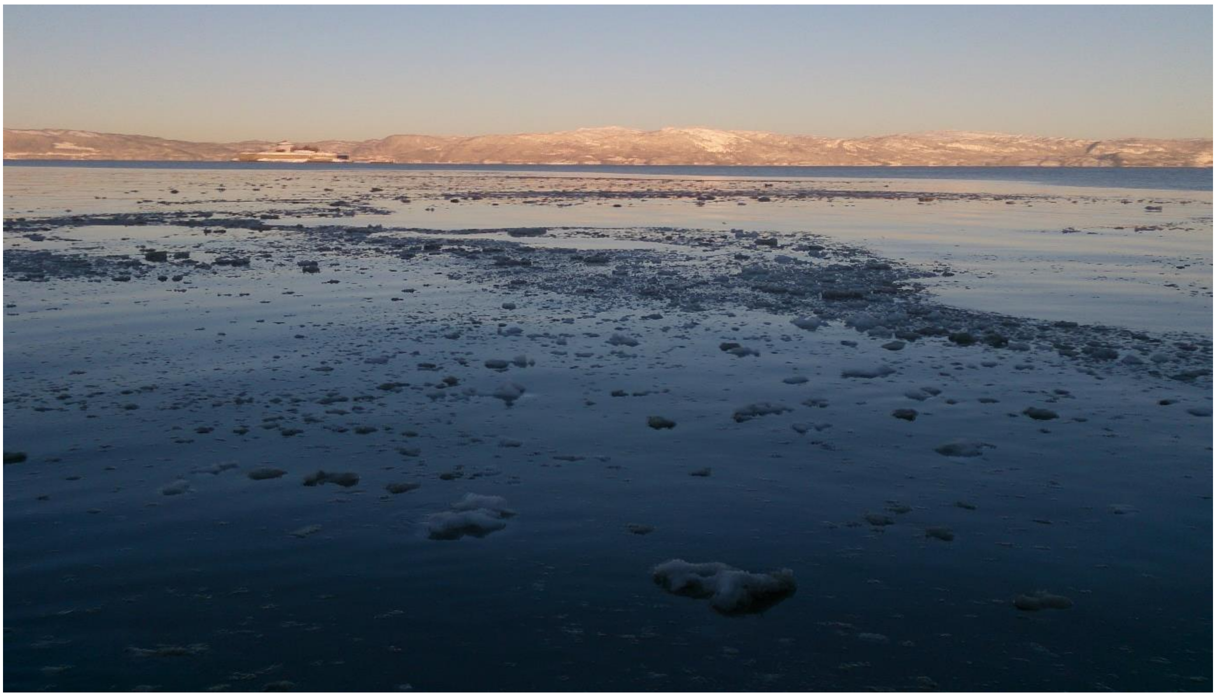
Figure 10. Present and previous snow dumping sites in Trondheim harbour. *During the winter of 2014/2015 and 2015/2016 only pier 68 was allowed for snow dumping.*

4.1 Winter of 2016

The winter of 2016 was a very snow rich winter. From January to March, 190.7 mm fell down as precipitation at the observation station at *Voll gård* (Meteorologisk institutt, 2016). This is 30.7 mm more than the average. A lot of snow was therefore dumped from pier 68. Despite that only pier 68 was allowed for snow dumping, some snow was also dumped from pier 30 in Ila. It has not succeeded in getting an overview over total amount of snow dumped from pier 68 as there are several companies and the snow dumping is not logged. *Trondheim Bydrift* however, dumped around 40,700 m^3 of snow (personal communication Rolf Magne Brødreskift 16.04.14). Both sand and salt were used as a part of winter road maintenance in Trondheim in 2016 (Trondheim Kommune, 2015).

Most of the snow was dumped from the right short side of pier 68 (see picture 5), only a few trucks dumped on the other side of the pier. The snow float mostly straight out in North East direction from the pier, but also the other directions were observed, and the snow spread far out on the fjord over a relative large area (see picture 6).

Picture 5. Snow dumping at pier 68 winter 2016. Photo: Hilde A. Hammer



Picture 6. Spread of the snow on the surface water. Photo: Hilde A. Hammer

5. Study area

5.1 Trondheim Harbour

Trondheim harbour lies in the Trondheimsfjord and stretches from Høvringen in west to Ladehammeren in east. It is a big transport harbor with together 68 piers. There are industries several places in the harbor, especially in the areas Nyhavna and Ila. The main surface current in the harbour goes from west to east and is around 1-10 cm/s, with max values of 50-100 cm/s (Laugesen et al., 2003 and references therein).

5.2 Pier 68

Pier 68 lies in the subarea Brattøra North, in the middle of Trondheim harbor, see *Figure 11*. This pier is also called the Tourist ship quay; as large cruise ships arrive to this pier. Most cruise ships arrive during the summer. The area is mainly a harbor area, and not a recreation area (NGI, 2011b). The water depth around the pier is mostly shallower than 20 m (see appendix C).

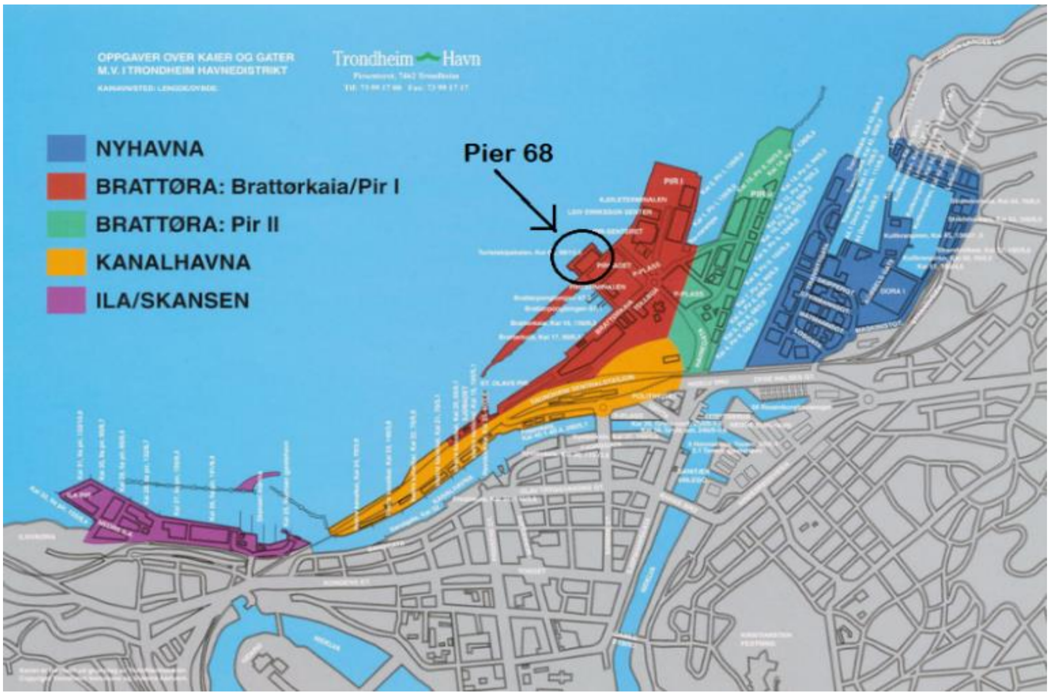


Figure 11. Trondheim harbour, with pier 68 marked with a circle. Figure from: *http://trondheimhavn.no/uploads/bilder/havna/Kart+Trondheim+havn.jpg*

6. Method

The method chapter is divided into the following sections: **6.1** preparations before sampling, **6.2** sampling, **6.3** sample preparations before analysis, **6.4** analysis, **6.5** quality assurance and **6.6** data handling.

6.1 Preparations before sampling

Only the DGTs needed preparation before sampling, and are described in **section 6.1.1.**

6.1.1 Preparation of DGTs

The DGTs had to be made before the sampling. The binding gel and the diffusive gel used were pre made and pre cut as hydrated disks from the manufacturer, DGT Research Ltd, and were ready to be used. Chelex 100 gel was used as a binding gel. This gel is 0.40 mm thick, while the diffusive gel is 0.78 mm thick. First, the Chelex gel was placed on top of the bottom part of the DGT. The gel has two sides, and were tried to be placed with the rough side up (which was a bit difficult to see)(*see picture 7*). Then the diffusive gel was placed on top of the Chelex gel and the filter placed on top of the diffusive gel. A plastic tweezer was used for placing the layers. In the last step the cap was put on and the filter was moistened with MQ-water.

The completed DGTs were placed in a zip bag with a few drops of the liquid from the diffusive gel bottle and stored in a refrigerator (temperature around 4 ºC), until the sampling. All the steps were performed in a LAF bench, and gloves were used during the preparation.

Picture 7. The bottom part of the DGT with the rough side of the Chelex gel can be seen. Photo: Hilde A. Hammer

Picture 8. *A completed DGT can be seen. Photo: Hilde A. Hammer.*

6.2 Sampling

Most of the sampling took place between January – April 2016. In this section each of the samplings are described, and is divided into the following sections: **section 6.2.1** Snow, **section 6.2.2** Sediment, **section 6.2.3** sedimenting material **section 6.2.4** water column (DGT), **section 6.2.5** surface water, and **section 6.2.6** water column (POM).

6.2.1 Snow

Snow samples were collected at four different locations in the city during January 2016. The samples were collected by shoving 50 mL plastic tubes into the snow. Both snow that appeared white and snow which was more brown was sampled. In total 17 samples was collected, see **Table 6.** After the sampling the tubes were put in a freezer (-23 ºC) until the sample preparation.

Table 6. *Overview over the snow samples taken.*

Location	Sampling date	No. of samples	Type of area
L1	24.01.16	5	Pedestrian zone (but open for driving with permission)
	27.01.16	1	
L2	24.01.16	6	Close to highly trafficated road.
	27.01.16	1	
L3	24.01.16	3	Close to highly trafficated road.
L4	27.01.16	1	Close to highly trafficated road.

***Picture 9.** One of the sampling sites for the snow samples (location L2). Samples were of both the white and brown part. Photo: Hilde A. Hammer.*

6.2.2 Sediment

Sediment samples were taken outside pier 68 in October 2014, May 2015 and February 2016. The samples from 2014 and 2015 were taken in increasing distance from the long side of the pier, while the samples taken in 2016 was taken with increasing distance from the short side of the pier, see *Figure 12.* All the samples were taken with a box corer from NTNUs boat *Gunnerus*, and the top layer (0-2 cm) was sampled. In October, samples from different depths in the sediment were also taken at all the sample points (the depths varies from 8-16 cm down in the sediment).

A core sample was also taken at Østmarka at 195 cm depth, see *Figure 13.*

After the sampling the samples were freeze dried (-23°C).

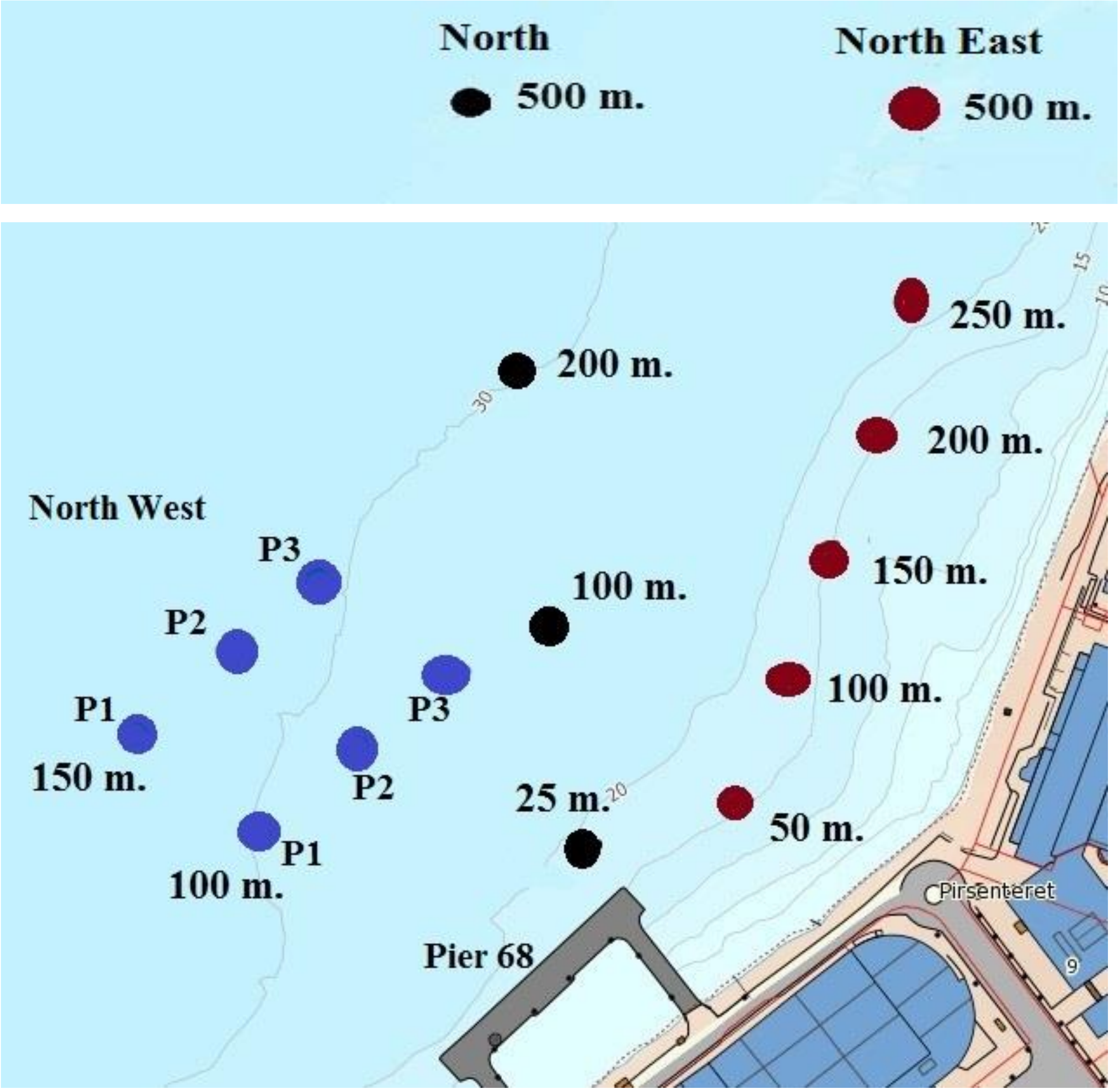


Figure 12. Map showing the approximately sampling points for the sediment samples taken. *The map is just for illustration and does not show the accurate positions. Samples in North West direction were taken in October 2014, samples in North direction were taken in May 2015 and samples in North East direction were taken in February 2016.*

Figure 13. *Approximately location core sample Østmarka.*

Picture 10. Sediment sampling with box corer 02.02.16. Photos by: Hilde Alida Hammer.

6.2.3 Sedimenting material

Three sediment traps were out in the fjord from January 22 to March 15 2016 (53 days). The traps were placed about 41, 89 and 136 meters in the North East direction of pier 68, due to that most of the snow floats in this direction. The approximately positions can be seen in Figure 14 (exact positions can be seen in appendix D). The traps used were similar to the one described in section 2.14. The tubes were 1-meter-long and had a diameter of 105 mm, and were placed 5 meter above the sediment, to ensure that particles from the sediment were not sedimenting in the traps.

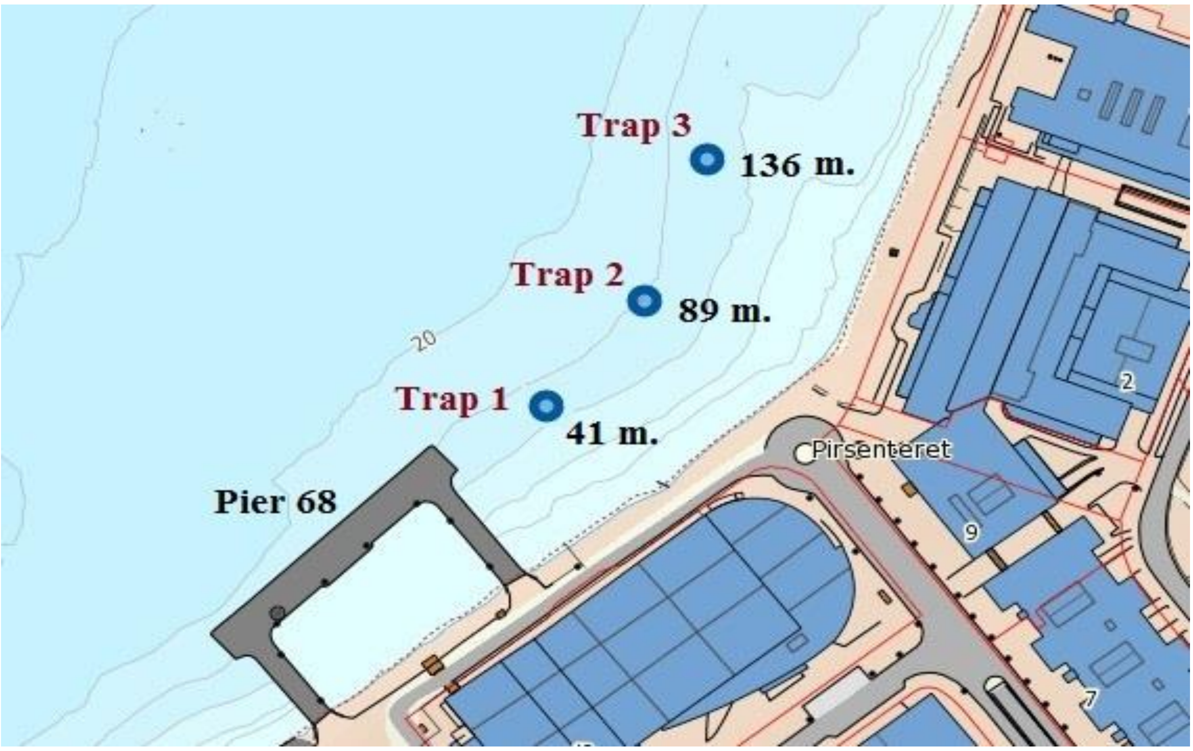
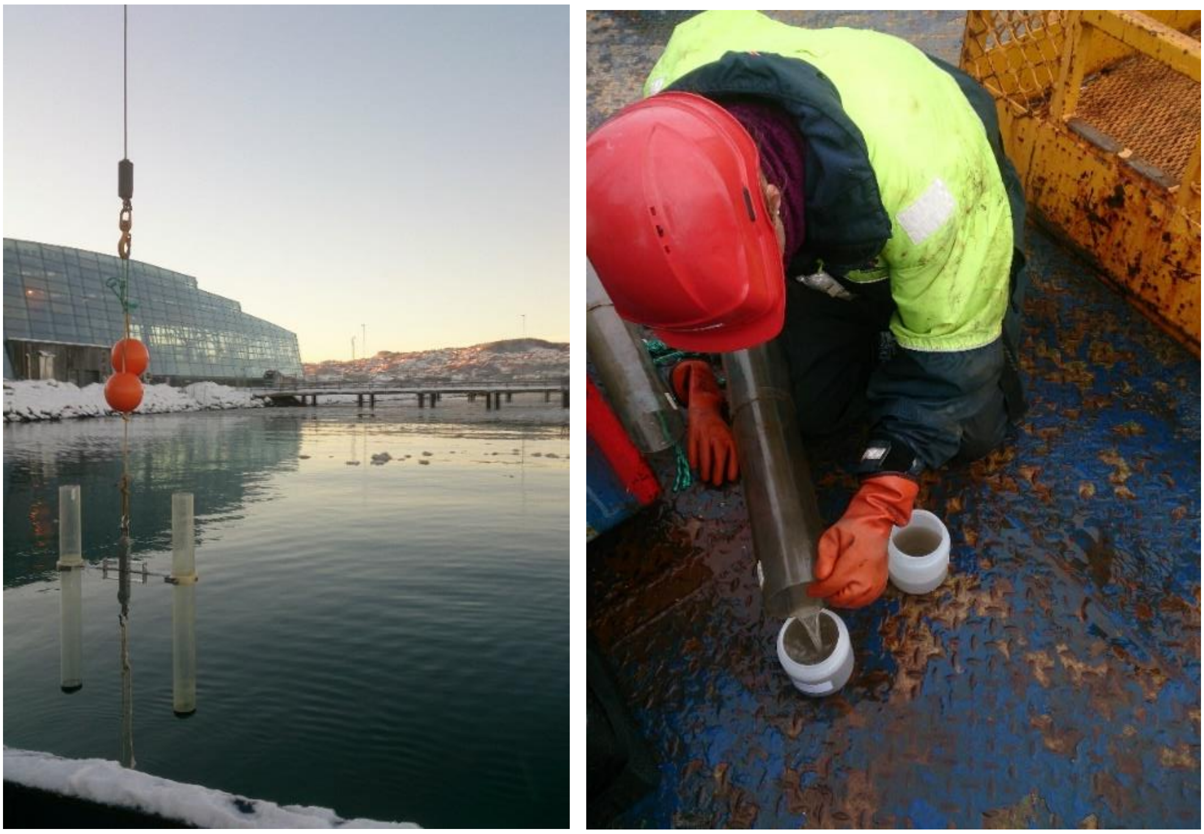


Figure 14. The location of the sediment traps that were outside pier 68 can be seen. *The traps were placed about 41 (trap 1), 89 (trap 2) and 136 (trap 3) meters North East of pier 68.*

When the sediment traps were taken up as much as possible of the water above the material in the tubes were removed, and the remaining water and the material were held over into sample boxes. Both the output and the uptake of the traps were done by using Trondheim Harbours boat *Munkholmen II* and performed by Anita Witlock Nybakk from NGI and with help from the staff onboard.



Picture 11. *To the left: out put of sediment trap. To the right: Sediment and the remaining water in the tubes poured over into the sampling boxes by Anita W. Nybakk. Photo by: Hilde Alida Hammer.*

6.2.4 Water column (DGT)

DGTs were out in the water from January 21 to February 21 2016 and from April 7 to April 19 2016. They were attached inside an equipment, seen in *picture 12*, which was standing at the bottom, approximately 1 m above the sediment. The sampling point was approximately 68.5 meters in line-of-sight from where the snow is dumped, see location in Figure *15*.

For the first sampling round (January – February 2016) three DGTs were out at the same time before they were replaced by three new DGTs. In total 15 DGTs were out. For the second sampling round (April 2016) only two DGTs were out at the same time, due to one of the DGT sampling holders got broken. In total six DGTs were out.

The time the DGTs were out variated from 2-10 days, and were noted down, see appendix E.

Picture 12. The equipment the DGTs were inside during sampling.

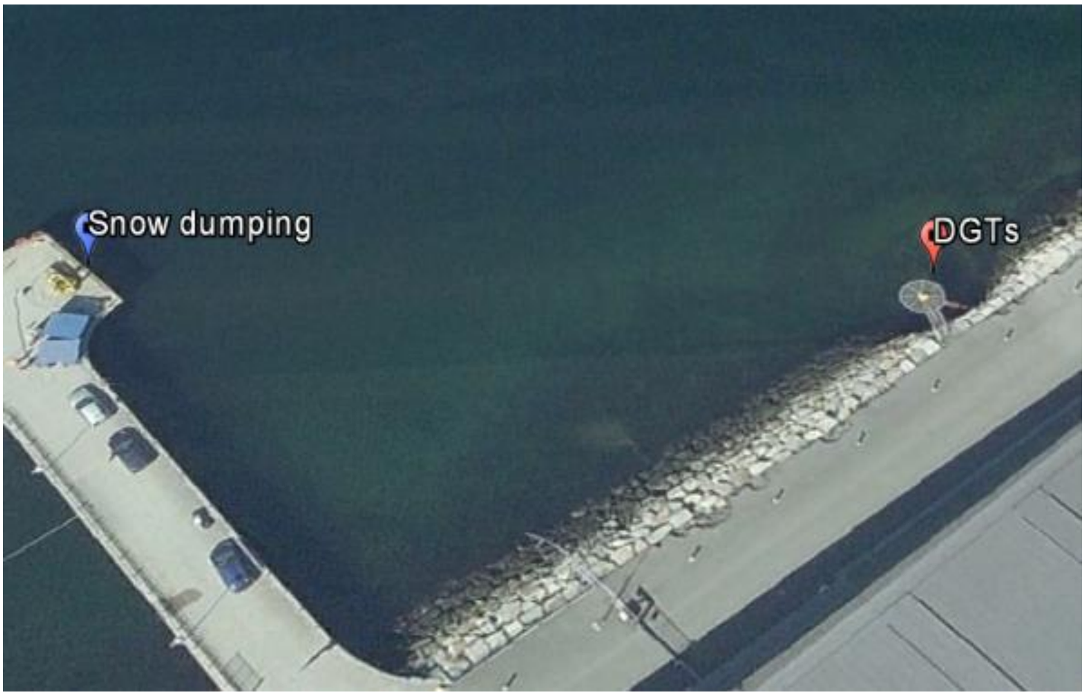


***Figure 15**. Location of the DGT sampling.*

When the DGTs were taken up, they were opened and the Chelex-gel was carefully transferred, by using a plastic tweezer, to a PP-vial containing acid (1 M HNO_3, about 1 mL).

6.2.5 Surface water

Surface water samples were taken at 4 different places, *Figure 16.* The samples were taken by using a plastic bottle tied to a rope. The bottle was thrown out on the surface water, left for some minutes for the water to flow into the bottle, and then taken up. An overview over number of samples can be seen in **Table *7.***

The sea water was filtrated through 0.45 µm filters into PP-vials (about 10 mL) to get the dissolved fraction, which is the most bioavailable fraction. After filtration, acid was added (3 drops of 65% HNO_3).

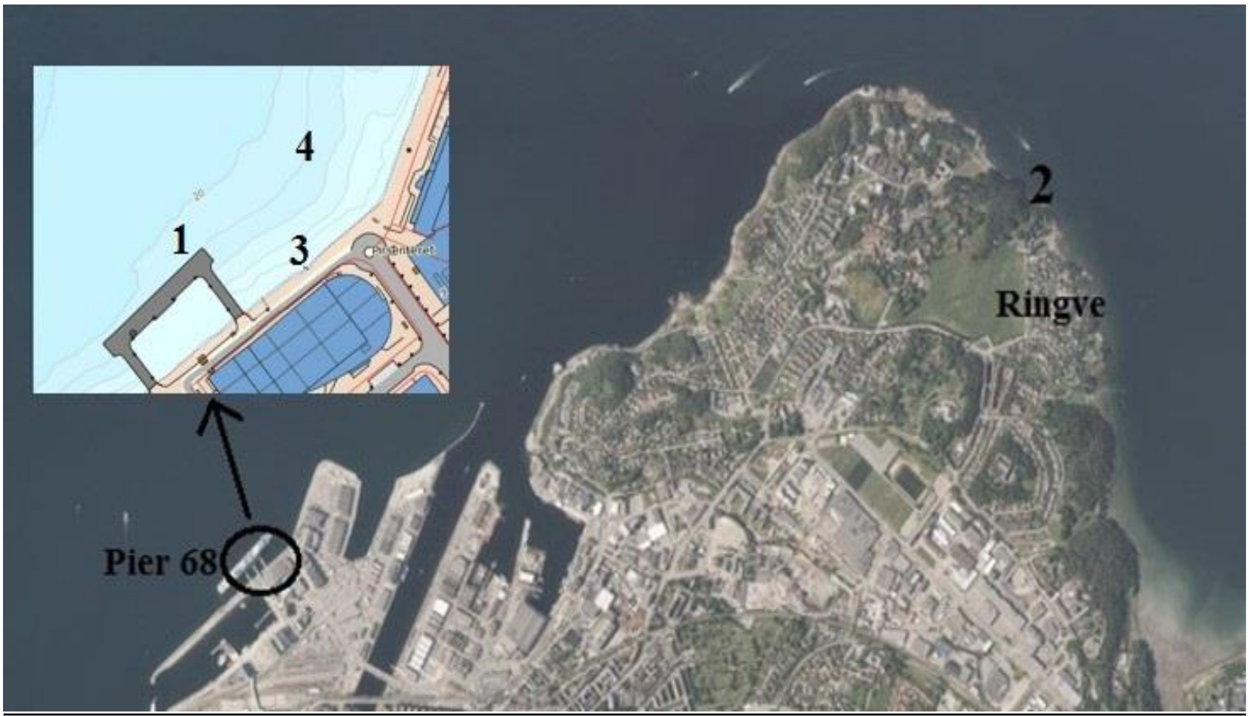


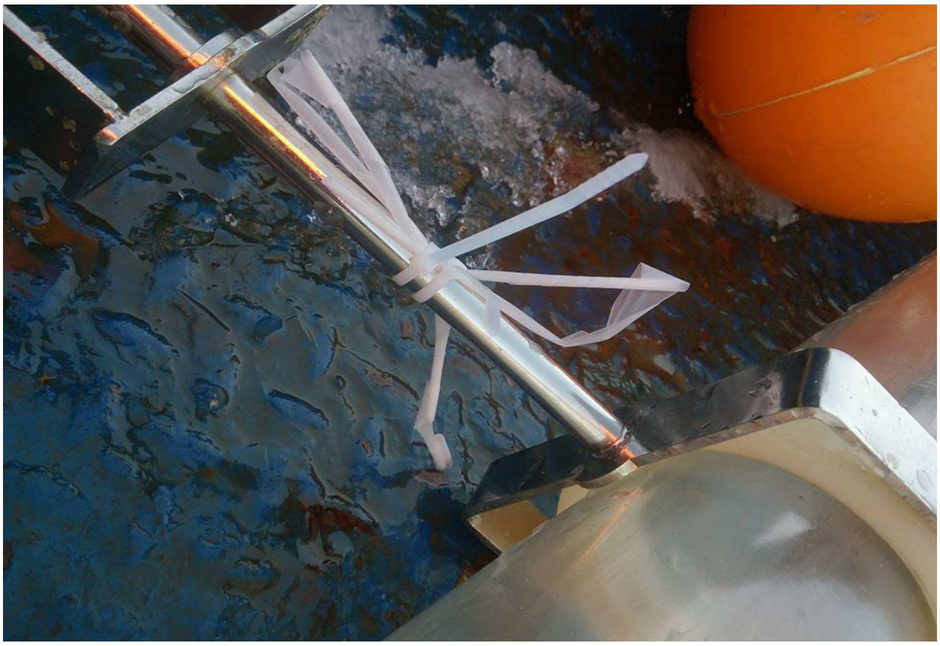
Figure 16. *The sampling sites where surface water samples have been taken.*

Table 7. *Overview over surface water samples taken. *Place 3 is the same location as the DGT sampling.*

Place	Period	No. of samples	Comments:
1	Jan-Mar. 2015	8	No snow dumping during time of sampling.
2	Jan-Mar. 2015	6	Background.
3*	Jan-Feb. 2016	6	During snow dumping / snow in surface water.
	April 2016	16	After snow dumping.
4	February 2016	3	During snow dumping, samples taken with increasing distance from the pier.

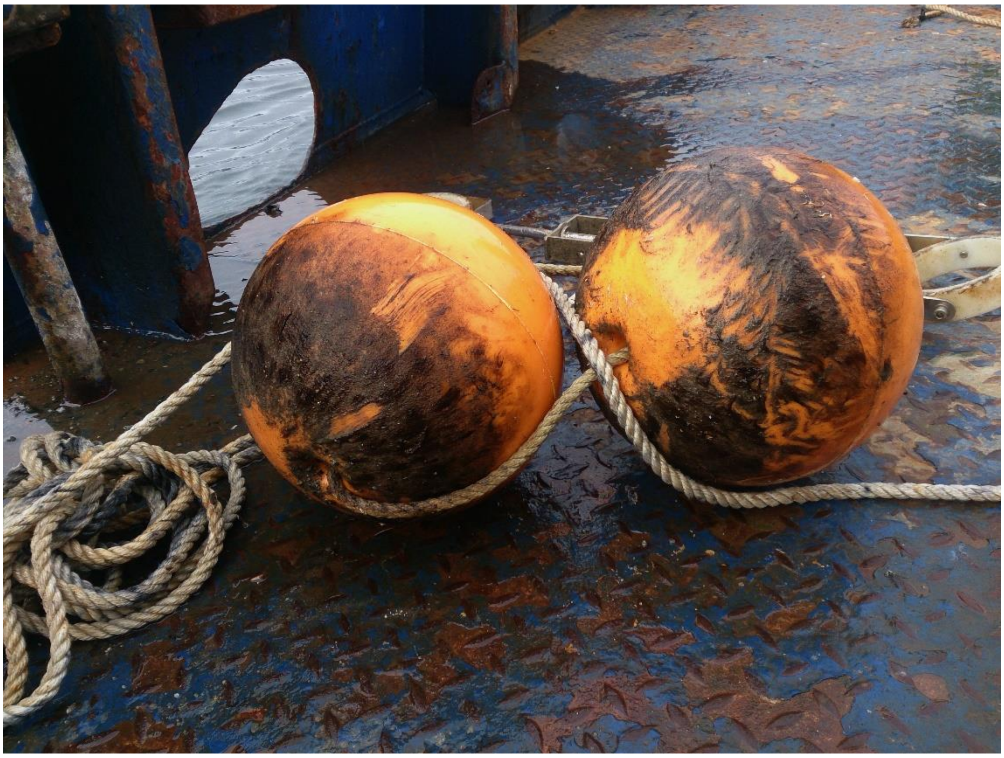
6.2.6 Water column (POM)

POM (55 µm) strips were attached on the sediment traps, see *picture 13* . They were out in the same period as the sediment traps, and at the same locations, see section 6.2.3 When taken up they were put inside aluminum foil and sent to NGI Environmental lab for analysis.



Picture 13. POM strip attached to the sediment trap. Photo: Hilde Alida Hammer.

Seen during sampling:



Picture 14. Buoyance buoys from the sediment traps covered with grease after uptake. Photo: Hilde A. Hammer.

Picture 15. Polluted snow seen on the water. Photo: Hilde A. Hammer.

6.3 Sample preparation before analysis

The surface water samples didn't have any further treatment after the sampling described in section *6.2.5.* For the sediment, snow and DGT samples the preparations were done at NTNU and are described in section **6.3.1** for the sediment samples, in section **6.3.2** for the snow samples and in section **6.3.3** for the DGT samples. The preparation of the material from the sediment traps and the POMs are described in section 6.4.2 and 6.4.3, respectively.

6.3.1 Sediment samples

Between 200-300 g. of the freeze dried sediment samples (see *picture 16*) was weighted into separate UltraClave tubes and nitric acid (HNO_3, 50%, 9 mL) was added. They were then run in UltraClave to be decomposed. The UltraClave were administered by Syverin Lierhagen, chief engineer at Institute of Chemistry at NTNU.

Picture 16. The freeze-dried sediment samples from February 2016 (direction North East). Photo: Hilde Alida Hammer.

After the decomposition in the UltraClave, the content in the UltraClave tubes were poured over into a Teflon bottle and diluted with Milli-Q (MQ)-water until the weight showed 109.8 ± 0.5 g. This was done for all the samples separately. If the weight went outside this interval, the weight was noted and corrected for in the calculation of the results. About 15 mL of each of the samples were held over into PP-vials and ready for analysis on ICP-MS.

The samples from the different sampling rounds were prepared at different days (and the samples from October 2014 were decomposed by master student Tony Helmersen Johansen).

6.3.2 Snow samples

Dissolved fraction

The snow samples from January 24 (batch 1) were left on the bench to melt in room temperature. After melting the sample had partitioned into a sedimented part and an aqueous part, see picture 15. A fraction of the aqueous part was filtrated through a 0.45 µm filter into a PP-vial. After filtrating, acid was added to the vials (3 drops of 65% HNO_3). This was done for all the 14 snow samples, and about 10 mL of melted snow was filtrated from each sample.

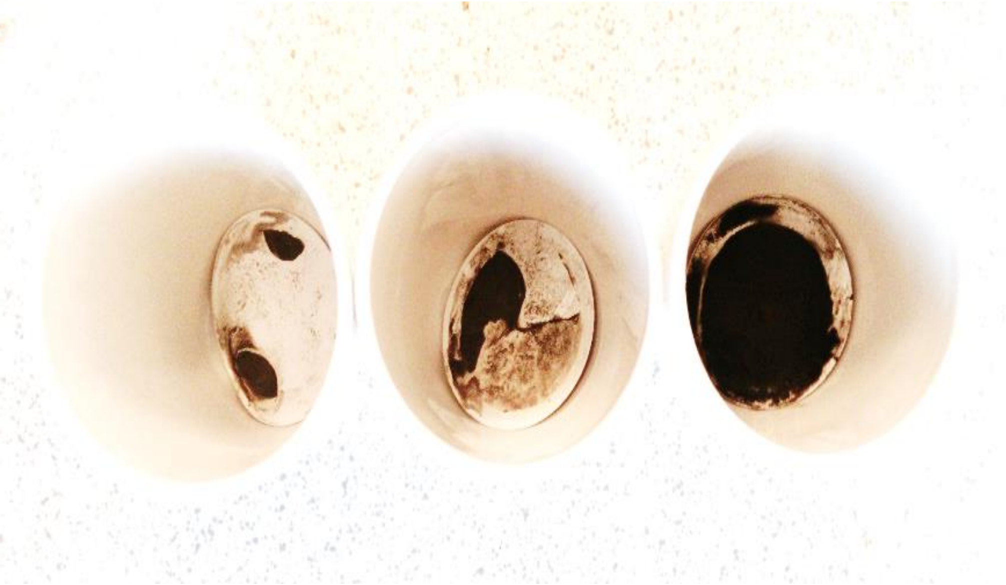
For the three other snow samples (samples from January 27, batch 2); they were melted in room temperature and shaken (to mix the particulate- and the dissolved phase). A fraction of the mixed phase was filtrated through a 0.45 µm filter and into a PP-vial. As much as possible of the melted snow was filtrated before the filter got clogged. The sample was then diluted with MQ-water to about 10 mL (weight noted down) and added acid (3 drops of 65% HNO_3).

Picture 17. One of the melted snow samples. The sedimented (particulate) material can clearly by seen in the bottom of the tube. Photo: Hilde A. Hammer.

Particulate fraction

The filters used for the three last snow samples were inside capsules that could be opened so that the filters could be taken out. The filters were weighted before the filtration. The filters with the particulate material were dried in an oven at x ºC overnight to evaporate the water from the sediment. The filters were again weighted after the drying, to find the dry weight of the particulate material. Then they were put into UC-tubes and added acid (HNO_3, 50%, 9 mL), before they were run in UltraClave. After the UltraClave the samples was treated the same way as after the UltraClave in section 6.3.1.

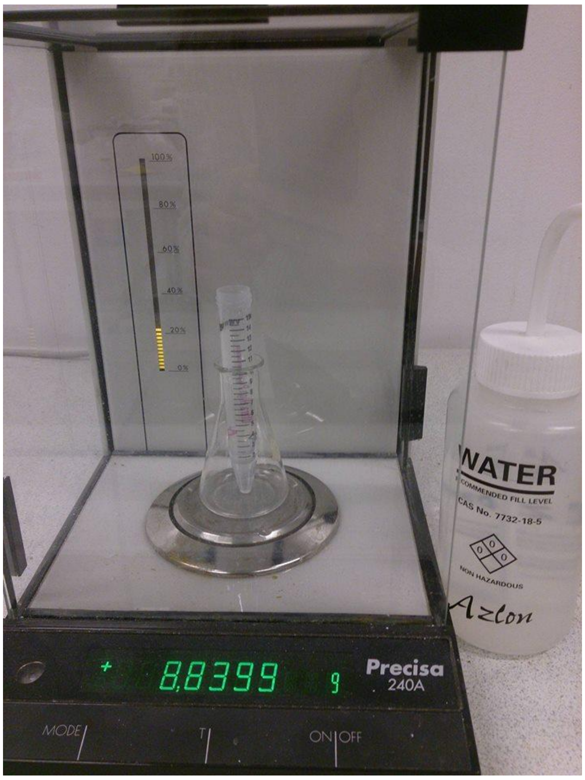
The amount of deposited particulate material varied between the three samples, see picture 18. The weight of the particulate material and the amount of filtrated snow can be seen in appendix F.



Picture 18. The particulate material deposited on the filters after filtrating melted snow samples from batch 2. From left to right: sample 1, 2 and 3.

6.3.3 DGTs

The Chelex-gel was laying in the acid for 12-24 hours so that protons from the acid had time to replace metal ions in the Chelex-gel (picture 19, to the right). The liquid, referred to as eluate, were then poured over into 15 mL PP-vials on a weight (see picture 19, to the left) and diluted about 10 times with MQ-water. As much as possible of the eluate was poured over. The weight of the eluate, and the weight after dilution, were noted, and can be seen in appendix G.



Picture 19 (to the left). Weighting of eluate during DGT preparation. Picture 20 (to the right) Chelex-gel laying in acid. Photos: Hilde Alida Hammer.

6.4. Analysis

The analysis of the snow, surface water, sediment and DGT samples are described in section **6.4.1**, the analysis of the material from the sediment traps are described in section **6.4.2** and the analysis of the POMs are described in section **6.4.3.**

6.4.1 Snow, surface water, sediment and DGT samples

The snow, sea water, sediment, and DGT samples were analysed for the selected heavy metal(loid)s on ICP-MS at NTNU, by Syverin Lierhagen. The sea water samples were diluted 10x and acidified to 0.1M with Scan Pure HNO_3 before analysis. The other samples did not have any further treatment after the sample preparations described in section 6.3.

The ICP-MS used was a ELEMENT 2 from Thermo Electronics, and is a High Resolution ICP-MS (HR-ICP-MS). The MS device is a magnetic sector systems technology which has a high resolving capability. The high resolving capability is efficient in removing interferences due to spectral overlap, but leads to a lower sensitivity (Thomas, 2004). The instrument can still also be run in low and medium resolution. All the samples were scanned 3 times, and both low, medium and high resolution were used depending on the metal.

6.4.2 Sediment traps

The material from the sediment traps was sent to Eurofins Environment Testing Norway AS. The material from each of the two tubes from the same sediment trap, were mixed together as one sample and analysed for the selected heavy metal(loid)s and PAHs. For the material from trap 1, particle fractionation was also performed (as there was enough material in this trap).

The material was first homogenised by mixing it well together. Then different parts of the sample were taken out for the different parameters (heavy metals, PAHs and particle fractionation). For the analysis of heavy metals, acid (7M, HNO_3) was added and the samples were heated before they were analysed on the instrument. Type of instrument used for the analysis of the different heavy metals and the ISO followed can be seen in **Table 8.** For the PAHs the sample was shaken together with a solvent (n-Hexane) for up to 2 hours to extract the PAHs from the particles and into the solvent. The extract was then analysed with GC-MS and ISO EN 12880 was followed.

Table 8. *The different analysis instruments used for the analyses of heavy metals in the material from the sediment traps, and the ISO standard used.*

Metal	Analytical instrument used	ISO standard followed
As	ICP-MS	NS EN ISO 17294-2
Pb	ICP-MS	NS EN ISO 17294-2
Cd	ICP-MS	NS EN ISO 17294-2
Cu	optical emission spectrometry (ICP)	NS EN ISO 11885
Cr	ICP-MS	NS EN ISO 11885
Hg	Atomic absorption spectrometry (AAS)	NS EN ISO 12846
Ni	ICP-MS	NS EN ISO 11885
Zn	ICP-MS	NS EN ISO 11885

6.4.3 POM

The POMs were sent to the NGI Environmental laboratory and analysed for PAHs and PCBs. The lab is accredited by Norwegian Accreditation in accordance with NS-EN ISO/IEC 17025.

At the lab POM got cleaned, added 15 mL heptane and 20 µL internal standard, and shaken for three days. Then the heptane was reduced to about 1 mL in a vacuum centrifuge and purified on a silica column. The sample was then reduced again to the desired volume and analysed for PAHs and PCBs on GC-MS. The experiment was performed at room temperature (20 ± 5 ° C). The method is not accredited.

6.5 Quality assurance

During sampling and sample preparation

As a quality assurance during sampling and sample preparation the same procedure was followed every time for each of the sampling types (except for the DGTs) and preparations of samples from each sampling round were done at the same day and place (except for the DGTs). Ultra-pure nitric acid (HNO_3) was used because it is a strong acid that dissolves most elements and gives little interferences in the ICP-MS. The sea water and DGT samples were kept in a refrigerator prior to analysis. The filters used when filtrating the sea water and the melted snow samples were filtrated through before collecting the sample. Certified PP-vials were used and acid was added to the filtrated sea water and snow samples to avoid metals being adsorbed on the inside of the tube. Gloves were used during sampling and sample preparation.

For the surface water and snow samples ISO 5667-3:2012 (water quality – sampling – part 3: Preservation and handling of water samples) was followed, and for the sediment samples ISO 5667-15:2009 (Water quality Sampling Part 15: Guidance on the preservation and handling of sludge and sediment samples) was followed.

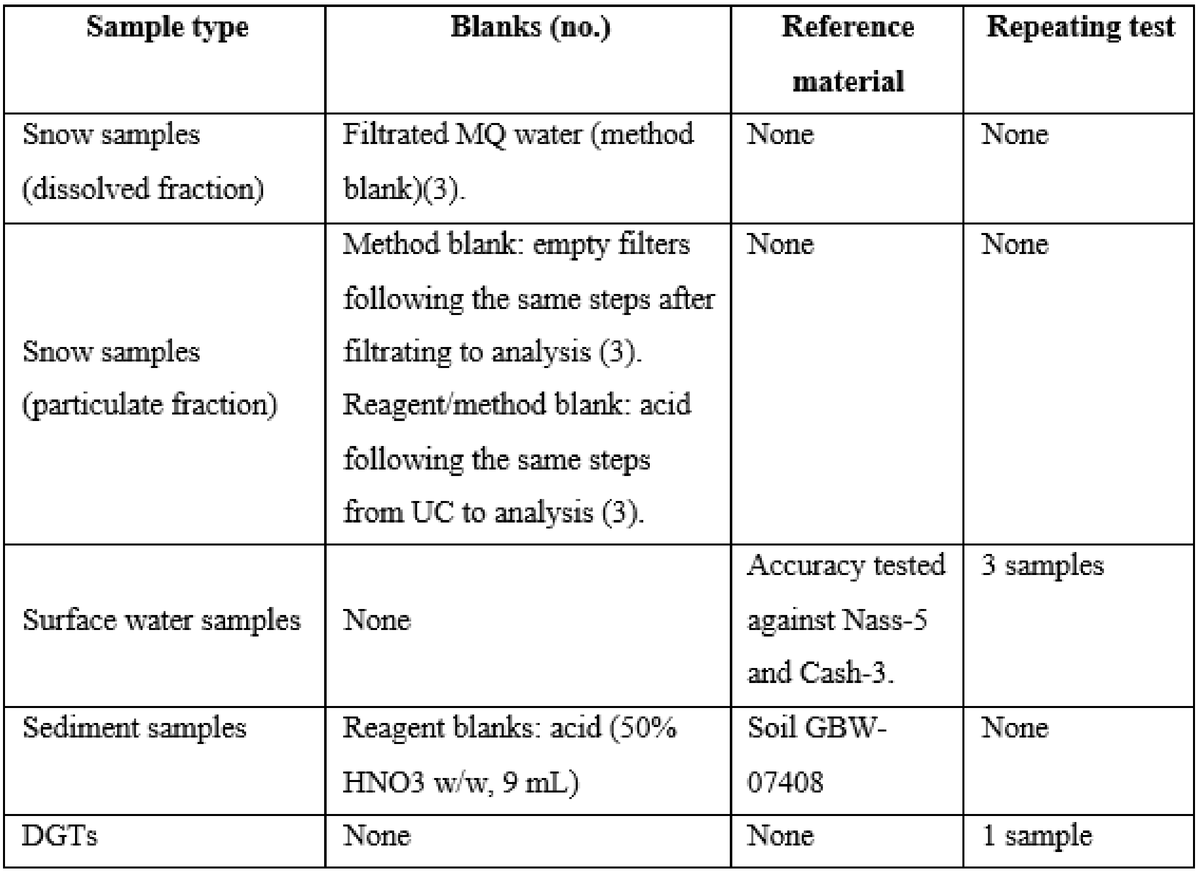
Method validation

At NTNU the accuracy of the ICP-MS is checked by using certified reference material, and the reproducibility is checked by repeated analyses of certified reference material. The machine is also involved in ring tests (and was best in a Nordic ring test where 15 laboratories was involved a few years ago (pers. Communication Syverin Lierhagen 29.04.16). In ring tests certified material is analysed by different labs to check which labs are within the accepTable values.

During analysis

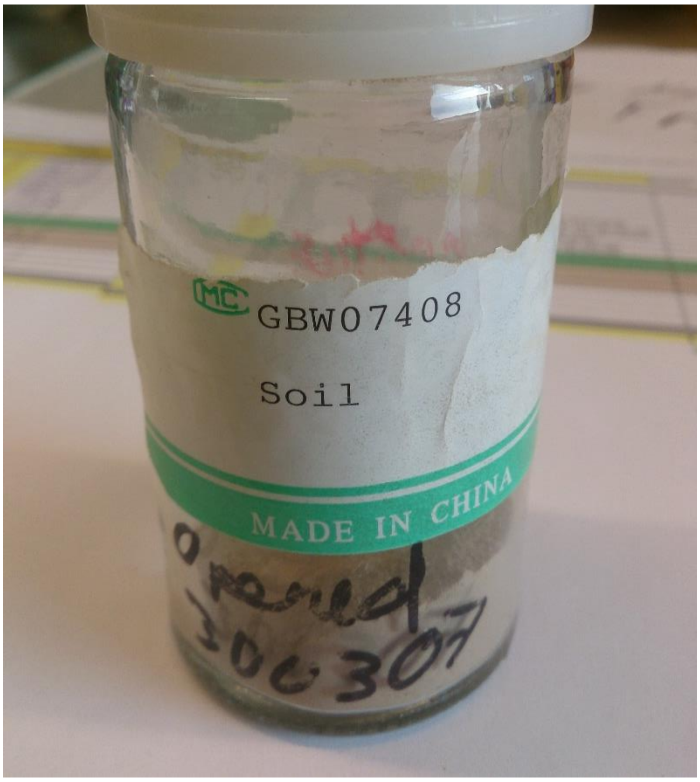
The samples analysed on the ICP-MS at NTNU were scanned 3 times, as mentioned in section 6.4. Some of the samples were scanned additionally 3 times (repeating test). In addition, blanks and reference material were used for some of the sample types, see ***Table 9.***

Table 9. Overview over blanks, reference material and repeating tests for the samples analysed at NTNU.



Sample type	Blanks (no.)	Reference material	Repeating test
Snow samples (dissolved fraction)	Filtrated MQ water (method blank)(3).	None	None
Snow samples (particulate fraction)	Method blank: empty filters following the same steps after filtrating to analysis (3). Reagent/method blank: acid following the same steps from UC to analysis (3).	None	None
Surface water samples	None	Accuracy tested against Nass-5 and Cash-3.	3 samples
Sediment samples	Reagent blanks: acid (50% HNO3 w/w, 9 mL)	Soil GBW-07408	None
DGTs	None	None	1 sample

The reference material Soil GBW-07408 (see picture 21) is soil with certified concentrations of a range of metals and have the similar matrix as the sediment samples. The material was prepared following the same procedure as the preparation of the sediment samples described in section 6.3.1.



Picture 21. Reference material Soil GBW-07408.

6.6 Data handling

Results from analysis

For the results from the ICP-MS analysis at NTNU the average value of the three scans were used directly in the results and calculations, as they are corrected for blanks and dilutions where applicable. For the repeating scans the average value of the two scans were used. The values from the analysis were given with more than 3 significant digits, but 3 significant digits were chosen to be given in the presentation of the results. The uncertainty will thus be in the last digit due to round-off. The spread in the three scans are given as a RSD-value. This is the instrument spread and represent 1 standard deviation (~67 % CI).

For the results from NGI (POMs) and Eurofins (sediment traps) the concentrations given in the analysis reports are used directly in the results and calculations. The results from NGI (POMs) were given with 3 significant digits so also here were 3 significant digits used in the presentation of the results, while the results from Eurofins (sediment traps) were given with 2 significant digits, and hence 2 significant digits are presented in the results.

NGI and Eurofins report measurement uncertainty (M.U.) which is given by:

M.U. = c*RSD*x,

where c = coverage factor, RSD = relative standard deviation and x is the measured value. Usually a coverage factor of 2 is used, which represent a 95 % CI (personal communication, Ada Kristoffersen, Eurofins, 16.04.29).

Results under detection limit (DL) and negative values are written as '< *DL value*'. In calculations; values equal to ½ DL was used for concentrations below DL.

Calculation of concentrations from the DGTs

The concentrations from the DGTs were found by inserting values for deployment time, temperature, concentration measured in ICP-MS, dilution factor and sample volume into pre-made excel files, see appendix H. The temperature was set to 4 degrees Celsius, as this temperature have been measured in the fjord during winter time earlier and is most likely representative as the temperature is quite stable. Gel volume, diffusion constant, diffusive gel thickness, filter thickness, membrane area and elution factor were already in the file, their values can be seen in appendix. The diffusion constant is the only factor varying for the selected metals. Since no good elution factors exist for Hg and As, they were not calculated from the DGTs. Concentrations were also calculated by hand for some of the concentrations to check if the results were the same. Example of calculation can be seen in appendix H.

Statistics

As a statistical handling p-values were calculated by using program in Excel. Two tailed t-test with different variances was chosen. And a CI 95 % was chosen, meaning that if the p-value is lower than 0.05 the two values are significant different with a 95 % certainty (confidence), and when the p-value were higher than 0.05 the two values are not significant different. When the p-values was below 0.05 the conclusion were drawn that the concentration that had the highest value were significant higher than the other (lower) value, even though it is strictly a two sided test.

7. Results

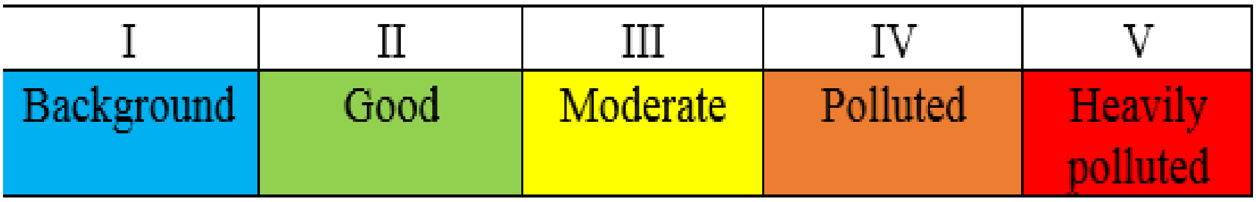
In this section the results from the sample analyses are presented. The results are presented in the following order: **7.1** snow samples, **7.2** sediment traps, **7.3** sediment samples, **7.4** surface water samples, **7.5** DGT samples **7.6** POM (PAHs) and **7.7** POM (PCBs).

RSD ranges for the metals are given for some of the results, and for the sediment traps and POM the measurement uncertainty (M.U.) are given.

All the results from the analyses can be seen in appendix I-K.

Overview over the detection limits in the ICP-MS can be seen in appendix L.

For the results compared with Klifs guideline the colours seen in *Figure 17* is used to mark the levels. The guideline used is guideline *TA-2229-2007* (Bakke et al., 2007). All the Tables in the guideline can be seen in appendix B.



I	II	III	IV	V
Background	Good	Moderate	Polluted	Heavily polluted

Figure 17. *Levels (I-V) and corresponding colours used when comparing concentrations with Klifs guideline.*

The guideline for sea water is meant for non-filtrated samples (see section 2.11). As the sea water samples are filtrated and the DGTs measure the labile fraction these samples will show lower concentrations than if the total concentrations of the metals were measured, and hence can fall into a lower level in the guideline. The dissolved fraction is besides this the most bioavailable fraction.

Both level I and II are considered as clean levels. Level III is also considered relatively good. It is when the concentrations are up in level IV and V they are considered as polluted. Trondheim Municipality have set level III as their goal when cleaning up in the sediments.

7.1 Snow samples

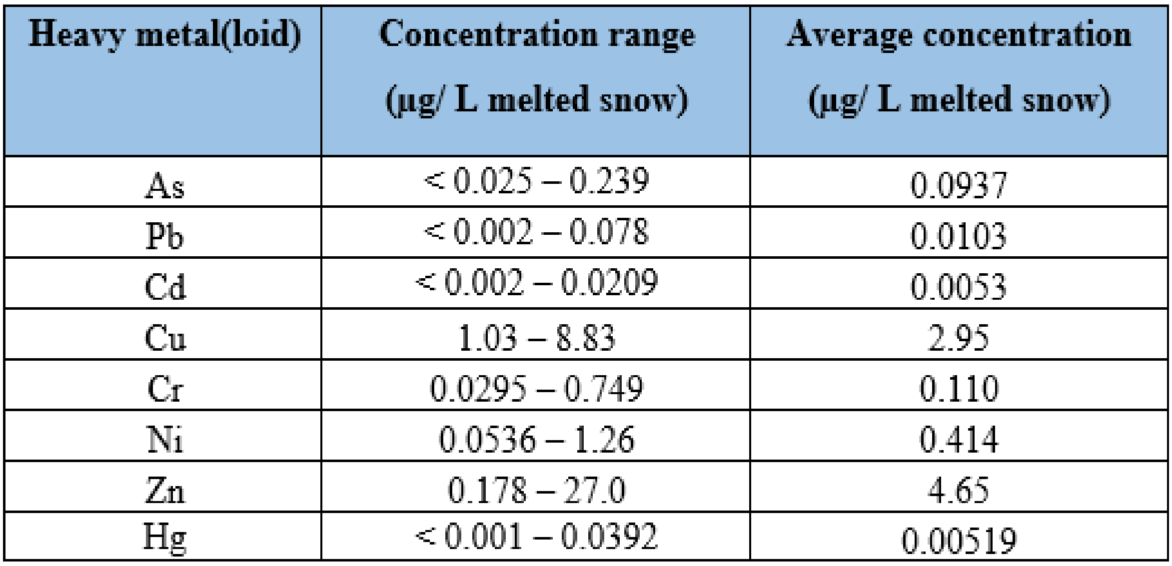
The results for the dissolved phase from the snow samples are presented in **section 7.1.1,** and the results for the particulate material are presented in **section 7.1.2.**

7.1.1 Dissolved phase

Batch 1

The concentration ranges and the average concentrations found for the heavy metal(loid)s in the dissolved phase in the melted snow samples from batch 1 can be seen in **Table 10**. The result shows highest average concentration of Zn, then follows (in decreasing order): Cu, Ni, Cr, As, Pb, Cd and Hg.

Table 10. Concentration ranges and average concentrations heavy metal(loid)s in the dissolved phase snow samples, batch 1. *(n = 14). RSD-values: Cu and Zn: 0.6 – 8 %, As, Pb, Cr, Ni, and Hg:0.6 – 22.6 %, Cd: 5.8 – 29.9 %.*



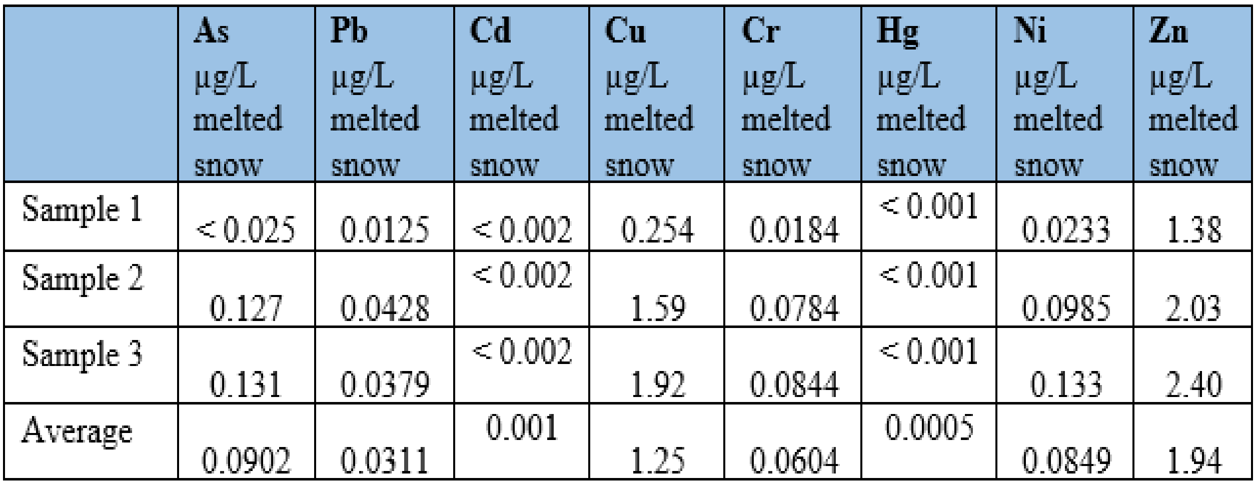
Heavy metal(loid)	Concentration range (µg/ L melted snow)	Average concentration (µg/ L melted snow)
As	< 0.025 – 0.239	0.0937
Pb	< 0.002 – 0.078	0.0103
Cd	< 0.002 – 0.0209	0.0053
Cu	1.03 – 8.83	2.95
Cr	0.0295 – 0.749	0.110
Ni	0.0536 – 1.26	0.414
Zn	0.178 – 27.0	4.65
Hg	< 0.001 – 0.0392	0.00519

Batch 2

The concentrations found for the heavy metal(loid)s in the dissolved phase in the melted snow samples from batch 2 can be seen in **Table 11.**

The result shows highest average concentration of Zn, then follows (in decreasing order): Cu, As, Ni, Cr, Pb, Cd and Hg.

Table 11. Concentrations of heavy metal(loid)s in the dissolved phase snow samples, batch 2.



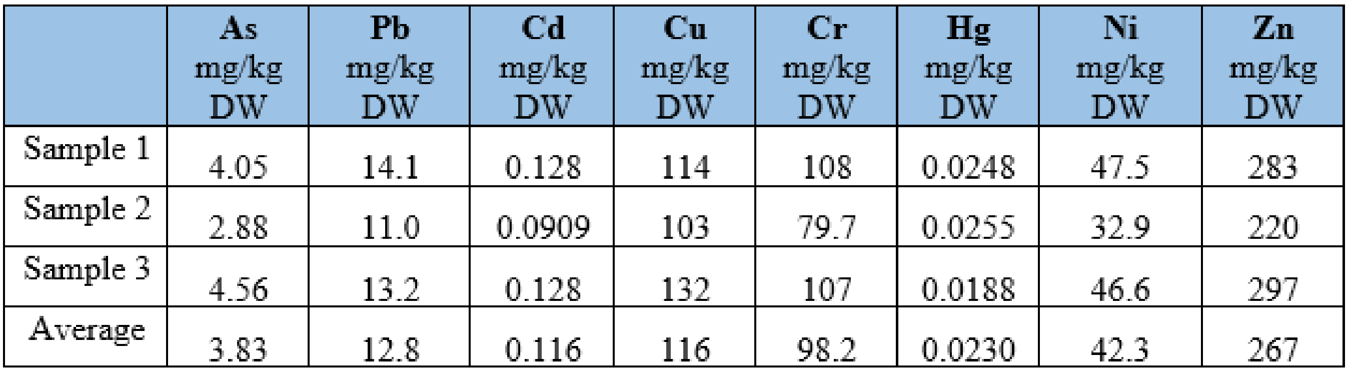
	As µg/L melted snow	**Pb** µg/L melted snow	**Cd** µg/L melted snow	**Cu** µg/L melted snow	**Cr** µg/L melted snow	**Hg** µg/L melted snow	**Ni** µg/L melted snow	**Zn** µg/L melted snow
Sample 1	< 0.025	0.0125	< 0.002	0.254	0.0184	< 0.001	0.0233	1.38
Sample 2	0.127	0.0428	< 0.002	1.59	0.0784	< 0.001	0.0985	2.03
Sample 3	0.131	0.0379	< 0.002	1.92	0.0844	< 0.001	0.133	2.40
Average	0.0902	0.0311	0.001	1.25	0.0604	0.0005	0.0849	1.94

7.1.2 Particulate material

The concentrations found for the heavy metal(loid)s in the particular material in the melted snow samples from batch 2 can be seen in **Table 12.**

The result shows highest average concentration of Zn, then follows (in decreasing order): Cu, Cr, Ni, Pb, As, Cd and Hg.

Table 12. Concentrations of heavy metal(loid)s in the particulate material snow samples, batch 2. (DW = dry weight). RSD-values: Pb, Cr, Ni, Cu and Zn: 0.2 – 3.4 %, As: 1.7 – 8.1 %, Cd: 4.9 – 9.10 % and Hg: 2.5 – 10.3 %.



	As mg/kg DW	**Pb** mg/kg DW	**Cd** mg/kg DW	**Cu** mg/kg DW	**Cr** mg/kg DW	**Hg** mg/kg DW	**Ni** mg/kg DW	**Zn** mg/kg DW
Sample 1	4.05	14.1	0.128	114	108	0.0248	47.5	283
Sample 2	2.88	11.0	0.0909	103	79.7	0.0255	32.9	220
Sample 3	4.56	13.2	0.128	132	107	0.0188	46.6	297
Average	3.83	12.8	0.116	116	98.2	0.0230	42.3	267

7.2 Sediment traps

The results for analysis of the sedimenting material from the sediment traps are presented in **section 7.2.1** for the heavy metal(loid)s and in **section 7.2.2** for PAHs.

7.2.1 Heavy metal(loid)s

The concentrations found for the heavy metal(loid)s in the sediment traps can be seen in **Table 13.** The concentrations are compared with Klifs guideline for marine sediments, as no guideline exists for sedimenting material. The average value for each metal and the measurement uncertainty (M.U.) can also be seen in the Table.

The result shows that all the heavy metal(loid)s were found in concentrations in level I in all the traps. The traps don't show much differences in concentrations for each metal, except for Pb (which is around twice as high in trap 2 compared to trap 1 and 3). Zn, Cu and Cr have the highest average concentrations and Cd and Hg have the lowest average concentrations.

Table 13. Concentrations of heavy metal(loid)s in the sediment traps. *(DW = dry weight)*

Heavy metal(loid)s (mg/kg DW)	**Sediment trap no.**				
	1	2	3	Average	MU. (%)
As	2.7	4.2	3.6	3.5	30
Pb	7.0	14	7.9	9.6	40
Cd	0.032	0.039	0.027	0.033	40
Cu	26	27	24	26	30
Cr	23	20	23	22	30
Hg	0.004	< 0.001	0.007	0.004	20
Ni	15	12	15	14	30
Zn	33	34	33	33	25

7.2.2 PAHs

The concentrations found for PAHs in the sediment traps can be seen in **Table 14**. The concentrations are compared with Klifs guideline for organic pollutants in marine sediment, as no guideline exists for sedimenting material.

Table 14. Concentrations of PAHs in the sediment traps. *(DW = dry weight). All PAHs under the detection limit are set to level I.*

	Sediment trap no.:		
PAHs (mg/kg DW)	1	2	3
Naphthalene	<0.010	<0.010	<0.010
Acenaphthylene	<0.010	<0.010	<0.010
Acenaphthene	<0.010	<0.010	<0.010
Fluorene	<0.010	<0.010	<0.010
Phenanthrene	0.042	0.017	0.021
Anthracene	< 0.010	<0.010	<0.010
Fluoranthene	0.061	0.033	0.052
Pyrene	0.060	0.037	0.058
Benz(a)anthracene	0.016	<0.010	0.016
Chrysene	0.052	0.030	0.050
Benzo(b)fluoranthene	0.022	0.014	0.026
Benzo(k)fluoranthene	<0.010	<0.010	<0.010
Benzo(a)pyrene	0.022	0.013	0.024
Indeno(1,2,3-cd)pyrene	<0.010	<0.010	0.013
Dibenzo(a,h)anthracene	<0.010	<0.010	<0.010
Benzo(ghi)perylene	0.015	0.011	0.020

The result shows that all the concentrations were in level I and II. The low molecular weight PAHs (naphthalene to anthracene) were below detection limit (0.010 mg/kg dry weight), except for phenanthrene which was found in level II in all the traps. Among the high molecular weight PAHs, fluoranthene, pyrene, benz(a)anthracene, chrysene and benzo(a)pyrene were found in level II in all the traps, and benzo(b)fluoranthene was found in level I in all the traps. For the rest of the high molecular weight PAHs they were both below and above the detection limit, and in level I and II, depending on which sediment trap. Benzo(k)fluoranthene and dibenzo(a,h)anthracene were below the detection limit in all the traps.

The concentrations are generally a bit lower in trap 2.

7.2.3 Amount

Trap 1 had most material within the tubes, see picture 22. The amount in trap 2 were a little lower, and trap 3 had lowest amount of material.

The average height of the material in trap 1 were about 2 cm (on average), in trap 2 about 1.5 cm and in trap 3 only a few mm The material in trap 1 was skewed and were lower on the other side (not shown in the picture).

Picture 22. *From left to right: the material in sediment trap 1, 2 and 3, respectively, can be seen. Substantially less amount was seen in trap 3, and most in trap 1. Photos: Hilde A. Hammer*

The exact weight of the material is not known, but out from the amount needed for the analysis of the different parameters (metals, PAHs and particle fractionation) the amount in trap 1 were at least 410 g. dry weight and the amount in trap 2 and 3 were at least 160 g. dry weight, see **Table 15.**

Table 15. Estimated amount of material in the sediment traps.

Sediment trap no.:	Estimated weight of material
1	> 410 g. dry weight
2	> 160 g. dry weight
3	> 160 g. dry weight

7.2.4 Particle fractionation

The results from the particle fractionation from the material from trap 1 can be seen in **Table 16.**

Table 16. Particle fractionation in trap 1.

Particle size	(w/w)
< 2 µm	3.1 %
< 63 µm	4.2 %

7.3 Sediment samples

The results from the top layer 0-2 cm in the sediment are presented in section 7.3.1. The results from the deeper layers (0~16 cm) taken in North West direction are presented in **section 7.3.2** and the results from the core sample from Østmarka are presented in **section 7.3.3.** All the concentrations are compared with Klifs guideline for marine sediments. The RSD-ranges are shown in the Table texts.

7.3.1 Top layer 0-2 cm

The concentrations found for the metals in the samples from the top layer (0-2 cm) for the directions North West, North and North East can be seen in **Tables 17, 18 and 19**, respectively. The concentrations were mostly found in level I, but also some concentrations in level II, especially for Cr.

Table 17. Concentrations of the heavy metal(loid)s in the sediment samples from direction North West (box-corer, top layer 0-2 cm). *DW = dry weight. RSD-values: Hg, Cr, Cu, Zn, Pb: 0.7 – 4.9 %, As: 10.2 – 13.5 %, Cd:3.9 – 34.6 %.*

Distance from pier:		100 m			150 m		
		Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
As	mg/kg DW	3.1	3.29	2.71	3.88	3.47	7.61
Pb	mg/kg DW	13	13.6	18.2	25.4	38.2	27.4
Cd	mg/kg DW	0.073	0.0653	0.0827	0.0804	0.305	0.191
Cu	mg/kg DW	18	15.9	20.1	28.6	27.2	28.1
Cr	mg/kg DW	69.5	63.3	78.2	92.0	94.6	87.5
Hg	mg/kg DW	0.0593	0.0529	0.0672	0.120	0.128	0.197
Ni	mg/kg DW	25.6	23.7	25.6	30.5	29.7	29.7
Zn	mg/kg DW	47.6	43.0	69.7	78.7	200	82.5

Table 18. Concentrations of the heavy metal(loid)s in the sediment samples from direction North (box-corer, top layer 0-2 cm). *DW = dry weight. RSD-values: Hg, Cr, Ni, Cu, Zn, Pb: 0.2 – 3.5 %, As: 3.5 – 8.9 %, Cd: 3.3 – 37.7 %.*

		Distance from pier			
		25 m	100 m	200 m	500 m
As	mg/kg DW	3.84	6.76	6.74	6.14
Pb	mg/kg DW	17.3	18.8	22.8	28.6
Cd	mg/kg DW	0.0514	0.135	0.0503	0.0406
Cu	mg/kg DW	26.5	21.7	25.9	18.9
Cr	mg/kg DW	64.1	81.7	91.1	60.3
Hg	mg/kg DW	0.0417	0.101	0.172	0.222
Ni	mg/kg DW	25.1	28.0	32.9	23.9
Zn	mg/kg DW	55.3	69.5	78.4	65.9

Table 19. Concentrations of the heavy metal(loid)s in the sediment samples from direction North East (box-corer, top layer 0-2 cm). *DW = dry weight. RSD-values: Cr, Cu, Zn, Pb: 0.6 – 3.5 %, Hg, Ni, As: 2.2 - 9.6 %, Cd:16.2 – 34.3 %.*

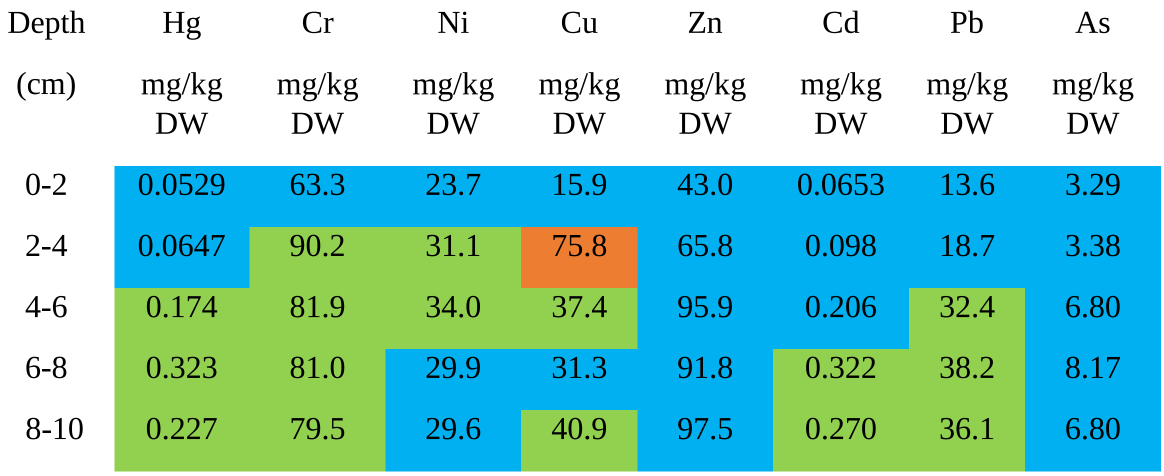
		Distance from pier.					
		50 m	100 m	150 m	200 m	250 m	500 m
As	mg/kg DW	9.52	4.78	7.26	4.52	3.27	5.77
Pb	mg/kg DW	23.3	14.8	26.4	24.1	19.2	18.3
Cd	mg/kg DW	0.0959	0.0477	0.0507	0.0720	0.0565	0.0470
Cu	mg/kg DW	48.9	17.3	34.1	27.5	21.3	20.6
Cr	mg/kg DW	120	70.1	97.9	82.8	79.8	78.5
Hg	mg/kg DW	0.107	0.0405	0.0991	0.0913	0.0798	0.116
Ni	mg/kg DW	37.2	24.8	32.1	28.4	24.8	29.8
Zn	mg/kg DW	93.5	53.5	80.4	74.6	59.5	59.3

7.3.2 Deeper layers direction North West

The concentrations of heavy metal(loid)s found in the deeper layers in sampling point 2, 4 and 5 in direction North West can be seen in **Tables 20, 21 and 22**, respectively. The results from the other sampling points can be seen in appendix O The concentrations in each layer are compared with Klifs guideline for marine sediments. The top layer 0-2 cm is also included.

The results show that the concentrations were mostly found in level I and II, but Cu had some concentrations in level III and IV, and Hg in level III – V. The concentrations in the other points (seen in appendix O) were all in level I and II.

Table 20. Concentrations of heavy metal(loid)s in the layers 0-10 cm in the sediment in the direction North West, sampling point 2. *DW = dry weight.*



Depth (cm)	Hg mg/kg DW	Cr mg/kg DW	Ni mg/kg DW	Cu mg/kg DW	Zn mg/kg DW	Cd mg/kg DW	Pb mg/kg DW	As mg/kg DW
0-2	0.0529	63.3	23.7	15.9	43.0	0.0653	13.6	3.29
2-4	0.0647	90.2	31.1	75.8	65.8	0.098	18.7	3.38
4-6	0.174	81.9	34.0	37.4	95.9	0.206	32.4	6.80
6-8	0.323	81.0	29.9	31.3	91.8	0.322	38.2	8.17
8-10	0.227	79.5	29.6	40.9	97.5	0.270	36.1	6.80

Table 21. Concentrations of heavy metal(loid)s in the layers 0-12 cm in the sediment in the direction North West, sampling point 4. *DW = dry weight.*

	Hg	Cr	Ni	Cu	Zn	Cd	Pb	As
	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW
0-2	0.120	92.0	30.5	28.6	28.6	0.0804	25.4	3.88
2-4	0.157	91.0	34.1	37.9	37.9	0.156	34.4	4.76
4-6	0.300	100	38.9	60.5	60.5	0.217	54.9	9.23
6-8	0.712	93.9	38.8	52.3	52.3	0.295	54.6	10.0
8-10	0.320	105	41.0	47.0	47.0	0.328	74.5	8.65
10-12	1.67	82.9	31.3	39.6	39.6	0.421	81.6	10.5

Table 22. Concentrations of heavy metal(loid)s in the layers 0-16 cm in the sediment in the direction North West, sampling point 5. *DW = dry weight.*

Depth	Hg	Cr	Ni	Cu	Zn	Cd	Pb	As
(cm)	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW
0-2	0.128	94.6	29.7	27.2	201	0.305	38.2	3.47
2-4	0.206	175	38.6	50.8	199	0.278	45.4	13.3
4-6	0.735	96.7	37.8	42.8	114	0.170	40.1	5.31
6-8	0.224	90.2	34.7	40.2	97.9	0.222	33.8	5.45
8-10	0.205	94.3	35.2	42.8	114	0.135	36.7	5.56
10-12	0.257	88.7	33.3	44.4	104	0.197	33.9	6.96
12-14	0.953	86.7	30.7	36.5	115	0.420	36.9	13.2
14-16	0.299	81.1	44.4	50.2	87.6	0.306	42.9	5.53

7.3.3 Østmarka

The concentrations of heavy metal(loid)s found in the core sample from Østmarka can be seen in **Table 23.**

The result shows that As, Pb, Cd, Cu, Hg and Zn had concentrations in level I, Cu in level II and Ni in level III.

Table 23. Concentrations of heavy metal(loid)s in the core sample from Østmarka. *DW = dry weight.*

Depth (cm)	As mg/kg DW	Pb mg/kg DW	Cd mg/kg DW	Cu mg/kg DW	Cr mg/kg DW	Hg mg/kg DW	Ni mg/kg DW	Zn mg/kg DW
195	3.51	11.0	0.0820	21.0	132	0.0223	55.6	75.4

7.4 Surface water

The results from the surface water samples from Ringve can be seen in **section 7.4.1** and for pier 68 in **section 7.4.2.** All the concentrations are compared with Klifs guideline for marine water. The RSD-ranges are shown in the Table texts. The surface sampling can be seen in section 6.2.5.

7.4.1 Ringve

The concentrations found in the surface water samples taken at Ringve in 2015 are seen in **Table 24**. The result shows that As, Cr and Ni had concentrations in level I, Pb and Zn in level I and II, and Cu in level II. Cd and Hg had concentrations below the detection limit in all the samples. Pb were found above the detection limit in only one sample.

Table 24. Concentrations of heavy metal(loid)s in the surface water samples from Ringve, 2015. *The numbers in the first row are the sampling dates.*

		22.01	17.02	28.02	06.03	14.03	21.03	Average
As	µg/L	1.27	1.28	1.17	1.16	1.30	1.13	1.22
Pb	µg/L	< 0.02	0.0754	< 0.02	< 0.02	< 0.02	< 0.02	0.0209
Cd	µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Cu	µg/L	0.552	0.543	0.425	0.483	0.399	0.496	0.483
Cr	µg/L	0.0938	0.114	0.138	0.133	0.106	0.137	0.12
Hg	µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ni	µg/L	0.335	0.241	0.289	0.290	0.381	0.376	0.319
Zn	µg/L	1.10	1.22	1.25	1.58	0.695	1.22	1.18

7.4.2 Pier 68

2015

The concentrations found of the heavy metal(loid)s in the surface water samples taken at pier 68 in 2015 are seen in Table **25.**

The result shows that most metals had concentrations in level I. Cu and Zn had concentrations in level I and II, and Pb, Cd and Hg had concentrations below the detection limit in all the samples.

2016

January and February

The concentrations found of the heavy metal(loid)s in the surface water samples taken at pier 68 in January and February 2016 are seen in ***Table 26.***

The result shows that As and Cd had concentrations in level I. Ni had concentrations in level I and II, Zn in level I-III and Cu in level II-IV. Pb and Cr had all their concentrations in level II. Hg had concentrations below the detection limit in all the samples.

Table 25. ***Concentrations of heavy metal(loid)s in the surface water samples from*** **pier 68, January - March 2015.** *The numbers in the first row are the sampling dates.*

Metals (µg/L)	**22.01**	**05.02**	**13.02**	**17.02**	**28.02**	**06.03**	**14.03**	**21.03**	**Average**
As	1.26	1.39	1.18	1.19	1.13	1.22	1.10	1.30	1.22
Pb	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Cd	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Cu	0.440	0.381	0.631	0.400	0.454	0.495	0.372	0.437	0.451
Cr	0.123	0.0986	0.0940	0.0919	0.131	0.131	0.129	0.0825	0.11
Hg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ni	0.327	0.311	0.334	0.248	0.288	0.378	0.291	0.347	0.316
Zn	1.36	0.79	1.50	1.94	2.62	1.45	1.27	1.37	1.54

Table 26. Concentrations of heavy metal(loid)s in the surface water samples from pier 68, January-February 2016. *The numbers in the first row are the sampling dates.*

		21.01	26.01	02.02	08.02	18.02	21.02	Average
As	µg/L	1.28	0.924	0.846	0.974	0.617	0.847	0.915
Pb	µg/L	0.189	0.187	0.148	0.0793	0.187	0.221	0.169
Cd	µg/L	0.0585	0.0222	0.0372	0.0284	< 0.02	0.0552	0.0353
Cu	µg/L	5.17	0.882	0.766	0.505	0.910	0.665	1.48
Cr	µg/L	2.09	1.69	2.21	1.51	1.57	2.29	1.89
Hg	µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ni	µg/L	0.833	0.38	0.289	0.342	0.266	0.342	0.409
Zn	µg/L	2.67	1.16	2.93	0.456	< 0.25	< 0.25	1.25

Out on the fjord

The concentrations found of heavy metal(loid)s in the surface water samples taken out on the fjord outside pier 68 in February 2016 can be seen in **Table 27.** The concentrations were found in level I – IV. As had concentrations in level I, Pb and Cr in level II, and Cu in level IV in all the samples. Cd and Ni had concentrations in level I and II and Zn had concentrations in level I – III.

Hg was below the detection limit in all the samples and are hence set to level I.

Table 27. Concentrations of heavy metal(loid)s in the surface water samples out on the fjord, 2016.

Metals	Unit	Point 1	Point 2	Point 3	Average
As	µg/L	1.23	0.848	1.05	1.04
Pb	µg/L	0.174	0.286	0.135	0.198
Cd	µg/L	0.0693	0.0265	0.0525	0.0494
Cu	µg/L	2.53	1.74	1.54	1.94
Cr	µg/L	2.52	2.24	2.78	2.51
Hg	µg/L	< 0.01	< 0.01	< 0.01	< 0.01
Ni	µg/L	0.417	0.417	0.683	0.506
Zn	µg/L	10.3	1.78	0.0149	4.03

April

The concentrations found of the heavy metal(loid)s in the surface water samples taken at pier 68 in April 2016 can be seen in **Table 28.** The result shows that the concentrations were mostly found in level I. As, Cd, and Cr had concentrations in level I in all the samples. Ni and Zn in level I and II, and Cu had concentrations in level II and III.

Hg and Pb had concentrations below the detection limit in all the samples and are hence set to level I.

Table 28. Concentrations of heavy metal(loid)s in the surface water samples from pier 68, April 2016. *The numbers in the first row are the sampling dates.*

Metals	Unit	12.04	15.04	17.04	19.04	Average
As	µg/L	1.39	0.796	1.14	1.01	1.084
Pb	µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Cd	µg/L	0.0237	< 0.02	0.0273	0.0265	0.0219
Cu	µg/L	0.625	0.645	0.769	0.611	0.663
Cr	µg/L	0.0663	0.122	0.123	0.0427	0.0885
Hg	µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ni	µg/L	0.399	0.602	0.487	0.373	0.465
Zn	µg/L	1.24	1.46	2.26	1.54	1.63

7.5 DGTs

January and February 2016

The average concentrations for the DGTs that were out in each period in January and February can be seen in **Table 29.**

The result shows that Cd, Cr, Ni and Zn had average concentrations in level I in all the periods. Pb had also most of the average concentrations in level I, except for the period between 08.02-18.02 were it had an average concentration in level II. Cu had average concentration in level V in the first period and level IV in the rest of the periods, and were found in highest concentrations of the metals.

April 2016

The results from all the DGTs that were out in April can be seen in **Table 30.** All the concentrations are compared with Klifs guideline for metals in sea water.

The first two DGTs had concentrations of Pb, Cd, Cr and Ni in level I, Zn in level II and Cu in level IV. DGTs 4-6 shows some high values in level IV and V, and are most likely contaminated and do not represent concentrations in the water during that periods (see discussion in section 8.9.4).

Table 29. Average concentrations in the DGTs from January-February 2016. *Most of the RSD-values are under 5 %, except for Cr which have more of the values between 5 – 10 %.*

Metal (µg/L)	Period **21.01-26.01**	Period **26.01-02.02**	Period **02.02-08.02**	Period **08.02-18.02**	Period **18.02-21.02**	**Average**
Pb	0.0282	0.0217	0.0355	0.118	0.0430	0.0493
Cd	0.0104	0.0107	0.0132	0.00962	0.0112	0.011
Cu*	8.35*	0.911	5.77	5.70	3.75	4.90
Cr	0.0527	0.041	0.0480	0.0948	0.0778	0.0629
Ni	0.166	0.266	0.419	0.163	0.174	0.238
Zn	1.14	0.806	1.43	0.775	0.935	1.02

*could be contamination, see section 8.9.4.

Table 30. Results all DGTs from April 2016*. *RSD-values Pb and Cu: 0.4 – 4.2 %, Zn: 3.5 – 5.7 %, Ni:7.4 – 15.5 %, Cd: 11.8 – 35.8 % and Cr: 1.5 – 29 %.*

DGT no:	**Period**	**Pb µg/L**	**Cd µg/L**	**Cu µg/L**	**Cr µg/L**	**Ni µg/L**	**Zn µg/L**
1	07.04 – 15.04	0.0280	0.0158	5.17	0.0228	0.472	1.73
2	07.04 – 15.04	0.0210	0.0178	2.19	0.0150	0.376	1.82
3*	15.04 – 17.04	40.5*	0.0511*	6.69*	0.236*	0.824*	17*
4*	15.04 – 17.04	40.7*	0.0494*	5.80*	0.229*	0.771*	14*
5*	17.04 – 19.04	55.7*	0.0396*	20.7*	3.86*	0.964*	16*
6*	17.04 – 19.04	51*	0.0399*	32.8*	0.410*	1.30*	26*

*Contamination is suspected in the four last DGTs, see section 8.10.4 for further discussion.

7.6 POM: PAHs

The concentrations of PAHs in POM can be seen in **Table 31.** The concentrations are compared with Klifs guideline for PAHs in sea water.

The result shows that in POM1 and POM3 all of the detected PAHs were in level II. Indeno(1,2,3-cd)pyrene, dibenzo(a,h)anthracene and benzo(ghi)perylene were not detected in POM1 and POM3. In POM2 most of the concentrations were in level II, except for acenaphthylene, phenanthrene and fluoranthene that were found in level III and pyrene in level V. Indeno(1,2,3-cd)pyrene and dibenzo(a,h)anthracene were not detected in POM2 either, but benzo(ghi)perylene was detected.

Table 31. PAH concentrations found in the POMs. Measurement uncertainty = 20 %. n.d. = not detected.

PAHs (ng/L)	POM1	POM2*	POM3
Naphthalene	164	273	148
Acenaphthylene	1.21	12.2	1.24
Acenaphthene	6.25	1390	57.0
Fluorene	7.66	671	38.1
Phenanthrene	33.3	1520	149
Anthracene	0.546	42.3	3.25
Fluoranthene	7.58	231	37.5
Pyrene	6.10	111	18.8
Benz(a)anthracene	0.180	2.09	0.393
Chrysene	0.780	3.53	0.881
Benzo(b)fluoranthene	0.286	0.263	0.306
Benzo(k)fluoranthene	0.174	0.172	0.158
Benzo(a)pyrene	0.307	0.107	0.0821
Indeno(1,2,3-cd)pyrene	n.d.	n.d.	n.d.
Dibenzo(a,h)anthracene	n.d.	n.d.	n.d.
Benzo(ghi)perylene	n.d.	0.0763	n.d.

7.7 POM: PCBs

The results for the PCBs can be seen in **Table 32**. PCB-28 and PCB-52 were detected in all the POMs. PCB-138 was only detected in POM 2. PCB-101, -118, -153 and -180 were not detected.

Table 32. Results PCBs from the POMs.

		POM 1	POM 2	POM 3
PCB-28	pg/L	10.9	6.26	6.18
PCB-52	pg/L	3.50	1.87	0.171
PCB-101	pg/L	n.d.	n.d.	n.d.
PCB-118	pg/L	n.d.	n.d.	n.d.
PCB-153	pg/L	n.d.	n.d.	n.d.
PCB-138	pg/L	n.d.	0.477	n.d.
PCB-180	pg/L	n.d.	n.d.	n.d.
SUM PCB	pg/L	14.4	8.61	7.88

8. Discussion

In the discussion the results presented in section 7 will be discussed. The main focus in the discussion is to evaluate if the water and the sediment are affected by the snow dumping with regard to the analysed metals and PAHs.

First the different sample types will be discussed separately, but links between them will be drawn. Dissolved and particulate phase snow samples are discussed in **section 8.1,** heavy metals in sedimenting material in **section 8.2,** concentrations of heavy metals in the sediment in **section 8.3**, concentrations of heavy metals in water in **section 8.4** and PAHs in the water column and in the sediment in **section 8.5.**

The deposition of fine and coarse particles in the sediment and deposition of the sedimenting material are discussed in **section 8.6**. PCB will be discussed shortly in **section 8.7**. In **section 8.8** some of the results from this study are compared with measurements from other areas in the harbour. Possible contribution from other sources will be discussed in **section 8.9.**

In the end (**section 8.10**) method will be discussed with focus on sample size RSD-values, accuracy, possible sources of errors and sampling methods.

In the discussion the heavy metal(loid)s will be refered to as ‘metals’ (including As).

All the p-values calculated can be seen in appendix N.

8.1 Dissolved and particulate phase snow samples

In total 17 snow samples (14 in batch 1 and 3 in batch 2) were melted and filtrated to get the dissolved phase (see section 6.3.2) and the particulate material from batch 2 was also analysed (also see section 6.3.2). First the dissolved phase will be discussed and then the particulate phase, before relating the concentrations and patterns found in the snow samples to snow quality and other studies.

Dissolved phase

Cu and Zn seems to dominate with highest concentrations in the dissolved phase in the snow samples, as seen in *Figure 19.* They also have the highest average concentrations (2.95 and 4.65 µg/L, respectively). It can therefore be assumed that these two metals will be contributed in highest concentrations of the studied metals to the water during snow dumping. A t-test showed that Cu and Zn were not significant different with a 95 % CI (p-value 0.446). After Cu and Zn, Ni seems to be contributed most. And **Cr, As, Pb, Cd** and **Hg** will most likely be contributed in lowest concentrations (average values below 0.0110 µg/L), with lowest contribution from **Cd** and **Hg**, as they had the lowest concentrations in the snow samples.

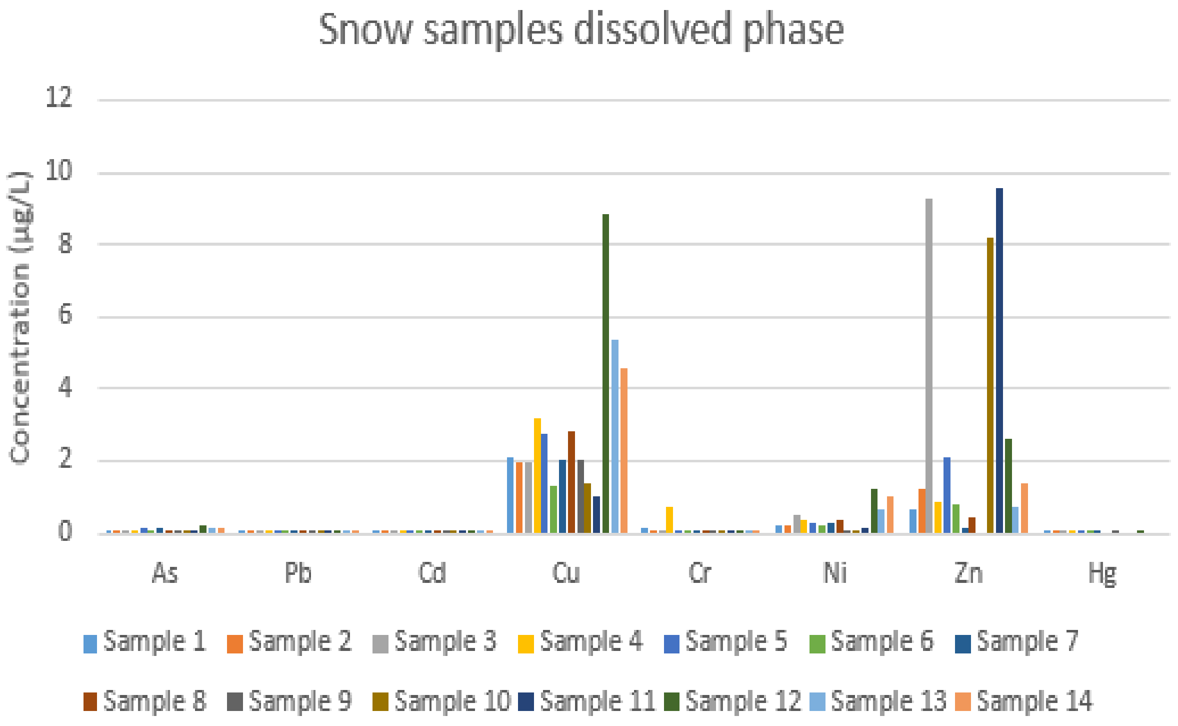


Figure 18. *Concentrations found in dissolved phase from the melted snow samples in batch 1.*

The samples from *batch 2* were not much different from batch 1, with regard to pattern in average concentrations. **Zn** and **Cu** also had the highest average concentrations in these samples (1.94 and 1.25 µg/L, respectively).

Particulate phase

In the particulate material (the particles in the melted snow samples from batch 2) in the snow samples, **Zn** was found with the highest average concentration (267 mg/kg dry weight), see **Figure 20**. **Zn** is significantly higher than the other metals with a 95 % CI (p-values below 0.05). It may therefore be suggested that **Zn** most likely have the highest concentrations in the particulate material in the snow and might therefore be contributed in highest concentration in the particulate fraction during the snow dumping. Next the contribution will most likely be highest from **Cu** and **Cr**, which had about the same average concentrations (116 and 98.2 mg/kg dry weight, respectively) and are not significant different with a 95 % CI (p-value 0.223).

The average concentrations then follow (in decreasing order) **Ni** > **Pb** > **As** > **Cd** > **Hg**, see Figure. The concentrations are significant different with a 95 % CI (p-values below 0.05). It might therefore be suggested that the contribution of concentrations in the particulate material in the snow will follow the sequence mentioned above, with highest concentrations from **Ni** and lowest from **Hg**.

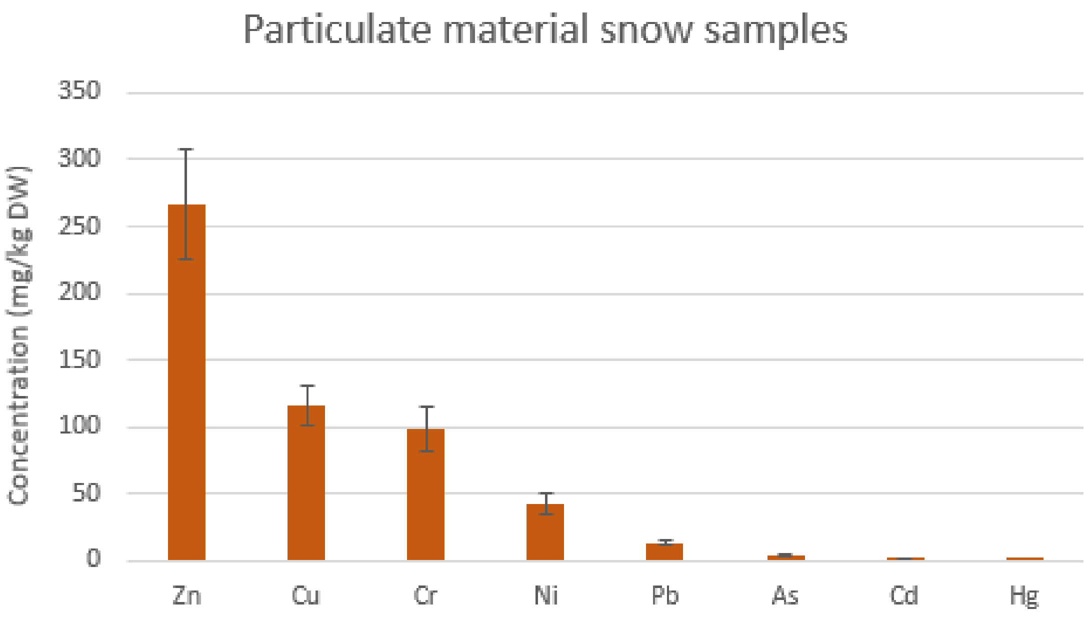


Figure 19. Average concentrations, particulate phase in the snow samples (batch 2). The error bars show ± 'one standard deviation'.

Both in the dissolved phase and particulate material the contribution seems to be highest from **Zn** and **Cu**, but also **Ni** and **Cr**, and lowest from **Cd** and **Hg**. The concentrations are considerably higher in the particulate phase than in the dissolved phase for all the metals, as expected from the theory (see section 2.6.1). Most of the metals are therefore particulate bound in the snow.

Snow quality and other studies

These findings fits well with previous studies of snow samples from urban areas (see section 2.6.1), where also **Zn, Cu, Ni and Cr** are most often found in highest concentrations. The results from these snow samples therefore seems to be representative for which metals that will be contributed in highest concentrations to the water during snow dumping. This can also indicate that traffic is most likely the dominant source to the metals in the snow, since **Zn and Cu** are typical traffic related metals (see section 2.6.3) and the other studies also concluded that traffic is a major source (Bækken, 1994, Bjørgaas, 2010).

The concentrations in the dumped snow will however show variations to what is found in the snow samples analysed, as this is only a small fraction of the snow from the city (about 10 mL of melted snow in each sample) and the samples were only taken from 4 locations at two different days. Since the snow quality will vary both with time and location (Bjørgaas, 2010), snow from other places in the city, ands at different times, can have different concentrations than found in these samples. In addition, these samples were taken from the outer layer of the snow pile which is exposed to the sources. Deeper in the snow pile the concentrations of metals are most likely be lower. Large visual variations were seen in the dumped snow (from partly brown snow to pure white snow), that most likely indicate differences in snow quality.

8.2 Heavy metals in the sedimenting material

3 sediment traps were out at increasing distances (41, 89 and 136 m) from the pier in the North East direction for 55 days (see section 6.2.3) to collect sedimenting particles in the area during snow dumping. The material was then analysed for the selected metals and PAHs, as described in section 6.4.2). In this section the heavy metals in the sedimenting material will be discussed (the PAHs will be discussed in section 8.5.2).

The concentrations were found in level I for all the metals in all the traps (see section 7.2.1). The sedimenting material therefore seems to have low concentrations of the selected metals, even though most of the metals are particulate bound in the snow (Sansalone et al., 2003).

The material in the traps show a similar distribution between the metals as found in the particulate material in the snow samples, see *Figure 21*. This is not unexpected as the snow dumping was the main activity in this area during the period the traps were out, and have therefore contributed with most particles. Other possible sources are discussed in section 8.9. It also again indicates (see section 8.1) that the pattern found in the particulate material in the snow samples seem to be quite representative for the particulate material in the dumped snow.

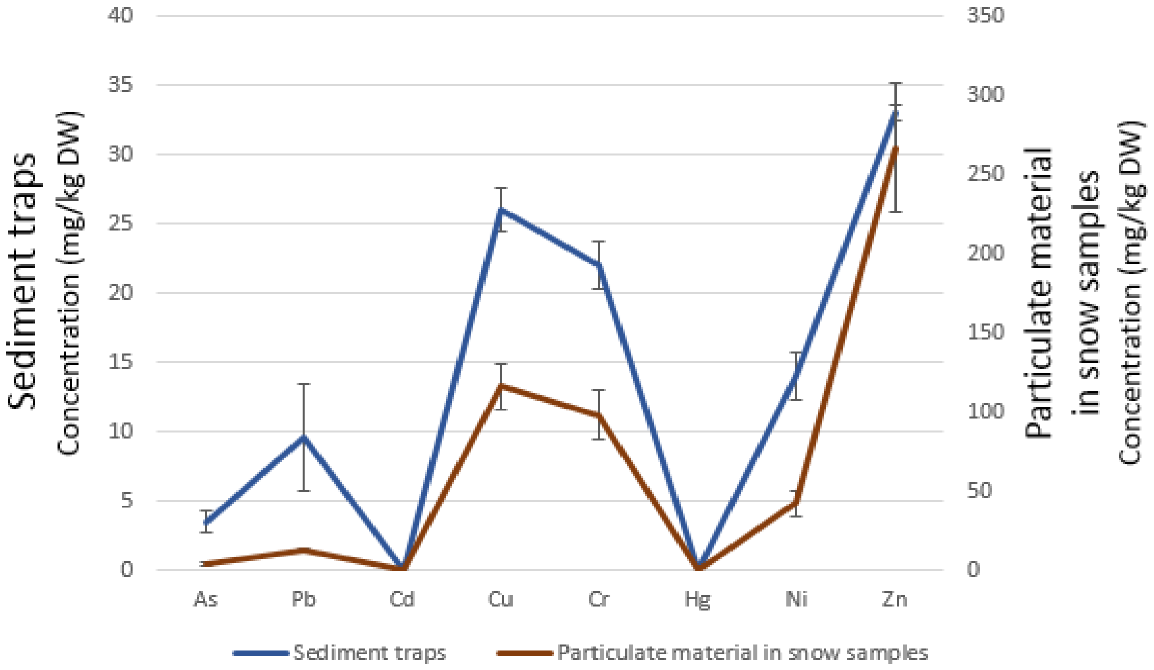


Figure 20. Average concentrations found in the sediment traps and in the particulate material in the snow samples. The error bars show ± 'one standard deviation'.

The concentrations found of the metals in the sediment traps are however lower than the concentrations in the particulate material in the snow samples (Figure 21). This could be due to that only the finer particles were analysed in the particulate material in the snow samples (see section 6.3.2), while both fine and coarse particles were analysed in the material from the traps (see section 6.4.2). Since the metals mostly adsorb to the surface of particles, smaller particles can bind more metals per mass than larger particles (Sansalone et al., 2003). In the analysis the coarser particles contribute with more mass to the overall total mass, leading lead to a dilution in the concentrations.

Picture 23. Material in the sediment traps. Both fine and coarser particles were analysed. Photo: Hilde A. Hammer.

Higher concentrations could therefore be expected in the finer particles in the trap. How much higher is difficult to give exactly, as the amount of material in the traps and the amount of coarser particles are unknown. But since the since the concentrations in the sediment were mostly found in level I and II (see section 8.3.1) the sedimenting material don't seem to contribute much with high concentrations.

8.3 Concentrations of heavy metals in the sediment

In total 17 samples were taken of the top layer (0-2 cm) of the sediment in 3 different directions from pier 68; North West (6 samples), North (4 samples) and North East (6 samples) (see section). In direction North West, samples were also taken from deeper layers (down to 8-16 cm). In addition, a sample was taken from 195 cm depth at Østmarka (see section 6.2.2). The concentrations found in the top layer will be discussed first in **section 8.3.1**, and be compared with the concentrations found of heavy metals in the particulate material in the snow in **section 8.3.2.** Then the deeper layers will be discussed and compared with the concentrations found in the sample from Østmarka in **section 8.3.3.** Differences in concentrations between the sampling points will be discussed in *section 8.6.2*.

8.3.1 Top layer, 0-2 cm

In the sediment samples taken from the top layer (0-2 cm) in the sediment outside pier 68, all the metals were found in level I and II (see section 7.3.1). The sediment therefore seems to be in good condition in this layer with regard to the metals analysed. However, since the sediment can be quite inhomogeneous, higher concentrations might be present in areas not sampled. As the concentrations in the previous sediment samples taken at pier 68 (see section 3.2) also showed most of the concentrations in level I and II, the assumption that these levels seem to dominate is strengthened.

The highest concentration found for each metal are well below the limit for level III for most of the metals, see **Table 33**.

Table 33. Highest concentrations found in the samples from the top layer (0-2 cm) in the sediment (except sampling points 500 m out) and the limits between level II and III, and III and I. *The concentrations are shown with the RSD-values. Cu are marked due to its close concentration to level III and IV.*

	Highest concentration found in the sediment (mg/kg DW)	Limit between level II and III (mg/kg DW)	Limit between level III and IV (mg/kg DW)
As	9.52 ± 0.36	52	76
Pb	38.2 ± 0.7	83	100
Cr	120 ± 3	560	5900
Cu	**48.9 ± 1.6**	**51**	**55**
Cd	0.305 ± 0.012	2.6	15
Hg	0.197 ± 0.002	0.63	0.86
Ni	37.2 ± 2.4	46	120
Zn	200 ± 3	360	590

For **Cu** however, the highest concentration found (48.9 mg/kg dry weight) is close to the level III limit. Level III is still considered as an acceptable level in the harbour, but there is also a low concentration difference between level III and IV for **Cu** (see Table 32). This could indicate that Cu is prone to higher levels than level II in the sediment. As also was pointed out by Bækken and Tjomsland (2001)in their conclusion that Cu should be followed up due to that it had occasionally high concentrations in the sediment.

It could be expected that the sediment in the direction North East have higher concentrations than the other two directions, as most of the snow floats in this direction (see section 4.1). Besides higher concentrations of **Cu and Cr** in sampling point 50 m from the pier in the direction North East (see section 8.6.2), this direction were found not to be significant different with a 95 % CI from the other two directions (all p-values > 0.05, see appendix N) with respect to concentrations. This can also be seen in *Figure 22***.**

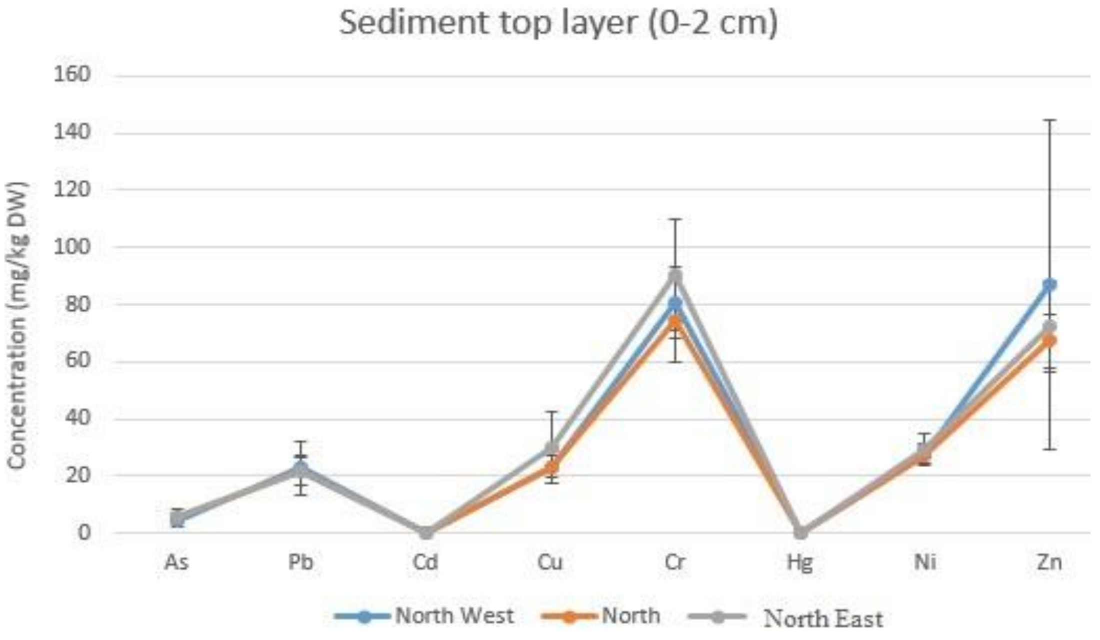


Figure 21. Average concentrations in the sediment samples from the top layer (0-2 cm) for each of the directions. *Sampling points 500 m are not included. The error bars show ± 'one standard deviation'.*

The samples were also taken at different times of the year; the samples taken in North West direction were taken in the month of October, the samples taken in North direction were taken in the month of May and the samples taken in North East direction were taken in the month of February. The samples taken in direction North East were therefore more affected by the snow dumping, but despite this the concentrations in this direction were not different from the other directions, again indicating that the snow dumping don’t seem to contribute with very polluted masses.

8.3.2 Comparison of concentrations in the particulate material in snow and in the sediment (top layer, 0-2 cm)

In *Figures 23, 24, and 25* the average concentrations found in the particulate material in the snow samples and the average concentrations found in the sediment samples from the top layer (0-2 cm) (except for sampling points 500 m out) from all the directions can be seen. Discussion follows under the Figures.

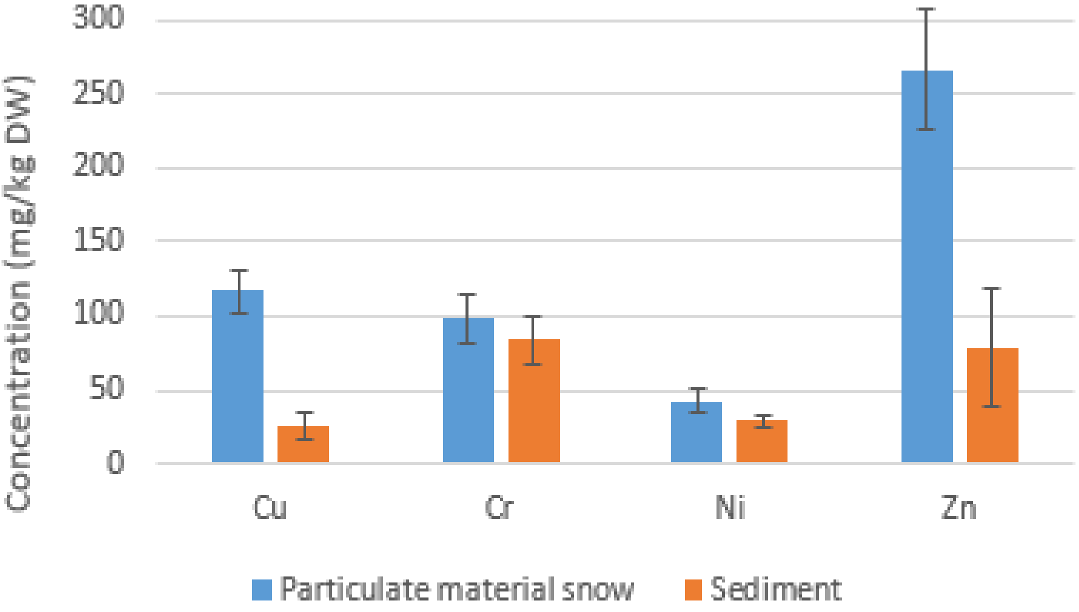


Figure 22. Average concentrations of Cu, Cr, Ni and Zn in particulate material snow samples and in the sediment samples (except sediment samples taken 500 m out). *The error bars show ± ‘one standard deviation’.*

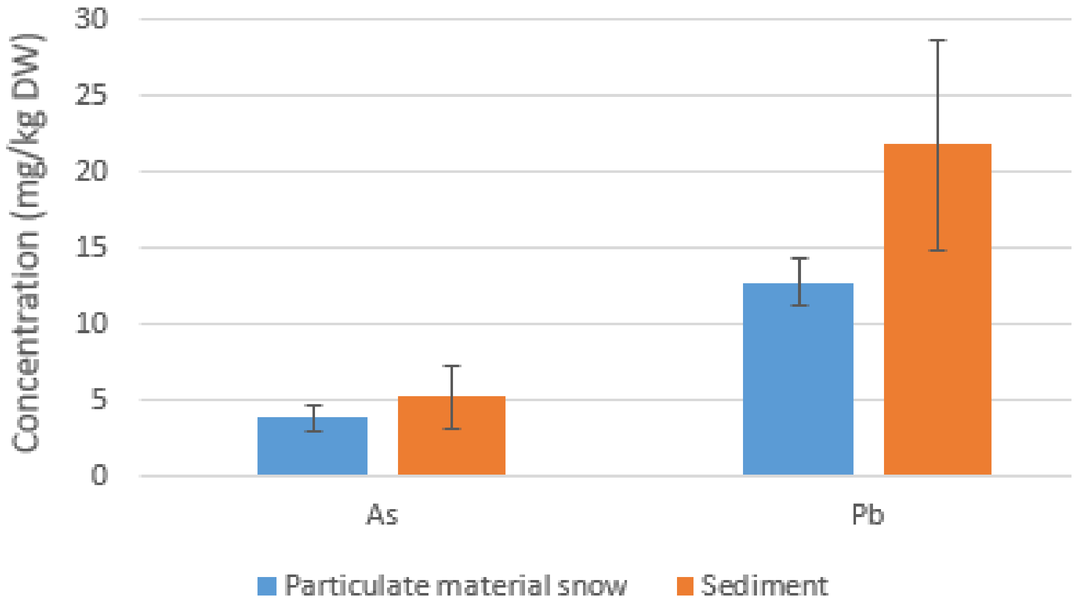


***Figure 23**. **Average concentrations of As and Pb in particulate material snow samples and in the sediment samples (except sediment samples taken 500 m out).** The error bars show ± 'one standard deviation'.*

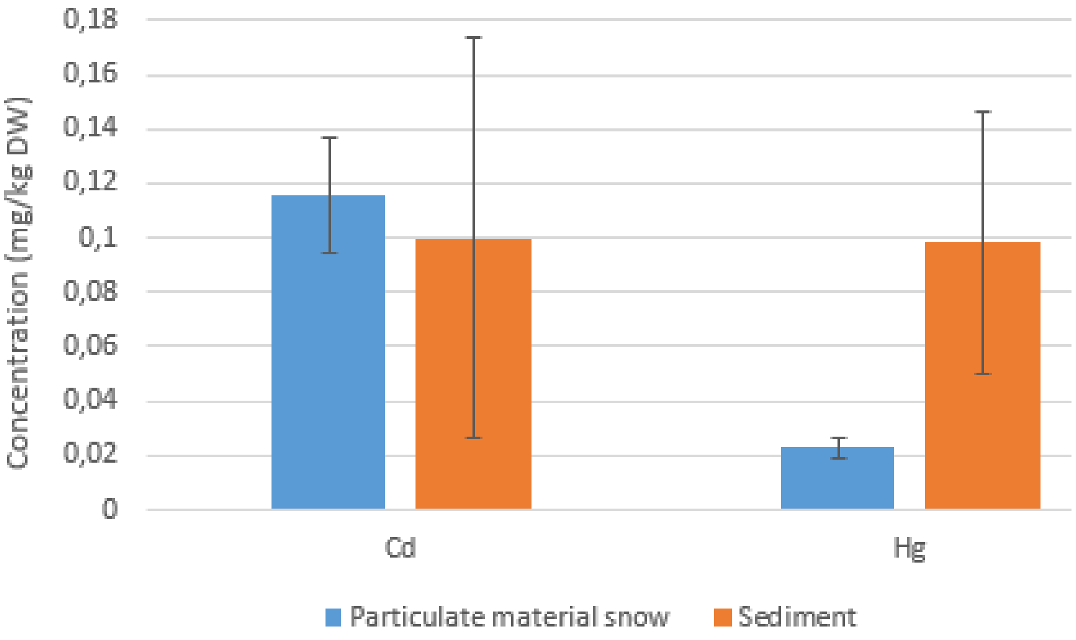


***Figure 24. Average concentrations of Cd and Hg in particulate material snow samples and in the sediment samples (except sediment samples taken 500 m out).** The error bars show ± 'one standard deviation'.*

Cu and Zn

For **Cu and Zn** it is found significant lower average concentrations with a 95 % CI in the sediment samples than in the particulate material in the snow samples (p-values 0.0054 and 0.0061, respectively). Indicating that the concentrations found in the sediment will mostly be lower than in the particulate material in the snow. This could mean that **Cu and Zn** are well spread in the sediment.

As, Cd, Ni, Cr

As, Cd, Ni and Cr have not significantly different average concentration with a 95 % CI in the sediment samples and in the particulate material in the snow samples (p-values 0.11, 0.53, 0.095 and 0.26, respectively). This indicates that the concentrations found in the particulate material in the snow don't distinguish much from the concentrations in the sediment.

It can also be noted that **Cr** has a significant higher average concentration with a 95 % CI (p-value $5.8*10^{-10}$) than **Cu** in the sediment samples, which is different from the pattern found in the particulate material in the snow samples, where the average concentrations were not significant different (see section 8.1). This can be explained by that **Cu** have a significant lower average concentration with a 95 % CI in the sediment samples, while **Cr** is not significantly lower in the sediment samples (see Figure 23).

Pb, Hg

Pb and Hg have a significant higher average concentration with a 95 % CI (p-values 0.00082 and 0.00010, respectively) in the sediment samples than in the particulate material on the snow samples. The reason for this can be due to that both **Pb and Hg** are used to a lesser degree now than earlier (Alloway, 2013). They have therefore most likely lower concentrations in the snow now than earlier, but are still found in higher concentrations in the sediment, as the sediment can still contain particles from previous sources.

8.3.3 Deeper layers North West direction

In the sediment samples taken down to 8-16 cm in the sediment in the same sampling points as the top layer (0-2 cm) in direction North West, the concentrations seem to be a bit higher than in the top layer (0-2 cm) for all the metals. Most of the concentrations are however in level I and II, except for **Cu and Hg** which have some concentrations in level III and IV, and III to V, respectively (see section 7.3.2 and appendix O). This could mean that the concentrations from the snow dumping are lower now than earlier. However, the layer 2-16 cm which the samples were taken from are strictly not deep enough to see any historical trend, as this layer is still considered as a part of the top layer. A lot of changes can still occur in these layers; metals can diffuse up and down the layers, redox-reactions can happen, they can be affected by organisms and be swirled up due to boats, currents etc. (Laugesen et al., 2003, Manahan, 2010, Kennish, 2000). In addition, the amount of material from the snow dumping will vary from year to year and other sources also contribute with particles to the sediment, which makes it even more difficult to see any trend in the layers.

What however can be seen is that the layers have higher average concentrations than the concentration found in the sediment sample from Østmarka for all the metals, except for **Cr and Ni**, see **Table 34.** The concentrations are just compared directly without any t-test, as it was only 1 sample from Østmarka.

Table 34. Concentrations found in the core sample from Østmarka (195 cm down in the sediment) and the average concentrations of the different layers in the samples taken at direction North West at pier 68 (from 2 – 8 and 16 cm down in the sediment).

	Hg mg/kg DW	Cr mg/kg DW	Ni mg/kg DW	Cu mg/kg DW	Zn mg/kg DW	Cd mg/kg DW	Pb mg/kg DW	As mg/kg DW
Østmarka	0.0223	132	55.6	21.0	75.4	0.0820	11.0	3.51
Pier 68	0.268	85.0	31.4	34.8	88.2	0.204	31.4	6.06

Since the sediment sample taken at Østmarka is deep enough (depth = 195 cm) to represent background levels, this can indicate that **Hg, Cu, Zn, Cd, Pb and As** have been contributed to the sediment outside pier 68 and reached higher concentrations than the natural background concentrations, especially **Hg and Pb** which are found in one level higher in the sediment outside pier 68. **Ni and Cr** have been contributed with lower concentrations than the natural background concentrations, and are thus lower than the background concentrations. This is explained by that **Cr and Ni** are naturally high in the sediment in Trondheim (Andersson et al., 2011). The snow dumping are therefore an anthropogenic source of pollutants to the sediment outside pier 68, but the concentrations are within acceptable values (below level IV).

8.4 Concentrations of heavy metals in the water

Samples were taken both in the surface water (manual water samples) and in the water column (using DGTs) (see section 6.2.5 and 6.24, respectively). The results will first be discussed separately, surface water in **section 8.4.1** and water column in **section 8.4.2**, and then a comparison of the concentrations in the surface water and in the water column will be done in **section 8.4.3**. In **section 8.4.4** the concentrations found in the surface water and in the water column will be compared with the concentrations found in the dissolved phase in the snow samples.

8.4.1 Surface water

Manual samples were taken of the surface water outside pier 68 in January and February 2015 and 2016, and in April 2016. Samples were also taken at Ringve in 2015. The samples taken at pier 68 in 2016 was taken at the same location, but the samples from 2015 was taken at a different location at pier 68 (see section 6.2.5).

In 2015

In 2015 there was very little snow dumping at pier 68 (see section 4). The concentrations in the samples from the surface water at pier 68 are also quite similar to the concentrations found at Ringve, see *Figure 26.* By performing a t-test the average concentrations were found not to be significantly different between the two sites with a 95 % CI (p-values below 0.05, see Appendix N). The concentrations at Ringve were meant to represent background levels (not affected by snow dumping or the activities in the harbour). It therefore seems likely that the samples taken at pier 68 in 2015 are not very affected by the snow, and can therefore represent concentrations at pier 68 when there is no snow dumping. The concentrations may therefore be suggested to be mostly in level I for **As, Pb, Cr, Hg, Cd and Ni**, in level I and II for **Zn** and level II for **Cu** at pier 68 when there is no/little snow dumping.

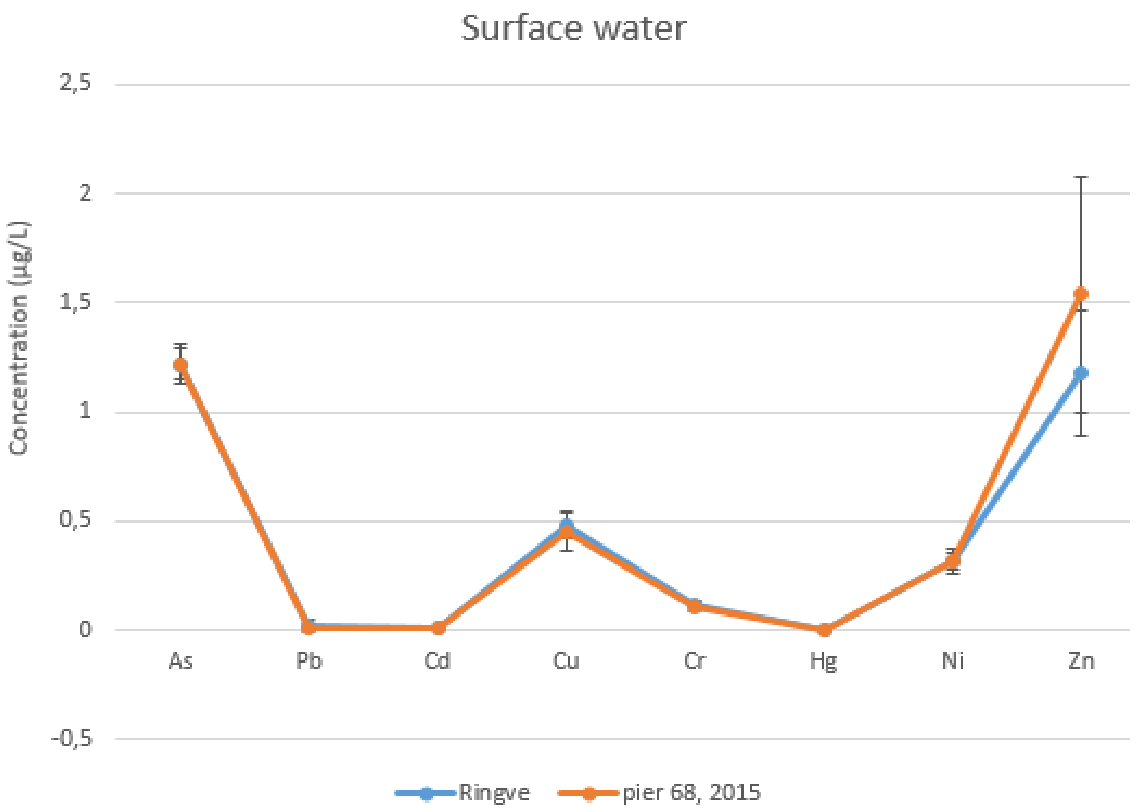


Figure 25. *Concentrations in surface water in samples taken at Ringve and pier 68 in 2015. The error bars show ± 'one standard deviation'.*

During snow dumping

During snow dumping **As, Cd, Hg**, and **Ni** were still found with average concentrations in level I, see **Table 35. Zn** had an average concentration in level I during snow dumping, compared to level II in 2015 (without snow dumping). **Pb, Cr** and **Cu** were found with average concentrations in higher levels during snow dumping, level II for **Pb** and **Cr** and level IV for **Cu**. Concentrations in level IV is high and might therefore have a higher risk of harm on aquatic organisms. Studies have shown however, that much of the dissolved **Cu** is not bioavailable (Neff, 2002) and might therefore not necessarily pose a risk to organisms. But it should anyway be avoided having concentrations in this level in the water to maintain a good quality.

Table 35 Average concentrations in surface water samples taken at pier 68 in 2015 and during snow dumping and change in %.

Metals (µg/L)	2015	During snow dumping	Change (%)	Significantly different (p-value < 0.05)
As	1.22 ± 0.094	0.915 ± 0.22	- 25 %	x
Pb	< 0.02	0.169 ± 0.050	~ 1590 %	x
Cd	< 0.02	0.0353 ± 0.018	~ 253 %	x
Cu	0.451 ± 0.083	1.48 ± 1.8	228 %	
Cr	0.110 ± 0.020	1.89 ± 0.34	1618 %	x
Hg	< 0.01	< 0.01	-	
Ni	0.316 ± 0.040	0.409 ± 0.21	29 %	
Zn	1.54 ± 0.54	1.25 ± 1.3	- 19 %	

Except for **Cu** (and one concentration found in level III for **Zn** (see section 7.4.2)), the quality in the surface water seemed to be in good condition during snow dumping with regard to these metals as all the concentrations of the other metals were found in level I and II (see 7.4.2). The average concentrations are also well below level III, see **Table 36.** Only the average concentration of Zn is near the limit to level III.

Table 36. Average concentrations in the surface water samples taken at pier 68 during snow dumping and the limits for level III (all metals except Cu) and level V (for Cu).

Metals	Measured values during snow dumping (µg/L)	Limit level III (µg/L)
As	0.915 ± 0.22	4.8
Pb	0.169 ± 0.050	2.2
Cd	0.0353 ± 0.018	0.24
Cr	1.89 ± 0.34	3.4
Hg	< 0.01	0.048
Ni	0.409 ± 0.21	2.2
Zn	1.25 ± 1.3	2.9
		Limit level V (µg/L)
Cu	1.48 ± 1.8	7.7

By performing a t-test it was found that **As, Pb, Cd** and **Cr** had significant different average concentrations with a 95 % CI between the two periods (p-values below 0.05, see Appendix N). **As** had therefore lower average concentration during snow dumping, while **Pb, Cd** and **Cr** had higher average concentrations during snow dumping, compared to the concentrations found in 2015. **Cr** and **Pb** had the highest change in % between the two periods, 1618 % and 1590 %, respectively, and **Hg and Zn** the lowest (see Table 35). **Cu** had a lower change (see Table 35) in average concentrations than **Pb** and **Cr,** but reached several concentrations in level III and IV (see Table 35). This reflects the small concentrations ranges between the different levels for **Cu** in the guideline (see appendix B).

Whether the concentrations in the surface water before the snow dumping in 2016 were similar to the concentrations found in 2015 is uncertain, as the samples are taken in different years and also at different locations (see section 6.2.5). It may be that the concentrations were generally higher in the water in 2016, so the increase/decrease was not so great, or that the concentrations were lower in surface water so that the increase/decrease during snow dumping was actually higher. Variations in concentration between years could be due to different factors, such as amount of particles present in the water, pH, tidal, temperature, contribution from other sources, and influence of river water. They can also vary in concentrations as they are non-conservative in water (Kennish, 2000).

Which of the metals that were significantly higher/lower during snow dumping can be more confirmed by comparing the concentrations with the concentrations found in the samples taken after the snow dumping. These samples are taken closer in time and also at the same location, which will strengthen the assumptions. When comparing the average concentrations for these two periods (during and after snow dumping) only **Pb** and **Cr** were found to be significantly different with a 95 % CI (p-values 0.00054 and $4.0 \cdot 10^{-5}$, respectively), meaning they had significant higher average concentration in the surface water during snow dumping.

After the snow dumping

Pb and **Cr** had average concentrations in level I again after snow dumping, see **Table 37. Cu**, however, had average concentration in level III after the snow dumping. This average concentration is significantly higher with a 95 % CI (p-value 0.0027) than the average concentration in 2015. This could mean that **Cu** is still high from the snow dumping. It can also be that **Cu** is in level III in this area, independent of the snow dumping. Since no samples were taken at this place before the snow dumping it’s not known.

Table 37. Average concentrations of metals in the surface water at pier 68 during snow dumping and after snow dumping, and their change in %.

Metals (µg/L)	**During snow dumping**	**After snow dumping**	**Change (%)**	**Significant different (p-value < 0.05)**
As	0.915 ± 0.22	1.12 ± 0.040	- 22 %	
Pb	0.169 ± 0	< 0.02	~94 %	x
Cd	0.0353 ± 0.018	0.0219 ±	38 %	
Cu	1.48 ± 1.8	0.661* ± 0.090	55 %	
Cr	1.89 ± 0 ± 0.34	0.0850 ± 0.058	96 %	x
Hg	< 0.01	< 0.01	-	
Ni	0.409 ± 0.21	0.465 ± 0.11	- 14 %	
Zn	1.22 ± 1.3	1.61 ± 0.72	- 32 %	

*Cu also had concentrations in level II, see section 7.4.2.

In *Figure 27 and 28***,** a total overview over the average concentrations found in the different periods can be seen. It can clearly be seen that **Cr** and **Pb** are significantly higher in the surface water during the snow dumping. **Cu** have one higher value (5.17 µg/L)(see section 7.4) leading to a large standard deviation. But even without this value, **Cu** is not significantly higher with a 95 % CI during snow dumping compared to after (p-value 0.36).

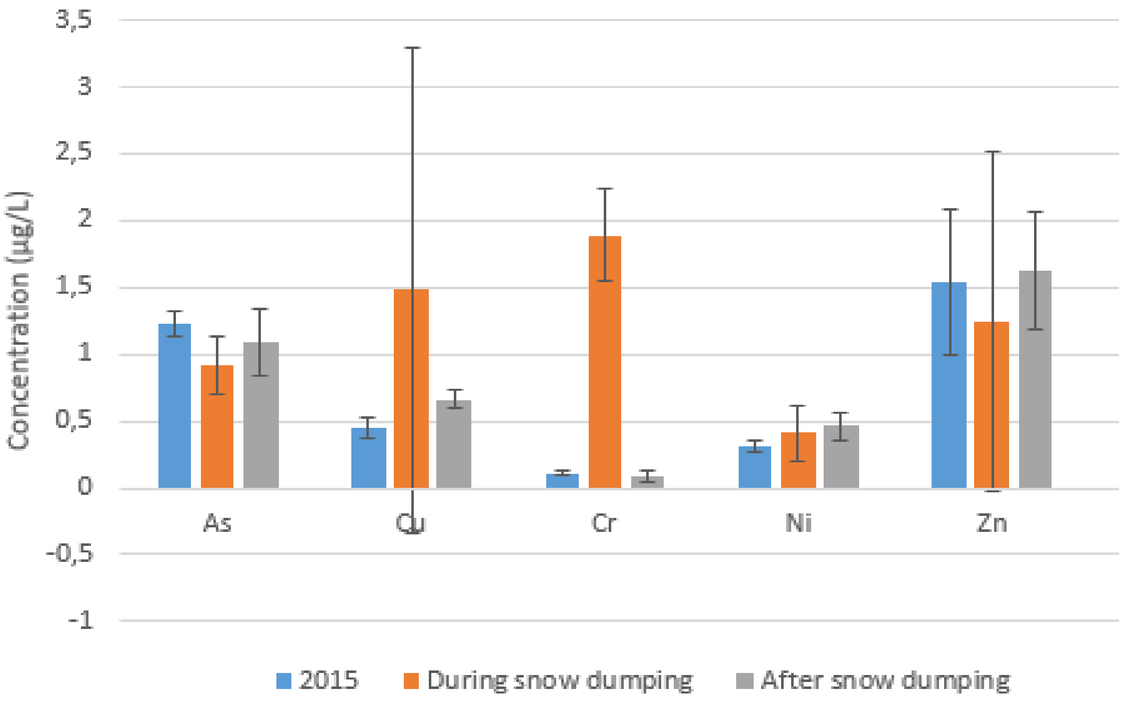


__Figure 26__. Average concentrations in the surface water samples taken at pier 68. The error bars show ± 'one standard deviation'.

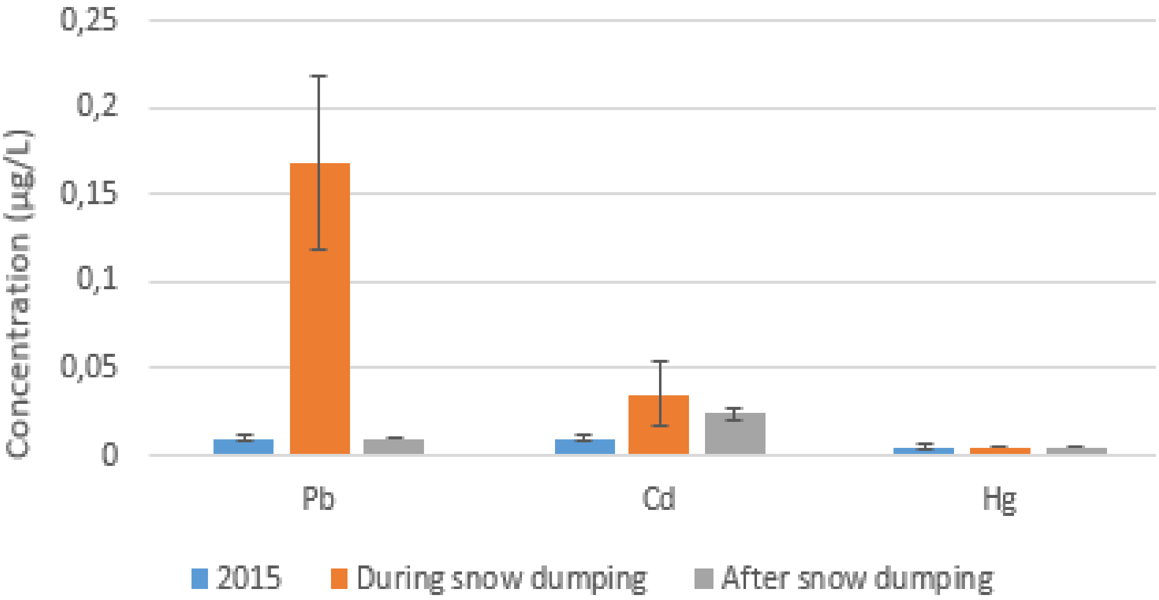


***Figure 27.** Average concentrations in the surface water samples taken at pier 68. The error bars show ± 'one standard deviation'.*

Out on the fjord

In the samples taken out on the fjord (see section 6.2.5), it seems that the average concentrations of all the metals are slightly higher than closer to land (where the other samples were taken) see *Figures 29 and 30.* Only **Cr** was found to be significantly different with a 95 % CI (p-value 0.03). The concentrations of the studied metals were therefore not found significantly higher concentrations in the samples taken further out, except for **Cr.**

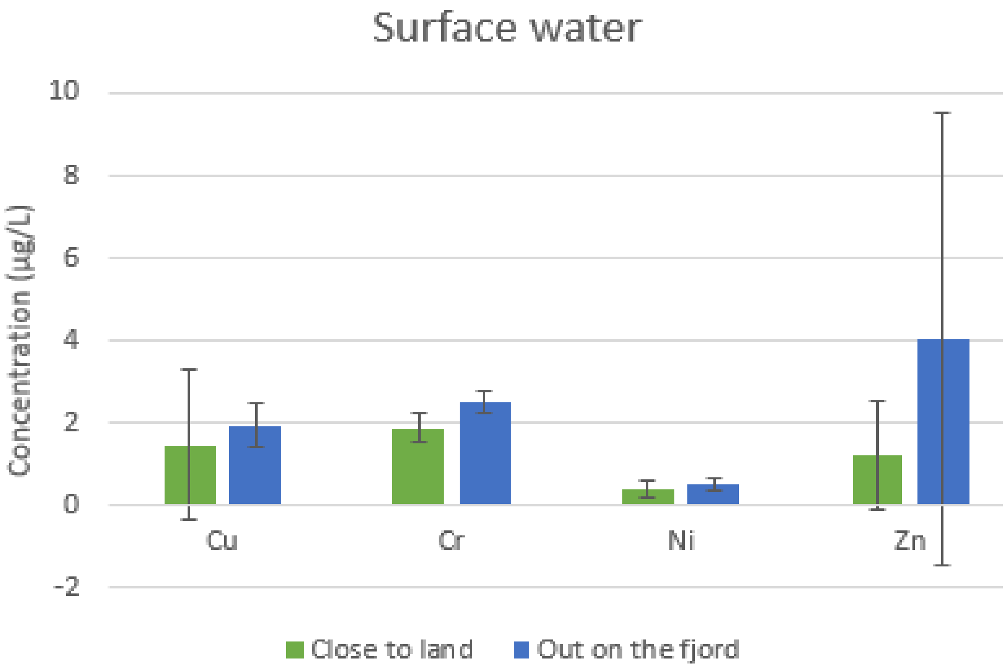


Figure 28. *Average concentrations of Cu, Cr, Ni and Zn in the surface water samples taken out on the fjord close to pier 68 (n=3). The error bars show ± 'one standard deviation'.*

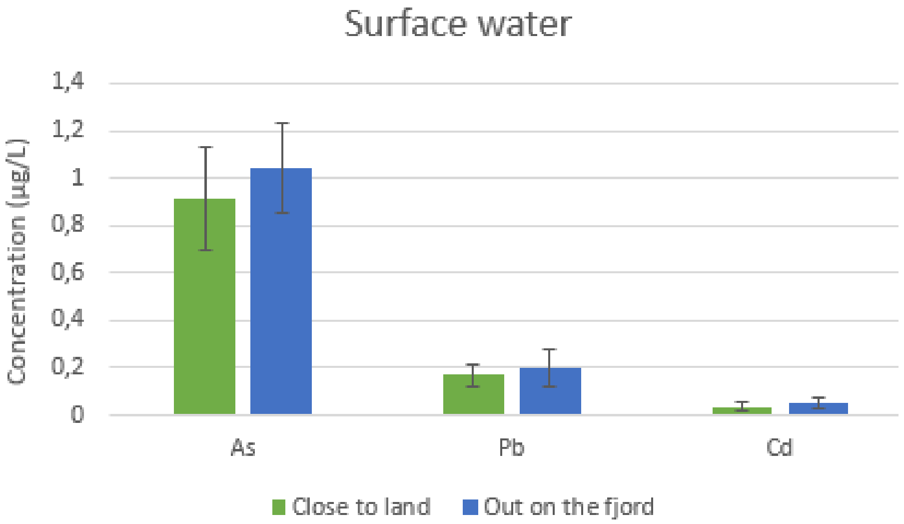


Figure 29. *Average concentrations of As, Pb and Cd in the surface water samples taken out on the fjord close to pier 68 (n=3). The error bars show ± 'one standard deviation'.*

8.4.2 Concentrations in the water column

In the water column during the snow dumping the average concentrations of **Pb, Cd, Cr, Ni,** and **Zn** were found in level I, see **Table 38.** The condition in the water column during the snow dumping therefore seemed to be good with regard to these metals. **Cu** was found with average concentration in level IV during the snow dumping, which is considered as high, and might therefore have a higher risk of harm on aquatic organisms (as mentioned in section 8.4.1).

Table 38. Average concentrations in the water column during (n = 15) and after (n = 2) snow dumping at pier 68.

Metal (µg/L)	**During snow dumping**	**After snow dumping**	**% change**	**Significant different (p-values < 0.05)**
Pb	0.0493	0.0245	50 %	
Cd	0.011	0.0168	+ 53 %	x
Cu	4.90	3.68	25 %	
Cr	0.0629	0.0189	70 %	x
Ni	0.238	0.424	+78 %	
Zn	1.02	1.78	+ 75 %	x

After the snow dumping the average concentration of **Cr** were significant lower with a 95 % CI (p-value 0.010), while **Zn** and **Cd** had significantly higher average concentrations with a 95 % CI (p-values 0.0023 and 0.048, respectively). This indicates that **Cr** had significantly higher average concentration in the water column during snow dumping, while **Zn** and **Cd** hade significantly lower average concentrations. **Pb, Cu** and **Ni** did not have significant different average concentrations during and after snow dumping, indicating that the concentrations of these were not affected by the snow dumping. See *Figures 31 and 32.* The average concentration of **Cr** (which were found significantly higher) was however in level I both during and after snow dumping, so the impact from the snow dumping was not so large.

Cu had still average concentration in level IV after the snow dumping. Cu might be in level IV in this area independent on the snow dumping, or it is still high after the snow dumping. It could also be a possibility that there is a contamination in the DGTs.

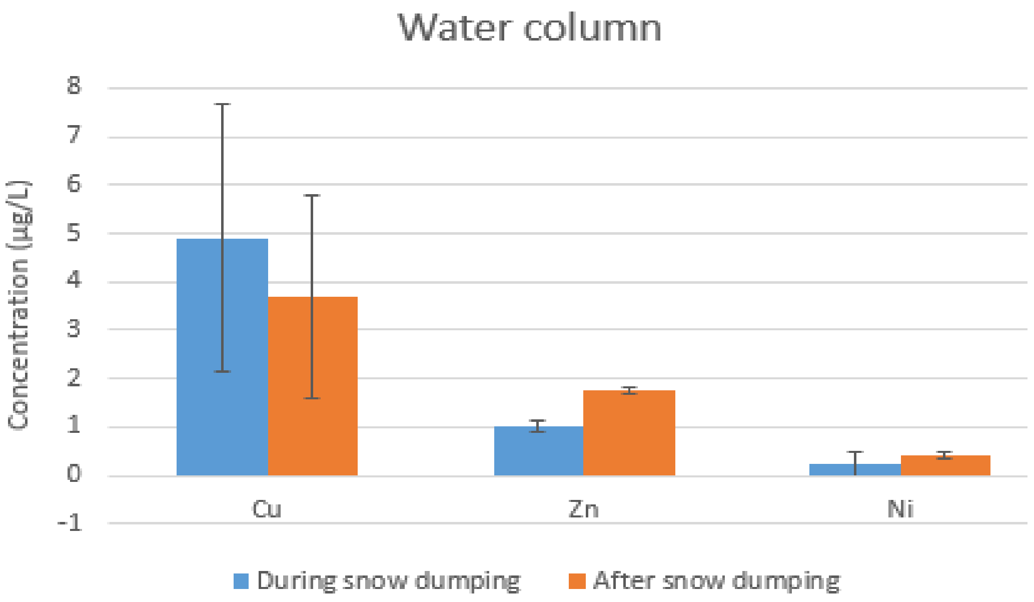


Figure 30. Average concentrations of Cu, Zn and Ni in the water column during and after snow dumping at pier 68. The error bars show ± 'one standard deviation'.

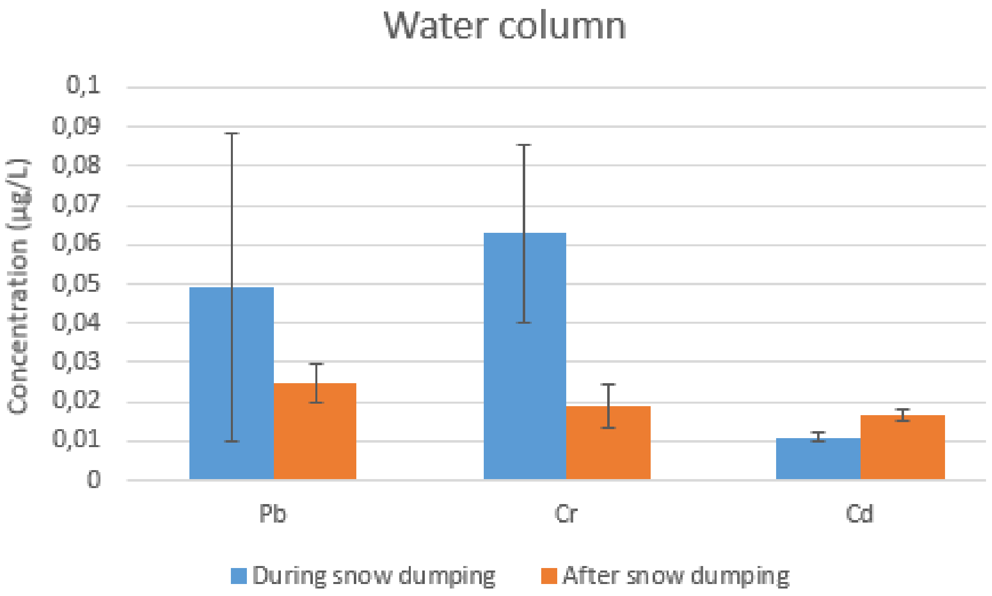


Figure 31. Average concentrations of Pb, Cr and Cd in the water column during and after snow dumping at pier 68. The error bars show ± 'one standard deviation'.

8.4.3 Surface water compared with water column

When comparing the average concentrations found in the samples of the surface water during snow dumping with the average concentrations found in the water column during snow dumping, the concentrations seemed to be lower in the water column, see **Table 39.** This is most likely explained by that snow were lying in the surface water during sampling of the surface water, which lead to higher concentrations in the surface water samples. As the snow melted, the metals most likely spread in the water column, and the concentrations got diluted.

Table 39. Average concentrations in surface water and DGT (water column) during snow dumping, and % lower concentrations in DGT.

Metal (µg/L)	Surface water samples	Water column	% lower in the water column	Significant different (p-values < 0.05)
Pb	0.169	0.0493	71 %	X
Cd	0.0353	0.011	69 %	X
Cu	1.48	4.90	-231 %	
Cr	1.89	0.0629	97 %	X
Ni	0.409	0.238	42 %	
Zn	1.25	1.02	18 %	

The average concentrations of **Pb, Cd,** and **Cr** are significantly different with a 95 % CI (p-values 0.002, 0.03 and $4.4*10^{-5}$, respectively) in the surface water and in the water column, meaning they were significantly lower, with a 95 % confidence, in the water column than in the surface water. This seems likely, especially for **Pb** and **Cr** which had significantly higher average concentration in the surface water during snow dumping (see section 8.4.1) and are therefore lower in the water column. This could also indicate that these metals to a larger degree stays in the surface water than the other metals, which were not find to be significantly higher in the surface water and in addition, not significantly lower in the water column.

Cu on the other hand, have higher average concentration in the water column with a 95 % CI (4.90 µg/L) than the surface water (1.48 µg/L), and most of the concentrations measured in the water column were higher than in the surface water samples (see Table 26 and 29). It could be that the concentrations are generally higher in the water column for Cu. However, the average concentrations are not significant different with a 95 % CI due to the large standard deviation in the surface water samples (p-value 0.051).

8.4.4 Trend seen in water compared with the dissolved phase snow samples

The highest increase of **Pb** and **Cr**, and not of **Zn, Cu** and **Ni**, found in the surface water during snow dumping were unexpected as **Zn, Cu** and **Ni** were expected to have the highest increase due to higher concentrations in the snow samples (see section 8.1). The explanation for this is unclear, but could as mention in section 8.4.3 be that **Pb and Cr** to a larger degree stays in the surface water than the other metals **Zn, Cu and Ni**, and are therefore found in higher concentrations. It could also be due to inhomogeneity of the metals in the surface water during sampling, different binding affinity for particles (and hence not measured in the filtrated water samples), or variations in the concentrations in the water (and only the lower concentrations were sampled).

8.5 PAHs in the water column and in the sedimenting material

PAHs were measured in the water column using POMs (see section 6.2.6) and in the sedimenting material from the snow dumping by analysing the material from sediment traps (see section 6.2.3). The POMs were attached on the sediment traps and both sampling types were therefore out in the water in the same time period (53 days). But POM, which is based on equilibrium with the concentrations in the surroundings (wag solutions, not dated) will represent the 3-4 last weeks of the sampling period. The sediment traps and the POMs, where located 41, 89 and 136 m out from pier 68 in the North East direction, and are referred to sediment trap 1, 2 and 3, and POM1, 2 and 3, respectively.

In this section the concentrations found in the water column will be discussed in **section 8.5.1,** and the concentrations found in the sedimenting material in **section 8.5.2**. In **section 8.5.3** the distribution of PAHs between water and particulate phase will be discussed and the distribution of the PAHs will be compared with snow samples in **section 8.5.4.**

8.5.1 PAHs in the water column

Both in the area around 50 m out and 140 m out from the pier in direction North East the all the PAHs were found in level II (see section 7.6). Around 100 m out most of the PAHs were also found in level II, but acenaphthylene, phenanthrene and fluoranthene were found in level III and pyrene in level V (also see section 7.6). The high concentrations found around 100 m out are much higher than around 50 m and 140 m out and lies outside the measurement uncertainty, see *Figure 33***.** They are also much higher than concentrations measured in POMs that were out at different areas in the harbour January to March 2015 in a study performed by NGI (see section 8.8.2)(NGI, 2015).

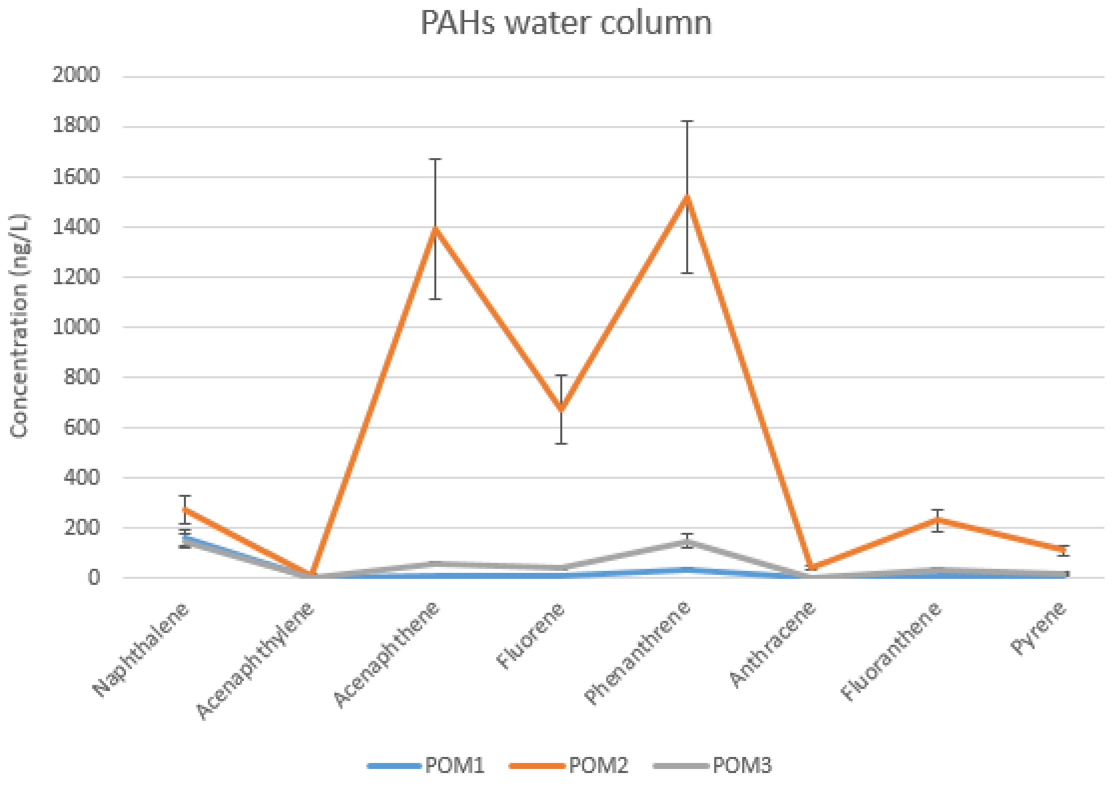


Figure 32. Concentrations found in each POM for naphthalene to pyrene*. The error bars show the measurement uncertainty (20 %). POM2 show significantly higher concentrations of some of the PAHs.*

To find such high concentration differences considering that the POMs were in the same area is a bit strange, but could be due to a very local impact (for instance oil leakage from a boat that accumulated in the area around POM2) or an error in the analysis. Another explanation can be that most of the PAHs follows the snow out to the area around 100 m, leading to higher concentrations in this area, but the concentrations seems to be too high to be solely from the snow. The reason is therefore unclear.

POM3 seem to show some higher concentrations than POM1, see *Figures 34 and 35*. The concentrations of **acenaphthene, fluorene, phenanthrene, fluoranthene, pyrene and benzo(a)pyrene** seem to be higher.

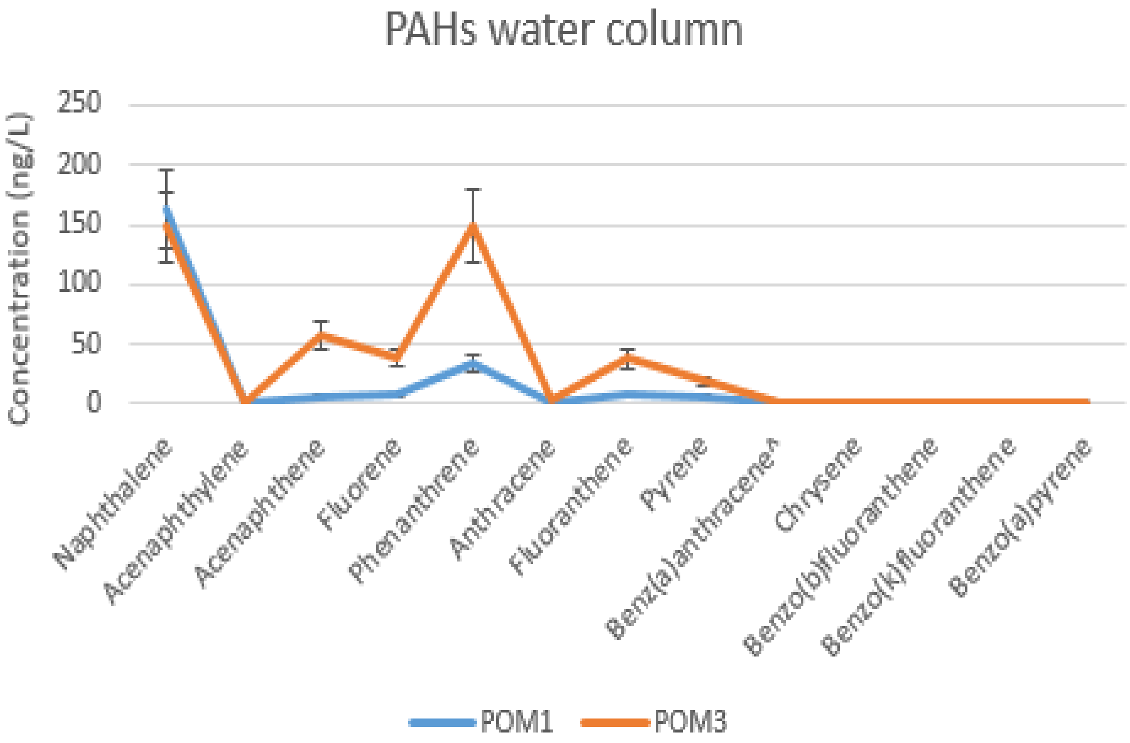


Figure 33. Concentrations found in POM1 and POM3 for naphthalene to benzo(a)pyrene. *The error bars show the measurement uncertainty (20 %). POM1 was about 50 m out from pier 68 in the direction North East, and POM3 was about 140 m out from pier 68 in the direction North East.*

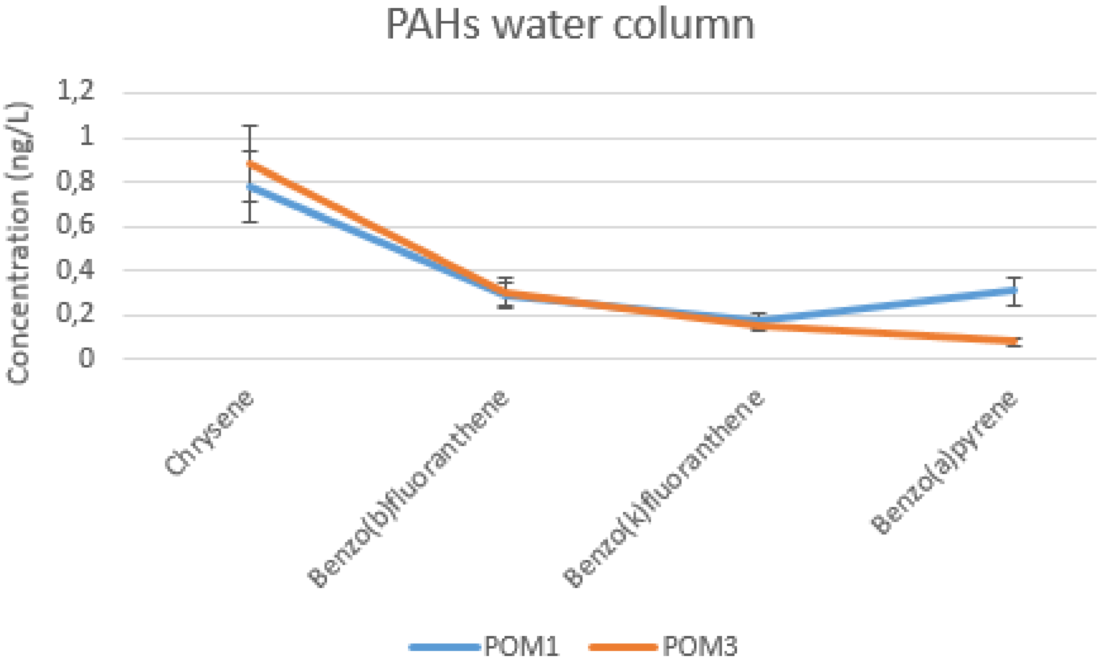


***Figure 34. Concentrations found in POM1 and POM3 for chrysene to benzo(a)pyrene**. The error bars show the measurement uncertainty (20 %). POM1 was about 50 m out from pier 68 in the direction North East, and POM3 was about 140 m out from pier 68 in the direction North East.*

In the water column, the concentrations of these PAHs (mentioned above) therefore seem to be higher in the area around 150 m than 50 m out from pier 68 in the direction North East. One explanation for this can be that more of the PAHs follow the snow out to this area before the snow melts, or it could be affected by a source that have not affected POM1 to the same degree.

As PAHs in the water column only were measured during snow dumping and not before and/or after, it is not known how much PAHs the snow dumping contributes with. But the concentrations of dissolved PAHs in the water column during snow dumping seems to not reach higher concentrations than level II around 50 m and 140 m out from the pier. The high concentrations around 100 m is uncertain whether it is from the snow.

8.5.2 PAHs in the sedimenting material

Since the sedimenting material had concentrations of PAHs in level I and II (see section 7.2.2), the snow dumping seems to contribute with low concentrations of PAHs to the sediment. How much the snow dumping has contributed to the high levels of PAHs in the sediment outside pier 68 is difficult to know as other sources can have contributed as well (see section 8.9). But it might be that the PAHs from the snow dumping have accumulated in the sediment over the years, as PAHs are slowly broken down in the sediment (SFT, 2000).

8.5.3 Distribution of PAHs between water and sediment

In the water column the low molecular weight PAHs were found to dominate, while in the sedimenting material the high molecular weight PAHs were found to dominate, see *Figure 36*. This agrees well with the theory (see section 2.4) that the low molecular weight PAHs are more soluble (and were therefore more present in the water column) and the high molecular weight PAHs are more bound to particles (and were hence more present in the sedimenting material). The high molecular weight PAHs will therefore to a higher degree affect the sediments than the low molecular weight PAHs, which tend to stay more in the water column.

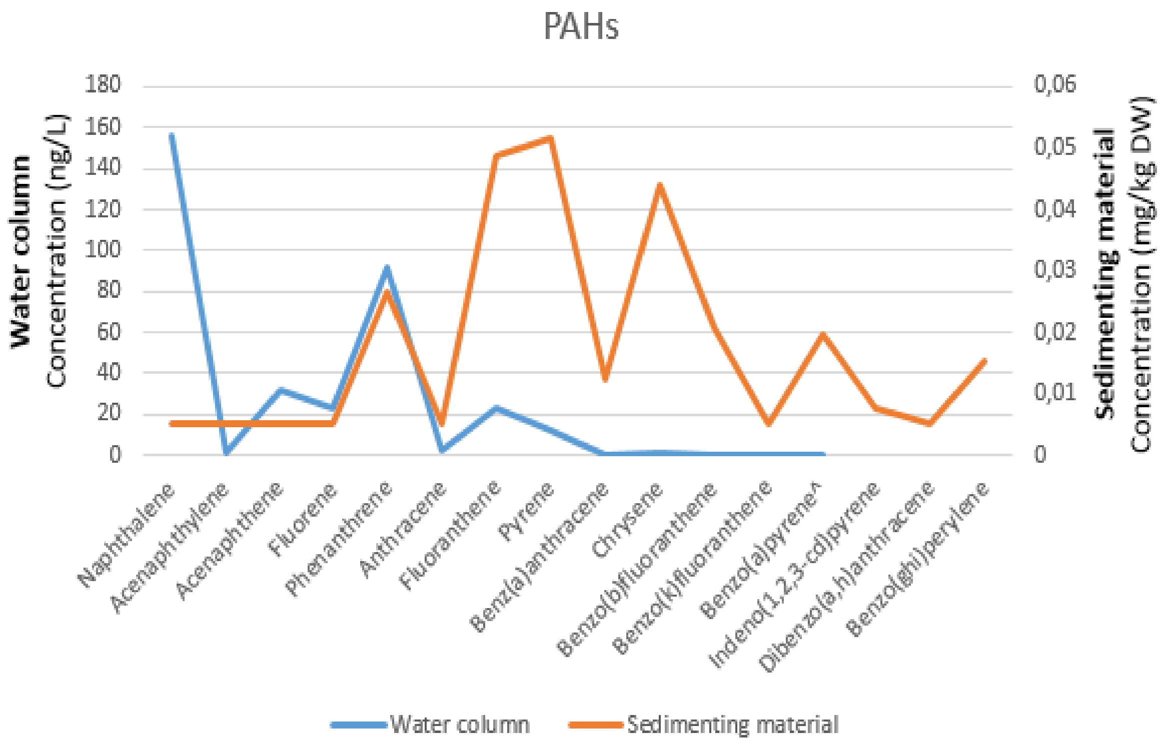


Figure 35. Average concentrations of PAHs in the sediment traps (n=3) and in the water column (n=2)(except POM2). *The x-axis shows an increasing molecular weight of the PAHs.*

Phenanthrene was the only low molecular weight PAH found above detection limit (0.010 mg/kg dry weight) in the sediment trap. It is not necessarily more hydrophobic than the other low molecular weight PAHs (and therefore found in higher concentrations in the sediment traps). Out from the molecular arrangement phenanthrene could actually be expected to be more soluble than fluorene and anthracene (which were found below detection limit, 0.010 mg/kg dry weight), as it has an angular structure, see *Figure 37***.** The reason is most likely that phenanthrene is found in higher concentrations in snow than the other low molecular weight PAHs, as found by Støver et al. (2007) and Larsen et al. (2003), see section 2.6.2.

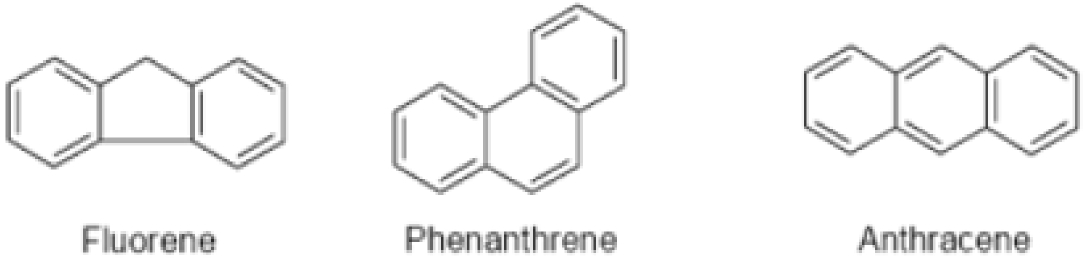


Figure 36*. Molecular arrangements of fluorene, phenanthrene and anthracene.*

High molecular weight PAHs were also detected in the POMs, which shows that despite being generally more hydrophobic than the low molecular weight PAHs (Neff, 1979), they can be dissolved in the water phase. Especially **fluoranthene and pyrene** were present in relatively high concentrations compared to the other high molecular weight PAHs (see section 7.6, Table 31). This can be explained by that they are the two PAHs present in higher concentrations in snow (see section 2.6.2) and that they are the lightest of the high molecular weight PAHs. The other high molecular weight PAHs, were found in lower concentrations in the POMs as they have lower concentrations in snow and are also more hydrophobic. Even in the sediment traps some of the high molecular weight PAHs were found low or below detection limit, reflecting their lower abundancy in snow.

8.5.4 Compared with snow samples

When comparing the distribution of PAHs found in the water column with the distribution found in the sedimenting material with the distribution of PAHs found in the snow samples taken in Trondheim by Støver et al. (2007), the distribution of PAHs in the sedimenting material fits best, see *Figure 38.*

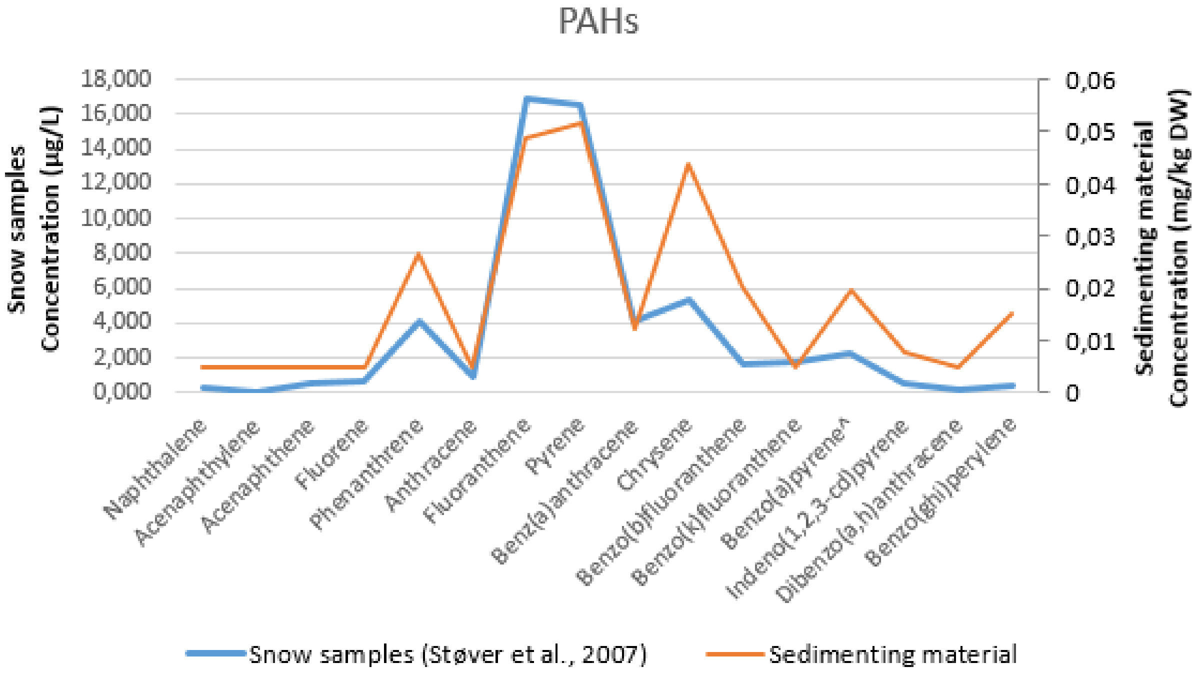


Figure 37. Distribution of PAHs in snow samples from Støver et al. (2007) compared with the distribution in the sedimenting material in this study.

This can therefore indicate that most of the PAHs in snow are particulate bound. The PAHs found in highest concentrations in the sedimenting material are also the PAHs found in highest concentrations in analysed snow samples in other studies (Støver et al., 2007, Viskari et al., 1997, Larsen et al., 2003, Ranneklev et al., 2013, Bækken, 1994), and are pyrene, fluoranthene, chrysene and phenanthrene. The snow therefore seems to contribute most with these PAHs in the particulate phase, but the concentrations are not high, since the concentrations in the sedimenting material were found in level I and II (see section 7.2.2).

In the water column naphthalene and phenanthrene seemed to have the highest concentrations, see *Figure 36*. In the snow samples Støver et al., (2007) and Larsen et al. (2003) analysed, naphthalene was found to be in lowest concentration and phenanthrene in highest concentration of the low molecular weight PAHs. So to what degree naphthalene comes from the snow is uncertain. When comparing the concentrations found in this study with the concentrations found in the water column in other areas in the harbour (using POM) in another study (see section 8.8.2) naphthalene was found in higher concentrations in the water column during snow dumping than in any of the other areas, which seems like a strong indication of that naphthalene mostly comes from the snow.

8.6 Deposition of the particles from the snow dumping

Sediment traps were placed in increasing distances from the pier (41, 89 and 136 m, see section 6.2.3) to study the degree of decrease in sedimenting material away from the pier, and samples from the top layer (0-2) in the sediment were taken in increasing distances out from the pier in 3 directions (see section 6.2.2) to study where the particles from the snow dumping seems to deposit. Since it was only 1 sample from each distance from the pier, p-value could not be calculated (except for the samples in direction North West) and the assumptions were therefore based on where the concentrations seemed to be higher. It was tried to estimate where most of the sedimenting material from the snow dumping deposited in the sediment, in **section 8.6.1**, and where the fine and coarse particles seem to deposit in the sediment, in **section 8.6.2**. In **section 8.6.3** the deposition of PAHs in the sediment are discussed briefly.

8.6.1 Sedimenting material

As it was most material in trap 1, less in trap 2 and least in trap 3 (see section 7.2.3), most material will sediment nearest the snow dumping site and the amount of sedimenting material will decrease with increasing distance from the pier. Within what distance most of the material will deposit is difficult to say exactly since traps were only out at 41, 89 and 136 m from the pier. But as it was substantially less material in trap 3 than in trap 1 and 2, it can be assumed that most material sediment within 100 m from the dumping site in the direction North East. Bækken and Tjomsland (2001) also found a similar assumption in their study of deposition in the river Drammenselva (see section 3.1) and suggested that most material would settle within 100 m from the dumping site.

The amount of particles less than 2 µm (clay size) were found to constitutes only a very small part of the weight in trap 1, only 3.1 % (see section 7.2.4). The material therefore seems to be dominated by coarser particles in the trap, which also were seen (see section 8.2).

8.6.2 Deposition of coarse and fine particles

Coarse particles

Coarse particles about 0.5 cm in diameter in the sediment are expected to originate from the snow, due to gritting of winter roads. Coarse particles were seen in all the sampling sites up to 250 m in the North East direction, with substantially most in sampling point 50 m out (see picture 24). This indicates that most of the coarser material sediment closer to the pier, but also out to about 250 m (see picture 25). In the sampling point 500 m out, very little coarse particles were seen (see picture 26). In the sampling points North West and North, the presence and amount of coarser particles are not known (as this was not checked during the sampling).

Picture 24. Coarse particles seen at sampling point 50 m out from pier 68 in the North East direction. Most coarse particles were seen at this sampling point.

Picture 25. Coarse particles seen at sampling point 250 m out from pier 68 in the North East direction.

Picture 26. Very few coarse particles were seen at sampling point 500 m out from pier 68 in the North East direction.

Fine particles

Fine particles are here referred to particles smaller than 0.6 mm in diameter. The fine particles are excepted to be transported further out than the coarser particles, before they deposit (see section 2.9). Since the finer particles can contain more metals per mass (Sansalone et al., 2003), it can be assumed that most of the finer particles have deposited where the concentrations are highest in the sediment.

In the direction *North East* it seems that the concentrations are highest around 50 m and 150 m from the pier, with highest concentrations around 50 m for all the metals (except Pb). See Figure 39 for **Cu, Ni** and **Pb** (the graphs for the other metals can be seen in appendix Q). It therefore seems that most of the finer particles sediment in an area around 50 m from the pier, and a large part also sediment around 150 m out. Leading to that these areas can be more prone to higher concentrations of metals. The sedimentation and the concentrations might be even higher closer to the pier if assuming that more of the material sediment closer to the dumping site. In one of the earlier sediment samples taken at pier 68 (see section 3.2), **Cu** was found in level III (51.8 mg / kg dry weight) in the sediment right outside the dumping site.

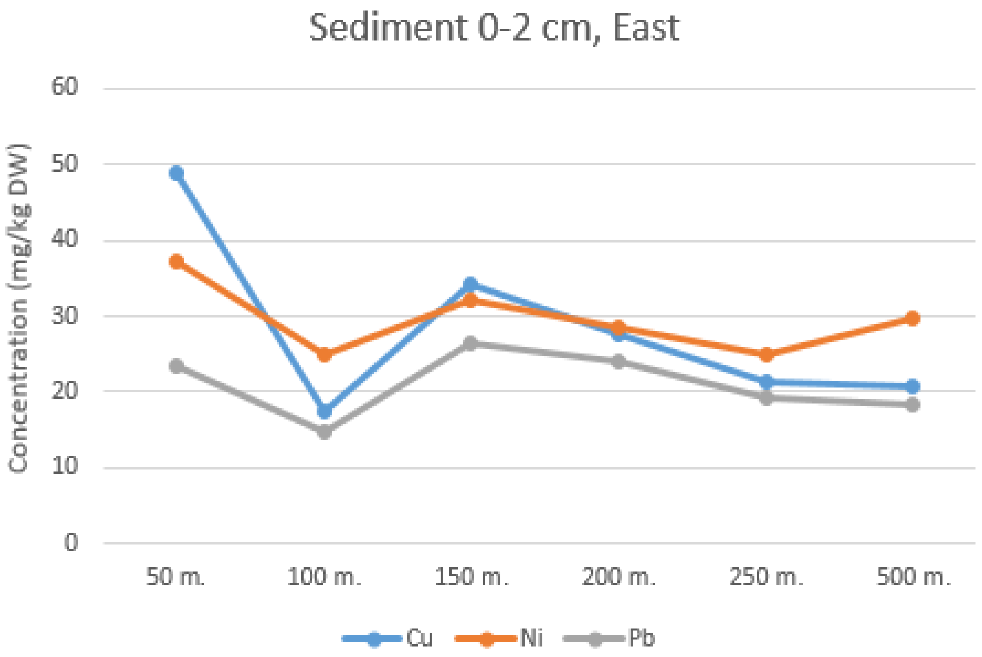


Figure 38. *Pb, Ni and Pb in the top sediment (0-2 cm) North East direction. The concentrations seem to be a bit higher in the sampling points 50 m and 150 m from the pier.*

In the sediment *North* of the pier, more variations were observed. **Ni, Zn, Cr** (see Figure 40) and **Cu** (see Figure 41) seem to have highest concentrations in the sample taken 200 m from the pier (Cu had also high concentration in the sample taken at 25 m) and **Cd** seem to have highest concentration in the sample taken 100 m from the pier. **Pb** and **Hg** increased in concentration for each sampling point, and **As** were almost the same in the samples taken 100, 200 and 500 m out, but seems to be higher here than 25 m out. Graphs for Ni, Zn, Cd, Pb, Hg and As can be seen in appendix Q.

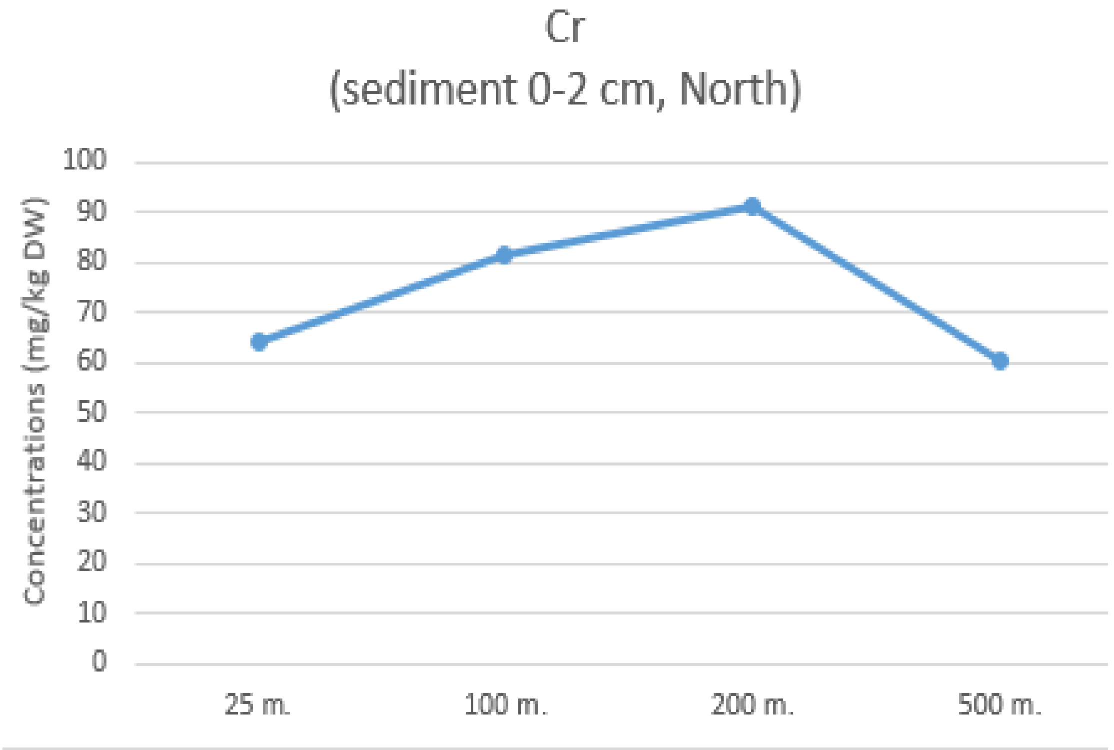


Figure 39. Concentrations of Cr found in the samples from top sediment North direction.

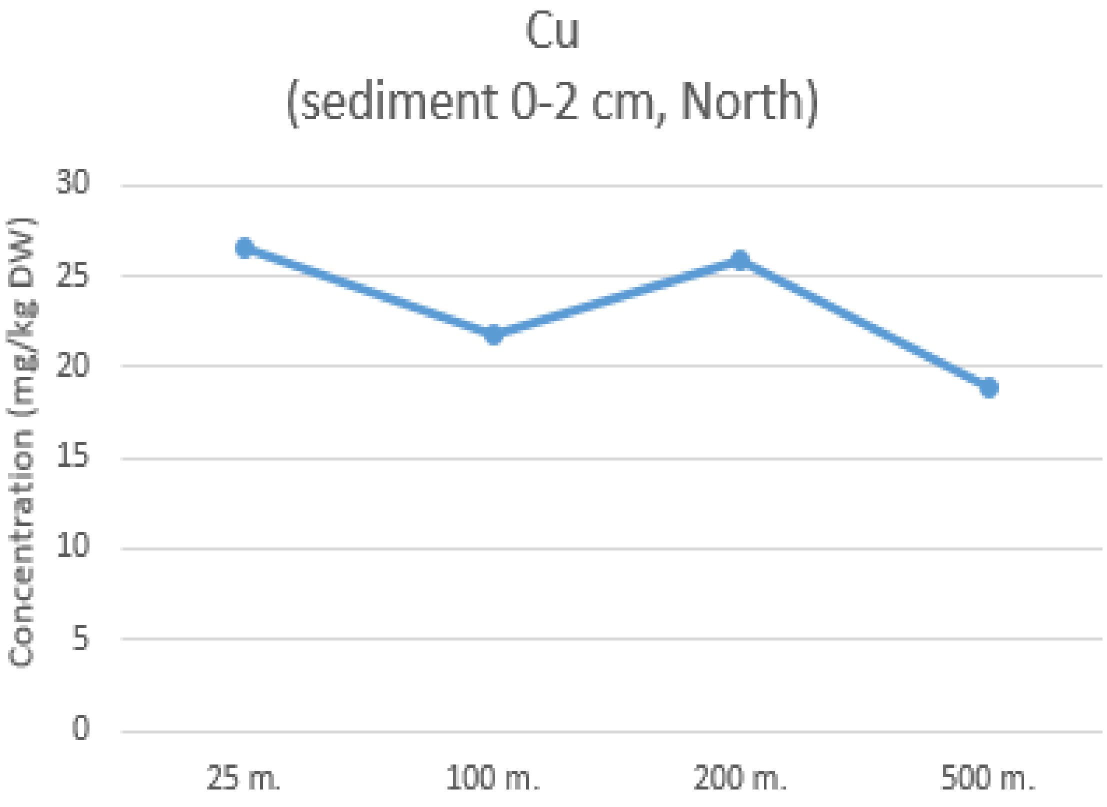


Figure 40. Concentrations of Cu found in the samples from top sediment North direction.

In the direction *North West*, **Pb, Cu, Cr** and **Ni** have significant higher average concentrations in the samples taken 150 m out than the samples taken 100 m out (p-values < 0.05, see appendix N). Graphs for Cu and Pb can be seen in Figure 42. The average concentrations for **As, Cd, Hg** and **Zn** were not significant different between the two sites (p-values > 0.05, see appendix N).

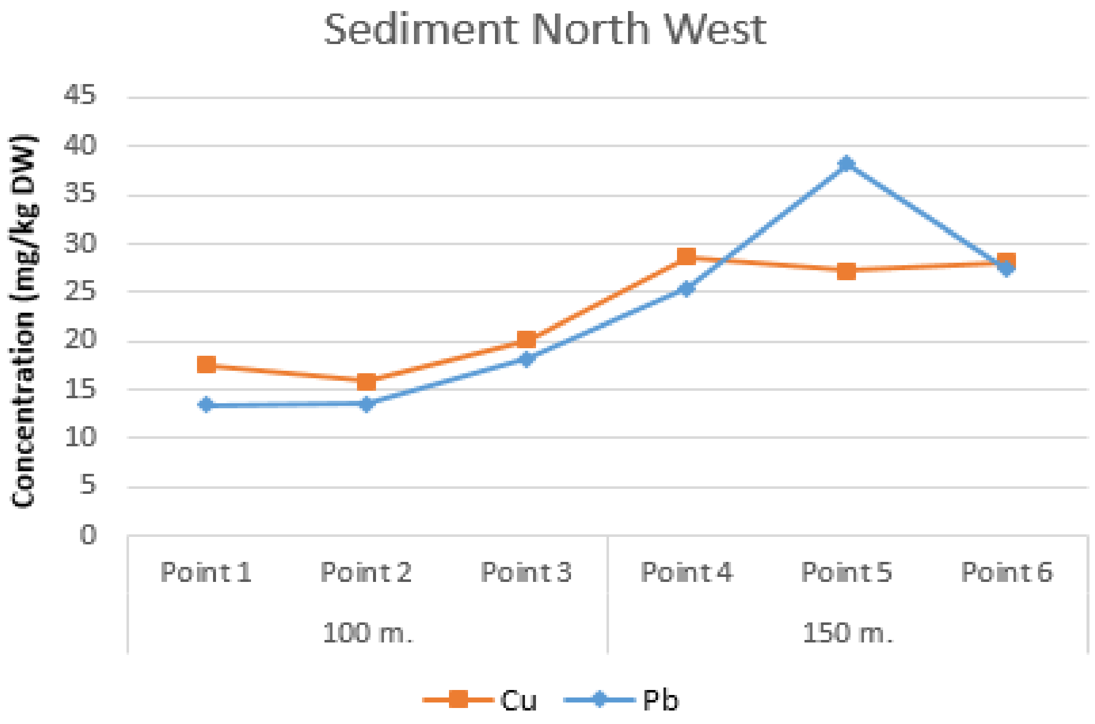


Figure 41. Cu and Pb in the top sediment North West direction.

Figure 43 shows an overview of where the different metals seems to have higher concentration in the sediment. It must be emphasised that the differences in concentrations are not large in reality, as the concentrations are in level I and II, which are considered as low concentrations. In addition, the sediment can be quite inhomogeneous that lead to a high degree of uncertainty.

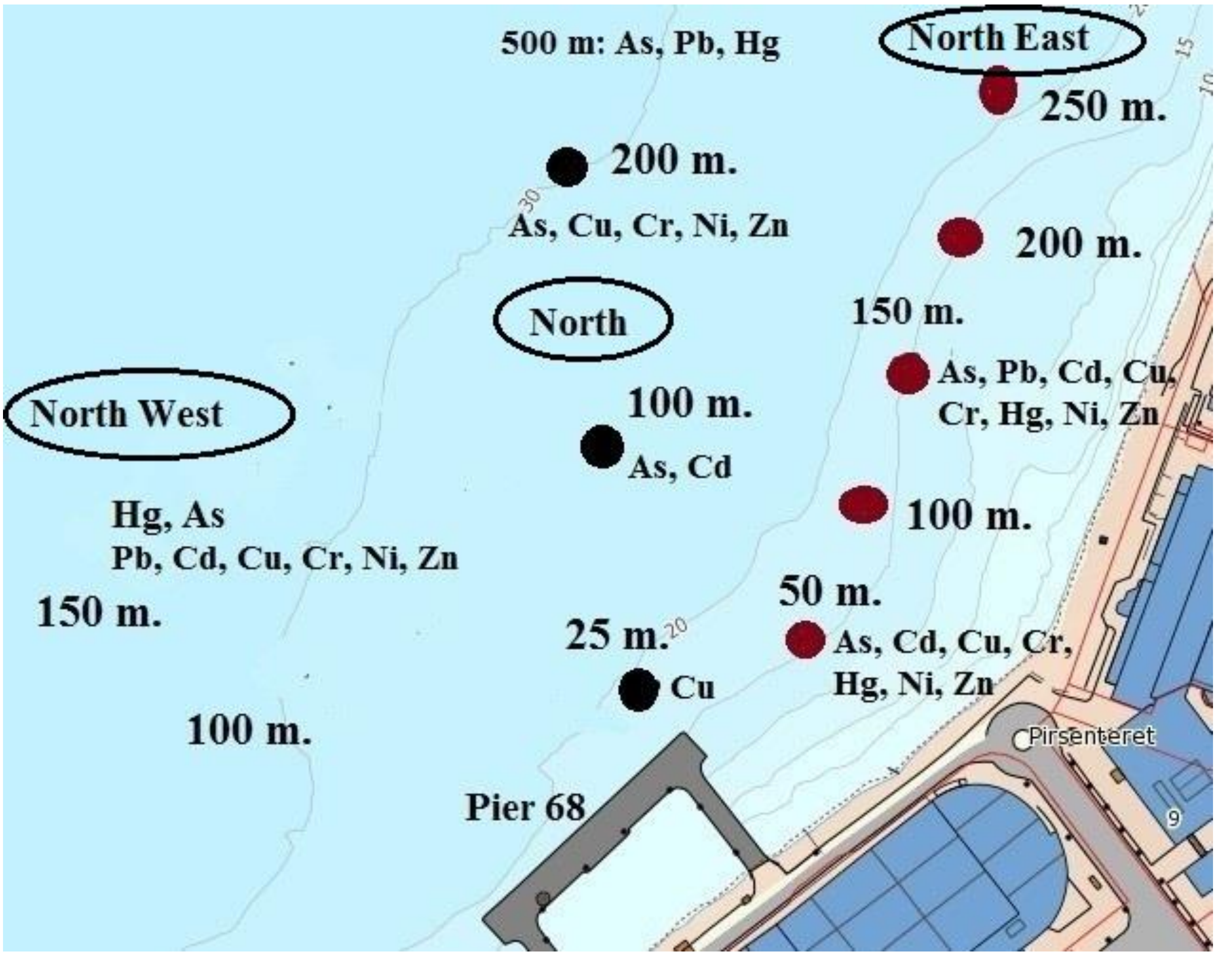


***Figure 42**. Overview over where in the sediment the metals <u>seems</u> to be in highest concentrations in the different directions. Pb, Cu, Cr and Ni had significantly higher average concentrations in the samples taken at 150 m than 100 m with a 95 % CI in the direction North West.*

It might be that the particles deposited somewhere else originally, but have been swirled up due to forces in the water, transported in the water and then deposited away from the original location. In the directions North West and North the cruise ships arriving to the pier can affect the sediment. The ships are very large leading to a lot of forces in the water during manoeuvring. Re-suspension due to propellers are believed to be a source of spread of sediment in areas shallower than 20 m (Daae and Rye, 2011). Since the depth is not much deeper than 20 m in the area outside the pier (see appendix C), the sediment will most likely be affected by the cruise ships. Especially the fine particles, that swirls up more easily (Schindl et al., 2005). The forces might also affect the sediment closest to the pier in the direction North East. The snow dumping itself can also lead to that sediment swirls up in the area outside the dumping site, and deposit further out. This could explain why high concentrations was seen both at 50 and 150 m out. The particles that deposit right outside the dumping site, might be swirled up due to the forces from the dumped snow and deposited again around 50 m out, while most of the fine particles in the area 150 m out have deposited from the melting snow.

The fine particles can also flocculate together and become larger(Neff, 1979)(Neff, 1979) and hence deposit faster in the sediment. Influence of river water can contribute with particles, but can also reduce the flocculation, due to lower salinity in the water (Neff, 1979). In addition, can currents and tidal affect the deposition. Many factors are therefore affecting the deposition of particles in the water.

8.6.3 Deposition of PAHs in the sediment

Since PAHs were not measured in the sediment samples, the deposition of PAH in the sediment is difficult to know anything about. But when looking at the concentrations found in the sediment traps, it looks like the concentrations of the detected PAHs are lower in trap 2, see *Figure 44***.** The differences are not large, but some of them are outside the measurement uncertainty.

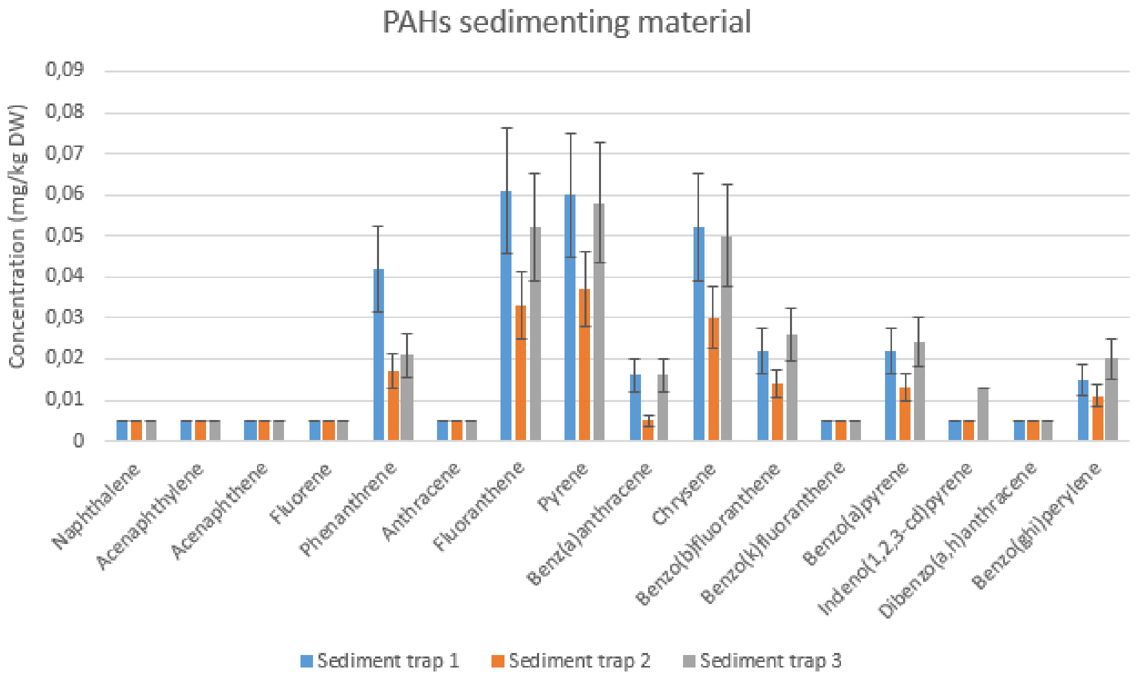


Figure 43. Concentrations of PAHs in the sediment traps. *The error bars show the measurement uncertainty, which is 25 % for all the PAHs found above the detection limit.*

This can indicate that particles sedimenting around 100 m from pier 68 in direction North East (where the trap was) can contain lower concentrations of PAHs, and some higher concentrations in the areas around 50 and 140 m from the pier.

8.7 PCBs

PCBs was measured in the water column by the POMs. Only 3 of the 7 PCBs were found above the detection limit, see Figure 44. The PCBs found in highest concentrations, and in all the traps were PCB-28 and PCB-52. The PCBs detected seems to be higher in POM1, which means in the area around 50 m from the pier in the direction North East. As for the PAHs in POMs, it is difficult to know how much that comes from the snow dumping, but as there seems to be highest concentration in POM1 (which is closer to the dumping site) this could indicate that the snow has affected.

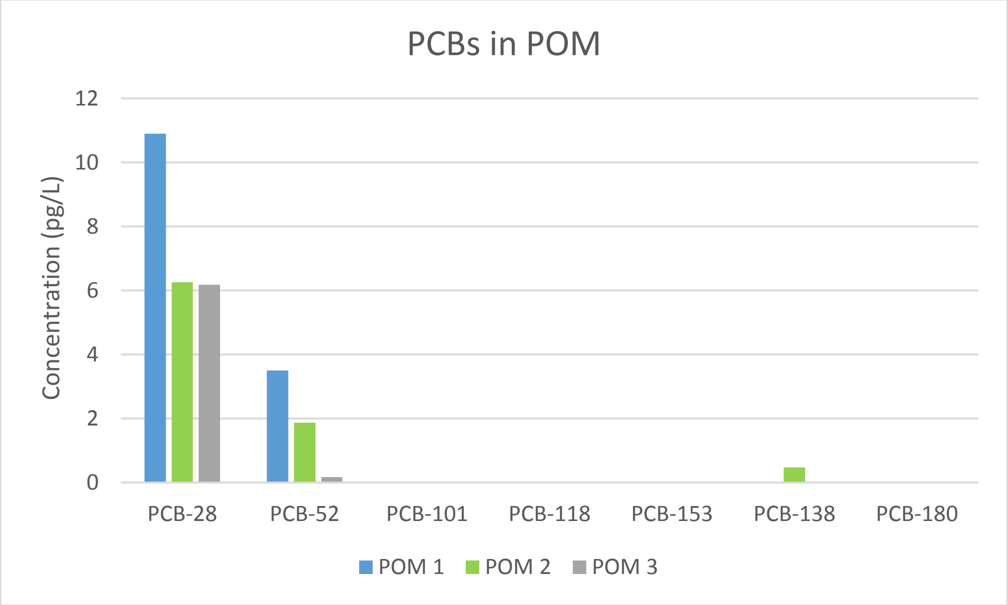


Figure 44. PCBs found in the water column.

8.8 Comparison with results from other areas in the harbour (other studies)

In this section the results from this study are compared with concentrations found in other areas in the harbour in previous measurements.

The section is divided into **8.8.1** Sedimenting material, **8.8.2** PAHs in the water column.

8.8.1 Sedimenting material

Amount

NGI had sediment traps out at different places in the harbour in 2009/2010 for 70 days and found the natural sedimentation to be 0.68 – 2.56 mm/year (NGI, 2011a, NGI, 2011b). Meaning that the sediment will have an increase of 0.68 – 2.56 mm each year due to natural sedimentation. As the material in the sediment traps were found to be 1.5-2 cm in height in the area within 100-120 m from the pier in the North East direction (see section 7.2.3) the snow dumping contributes with significantly more sedimenting material than the natural sedimentation in this area. Regarding mass, the weight of material from traps that were out at different places in the harbour from January – March 2015 (locations can be seen in appendix R) varied from 4.6 – 79 g. dry weight (NGI, 2015), while in the traps from the snow dumping the weight were more than 160 g. dry weight for trap 2 and 3, and more than 410 g. dry weight for trap 1 (see section 7.2.3). Again the mass from the snow dumping is larger.

With higher sedimentation, the need for dredging to maintain sufficient water depth increases. On the other hand, since the sediment is not very polluted in this area this eases the dredging process. Dredging in polluted sediment is much more demanding with respect to spread during the process and where to put the masses after dredging (pers. Communication Silje Salomonsen 16.05.12). On the long side of the pier the amount of sedimenting material is most likely less, and the cruise ships will contribute with spread of the sediment outside the pier.

Concentrations

When comparing the concentrations in the traps, the material in the traps that were out in other areas in the harbour in other studies, have mostly higher levels than found in the sediment traps in this study, see *Tables 40 and 41*. In the tables the average concentrations from the sediment traps outside pier 68 during snow dumping (this study) is shown to the right. The traps from 2009/2010 represent the natural sedimentation in the harbour around the traps (NGI, 2011b) and the traps from 2015 were meant to represent background concentrations in the "Cleaner harbour" project.

It can be seen from the tables that the concentrations found in the sediment traps during the snow dumping (this study) seem to have lower concentrations than found in the other traps. This can indicate that the material from the snow dumping have lower concentrations of metals than the natural sedimentation and background sedimentation in the studied areas.

Table 40. *Sediment traps in different areas in the harbour November 2009 to January 2010 (70 days) (NGI, 2011a, NGI, 2011b)(DW = dry weight).*

		Sediment traps **other areas** in the harbour (NGI, 2011a, NGI, 2011b)									**This study**
		F1	F2	F3	F4	F5	F6	F8	F9	F11	**Pier 68**
As	(mg/kg DW)	8.4	320	120	19	20	6.8	6.1	12	20	3.5 ± 0.75
Pb	(mg/kg DW)	39	490	280	75	84	43	36	100	42	9.6 ± 3.8
Cd	(mg/kg DW)	2.2	11	5.7	1.9	2.4	1.5	1.1	1.8	2.1	0.033 ± 0.0060
Cu	(mg/kg DW)	130	970	370	99	87	92	150	140	67	26 ± 1.5
Cr	(mg/kg DW)	61	69	73	75	79	78	41	75	71	22 ± 1.7
Hg	(mg/kg DW)	0.70	0.28	0.34	0.21	0.19	0.15	0.14	0.60	0.096	0.004 ± 0.0033
Ni	(mg/kg DW)	43	35	44	49	53	52	25	39	48	14 ± 1.7
Zn	(mg/kg DW)	280	1500	820	270	300	160	260	360	190	33 ± 0.58

Table 41. *Sediment traps in different areas than pier 68 in the harbour January to March 2015 (NGI, 2015)(DW = dry weight).*

		Sediment traps **other areas** in the harbour (NGI, 2015)								**This study**
		BI	I1	I2	N	K1	K2	K3	Ref	**Pier 68**
As	mg/kg DW	11	110	60	4.4	15	15	7.6	6.1	3.5 ± 0.75
Pb	mg/kg DW	56	240	120	24	71	56	30	23	9.6 ± 3.8
Cd	mg/kg DW	0.16	2.2	0.95	0.39	0.25	0.19	0.22	0.2	0.033 ± 0.0060
Cr	mg/kg DW	73	48	40	56	93	100	73	71	26 ± 1.5
Cu	mg/kg DW	59	5500	210	43	86	86	65	66	22 ± 1.7
Hg	mg/kg DW	<0.10	0.28	0.19	<0.10	0.16	<0.10	<0.10	<0.10	0.004 ± 0.0033
Ni	mg/kg DW	41	26	23	31	55	60	48	48	14 ± 1.7
Zn	mg/kg DW	110	2300	580	120	220	200	150	150	33 ± 0.58

PAHs

The concentrations of PAHs in the traps from the other areas in the harbour were also higher than in the traps during the snow dumping, see **Table 42.** Indicating that the snow don't contribute with very high concentrations of PAHs to the sediments, but as mentioned in section 8.5.2, the PAHs can accumulate in the sediment over time.

Table 42. Sediment traps other places in the harbour (in studies from (NGI, 2015)) compared with the average concentrations found in the sediment traps outside pier 68 during snow dumping. *The levels for the PAHs below detection limits in the traps from the other areas are set to level II (but might also be in level I).*

	Sediment traps other areas in the harbour (NGI, 2015)								
PAH (mg/kg DW)	**BI**	**I1**	**I2**	**N**	**K1**	**K2**	**K3**	**Ref**	**Pier 68**
Naphthalene	<0.050	<0.050	<0.050	0.16	0.14	0,062	<0.050	<0.050	<0.010
Acenaphthylene	<0.050	<0.050	<0.050	0.29	<0.050	<0,050	<0.050	<0.050	<0.010
Acenaphthene	<0.050	<0.050	<0.050	0.13	<0.050	<0,050	<0.050	<0.050	<0.010
Fluorene	<0.050	<0.050	<0.050	0.40	0.064	<0,050	<0.050	<0.050	<0.010
Phenanthrene	0.36	0.13	0.31	2.8	1.6	0.38	0.37	0.44	0.0267
Anthracene	0.088	0.067	0.10	0.85	0.20	0.15	0.056	0.059	<0.010
Fluoranthene	0.76	0.37	0.70	5.8	2.3	1,2	1.0	0.85	0.0487
Pyrene	0.53	0.30	0.56	4.0	1.3	0.82	0.66	0.56	0.0517
Benz(a)anthracene	0.25	0.16	0.28	2.1	0.29	0.32	0.14	0.11	0.0123
Chrysene	0.23	0.15	0.24	1.5	0.33	0.35	0.17	0.10	0.044
Benzo(b)-fluoranthene	0.22	0.13	0.26	1.8	0.26	0.32	0.12	0.11	0.0207
Benzo(k)-fluoranthene	0.13	0.098	0.16	0.90	0.17	0.19	0.080	0.060	<0.010
Benzo(a)pyrene	0.26	0.19	0.33	2.2	0,35	0.31	0.13	0.12	0.0197
Indeno(1,2,3-cd)-pyrene	0.24	0.15	0.30	2.3	0,33	0.32	0.15	0.13	<0.010
Dibenzo(a,h)-anthracene	<0.050	<0.050	0.052	0.28	<0.050	<0.050	<0.050	<0.050	<0.010
Benzo(ghi)-perylene	0.24	0.14	0.26	1.9	0.32	0.30	0.16	0.14	0.0153

8.8.2 PAHs in the water column

Compared with POMs that were out at different areas in the harbour in January to March 2015 (see locations in Appendix R) the concentrations found in the POMs outside pier 68 during dumping were in the same level (level II) for all the 16 PAHs, see **Table 43.**

Naphthalene was however observed to be higher in the POMs that were out during the snow dumping than in the other POMs, and POM 3 shows higher concentrations of acenaphthene, fluorene, fluoranthene and pyrene. This could indicate that the higher concentrations originate from the snow dumping, as it seems that lower concentrations are generally more common in the harbour.

Table 43. *POMs from (NGI, 2015) compared with POMs this study.*

		Average concentrations other areas in the harbour	Concentrations measured in this study (POM1)	Concentrations measured in this study (POM3)
Naphthalene	ng/L	17.6 ± 2.7	164 ± 33	148 ± 30
Acenaphthylene	ng/L	3.13 ± 0.31	1.21 ± 0.24	1.24 ± 0.25
Acenaphthene	ng/L	4.4 ± 0.47	6.25 ± 1.3	57.0 ± 11
Fluorene	ng/L	6.08 ± 0.57	7.66 ± 1.5	38.1 ± 7.6
Phenanthrene	ng/L	18.9 ± 4.9	33.3 ± 6.7	149 ± 30
Anthracene	ng/L	0.455 ± 0.24	0.546 ± 0.11	3.25 ± 0.65
Fluoranthene	ng/L	3.78 ± 1.3	7.58 ± 1.5	37.5 ± 7.5
Pyrene	ng/L	3.29 ± 1.4	6.10 ± 1.2	18.8 ± 3.8
Benz(a)anthracene	ng/L	0.116 ± 0.10	0.180 ± 0.036	0.393 ± 0.079
Chrysene	ng/L	0.311 ±0.16	0.780 ± 0.16	0.881 ± 0.18
Benzo(b)fluoranthene	ng/L	0.198 ± 0.13	0.286 ± 0.057	0.306 ± 0.061
Benzo(k)fluoranthene	ng/L	0.151 ± 0.11	0.174 ± 0.035	0.158 ± 0.032
Benzo(a)pyrene	ng/L	0.0628 ± 0.053	0.307 ± 0.061	0.0821 ± 0.016
Indeno(1,2,3-cd)pyrene	ng/L	0.0356 ± 0.020	n.d.	n.d.
Dibenzo(a,h)anthracene	ng/L	0.0101 ± 0.0050	n.d.	n.d.
Benzo(ghi)perylene	ng/L	0.019 ±0.0093	n.d.	n.d.
Sum PAH-16	ng/L	58.3 ± 5.9	164	148

8.9 Possible contribution from other sources

Since the sampling took place in open environment, other sources than the snow dumping might have contributed with metals and PAHs in the samples. Possible sources of metals and PAHs to sea water are, as mentioned in section, river inflow, atmospheric deposition, antifouling paints from boats, boat exhaust, oil leakage (PAH), creosote (PAHs), urban runoff, wastewater from industry or municipality, sewage and other nonpoint sources. Especially Pb, Cu and Cr can be found in in the water as they are often used in paint on boats and Cu which is used as an antifouling agent (SFT, 2000, Jartun and Volden, 2005).

There are industry areas and activities in the harbor (as mentioned in section), which can spread metals and PAHs to the basin where they can be spread further in the water. In Nyhavna, there is for instance a storage area for the metal debris, and there is found active spreading of the PAH, Pb, Cu and Zn to the basin in this area (Egede-Nissen et al., 2008). The wastewater treatment plants, Høvringen and Ladehammeren, have direct outlet in the fjord and discharge metals in the effluent water (Laugesen et al., 2003). In samples taken of the effluent water in 2005-2009 the average concentrations of for instance Cu were in level V (NGI, 2011b). There is a lot of boat traffic in the harbor and close to pier 68 the express ferry terminal lies, where there are daily departures. There is creosote impregnated pier structures in the harbor that can leak out PAH’s (Laugesen et al., 2003). Leaching from masses on land can also happen. In the area where pier 68 is located it is used masses corresponding to urban soil (Laugesen et al., 2003), which can leak out metals to the basin (NGI, 2011b). Activities in the harbour in connection with the “Cleaner Harbour” project could also have affected. The sand catch basins in the city have outlet in the fjord, leading to that material entering these can reach the fjord. River Nidelva can bring with it contaminants from sources along the river course and lead them out into the fjord. There is a large mass transport in Nidelva (NGI, 2011c).

How much each of the possible sources have contributed is uncertain as it was not studied in this thesis. The spread from industrial areas is most likely less during the winter as most of the spread to the basin occurs during flushing of the pier and runoff during rain. There is no industry in the actual sampling area and it can be assumed that the spread from other areas are relatively well diluted if/when they reach pier 68, but any influence cannot be excluded. There are few boats in the area outside pier 68, besides the express ferries During the sampling period in 2016 only one boat came to pier 68, a large marine boat. The boat used for the outset and uptake of the traps is also a possible source. The river has one of its outlets west of pier 68 and due to the surface currents the river water may spread to pier 68.

In the water samples and DGT's where samples were taken also after snow dumping, the assumptions about which metals that had an increase in concentration during the snow dumping and that was most likely caused by the snow dumping is strengthened. In the POM's it is more difficult to know how much of the concentrations that are caused by the snow dumping, as the POMs were only out during snow dumping. The same applies for sedimentation traps, but since the snow dumping contributes with much particulate material, the material in the traps would most likely be dominated by particles from the snow dumping. Natural sedimentation would have happened in the traps during the sampling time, but since the natural sedimentation in the harbor is found to be substantially lower than the sedimentation from the snow dumping (see section 8.8.1), it is believed that it had little contribution to the concentrations. Any contribution can be assumed to have affected most in trap 3, since this trap had least material. There was a possibility that material from covering of sediment in Brattøra could spread and deposit in traps. This would have been seen as lighter material in the traps, but since this was not seen it had probably little impact. In the sediment samples it is more difficult to know how much of the concentrations that have originated from the snow dumping, as the sediment can still have concentrations from earlier sources.

8.10 Method

8.10.1 Sample size

The sample size is low for the particulate phase snow samples (3 samples) and the surface water samples (1 sample from each sampling, except in April). More samples could have given more representative concentrations and showed more of the variation. It was for instance observed that samples taken right after each other in the surface water in April showed concentrations of As ranging from 0.955 to 2.02 µg/L which ends up in two different levels in the guideline. Few samples will therefore have less basis for certain conclusion. In addition, there are uncertainty in the results.

The DGTs was better covered as it was 3 replicates out at the same time, and 3 sediment traps in the studied area is also quite good covered.

The sediment is also quite good covered, with samples in different directions and different distances from the pier, but more replicates from each sample could have been taken to cover the concentration variations (inhomogeneity) in the sediment. In addition, only very small amounts of sediment were analyzed.

The sample size was a bit reduced due to that several different sampling methods were chosen to get a broader overview of the condition during the snow dumping and the number of samples therefore had to be reduced due to time and costs.

8.10.2 Spread in the results (RSD-values)

The relative standard deviation (RSD) values are higher in sea water than in the sediment samples. This is mainly because the metals are present in much lower concentrations in seawater. In addition, sea water is more difficult to analyse, as there are many ions present in higher concentrations. It is therefore difficult to measure metals in seawater and leads to more spread in the measurements and higher RSD values. Several metals have also concentrations close to the DL. Seawater samples are additionally diluted 10x because of all the ions in the sample. This makes it even harder to detect the already low concentrations of the metals. For the seawater samples, most of the RSD values were above 10, and some very high (up to around 100 %). Ideally they should be below 25 % for sea water and less than 10 % for sediment samples and the DGT samples. In the sediment samples, where metals are present in higher concentrations, the RSD values were lower. Most values were below 5 %. Which is good.

The same is seen in the snow samples, where there are higher concentrations of metals in the particulate material than in the dissolved phase, and thus lower RSD values in the analysis of the particulate material. Most RSD values were below 5 %, while in dissolved phase most values were between 10-20 %. The sediment samples and the particulate material in the snow samples therefore have a generally a lower spread in the measurements than the sea water samples and the dissolved phase snow samples and gives more reliable results.
The RSD values also varied among the different metals. Cu, and Zn had generally the lowest RSD values, which are most likely due to that they are present in highest concentrations. Hg

and Cd had often the highest RSD values due to that are present in lower concentrations and consequently more difficult to provide reliable measurements, as they are close to the detection limit.

8.10.3 Accuracy

Reference material, GBW-soil was analysed for validation (see section 6.5). The average recovery in % for the selected metals can be seen in **Table 44**. Overall, recovery for all selected elements were within 69 – 88 %, indicating that the method used for decomposition and ICP-MS analyses was acceptable.

Table 44. Recovery % for the analysed reference material (n=3).

Metal	Hg	Cr	Ni	Cu	Zn	Cd	Pb	As
Recovery (%)	75	86	84	78	80	84	69	88

8.10.4 Possible sources of errors

Sources of errors for all sample types will mainly be contamination, mistakes done during sample preparation / processing of the sample (wrong reading of the weight, wrong dilution, etc.), contamination from the material used, and interferences in the instrument. In addition, there are possible sources of errors which are specific for the different sample types.

In the snow samples and the seawater samples it might be that the filters emitted substances to the sample. For the snow samples this should be corrected for as blanks were used, but in the seawater samples this was not corrected. The snow samples were left on the bench until they had melted. This could have led to an inhomogeneous portioning of the metals in the aqueous phase, which also followed in the filtrated samples as the tubes were not shaken before a part of the sample was poured into the syringe. Leading to an underestimation or overestimation of some metals. For batch 2 the sample was shaken before it was poured into the syringe. For the particulate material in the snow samples, material could have been lost from the filters during sample preparation, leading to a different weight than initially weight. In addition, it was difficult to find the exact weight since the amount of material was so small. There were also many steps in the preparation leading to higher chance of contamination. In the sediment traps there could have been leftovers in the tubes from previous sampling, but the tubes should be well cleaned after previous use. The sediment samples taken from direction North West was prepared by an another person. Might be that the sample preparation was performed differently, even though the same procedure should have been followed. Some of the seawater and the DGT samples were stored before analysis. They were however stored at 4 degrees Celsius and the impact of this is probably less than if they had been analysed at different times. According to ISO 5667-3:2012, they should be analyzed within 6 months, which they were. Cigarette smoke can lead to contamination of the POM's, but this was avoided during output and uptake of the sediment traps, and should therefore not have affected.

Samples prepared and/or analysed on different days and/or different labs may have different sources of errors. This leads to different backgrounds for the samples and that they are not really comparable. Samples of the same type was prepared in the same lab (see section), but the sediment samples and the snow samples (batch 2) was prepared in a different lab than the DGTs and the filtrated snow samples (batch 1). They can therefore have different sources of errors, such as from the air in the lab, contamination from the bench etc. Samples from the same sampling round were analysed together, but samples from different sampling rounds, for example the sediment samples taken in October and the sediment samples taken in February were analysed on different days. This can lead to different sources of errors and a less equal comparison basis.

DGTs

Possible sources of errors in the DGTs are related to the preparations before and after sampling, that the DGTs had been used before, different temperature in the water than used in the calculations and wrong in the calculations. The preparations had several steps, involving weighing, diluting, and transfers, which lead to increased sources of errors and possible contamination. The tweezer could for instance have been contaminated and transferred this to the gels or the wrong number had been read from the weight. The gel could get cracks. It was difficult to see whether the rough side were placed up or down, and were most likely placed different ways in the DGTs. The DGTs had been used before. Substances from previous sampling could therefore be present if the DGTs were not cleaned properly. The DGTs could also be broken or damaged. The top was often very hard to open, and a tool was used to open some of the DGTs. The tool was however only used on the outside and did not touch the gel.. The DGTs that were out first were stored before the last DGTs were ready. This had most likely less impact than if they had been analyzed at different times. Biofouling were not seen on the DGTs when they were taken up.

The high concentrations in the 4 last DGTs from April are highly likely to be due to contamination. They were prepared in a different lab bench than the DGTs from January and February and at a different day (but same bench) as the other 2 DGTs from April, but the reason seems to be the plastic bag they were put in. They were put in a different type of plastic than the other DGTs, which might have led to the contamination. In addition, these DGTs were out for only 2 days. The contamination will have a larger effect when the sampling time is shorter (Børset, 2014).

The DGTs from January and February have also some high concentrations of Cu, and the concentrations are very variable for some of the DGTs that were out at the same time (see appendix M). For instance, from 1.03 – 15.9 µg/L in the first 3 DGTs. Whether this is due to contamination or if the concentrations vary due to natural variations in the water is uncertain. It could also be wrong in the weighting and/or dilution leading to such differences in the results. Also others have found that the DGTs are susceptible to contamination (Børset, 2014, Sæth, 2009).

8.10.5 Sampling methods

Sediment traps seems to be a good way to study the amount of sedimenting material from the snow dumping, but as the coarser particles also was decomposed during the analysis the result gives lower concentrations than the concentrations of the finer particles. Analyzing the finest and the coarsest in two different factions could have given more representative concentrations of the potential bioavailable concentrations of metals.

POMs to measure the PAH's and PCB's in water is a good method as very low concentrations, which would not have been detected in manual samples, could be detected. In addition, use of POMs is a simple method which is little time-consuming.

It may seem that taking manual water samples is better than using DGTs. Although manual water samples require more samples to cover a period, they can provide a more reliable result by avoiding all the possible sources of errors associated with DGTs. In addition, the DGTs are also a bit time consuming due to preparation before use and after sampling.

The sediment samples represent the concentrations in the sediment where the sample is taken. But as the sediment can be very inhomogeneous, concentrations may vary considerably within a small area, and the concentration obtained can therefore depend on were in the sediment the sample is taken.

Various sampling methods are not really comparable (as were done in this thesis), for example the manual water samples and the DGTs, as they measure by different principles and have different sources of errors associated with them. If manual water samples had been taken in the water column they would most likely showed different concentrations than measured in the DGTs.

9. Conclusion

The snow dumping seems to only have a marginal effect on water and sediment quality in the area used for snow dumping. Few of the metals were found in significantly higher concentrations in the surface water during the snow dumping period, and the concentrations were mostly in level I and II. The metals therefore seem to be generally well spread in the water, and/or the snow dumping don’t contribute with high concentrations. Cu differed from the other metals with high concentrations in the water column both during and after snow dumping, but might not be due to the snow dumping. The concentrations of PAHs in the water column seemed to be within acceptable concentrations, except for some very high concentrations around 100 m from the pier in the direction North East which might not be solely from the snow dumping. The sedimenting material seemed to have low concentrations of both metals and PAHs, and were found in lower concentrations than the natural sedimentation in the harbour. The snow dumping hence seem to contribute with quite clean masses, as is reflected in the sediment, where the levels I and II dominated for the selected metals. Cu however, as in water, seems to be prone to concentrations in level III and IV in the sediment, especially right outside the dumping site and around 50 m out in the direction North East. PAHs from the snow dumping might also accumulate in the sediment outside pier 68, leading to high concentrations.

The snow dumping will contribute with material to the sediment so the need for dredging increases, but as the sediment is not very polluted, this eases the dredging process. The winter this study was performed was a very snow rich year with a lot of snow dumping, so the amount of sedimenting material found in this study might not be every year.

Most of the material from the snow dumping will sediment within 100 m from the pier in direction North East, with most material closest to the pier. Most of the finer particles seem to sediment 150 m from the pier in the direction North West, and 50 and 150 m in the direction North East. In the North direction most sedimented around 200 m from the pier.

The results from this study show much of the same as previous studies on snow dumping in harbours and rivers other places.

10. Further work

Further work can be to:

- Study whether high concentrations of acenaphthylene, phenanthrene, fluoranthene and pyrene in the water column can come from the snow dumping.
- Take more samples in the sediment in the areas where the concentrations seem to be higher, to get an overview over the condition in the sediment. Especially outside the dumping site and in the area around 50 m from pier 68 in the North East direction.
- Take snow samples regularly to keep track of the concentrations and pollutants in the snow.
- Log all the snow dumping to have an overview of the amount of snow dumped in the harbour.
- To study whether the PAHs from the snow dumping accumulate in the sediment and lead to the high concentrations.
- The snow dumping could be considered moved to other areas in the harbour to contribute with dilution in the sediment, especially in polluted areas.

Reference list

AAMOT, E., STEINNES, E. & SCHMID, R. 1996. Polycyclic aromatic hydrocarbons in Norwegian forest soils: Impact of long range atmospheric transport. *Environmental Pollution,* 92**,** 275-280.

ALLOWAY, B. J. 2013. *Heavy metals in soils. Trace Metals and Metalloids in Soil and their Bioavailability,* Whiteknights, Reading, UK, Springer.

AMLO, S. & BAKKE, K. 2010. Kartlegging av nyere fraksjoner av farlig avfall i bygg. In english: Identification of new building components that should be classified as hazardous waste.

ANDERSEN, M. K., ATAEI, M., BURAAS, I. K., DREIÅS, G. M., GABRIELSEN, K. M., GRANLY, T., HOLTEN, M. A., ISAKSEN, M. E., LILLEVIK, M., LØNMO, N. H., MOEN, I. M., PAULSRUD, L. E., RUSTI, E. H., SOM, B. & SØRENSEN, L. 2009. Kartlegging av miljøgifter i eksteriørmaling på bygninger i Midtbyen i Trondheim. In english: Mapping of pollutants in exterior paint on buildings in central Trondheim. Trondheim.

ANDERSSON, M., EGGEN, O., FINNE, T. E. & OTTESEN, R. T. 2011. Områder i Norge med naturlig høyt bakgrunnsnivå (over normverdi) - betydning for disponering av masser. In english: Areas in Norway with naturally high background levels (above the norm value) - impact on the disposition of masses.: NGU.

BAKKE, T., BREEDVELD, G., KÄLLQVIST, T., OEN, A. & EEK, E. 2007. Veileder for klassifisering av miljøkvalitet i fjorder og kystfarvann - Revisjon av klassifisering av metaller og organiske miljøgifter i vann og sedimenter 2229/2007. In English: Guidelines on classification of environmental quality in fjords and coastal waters – A revision of the classification of water and sediments with respect to metals and organic contaminants 2229/2007.

BAKKEN, T. 2000. Topografien i Trondheimsfjorden (The topography in the Trondheimsfjord). *In:* SAKSHAUG, E. & SNELI, J.-A. (eds.) *Trondheimsfjorden.* Trondheim: Tapir forlag.

BELL, S. 2001. A Beginner's Guide to Uncertainty of Measurement. U.K.: The National Physical Laboratory.

BJØRGAAS, H. 2010. *Spatial and Temporal Variations in Urban Snow Quality in the city of Trondheim, Norway.* Master Thesis, NTNU.

BREEDVELD, G., SKEI, J. & HAUGE, A. 2010. Contaminants in Norwegian fjord sediments: industrial history or future source? *Journal of Soils and Sediments,* 10**,** 151-154.

BRULAND, K. W. & LOHAN, M. C. 2003. Controls of Trace Metals in Seawater. *Treatise on Geochemistry,* 6**,** 23-47.

BRUZZONITI, M. C., FUNGI, M. & SARZANINI, C. 2010. Determination of EPA's priority pollutant polycyclic aromatic hydrocarbons in drinking waters by solid phase extraction-HPLC. *Analytical Methods,* 2**,** 739-745.

BÆKKEN, T. 1994. Trafikkforurenset snø i Oslo. In english: Traffic polluted snow in Oslo.

BÆKKEN, T. & TJOMSLAND, T. 2001. Trafikkforurenset snø i Drammen sentrum Konsekvenser av snødumping for vann- og sedimentkvalitet i Drammenselva. In english: Traffic polluted snow i Drammen city. The consequences of snow dumping for the water and sediment quality in the River Drammenselva.

BØRSET, K. 2014. *Uttesting av stabiliteten til DGT-prøvetakere for metallbestemmelse. (In english: Testing of the stability of DGT samplers for metal determination).* Master, NTNU.

CH2M 2006. Evaluation of Snow Disposal into Near Shore Marine Environments. Alaska.

DAAE, R. L. & RYE, H. 2011. Oppvirvling av sediment fra skipstrafikk i Trondheim Havn.

DAVIS, A. P., SHOKOUHIAN, M. & NI, S. 2001. Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere,* 44**,** 997-1009.

DUFFUS, J. H. 2002. " Heavy metals" a meaningless term?(IUPAC Technical Report). *Pure and Applied Chemistry,* 74**,** 793-807.

EGEDE-NISSEN, C., EINARSDÓTTIR, D. M., HAUG, S., HOVDE, G., NAUSTE, K. B. & SKÅRN, J. S. 2008. Kartlegging og identifisering av aktive forurensningskilder til havnebassenget i Trondheim.

FERNANDES, M. B., SICRE, M. A., BOIREAU, A. & TRONCZYNSKI, J. 1997. Polyaromatic hydrocarbon (PAH) distributions in the Seine River and its estuary. *Marine Pollution Bulletin,* 34**,** 857-867.

FHI. 2005. *Veitrafikk og luftforurensninger* [Online]. Available: http://www.fhi.no/artikler/?id=52167 [Accessed 05.03.16].

FLORENCE, T., MORRISON, G. & STAUBER, J. 1992. Determination of trace element speciation and the role of speciation in aquatic toxicity. *Science of the Total environment,* 125**,** 1-13.

GLENN, D., III & SANSALONE, J. 2002. Accretion and Partitioning of Heavy Metals Associated with Snow Exposed to Urban Traffic and Winter Storm Maintenance Activities. II. *Journal of Environmental Engineering,* 128**,** 167-185.

HANSEN, H. T. 2015. *Retningslinjer for håndtering av snø vintersesong 2015/16 - Harstad Kommune. (In english: Guidelines for snow handling winter season 2015/16 - Harstad municipality)* [Online]. Harstad Kommune. Available: http://www.harstad.kommune.no/retningslinjer-for-handtering-av-sno-vintersesong-201516-harstad-kommune.5804570-177575.html [Accessed 2015.11.02].

HARRIS, D. C. 2010a. Quality Assurance and Calibration Methods. *Quantitative Chemical Analysis.* 8th ed. USA: W. H. Freeman and Company.

HARRIS, D. C. 2010b. Statistics. *Quantitative Chemical Analysis.* USA: W. H. Freeman and Company.

HÅØYA, A.-O. & AABØE, R. 2004. Gjenbruk av bildekk i vegbygging – Tekniske og miljøtekniske vurderinger (Reuse of tires in road construction - Technical and environmental engineering assessments). *Gjenbruksprosjektet; 5.* Statens Vegvesen.

JARTUN, M. & VOLDEN, T. 2005. Miljøtilstanden ved opplagsplasser og pussesteder ved 11 småbåthavner i Trøndelag.

KENNISH, M. J. 2000. *Practical handbook of marine science*, crc press.

LARSEN, L.-H., EVENSET, A., BERG, I. A. T. K. & SKJEGSTAD, N. 2003. Opprydding av forurenset sediment i Tromsø havn; Kartlegging av kilder til forurensning i Tromsø indre havneområde og Tromsøysund. (Cleanup of contaminated sediments in Tromsø harbor ; Mapping of the sources of pollution in Tromsø inner harbor area and Tromsøysund.). Tromsø: Akvaplan-niva.

LAUGESEN, J., MØSKELAND, T. & KELLEY, A. 2003. Tiltaksanalyse for opprydding i forurensede sedimenter i Trondheim havn og omgivelser. (Measures Analysis for cleanup of contaminated sediments in Trondheim harbor and surroundings).

MANAHAN, S. E. 2010. *Environmental chemistry,* Florida, USA, CRC Press Taylor & Francis Group.

METEOROLOGISK INSTITUTT. 2016. *Været som var (detaljert)Trondheim (Sør-Trøndelag). In english:* [Online]. Available: https://www.yr.no/sted/Norge/S%C3%B8r-Tr%C3%B8ndelag/Trondheim/Trondheim/detaljert_statistikk.html [Accessed 2016.04.02.

MILER, M. & GOSAR, M. 2009. Characterisation of solid airborne particles in urban snow deposits from Ljubljana by means of SEM/EDS = Opredelitev trdnih zracnih delcev v sneznem depozitu iz urbanega obmocja Ljubljane s SEM/EDS. *RMZ - Materials and geoenvironment,* 56**,** 266-282.

MILESTONE. not dated. *UltraCLAVE* [Online]. Available: http://www.milestonesci.com/#!ultraclave/zv3oi.

MILJØDIREKTORATET. 2013. *Opprydding i prioriterte områder. (In english: Cleanup in priority areas).* [Online]. Miljødirektoratet (the Norwegian Environment Agency) Available: http://www.miljodirektoratet.no/no/Tema/Forurenset_sjobunn/Opprydding-i-prioriterte-omrader/ [Accessed 05.02. 2016].

MILJØDIREKTORATET. 2015. *Polyklorerte bifenyler (PCB) (In english: Polychlorinated biphenyls (PCB))* [Online]. Miljødirektoratet (The Norwegian Environment Agency). Available: http://www.miljostatus.no/Tema/Kjemikalier/Noen-farlige-kjemikalier/PCB/ [Accessed 2016 05 09].

NCC. not dated. *Snøsmelteanlegget (In english: snow melting tank)* [Online]. Available: http://www.ncc.no/prosjekter/snosmelteanlegget/ [Accessed 2016.01.02].

NEFF, J. M. 1979. *Polycyclic aromatic hydrocarbons in the aquatic environment : sources, fates and biological effects.,* London, Applied Science Publ.

NEFF, J. M. 2002. Bioaccumulation Mechanisms. *Bioaccumulation in marine organisms: effect of contaminants from oil well produced water.* Elsevier.

NGI. 2010. *Plaststrimler mot forurensning. (In english: plastic strips against pollution.)* [Online]. forskning.no. Available: http://forskning.no/miljoovervakning-kjemi/2010/04/plaststrimler-mot-forurensning [Accessed 2016.02.05.

NGI 2011a. Delrapport 1A: Datarapport. Rev.01.

NGI 2011b. Delrapport 1B: Risikovurdering. Rev.01.

NGI 2011c. Trondheim Havn. Helhetlig tiltaksplan for Trondheim havnebasseng, delrapport 4, tiltaksplan.

NGI 2015. Månedsrapport mars og april 2015. (In english: Monthly report March and April 2015.).

OTTESEN, R. T. Forurensning i bymiljø. Hvor ren er gammel asfalt? (Pollution in urban environment. How clean is old asphalt?). NGU.

OTTESEN, R. T. 2015. *Overbank-sediments* [Online]. NGU,. Available: https://www.ngu.no/en/topic/overbank-sediments [Accessed 2016.03.02.

OTTESEN, R. T. & LANGEDAL, M. 2006. Byjord - En giftig historie. (In english: Urban soil - A toxic history).

OTTESEN, R. T., LANGEDAL, M., CRAMER, J., ELVEBAKK, H., FINNE, T. E., HAUGLAND, T. & JÆGER, Ø. 2001. Forurenset grunn og sedimenter i Trondheim Kommune: Datarapport. In english: Contaminated soil and sediments in Trondheim Municipality: Data Report. Trondheim: NGU.

OTTESEN, R. T., STØVER, L. & BERTHELSEN, B. O. 2011. Helse- og miljøskadelige stoffer i støtdempende fallunderlag på lekearealer for barn.

PETTERSEN, A. & BREEDVELD, G. 2009. Dypvannsdeponi ved Malmøykalven Sluttrapport del 1: Miljøkvalitet.

QIAN, Y., YASUNARI, T. J., DOHERTY, S. J., FLANNER, M. G., LAU, W. K. M., MING, J., WANG, H., WANG, M., WARREN, S. G. & ZHANG, R. 2014. Light-absorbing particles in snow and ice: Measurement and modeling of climatic and hydrological impact. *Advances in Atmospheric Sciences,* 32**,** 64-91.

RANNEKLEV, S. B., TJOMSLAND, T. & KEMPA, M. 2013. Dumping av trafikkforurenset snø fra Drammen sentrum ved Holmennokken. Konsekvenser for vann-og sedimentkvalitet i Drammenselva og Drammensfjorden. In english: Dumping of traffic polluted snow from Drammen center at Holmennokken. Consequences for water and sediment quality in river Drammenselva and in the Drammensfjord.: NIVA.

REASEARCH, D. 2015. *Background and Theory of DGT* [Online]. Available: http://www.dgtresearch.com/dgtresearch/dgtresearch.pdf [Accessed 2016.06.01.

REINOSDOTTER, K. & VIKLANDER, M. 2006. Handling of Urban Snow with Regard to Snow Quality. *Journal of Environmental Engineering,* 132**,** 271-278.

REINOSDOTTER, K., VIKLANDER, M. & MALMQVIST, P.-A. 2003. Comparison of the effects of using local and central snow deposits: A case study in Luleå. *Water Science and Technology,* 48**,** 71-79.

SANDEFJORD 2005. Trafikkforurenset snø analysering av miljøgifter.

SANSALONE, J. & BUCHBERGER, S. 1996. Characterization of Metals and Solids in Urban Highway Winter Snow and Spring Rainfall-Runoff. *Transportation Research Record: Journal of the Transportation Research Board,* 1523**,** 147-159.

SANSALONE, J. & BUCHBERGER, S. 1997. Partitioning and First Flush of Metals in Urban Roadway Storm Water. *Journal of Environmental Engineering,* 123**,** 134-143.

SANSALONE, J., GLENN III, D. & TRIBOUILLARD, T. 2003. Physical and Chemical Characteristics of Urban Snow Residuals Generated from Traffic Activities. *Water, Air, and Soil Pollution,* 148**,** 45-60.

SANSALONE, J. J. & GLENN, D. W. 2002. Accretion of Pollutants in Snow Exposed to Urban Traffic and Winter Storm Maintenance Activities. I. *Journal of Environmental Engineering,* 128**,** 151-166.

SCHINDL, G., STUDNICKA, M., ECKELHART, A. & SUMMER, W. Hydrological and instrumentation aspects of monitoring and analysing suspended sediment transport crossing international borders. Sediment budgets: proceedings of the International Symposium on Sediment Budgets: held during the Seventh Scientific Assembly of the International Association of Hydrological Sciences (IAHS) at Foz do Iguaço, Brazil, 3-9 April, 2005, 2005. IAHS Press, 227.

SFT 2000. Miljøgifter i norske fjorder. Ambisjonsnivåer og strategi for arbeidet med forurenset sjøbunn. In english: Pollutants in Norwegian fjords. Ambition levels and strategy for work on contaminated sediments. Oslo.

SNEDDON, J., MASURAM, S. & RICHERT, J. C. 2007. Gas Chromatography-Mass Spectrometry-Basic Principles, Instrumentation and Selected Applications for Detection of Organic Compounds. *Analytical Letters,* 40**,** 1003-1012.

SNILSBERG, GUSTAFSSON & TERVAHATTU 2008. MILJØVENNLIGE VEGDEKKER Statusrapport på støv for Norge, Sverige og Finland.

STUMM, W. & MORGAN, J. J. 1996. *Aquatic chemistry: chemical equilibria and rates in natural waters.*

STØVER, L., BERTHELSEN, B. O., LANGEDAL, M. & SKAR, O. 2007. Innhold av miljøgifter i snø som dumpes i havnebassenget. (In english: Contents of contaminants in snow dumped in the harbour basin).

SÆTH, E. S. 2009. *Bruk av ICP-MS på filtrerte og ufiltrerte prøver og test av DGT for studier av metallers mobilitet i myr og våtmark med avrenning til vassdrag. In english: Use of ICP-MS on filtered and nonfiltered samples and test of DGT for the study of metals mobility in svamp and wetland with runoff into watercourses.* Master Thesis, NTNU.

THOMAS, R. 2004. *Practical guide to ICP-MS,* New York, U.S.A., Marcel Dekker, Inc.

TRONDHEIM KOMMUNE. 2015. *Salting og strøing. (Salting and gritting)* [Online]. Available: https://www.trondheim.kommune.no/content/1117715543/Stroing-og-salting [Accessed 2016.01.05.

TRONDHEIM KOMMUNE. 2016. *Brøyting. In english: plowing* [Online]. Available: https://www.trondheim.kommune.no/content/1117712643/Broyting [Accessed 2016.03.05.

VIKLANDER, M. 1997. *Snow quality in urban areas.*

VISKARI, E. L., REKILÄ, R., ROY, S., LEHTO, O., RUUSKANEN, J. & KÄRENLAMPI, L. 1997. Airborne pollutants along a roadside: Assessment using snow analyses and moss bags. *Environmental Pollution,* 97**,** 153-160.

VRANA, B., ALLAN, I. J., GREENWOOD, R., MILLS, G. A., DOMINIAK, E., SVENSSON, K., KNUTSSON, J. & MORRISON, G. 2005. Passive sampling techniques for monitoring pollutants in water. *TrAC Trends in Analytical Chemistry,* 24**,** 845-868.

WAG SOLUTIONS. not dated. *POM material* [Online]. Available: http://wag-solutions.no/pom-material/ [Accessed 2016.02.15].

WAGNER, K. 2004. *The use of diffusive gradients in thin films (DGT) for monitoring U and other trace metals in freshwater creeks potentially impacted by mining activities.* BSc, Charles Darwin University.

WHITE, K. E. 2005. *Bioavailability of Polycyclic Aromatic Hydrocarbons in the Aquatic Environment. (under the direction of Damian Shea). .*

WITT, G. 1995. Polycyclic aromatic hydrocarbons in water and sediment of the Baltic Sea. *Marine Pollution Bulletin,* 31**,** 237-248.

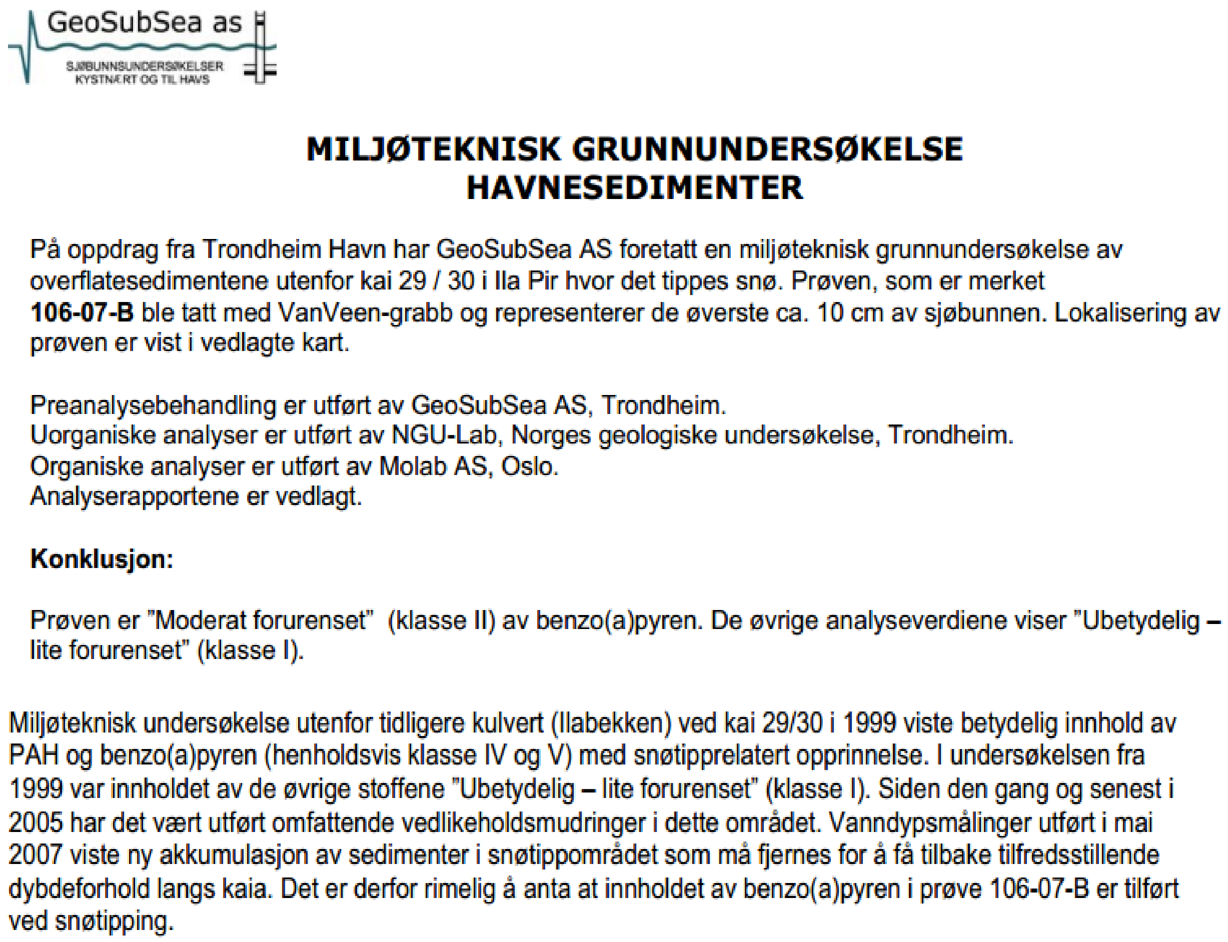
ZHANG, H. & DAVISON, W. 1994. In situ speciation measurements of trace components in natural waters using thin-film gels. *Nature,* 367**,** 546-548.

ZHANG, H. & DAVISON, W. 1995. Performance Characteristics of Diffusion Gradients in Thin Films for the in Situ Measurement of Trace Metals in Aqueous Solution. *Analytical Chemistry,* 67**,** 3391-3400.

ZITKO, V. 2000. Marine Pollution. *In:* WANGERSKY, P. J. (ed.) *Marine Chemistry.* Berlin, Heidelberg: Springer Berlin Heidelberg.

Appendix A: GeoSubSea 2007

Pier 29/30



GeoSubSea as
SJØBUNNSUNDERSØKELSER
KYSTNÆRT OG TIL HAVS

MILJØTEKNISK GRUNNUNDERSØKELSE HAVNESEDIMENTER

På oppdrag fra Trondheim Havn har GeoSubSea AS foretatt en miljøteknisk grunnundersøkelse av overflatesedimentene utenfor kai 29 / 30 i Ila Pir hvor det tippes snø. Prøven, som er merket **106-07-B** ble tatt med VanVeen-grabb og representerer de øverste ca. 10 cm av sjøbunnen. Lokalisering av prøven er vist i vedlagte kart.

Preanalysebehandling er utført av GeoSubSea AS, Trondheim.
Uorganiske analyser er utført av NGU-Lab, Norges geologiske undersøkelse, Trondheim.
Organiske analyser er utført av Molab AS, Oslo.
Analyserapportene er vedlagt.

Konklusjon:

Prøven er "Moderat forurenset" (klasse II) av benzo(a)pyren. De øvrige analyseverdiene viser "Ubetydelig – lite forurenset" (klasse I).

Miljøteknisk undersøkelse utenfor tidligere kulvert (Ilabekken) ved kai 29/30 i 1999 viste betydelig innhold av PAH og benzo(a)pyren (henholdsvis klasse IV og V) med snøtipprelatert opprinnelse. I undersøkelsen fra 1999 var innholdet av de øvrige stoffene "Ubetydelig – lite forurenset" (klasse I). Siden den gang og senest i 2005 har det vært utført omfattende vedlikeholdsmudringer i dette området. Vanndypsmålinger utført i mai 2007 viste ny akkumulasjon av sedimenter i snøtippområdet som må fjernes for å få tilbake tilfredsstillende dybdeforhold langs kaia. Det er derfor rimelig å anta at innholdet av benzo(a)pyren i prøve 106-07-B er tilført ved snøtipping.

SAMMENSTILLING AV ANALYSEDATA

Prøvenr.: **106-07-B**	**Område:** Kai 29/30, Ila Pir, Trondheim havn		**Dato:** 24.08.2007
Koordinater (EU89 UTM) E / N	568099	7034610	**Vanndyp:** ca. 8 m
Instrument: VanVeen-grabb - overflateprøve			

Klassifisering iflg. SFT 97:03	
I	Ubetydelig – lite forurenset
II	Moderat forurenset
III	Markert forurenset
IV	Sterkt forurenset
V	Meget sterkt forurenset

Analysedata

Element / kjemisk forbindelse		0 – ca. 10 cm	SFT 97: 03
As (Arsen)	mg/kg (ppm)	<	I
Cd (Kadmium)	mg/kg (ppm)	<	I
Cr (Krom)	mg/kg (ppm)	40,4	I
Cu (Kobber)	mg/kg (ppm)	23,3	I
Ni (Nikkel)	mg/kg (ppm)	28,1	I
Pb (Bly)	mg/kg (ppm)	7,3	I
Zn (Sink)	mg/kg (ppm)	49,3	I
Hg (Kvikksølv)	mg/kg (ppm)	0,01	I
PAH (EPA16)	µg/kg (ppb)	211	I
Benzo(a)pyren	µg/kg (ppb)	14	II
PCB (Σ 7)	µg/kg (ppb)	<	I
TBT	µg/kg (ppb)	<	I
Tørrstoff	%	88,5	
TOC	%	0,91	
Finfraksjon (< 63µm)	%	10,91	
Normalisert TOC	%	16,93	
Glødetap	%	IA	
Hovedklassifisering SFT 97:03			II

Forklaringer til analysedata:

- " < " : Konsentrasjonen av analysert element/kjemisk forbindelse ligger under analysemetodens deteksjonsgrense.
- " nd " : Kjemisk forbindelse er ikke påvist.
- " IA" : Analyse / beregning er ikke utført.

Teksturbeskrivelse av prøven i felt:

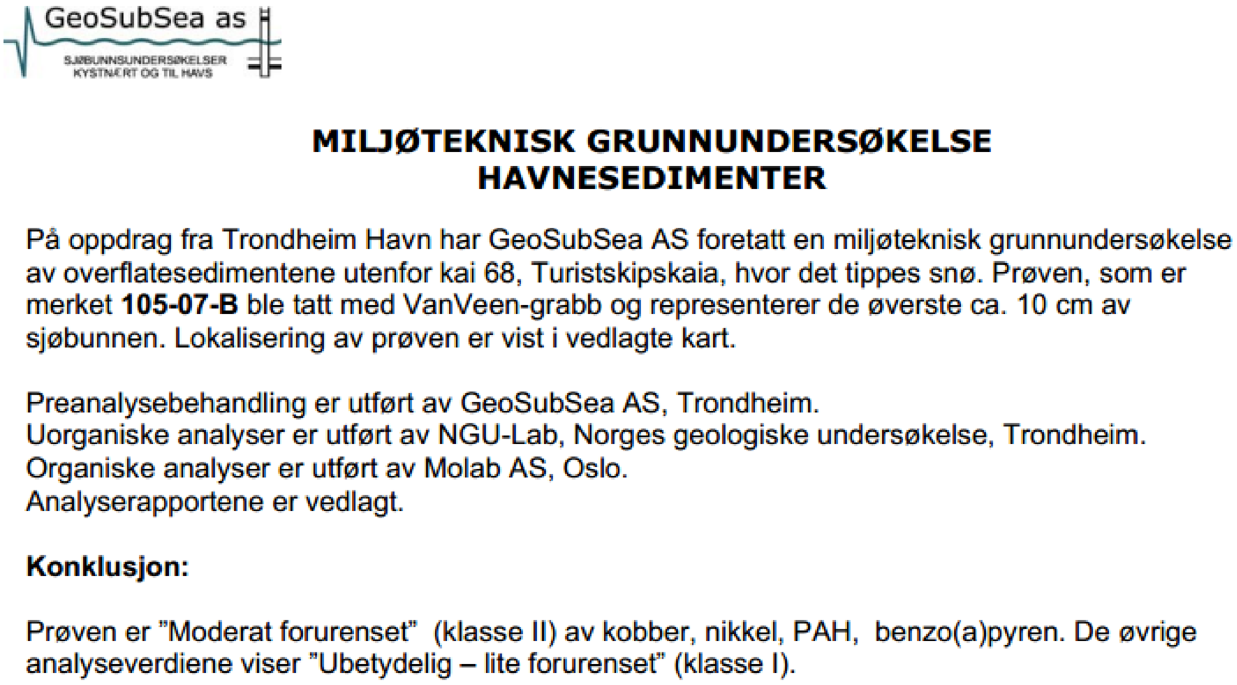
Grusig, sandig sediment med spredte stein.
Grå farge.

Anmerkning:
Ingen

Trondheim, 14.09.2007

Kristian Bjerkli

Pier 68:



GeoSubSea as

SJØBUNNSUNDERSØKELSER
KYSTNÆRT OG TIL HAVS

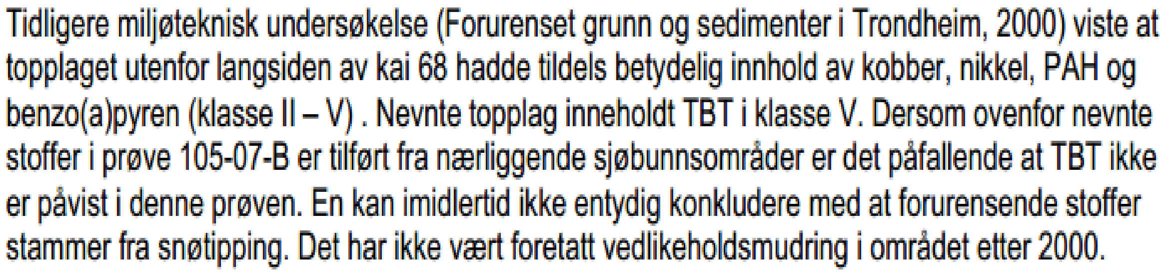
MILJØTEKNISK GRUNNUNDERSØKELSE
HAVNESEDIMENTER

På oppdrag fra Trondheim Havn har GeoSubSea AS foretatt en miljøteknisk grunnundersøkelse av overflatesedimentene utenfor kai 68, Turistskipskaia, hvor det tippes snø. Prøven, som er merket **105-07-B** ble tatt med VanVeen-grabb og representerer de øverste ca. 10 cm av sjøbunnen. Lokalisering av prøven er vist i vedlagte kart.

Preanalysebehandling er utført av GeoSubSea AS, Trondheim.
Uorganiske analyser er utført av NGU-Lab, Norges geologiske undersøkelse, Trondheim.
Organiske analyser er utført av Molab AS, Oslo.
Analyserapportene er vedlagt.

Konklusjon:

Prøven er "Moderat forurenset" (klasse II) av kobber, nikkel, PAH, benzo(a)pyren. De øvrige analyseverdiene viser "Ubetydelig – lite forurenset" (klasse I).



Tidligere miljøteknisk undersøkelse (Forurenset grunn og sedimenter i Trondheim, 2000) viste at topplaget utenfor langsiden av kai 68 hadde tildels betydelig innhold av kobber, nikkel, PAH og benzo(a)pyren (klasse II – V) . Nevnte topplag inneholdt TBT i klasse V. Dersom ovenfor nevnte stoffer i prøve 105-07-B er tilført fra nærliggende sjøbunnsområder er det påfallende at TBT ikke er påvist i denne prøven. En kan imidlertid ikke entydig konkludere med at forurensende stoffer stammer fra snøtipping. Det har ikke vært foretatt vedlikeholdsmudring i området etter 2000.

SAMMENSTILLING AV ANALYSEDATA

Prøvenr.: 105-07-B	**Område:** Kai 68, Turistskipskaia, Trondheim havn		**Dato:** 24.08.2007
Koordinater (EU89 UTM) E / N	569811	7035517	**Vanndyp:** ca.13 m
Instrument: VanVeen-grabb - overflateprøve			

Klassifisering iflg. SFT 97:03	
I	Ubetydelig – lite forurenset
II	Moderat forurenset
III	Markert forurenset
IV	Sterkt forurenset
V	Meget sterkt forurenset

Analysedata

Element / kjemisk forbindelse		0 – ca. 10 cm	SFT 97: 03
As (Arsen)	mg/kg (ppm)	2,4	I
Cd (Kadmium)	mg/kg (ppm)	0,14	I
Cr (Krom)	mg/kg (ppm)	43,6	I
Cu (Kobber)	mg/kg (ppm)	51,8	II
Ni (Nikkel)	mg/kg (ppm)	36,9	II
Pb (Bly)	mg/kg (ppm)	17,3	I
Zn (Sink)	mg/kg (ppm)	112	I
Hg (Kvikksølv)	mg/kg (ppm)	0,03	I
PAH (EPA16)	µg/kg (ppb)	483	II
Benzo(a)pyren	µg/kg (ppb)	18	II
PCB (Σ 7)	µg/kg (ppb)	<	I
TBT	µg/kg (ppb)	<	I
Tørrstoff	%	88,6	
TOC	%	1,06	
Finfraksjon (< 63µm)	%	12,2	
Normalisert TOC	%	16,9	
Glødetap	%	IA	
Hovedklassifisering SFT 97:03			II

Forklaringer til analysedata:

- " < " : Konsentrasjonen av analysert element/kjemisk forbindelse ligger under analysemetodens deteksjonsgrense.
- " nd " : Kjemisk forbindelse er ikke påvist.
- " IA" : Analyse / beregning er ikke utført.

Teksturbeskrivelse av prøven i felt:

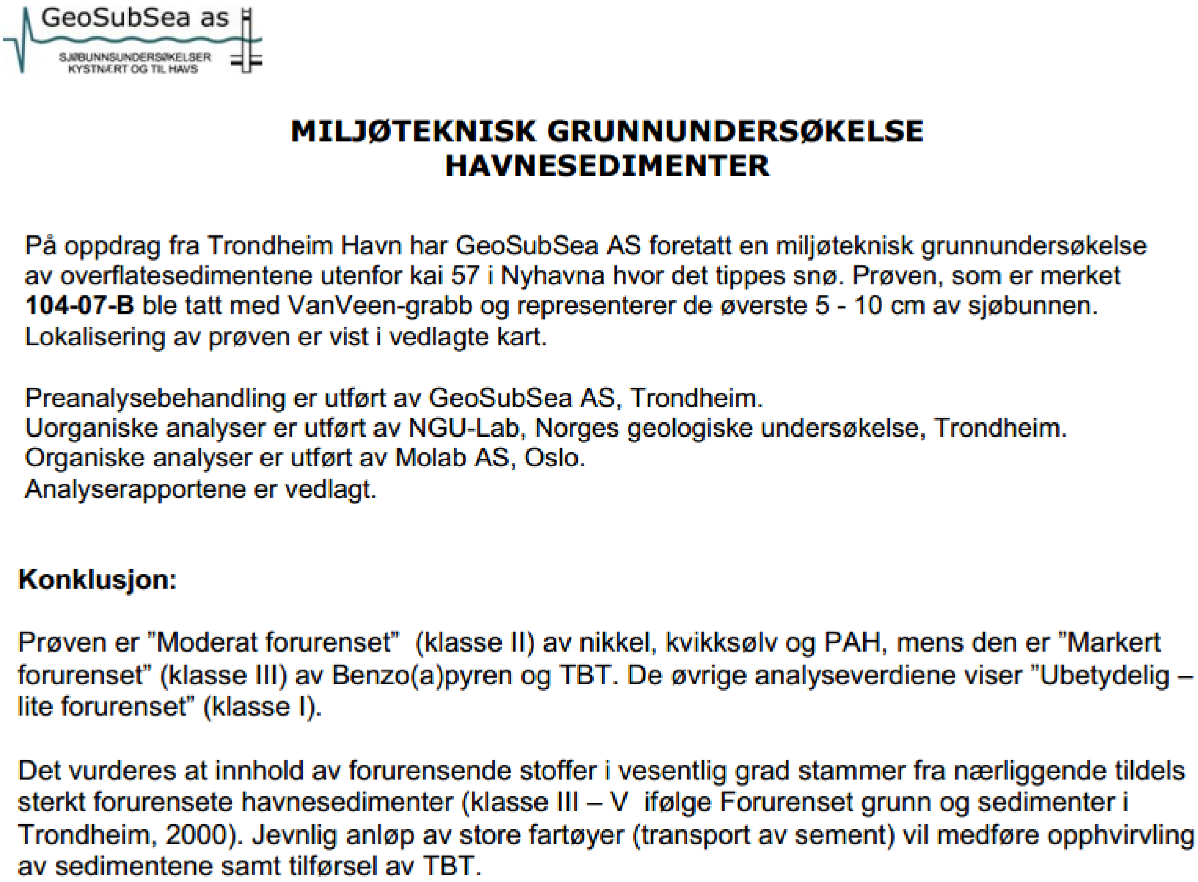
Sandig, grusig sediment med spredte stein.
Grå farge med spredte svarte korn.

Anmerkning:
Ingen

Trondheim, 14.09.2007

Kristian Bjerkli

Pier 57:



GeoSubSea as
SJØBUNNSUNDERSØKELSER
KYSTNÆRT OG TIL HAVS

MILJØTEKNISK GRUNNUNDERSØKELSE HAVNESEDIMENTER

På oppdrag fra Trondheim Havn har GeoSubSea AS foretatt en miljøteknisk grunnundersøkelse av overflatesedimentene utenfor kai 57 i Nyhavna hvor det tippes snø. Prøven, som er merket **104-07-B** ble tatt med VanVeen-grabb og representerer de øverste 5 - 10 cm av sjøbunnen. Lokalisering av prøven er vist i vedlagte kart.

Preanalysebehandling er utført av GeoSubSea AS, Trondheim.
Uorganiske analyser er utført av NGU-Lab, Norges geologiske undersøkelse, Trondheim.
Organiske analyser er utført av Molab AS, Oslo.
Analyserapportene er vedlagt.

Konklusjon:

Prøven er "Moderat forurenset" (klasse II) av nikkel, kvikksølv og PAH, mens den er "Markert forurenset" (klasse III) av Benzo(a)pyren og TBT. De øvrige analyseverdiene viser "Ubetydelig – lite forurenset" (klasse I).

Det vurderes at innhold av forurensende stoffer i vesentlig grad stammer fra nærliggende tildels sterkt forurensete havnesedimenter (klasse III – V ifølge Forurenset grunn og sedimenter i Trondheim, 2000). Jevnlig anløp av store fartøyer (transport av sement) vil medføre opphvirvling av sedimentene samt tilførsel av TBT.

SAMMENSTILLING AV ANALYSEDATA

Prøvenr.: **104-07-B**	**Område:** Kai 57, Nyhavna, Trondheim havn		**Dato:** 24.08.2007
Koordinater (EU89 UTM) E / N	57087	7035885	**Vanndyp:** ca. 5 m
Instrument: VanVeen-grabb - overflateprøve			

Klassifisering iflg. SFT 97:03	
I	Ubetydelig – lite forurenset
II	Moderat forurenset
III	Markert forurenset
IV	Sterkt forurenset
V	Meget sterkt forurenset

Analysedata

Element / kjemisk forbindelse		0 – ca. 10 cm	SFT 97: 03
As (Arsen)	mg/kg (ppm)	2,6	I
Cd (Kadmium)	mg/kg (ppm)	0,18	I
Cr (Krom)	mg/kg (ppm)	52,4	I
Cu (Kobber)	mg/kg (ppm)	34,9	I
Ni (Nikkel)	mg/kg (ppm)	37,0	II
Pb (Bly)	mg/kg (ppm)	12,4	I
Zn (Sink)	mg/kg (ppm)	101,0	I
Hg (Kvikksølv)	mg/kg (ppm)	0,18	II
PAH (EPA16)	µg/kg (ppb)	1112	II
Benzo(a)pyren	µg/kg (ppb)	103	III
PCB (Σ 7)	µg/kg (ppb)	1	I
TBT	µg/kg (ppb)	8	III
Tørrstoff	%	87,8	
TOC	%	1,07	
Finfraksjon (< 63µm)	%	33,8	
Normalisert TOC	%	12,95	
Glødetap	%	IA	
Hovedklassifisering SFT 97:03			III

Forklaringer til analysedata:

- " < " : Konsentrasjonen av analysert element/kjemisk forbindelse ligger under analysemetodens deteksjonsgrense.
- " nd " : Kjemisk forbindelse er ikke påvist.
- " IA " : Analyse / beregning er ikke utført.

Teksturbeskrivelse av prøven i felt:

Slamholdig, sandig, grusig masse med spredte stein. Mørk / tildels svart farge
Markert lukt av olje / kreosot.

Anmerkning:

En grabb-prøve som ble tatt ca. 10 m vest for den analyserte prøven viste svart, svampaktig masse med sterk olje/kreosot-lukt.

Trondheim, 14.07.2007

Kristian Bjerkli

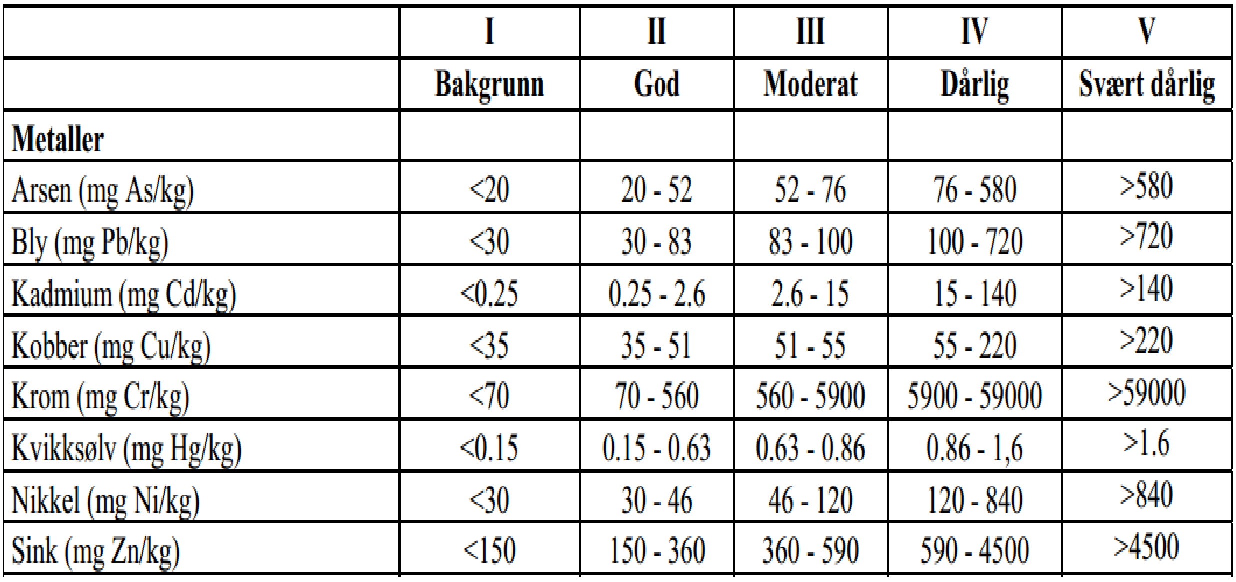
Appendix B: Klifs guideline Tables

All Tables from (Bakke et al., 2007).

1) Metal(loid)s in sea water

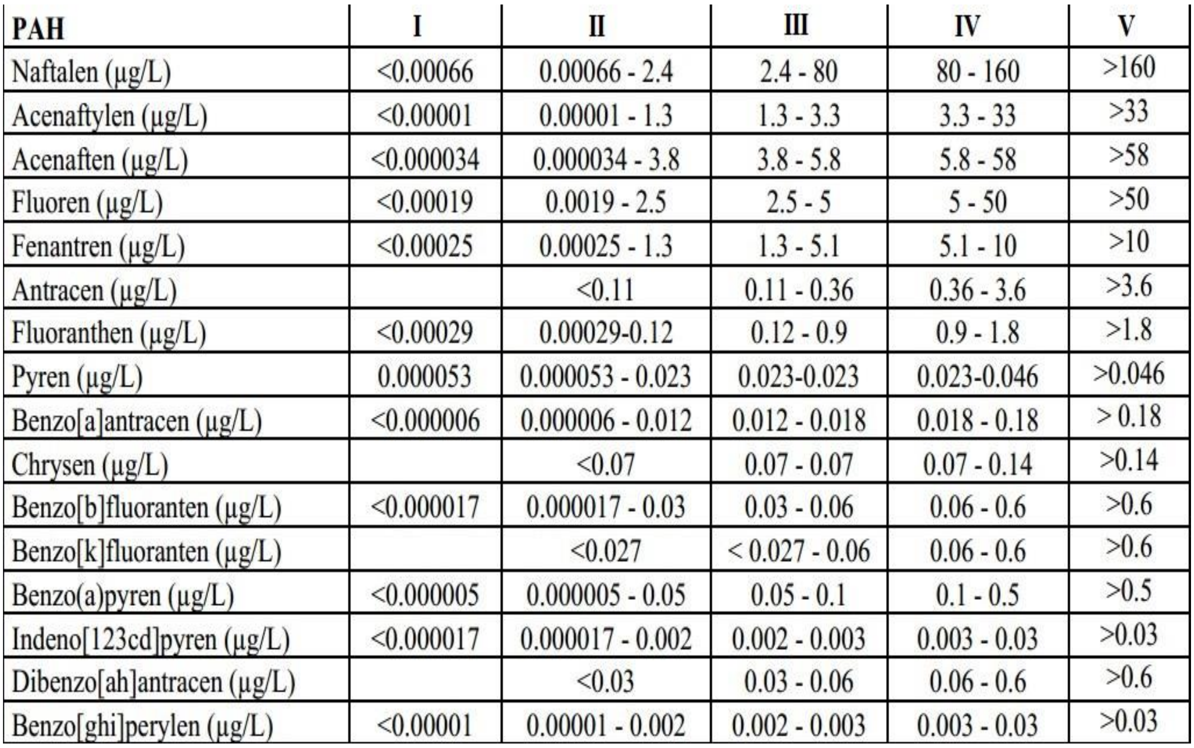
Levels	I	II	III	IV	V
Metals	Background	Good	Moderate	Polluted	Very polluted
Arsenic (µg/L)	< 2	2 – 4.8	4.8 – 8.5	8.5 - 85	> 85
Lead (µg/L)	< 0.05	0.05 – 2.2	2.2 – 2.9	2.9 - 28	> 28
Cadmium (µg/L)	< 0.03	0.03 – 0.24	0.24 – 1.5	1.5 - 15	> 15
Copper (µg/L)	< 0.3	0.3 - 0.64	0.64 – 0.8	0.8 – 7.7	> 7.7
Chromium (µg/L	< 0.2	0.2 – 3.4	3.4 - 36	36 - 360	> 360
Mercury (µg/L)	< 0.001	0.001 – 0.048	0.048 – 0.071	0.071 – 0.14	> 0.14
Nickel (µg/L)	< 0.5	0.5 – 2.2	2.2 - 12	12 – 120	> 120
Zinc (µg/L)	< 1.5	1.5 – 2.9	2.9 - 6	6 – 60	> 60

2) Metal(loid)s in marine sediment



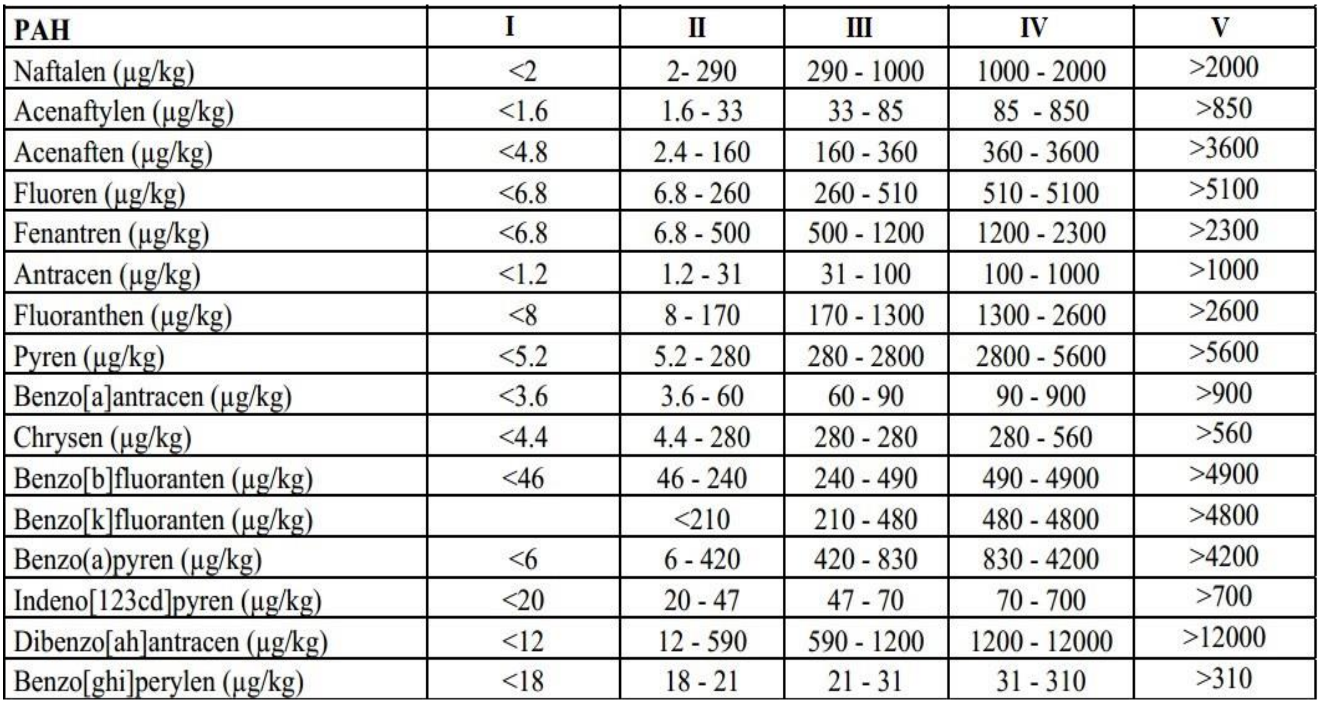
	I	II	III	IV	V
	Bakgrunn	**God**	**Moderat**	**Dårlig**	**Svært dårlig**
Metaller					
Arsen (mg As/kg)	<20	20 - 52	52 - 76	76 - 580	>580
Bly (mg Pb/kg)	<30	30 - 83	83 - 100	100 - 720	>720
Kadmium (mg Cd/kg)	<0.25	0.25 - 2.6	2.6 - 15	15 - 140	>140
Kobber (mg Cu/kg)	<35	35 - 51	51 - 55	55 - 220	>220
Krom (mg Cr/kg)	<70	70 - 560	560 - 5900	5900 - 59000	>59000
Kvikksølv (mg Hg/kg)	<0.15	0.15 - 0.63	0.63 - 0.86	0.86 - 1,6	>1.6
Nikkel (mg Ni/kg)	<30	30 - 46	46 - 120	120 - 840	>840
Sink (mg Zn/kg)	<150	150 - 360	360 - 590	590 - 4500	>4500

3) PAHs sea water



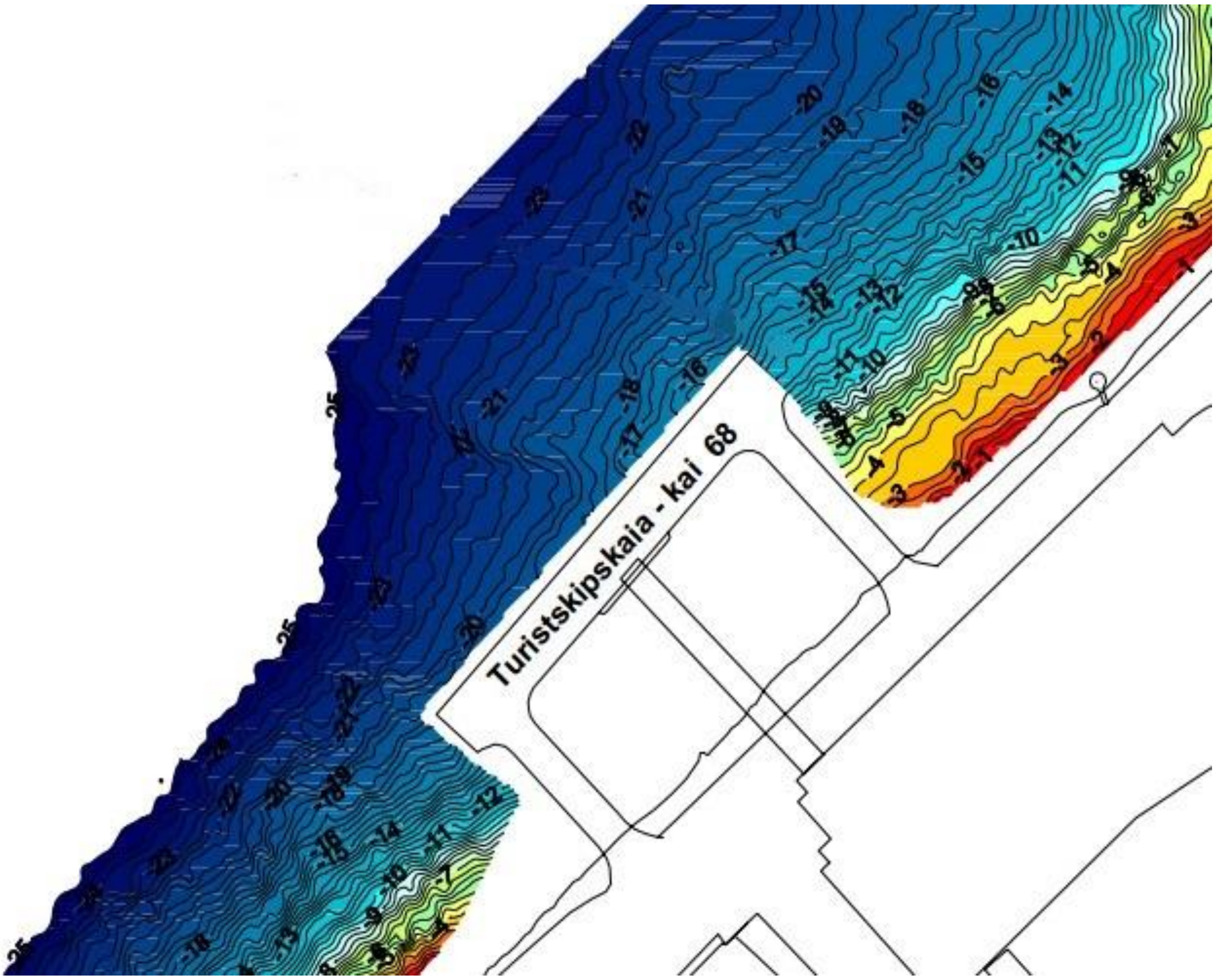
PAH	I	II	III	IV	V
Naftalen (µg/L)	<0.00066	0.00066 - 2.4	2.4 - 80	80 - 160	>160
Acenaftylen (µg/L)	<0.00001	0.00001 - 1.3	1.3 - 3.3	3.3 - 33	>33
Acenaften (µg/L)	<0.000034	0.000034 - 3.8	3.8 - 5.8	5.8 - 58	>58
Fluoren (µg/L)	<0.00019	0.0019 - 2.5	2.5 - 5	5 - 50	>50
Fenantren (µg/L)	<0.00025	0.00025 - 1.3	1.3 - 5.1	5.1 - 10	>10
Antracen (µg/L)		<0.11	0.11 - 0.36	0.36 - 3.6	>3.6
Fluoranthen (µg/L)	<0.00029	0.00029-0.12	0.12 - 0.9	0.9 - 1.8	>1.8
Pyren (µg/L)	0.000053	0.000053 - 0.023	0.023-0.023	0.023-0.046	>0.046
Benzo[a]antracen (µg/L)	<0.000006	0.000006 - 0.012	0.012 - 0.018	0.018 - 0.18	> 0.18
Chrysen (µg/L)		<0.07	0.07 - 0.07	0.07 - 0.14	>0.14
Benzo[b]fluoranten (µg/L)	<0.000017	0.000017 - 0.03	0.03 - 0.06	0.06 - 0.6	>0.6
Benzo[k]fluoranten (µg/L)		<0.027	< 0.027 - 0.06	0.06 - 0.6	>0.6
Benzo(a)pyren (µg/L)	<0.000005	0.000005 - 0.05	0.05 - 0.1	0.1 - 0.5	>0.5
Indeno[123cd]pyren (µg/L)	<0.000017	0.000017 - 0.002	0.002 - 0.003	0.003 - 0.03	>0.03
Dibenzo[ah]antracen (µg/L)		<0.03	0.03 - 0.06	0.06 - 0.6	>0.6
Benzo[ghi]perylen (µg/L)	<0.00001	0.00001 - 0.002	0.002 - 0.003	0.003 - 0.03	>0.03

4) PAHs sediment



PAH	I	II	III	IV	V
Naftalen (µg/kg)	<2	2- 290	290 - 1000	1000 - 2000	>2000
Acenaftylen (µg/kg)	<1.6	1.6 - 33	33 - 85	85 - 850	>850
Acenaften (µg/kg)	<4.8	2.4 - 160	160 - 360	360 - 3600	>3600
Fluoren (µg/kg)	<6.8	6.8 - 260	260 - 510	510 - 5100	>5100
Fenantren (µg/kg)	<6.8	6.8 - 500	500 - 1200	1200 - 2300	>2300
Antracen (µg/kg)	<1.2	1.2 - 31	31 - 100	100 - 1000	>1000
Fluoranthen (µg/kg)	<8	8 - 170	170 - 1300	1300 - 2600	>2600
Pyren (µg/kg)	<5.2	5.2 - 280	280 - 2800	2800 - 5600	>5600
Benzo[a]antracen (µg/kg)	<3.6	3.6 - 60	60 - 90	90 - 900	>900
Chrysen (µg/kg)	<4.4	4.4 - 280	280 - 280	280 - 560	>560
Benzo[b]fluoranten (µg/kg)	<46	46 - 240	240 - 490	490 - 4900	>4900
Benzo[k]fluoranten (µg/kg)		<210	210 - 480	480 - 4800	>4800
Benzo(a)pyren (µg/kg)	<6	6 - 420	420 - 830	830 - 4200	>4200
Indeno[123cd]pyren (µg/kg)	<20	20 - 47	47 - 70	70 - 700	>700
Dibenzo[ah]antracen (µg/kg)	<12	12 - 590	590 - 1200	1200 - 12000	>12000
Benzo[ghi]perylen (µg/kg)	<18	18 - 21	21 - 31	31 - 310	>310

Appendix C: depths outside pier 68



Appendix D: positions sediment traps

Sediment trap number	Approximately distance from pier (in meters)	Position
1	41	63º26.484 N 10º24.000 Ø
2	89	63º26.504 N 10º24.036 Ø
3	136	63º26.532 N 10º24.055 Ø

Appendix E: deployment times DGTs

DGTs January and February

DGT no:	Put out	Taken up	Deployment time
1 - 3	21.01.16 kl. 14.52	26.01.16 kl.15.45	5 d, 53 min
4 - 6	26.01.16 kl. 15.55	02.02.16 kl.13.31	6 d, 1296 min
7 - 9	02.02.16 kl. 13.39	08.02.16 kl. 08.40	5 d, 18 h, 1 m
10 - 12	08.02.16 kl. 08.47	18.02.16 kl. 16.59	10 d, 8 h, 12 m
13 - 15	18.02.16 kl. 16.29	21.02.16 kl. 19.13	3 d, 2 h, 44 m

DGTs April

DGT no:	Put out	Taken up	Time out
1	07.04.16 kl.17.35	15.04.16 kl.19.21	8 d, 1 h, 46 min
2	07.04.16 kl.17.35	15.04.16 kl.19.21	8 d, 1 h, 46 min
3	**15.04.16 kl.19.55**	**17.04.16 kl.17.57**	**2 d – 2 h + 2 min**
4	**15.04.16 kl.19.55**	**17.04.16 kl.17.57**	**2 d – 2 h + 2 min**
5	17.04.16 kl.18.10	19.04.16 kl.17.42	2 d – 28 min
6	17.04.16 kl.18.10	19.04.16 kl.17.42	2 d – 28 min

Appendix F: amount particulate material and dissolved fraction snow samples batch 2

Amount of particulate matter analysed in each sample, and amount of melted snow filtrated.

Sample no.	Amount particulate matter	Amount melted snow filtrated
1	10.7 mg	0.9786 mL
2	11.4 mg	9.8632 mL
3	35.9 mg	0.9741 mL

Appendix G: DGTs

DGTs January and February

DGT no:	Eluate	After dilution	Dilution factor	Time (s)
1	0.5810 g.	5.7465 g.	9.891	**435180 s**
2	0.5965 g.	5.9068 g.	9.902	**435180 s**
3	0.5359 g.	5.3086 g.	9.906	**435180 s**
4	0.7042 g.	7.0258 g.	9.977	596160 s.
5	0.6815 g.	6.8778 g.	10.09	596160 s.
6	0.6622 g.	6.6153 g.	9.99	596160 s.
7	0.7861 g.	7.8355 g.	9.968	**496860 s.**
8	0.7735 g.	7.7540 g.	10.02	**496860 s.**
9	0.8533 g.	8.6099 g.	10.09	**496860 s.**
10	0.6870 g.	6.8695 g.	9.999	893520 s.
11	0.6380 g.	6.3173 g.	9.902	893520 s.
12	0.5943 g.	6.3846 g.	10.74	893520 s.
13	0.5191 g.	5.1793 g.	9.977	**269040 s.**
14	0.6370 g.	6.3139 g.	9.912	**269040 s.**
15	0.3616 g.	3.5809 g.	9.903	**269040 s.**

DGTs April

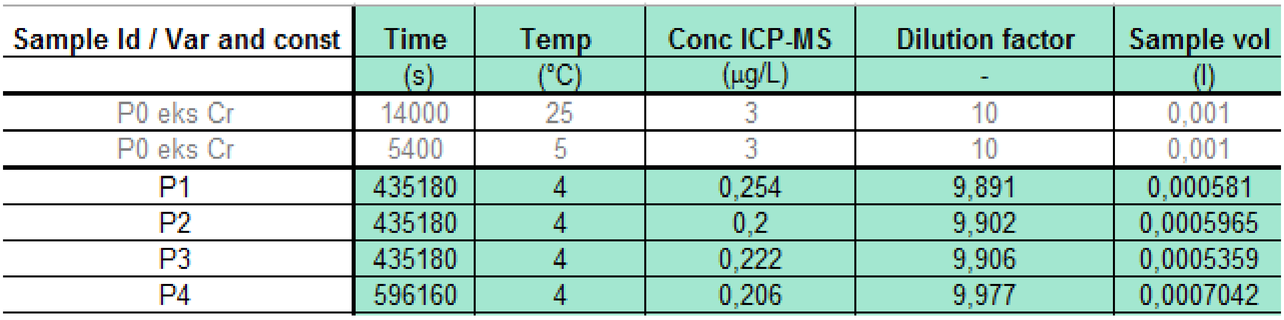
DGT no:	Eluate	After dilution	Dilution factor	Time (s)
1	0.7447	7.3417	9.859	
2	0.8476	8.5419	10.08	
3	0.8090	8.4959	10.50	
4	0.8987	8.5760	9.543	
5	0.8342	8.2623	9.904	
6	0.8956	8.8403	9.871	

Appendix H: calculation of concentrations from DGTs

Excel file

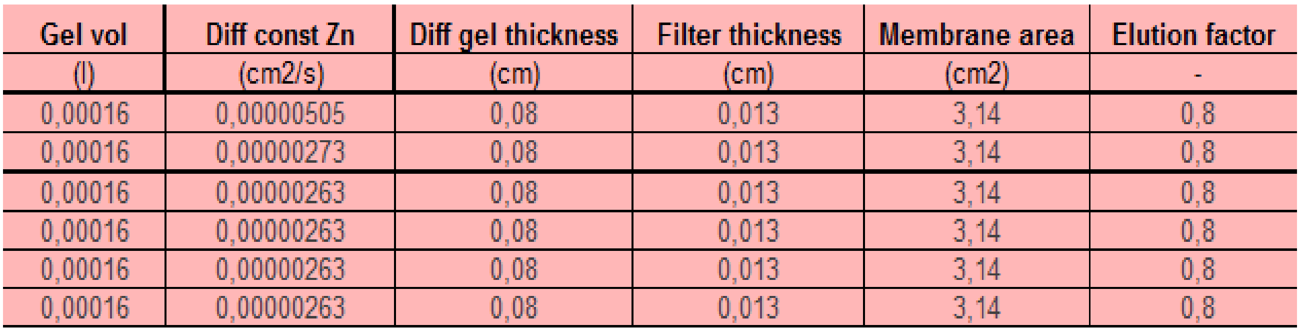
Example for Cr for the first four DGTs from January and February:

Values inserted:



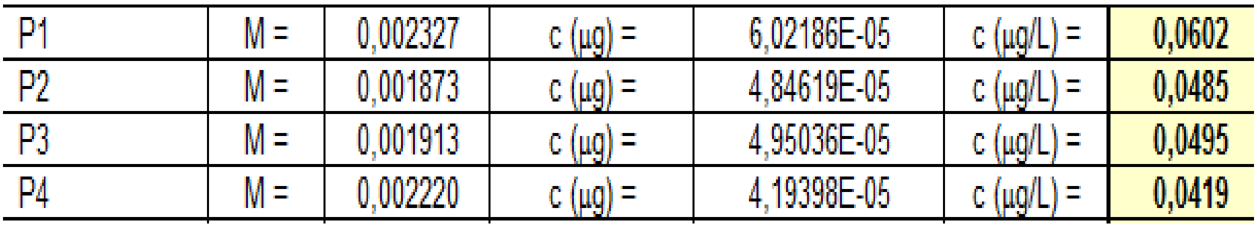
Sample Id / Var and const	Time	Temp	Conc ICP-MS	Dilution factor	Sample vol
	(s)	(°C)	(µg/L)	-	(l)
P0 eks Cr	14000	25	3	10	0,001
P0 eks Cr	5400	5	3	10	0,001
P1	435180	4	0,254	9,891	0,000581
P2	435180	4	0,2	9,902	0,0005965
P3	435180	4	0,222	9,906	0,0005359
P4	596160	4	0,206	9,977	0,0007042

Values in the file:



Gel vol	Diff const Zn	Diff gel thickness	Filter thickness	Membrane area	Elution factor
(l)	(cm2/s)	(cm)	(cm)	(cm2)	-
0,00016	0,00000505	0,08	0,013	3,14	0,8
0,00016	0,00000273	0,08	0,013	3,14	0,8
0,00016	0,00000263	0,08	0,013	3,14	0,8
0,00016	0,00000263	0,08	0,013	3,14	0,8
0,00016	0,00000263	0,08	0,013	3,14	0,8
0,00016	0,00000263	0,08	0,013	3,14	0,8

Output:



P1	M =	0,002327	c (µg) =	6,02186E-05	c (µg/L) =	0,0602
P2	M =	0,001873	c (µg) =	4,84619E-05	c (µg/L) =	0,0485
P3	M =	0,001913	c (µg) =	4,95036E-05	c (µg/L) =	0,0495
P4	M =	0,002220	c (µg) =	4,19398E-05	c (µg/L) =	0,0419

Calculation by hand:

Example for Cu from DGT1 from January:

5.36 µg/L = concentration ICP-MS
9.891 = dilution factor
0.581 mL = eluate
0.16 mL = gel volume
0.8 = elution factor
0.08 cm = diffusive gel thickness
0.013 cm = filter thickness
0.00000325 cm^2/s = diffusion constant for Cu at temperature 4 °C
435180 s = exposure time of DGT in water
3.14 cm^2 = area Chelex gel

Concentration of Cu from ICP-MS corrected for dilution: 5.36 µg/L * 9.891 = 53.02 µg/L

Mass of Cu in DGT gel:

$$\frac{53.02\ \mu g/L * (0.581+0.16) * 10^{-3}\ L}{0.8} = 0.0491\ \mu g$$

$$C_{DGT}: \frac{0.0491\ \mu g * (0.08+0.013) cm}{0.00000325\ \frac{cm^2}{s} * 435180\ s * 3.14\ cm^2} = 0.001028\ \mu g/cm^3 * 1000 = \underline{1.03\ \mu g/L}$$

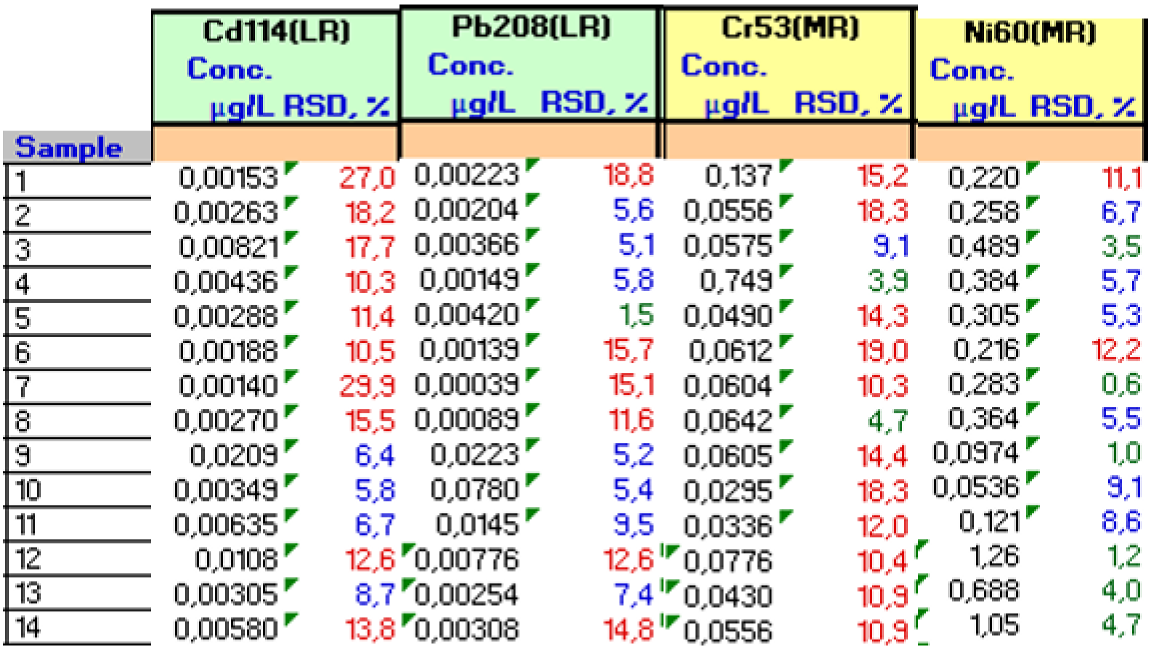
Diffusion constants used in the calculations (4 degrees Celcius).

Metal	Diffusion constant (cm^2/ s)
Cr	0.00000263
Cu	0.00000325
Ni	0.00000301
Zn	0.00000317
Pb	0.00000419
Cd	0.00000318

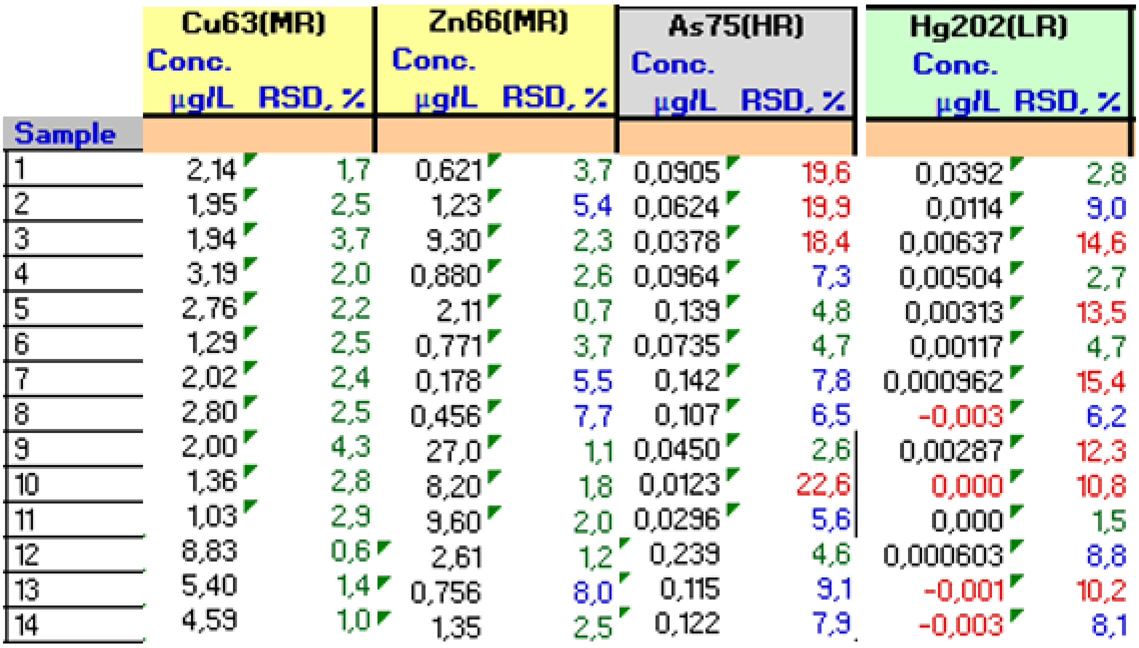
Appendix I: results ICP-MS

Snow samples, batch 1. Dissolved phase.

Results from ICP-MS snow samples 1-14, adjusted for blanks.

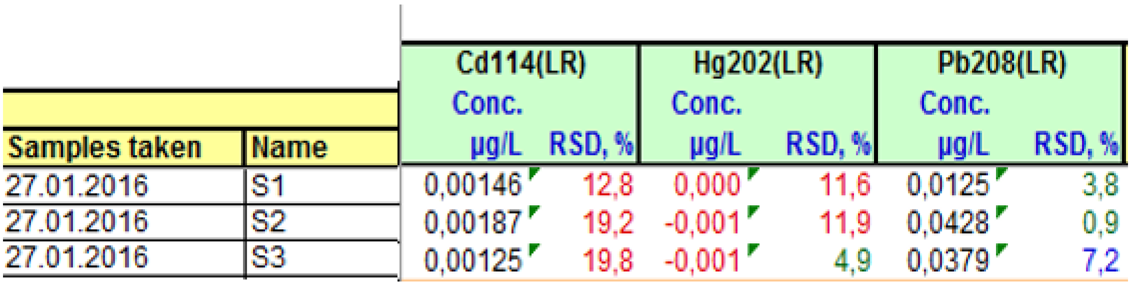


	Cd114(LR)		Pb208(LR)		Cr53(MR)		Ni60(MR)	
Sample	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %
1	0,00153	27,0	0,00223	18,8	0,137	15,2	0,220	11,1
2	0,00263	18,2	0,00204	5,6	0,0556	18,3	0,258	6,7
3	0,00821	17,7	0,00366	5,1	0,0575	9,1	0,489	3,5
4	0,00436	10,3	0,00149	5,8	0,749	3,9	0,384	5,7
5	0,00288	11,4	0,00420	1,5	0,0490	14,3	0,305	5,3
6	0,00188	10,5	0,00139	15,7	0,0612	19,0	0,216	12,2
7	0,00140	29,9	0,00039	15,1	0,0604	10,3	0,283	0,6
8	0,00270	15,5	0,00089	11,6	0,0642	4,7	0,364	5,5
9	0,0209	6,4	0,0223	5,2	0,0605	14,4	0,0974	1,0
10	0,00349	5,8	0,0780	5,4	0,0295	18,3	0,0536	9,1
11	0,00635	6,7	0,0145	9,5	0,0336	12,0	0,121	8,6
12	0,0108	12,6	0,00776	12,6	0,0776	10,4	1,26	1,2
13	0,00305	8,7	0,00254	7,4	0,0430	10,9	0,688	4,0
14	0,00580	13,8	0,00308	14,8	0,0556	10,9	1,05	4,7

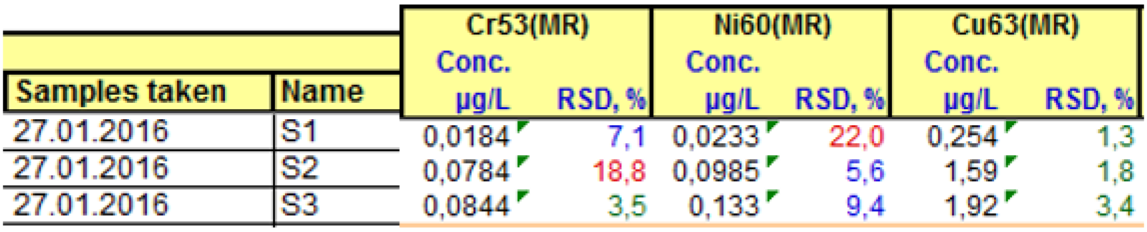


	Cu63(MR)		Zn66(MR)		As75(HR)		Hg202(LR)	
Sample	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %
1	2,14	1,7	0,621	3,7	0,0905	19,6	0,0392	2,8
2	1,95	2,5	1,23	5,4	0,0624	19,9	0,0114	9,0
3	1,94	3,7	9,30	2,3	0,0378	18,4	0,00637	14,6
4	3,19	2,0	0,880	2,6	0,0964	7,3	0,00504	2,7
5	2,76	2,2	2,11	0,7	0,139	4,8	0,00313	13,5
6	1,29	2,5	0,771	3,7	0,0735	4,7	0,00117	4,7
7	2,02	2,4	0,178	5,5	0,142	7,8	0,000962	15,4
8	2,80	2,5	0,456	7,7	0,107	6,5	-0,003	6,2
9	2,00	4,3	27,0	1,1	0,0450	2,6	0,00287	12,3
10	1,36	2,8	8,20	1,8	0,0123	22,6	0,000	10,8
11	1,03	2,9	9,60	2,0	0,0296	5,6	0,000	1,5
12	8,83	0,6	2,61	1,2	0,239	4,6	0,000603	8,8
13	5,40	1,4	0,756	8,0	0,115	9,1	-0,001	10,2
14	4,59	1,0	1,35	2,5	0,122	7,9	-0,003	8,1

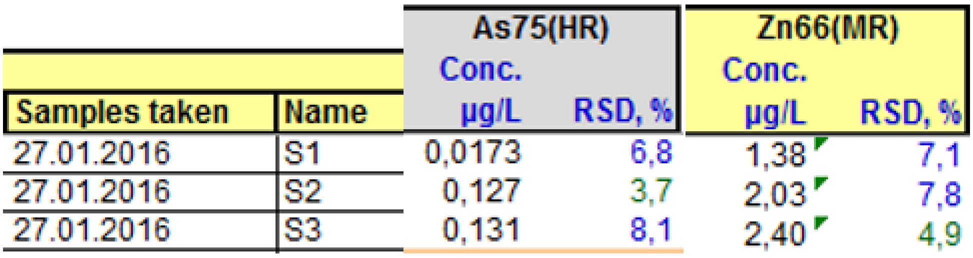
Snow samples, batch 2. adjusted for blanks.



		Cd114(LR)		Hg202(LR)		Pb208(LR)	
		Conc.		Conc.		Conc.	
Samples taken	Name	µg/L	RSD, %	µg/L	RSD, %	µg/L	RSD, %
27.01.2016	S1	0,00146	12,8	0,000	11,6	0,0125	3,8
27.01.2016	S2	0,00187	19,2	-0,001	11,9	0,0428	0,9
27.01.2016	S3	0,00125	19,8	-0,001	4,9	0,0379	7,2



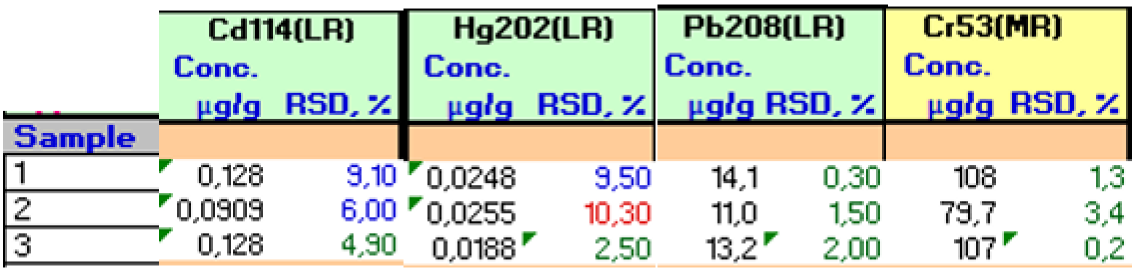
		Cr53(MR)		Ni60(MR)		Cu63(MR)	
		Conc.		Conc.		Conc.	
Samples taken	Name	µg/L	RSD, %	µg/L	RSD, %	µg/L	RSD, %
27.01.2016	S1	0,0184	7,1	0,0233	22,0	0,254	1,3
27.01.2016	S2	0,0784	18,8	0,0985	5,6	1,59	1,8
27.01.2016	S3	0,0844	3,5	0,133	9,4	1,92	3,4



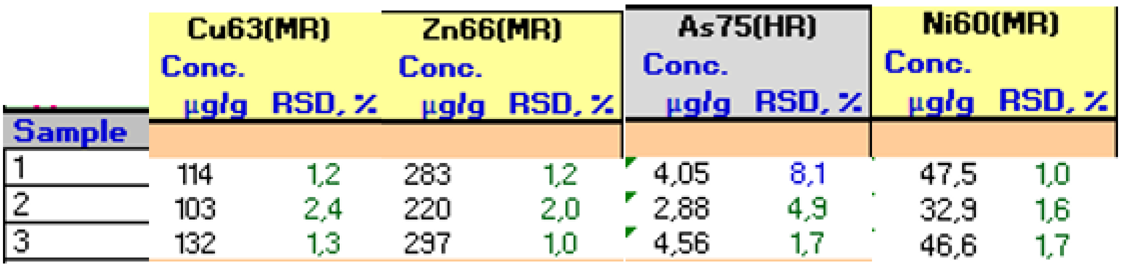
		As75(HR)		Zn66(MR)	
		Conc.		Conc.	
Samples taken	Name	µg/L	RSD, %	µg/L	RSD, %
27.01.2016	S1	0,0173	6,8	1,38	7,1
27.01.2016	S2	0,127	3,7	2,03	7,8
27.01.2016	S3	0,131	8,1	2,40	4,9

Snow samples batch 2, particulate material. adjusted for blanks.

.

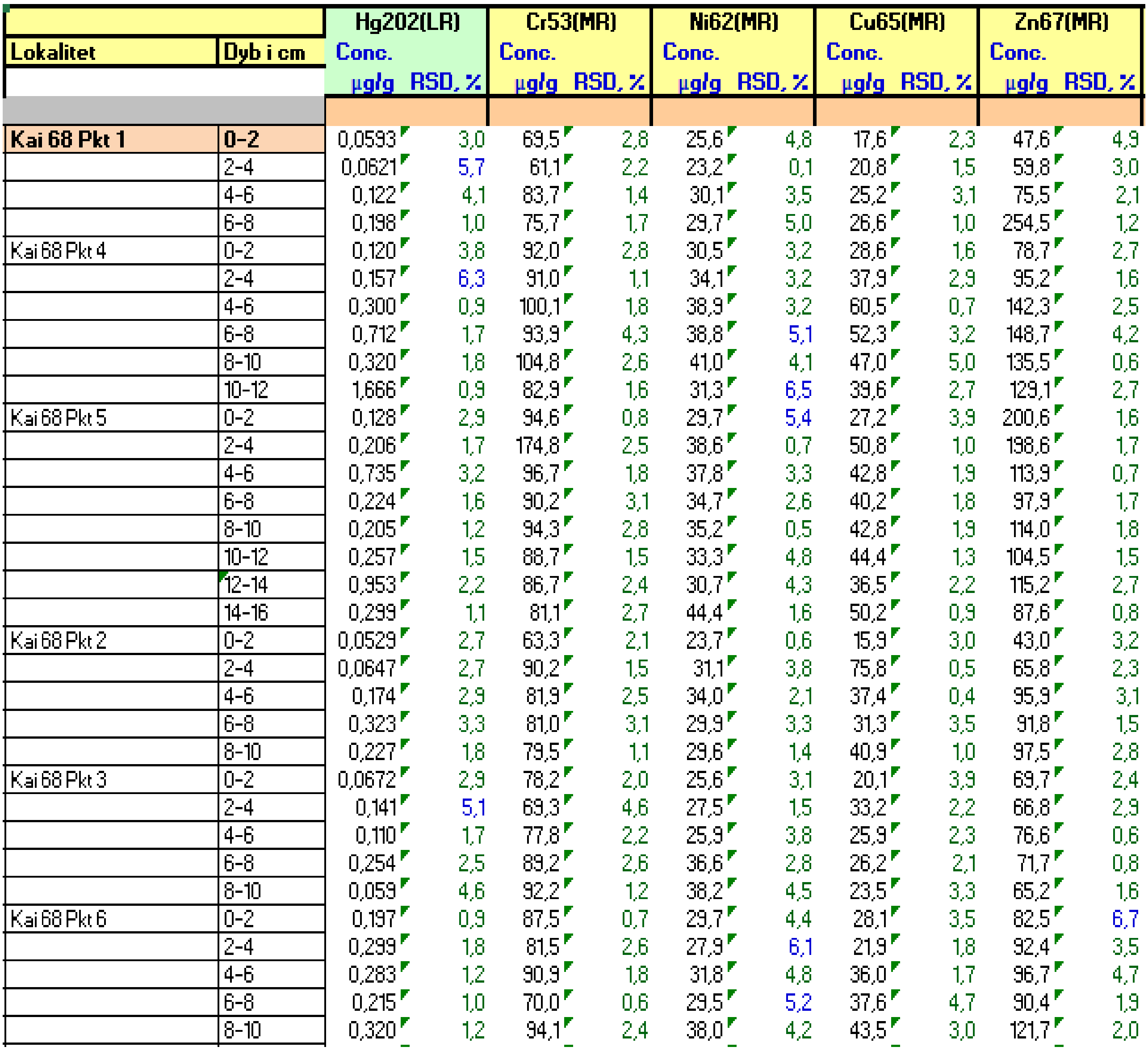


	Cd114(LR)		Hg202(LR)		Pb208(LR)		Cr53(MR)	
	Conc.		Conc.		Conc.		Conc.	
	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %
Sample								
1	0,128	9,10	0,0248	9,50	14,1	0,30	108	1,3
2	0,0909	6,00	0,0255	10,30	11,0	1,50	79,7	3,4
3	0,128	4,90	0,0188	2,50	13,2	2,00	107	0,2



	Cu63(MR)		Zn66(MR)		As75(HR)		Ni60(MR)	
	Conc.		Conc.		Conc.		Conc.	
Sample	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %
1	114	1,2	283	1,2	4,05	8,1	47,5	1,0
2	103	2,4	220	2,0	2,88	4,9	32,9	1,6
3	132	1,3	297	1,0	4,56	1,7	46,6	1,7

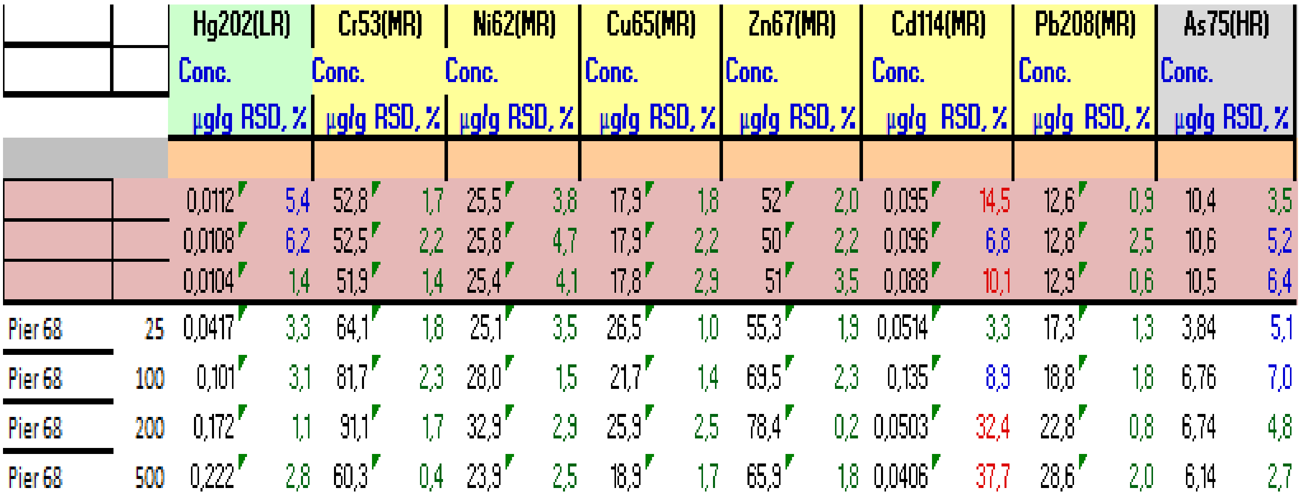
Sediment samples direction North West: corrected for blanks



		Hg202(LR)		Cr53(MR)		Ni62(MR)		Cu65(MR)		Zn67(MR)	
Lokalitet	Dyb i cm	Conc.		Conc.		Conc.		Conc.		Conc.	
		µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %
Kai 68 Pkt 1	**0-2**	0,0593	3,0	69,5	2,8	25,6	4,8	17,6	2,3	47,6	4,9
	2-4	0,0621	5,7	61,1	2,2	23,2	0,1	20,8	1,5	59,8	3,0
	4-6	0,122	4,1	83,7	1,4	30,1	3,5	25,2	3,1	75,5	2,1
	6-8	0,198	1,0	75,7	1,7	29,7	5,0	26,6	1,0	254,5	1,2
Kai 68 Pkt 4	0-2	0,120	3,8	92,0	2,8	30,5	3,2	28,6	1,6	78,7	2,7
	2-4	0,157	6,3	91,0	1,1	34,1	3,2	37,9	2,9	95,2	1,6
	4-6	0,300	0,9	100,1	1,8	38,9	3,2	60,5	0,7	142,3	2,5
	6-8	0,712	1,7	93,9	4,3	38,8	5,1	52,3	3,2	148,7	4,2
	8-10	0,320	1,8	104,8	2,6	41,0	4,1	47,0	5,0	135,5	0,6
	10-12	1,666	0,9	82,9	1,6	31,3	6,5	39,6	2,7	129,1	2,7
Kai 68 Pkt 5	0-2	0,128	2,9	94,6	0,8	29,7	5,4	27,2	3,9	200,6	1,6
	2-4	0,206	1,7	174,8	2,5	38,6	0,7	50,8	1,0	198,6	1,7
	4-6	0,735	3,2	96,7	1,8	37,8	3,3	42,8	1,9	113,9	0,7
	6-8	0,224	1,6	90,2	3,1	34,7	2,6	40,2	1,8	97,9	1,7
	8-10	0,205	1,2	94,3	2,8	35,2	0,5	42,8	1,9	114,0	1,8
	10-12	0,257	1,5	88,7	1,5	33,3	4,8	44,4	1,3	104,5	1,5
	12-14	0,953	2,2	86,7	2,4	30,7	4,3	36,5	2,2	115,2	2,7
	14-16	0,299	1,1	81,1	2,7	44,4	1,6	50,2	0,9	87,6	0,8
Kai 68 Pkt 2	0-2	0,0529	2,7	63,3	2,1	23,7	0,6	15,9	3,0	43,0	3,2
	2-4	0,0647	2,7	90,2	1,5	31,1	3,8	75,8	0,5	65,8	2,3
	4-6	0,174	2,9	81,9	2,5	34,0	2,1	37,4	0,4	95,9	3,1
	6-8	0,323	3,3	81,0	3,1	29,9	3,3	31,3	3,5	91,8	1,5
	8-10	0,227	1,8	79,5	1,1	29,6	1,4	40,9	1,0	97,5	2,8
Kai 68 Pkt 3	0-2	0,0672	2,9	78,2	2,0	25,6	3,1	20,1	3,9	69,7	2,4
	2-4	0,141	5,1	69,3	4,6	27,5	1,5	33,2	2,2	66,8	2,9
	4-6	0,110	1,7	77,8	2,2	25,9	3,8	25,9	2,3	76,6	0,6
	6-8	0,254	2,5	89,2	2,6	36,6	2,8	26,2	2,1	71,7	0,8
	8-10	0,059	4,6	92,2	1,2	38,2	4,5	23,5	3,3	65,2	1,6
Kai 68 Pkt 6	0-2	0,197	0,9	87,5	0,7	29,7	4,4	28,1	3,5	82,5	6,7
	2-4	0,299	1,8	81,5	2,6	27,9	6,1	21,9	1,8	92,4	3,5
	4-6	0,283	1,2	90,9	1,8	31,8	4,8	36,0	1,7	96,7	4,7
	6-8	0,215	1,0	70,0	0,6	29,5	5,2	37,6	4,7	90,4	1,9
	8-10	0,320	1,2	94,1	2,4	38,0	4,2	43,5	3,0	121,7	2,0

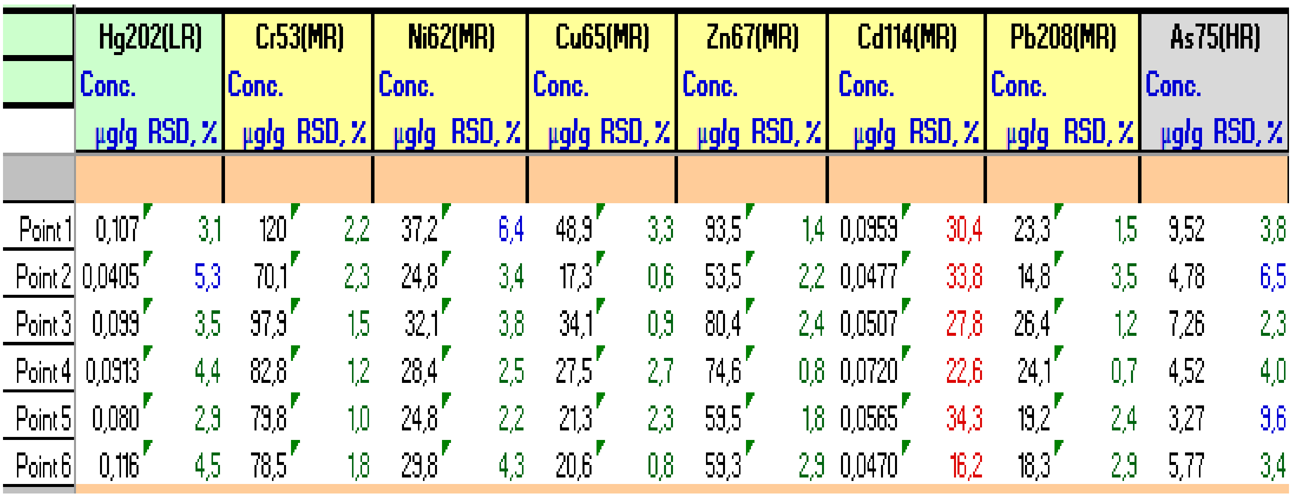
		Cd111(MR)		Pb208(MR)		As75(HR)	
Lokalitet	**Dyb i cm**	**Conc.**		**Conc.**		**Conc.**	
		µg/g	**RSD, %**	**µg/g**	**RSD, %**	**µg/g**	**RSD, %**
Kai 68 Pkt 1	**0-2**	0,0732	22,7	13,4	2,4	3,08	13,4
	2-4	0,103	30,6	17,0	2,4	3,12	7,7
	4-6	0,153	11,9	25,6	2,0	3,72	11,6
	6-8	0,410	11,0	40,3	1,9	8,65	12,6
Kai 68 Pkt 4	0-2	0,0804	34,6	25,4	1,3	3,88	13,3
	2-4	0,156	13,2	34,4	1,5	4,76	11,7
	4-6	0,217	6,4	54,9	1,8	9,23	12,9
	6-8	0,295	22,8	54,6	1,2	10,00	12,1
	8-10	0,328	0,6	74,5	1,3	8,65	11,7
	10-12	0,421	2,7	81,6	2,2	10,54	11,4
Kai 68 Pkt 5	0-2	0,305	3,9	38,2	1,8	3,47	9,3
	2-4	0,278	13,8	45,4	2,1	13,28	14,5
	4-6	0,170	16,1	40,1	1,9	5,31	11,8
	6-8	0,222	18,6	33,8	1,8	5,45	11,0
	8-10	0,135	32,8	36,7	1,6	5,56	8,9
	10-12	0,197	10,9	33,9	2,8	6,96	12,5
	12-14	0,420	0,8	36,9	1,8	13,16	12,4
	14-16	0,306	8,8	42,9	4,5	5,53	9,9
Kai 68 Pkt 2	0-2	0,0653	31,9	13,6	3,2	3,29	11,7
	2-4	0,098	24,4	18,7	2,3	3,38	9,7
	4-6	0,206	10,1	32,4	2,0	6,80	12,6
	6-8	0,322	4,0	38,2	1,1	8,17	9,3
	8-10	0,270	9,6	36,1	3,1	6,80	11,5
Kai 68 Pkt 3	0-2	0,0827	20,8	18,2	1,1	2,71	13,5
	2-4	0,167	38,3	19,3	1,8	4,12	10,5
	4-6	0,112	20,1	24,3	1,8	3,74	10,4
	6-8	0,100	11,6	24,7	1,6	4,86	11,0
	8-10	0,124	36,6	18,4	1,5	4,78	8,2
Kai 68 Pkt 6	0-2	0,191	12,6	27,4	3,1	7,61	10,2
	2-4	0,233	13,1	51,4	1,1	3,48	8,9
	4-6	0,054	42,4	54,5	1,3	10,11	9,5
	6-8	0,232	24,2	31,6	2,2	4,82	10,9
	8-10	0,429	18,8	54,7	3,7	8,88	13,2
		0,814	11,2	93,1	2,0	31,13	13,7

Sediment samples direction North: corrected for blanks



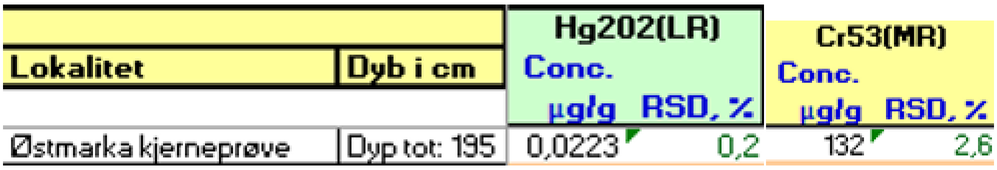
		Hg202(LR)		Cr53(MR)		Ni62(MR)		Cu65(MR)		Zn67(MR)		Cd114(MR)		Pb208(MR)		As75(HR)	
		Conc.		Conc.		Conc.		Conc.		Conc.		Conc.		Conc.		Conc.	
		µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %
		0,0112	5,4	52,8	1,7	25,5	3,8	17,9	1,8	52	2,0	0,095	14,5	12,6	0,9	10,4	3,5
		0,0108	6,2	52,5	2,2	25,8	4,7	17,9	2,2	50	2,2	0,096	6,8	12,8	2,5	10,6	5,2
		0,0104	1,4	51,9	1,4	25,4	4,1	17,8	2,9	51	3,5	0,088	10,1	12,9	0,6	10,5	6,4
Pier 68	25	0,0417	3,3	64,1	1,8	25,1	3,5	26,5	1,0	55,3	1,9	0,0514	3,3	17,3	1,3	3,84	5,1
Pier 68	100	0,101	3,1	81,7	2,3	28,0	1,5	21,7	1,4	69,5	2,3	0,135	8,9	18,8	1,8	6,76	7,0
Pier 68	200	0,172	1,1	91,1	1,7	32,9	2,9	25,9	2,5	78,4	0,2	0,0503	32,4	22,8	0,8	6,74	4,8
Pier 68	500	0,222	2,8	60,3	0,4	23,9	2,5	18,9	1,7	65,9	1,8	0,0406	37,7	28,6	2,0	6,14	2,7

Sediment samples direction North East: corrected for blanks



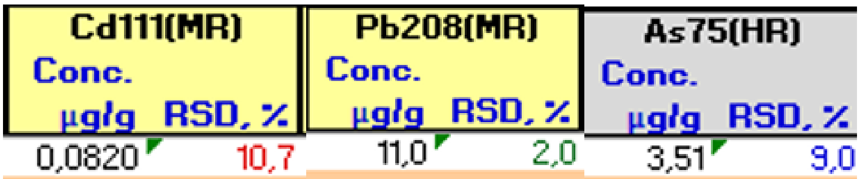
	Hg202(LR)		Cr53(MR)		Ni62(MR)		Cu65(MR)		Zn67(MR)		Cd114(MR)		Pb208(MR)		As75(HR)	
	Conc.		Conc.		Conc.		Conc.		Conc.		Conc.		Conc.		Conc.	
	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %	µg/g	RSD, %
Point 1	0,107	3,1	120	2,2	37,2	6,4	48,9	3,3	93,5	1,4	0,0959	30,4	23,3	1,5	9,52	3,8
Point 2	0,0405	5,3	70,1	2,3	24,8	3,4	17,3	0,6	53,5	2,2	0,0477	33,8	14,8	3,5	4,78	6,5
Point 3	0,099	3,5	97,9	1,5	32,1	3,8	34,1	0,9	80,4	2,4	0,0507	27,8	26,4	1,2	7,26	2,3
Point 4	0,0913	4,4	82,8	1,2	28,4	2,5	27,5	2,7	74,6	0,8	0,0720	22,6	24,1	0,7	4,52	4,0
Point 5	0,080	2,9	79,8	1,0	24,8	2,2	21,3	2,3	59,5	1,8	0,0565	34,3	19,2	2,4	3,27	9,6
Point 6	0,116	4,5	78,5	1,8	29,8	4,3	20,6	0,8	59,3	2,9	0,0470	16,2	18,3	2,9	5,77	3,4

Core sample sediment Østmarka:



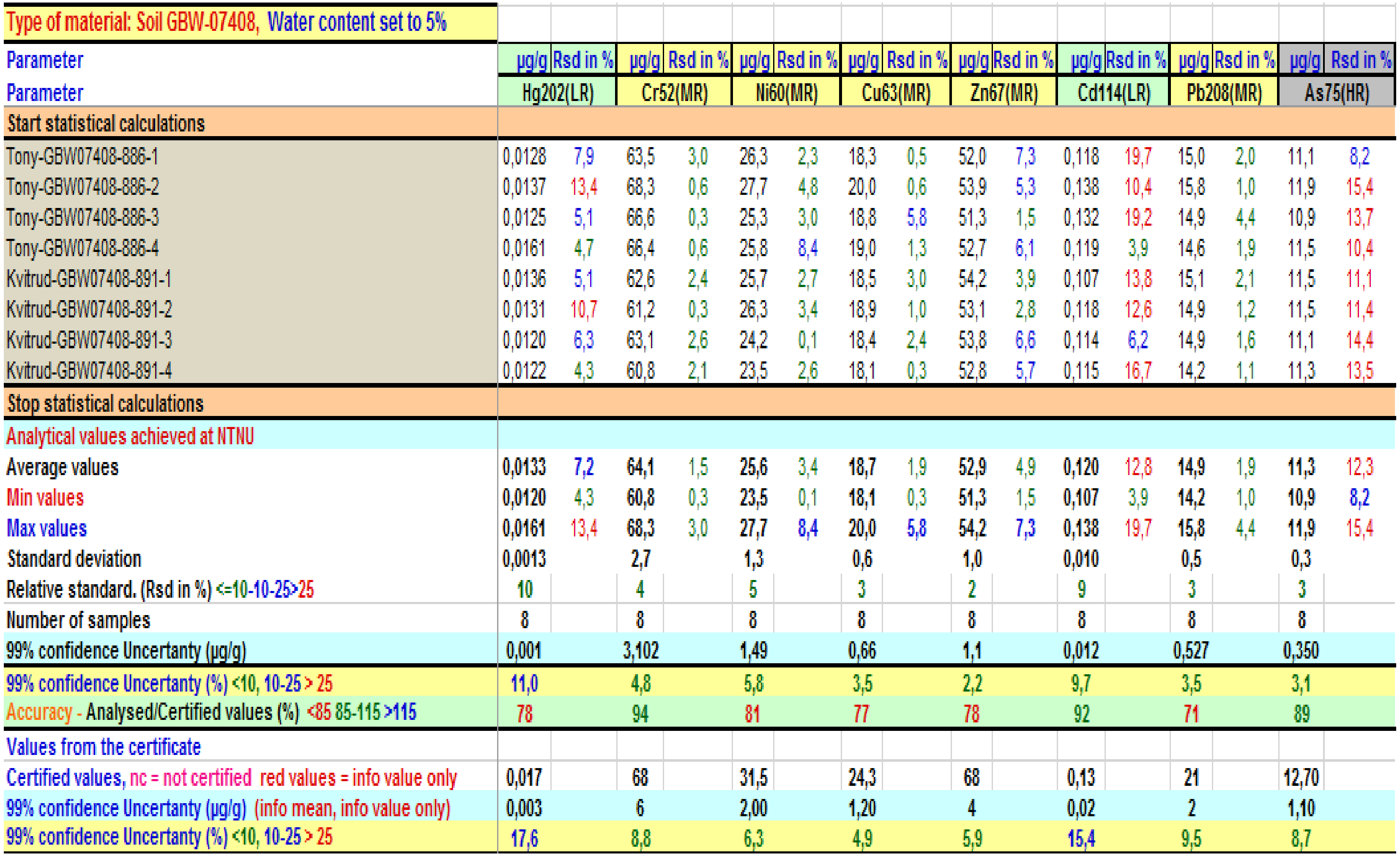
Lokalitet	Dyb i cm	Hg202(LR) Conc. µg/g	Hg202(LR) RSD, %	Cr53(MR) Conc. µg/g	Cr53(MR) RSD, %
Østmarka kjerneprøve	Dyp tot: 195	0,0223	0,2	132	2,6

Ni62(MR) Conc. µg/g	Ni62(MR) RSD, %	Cu65(MR) Conc. µg/g	Cu65(MR) RSD, %	Zn67(MR) Conc. µg/g	Zn67(MR) RSD, %
55,6	2,6	21,0	1,9	75,4	1,1



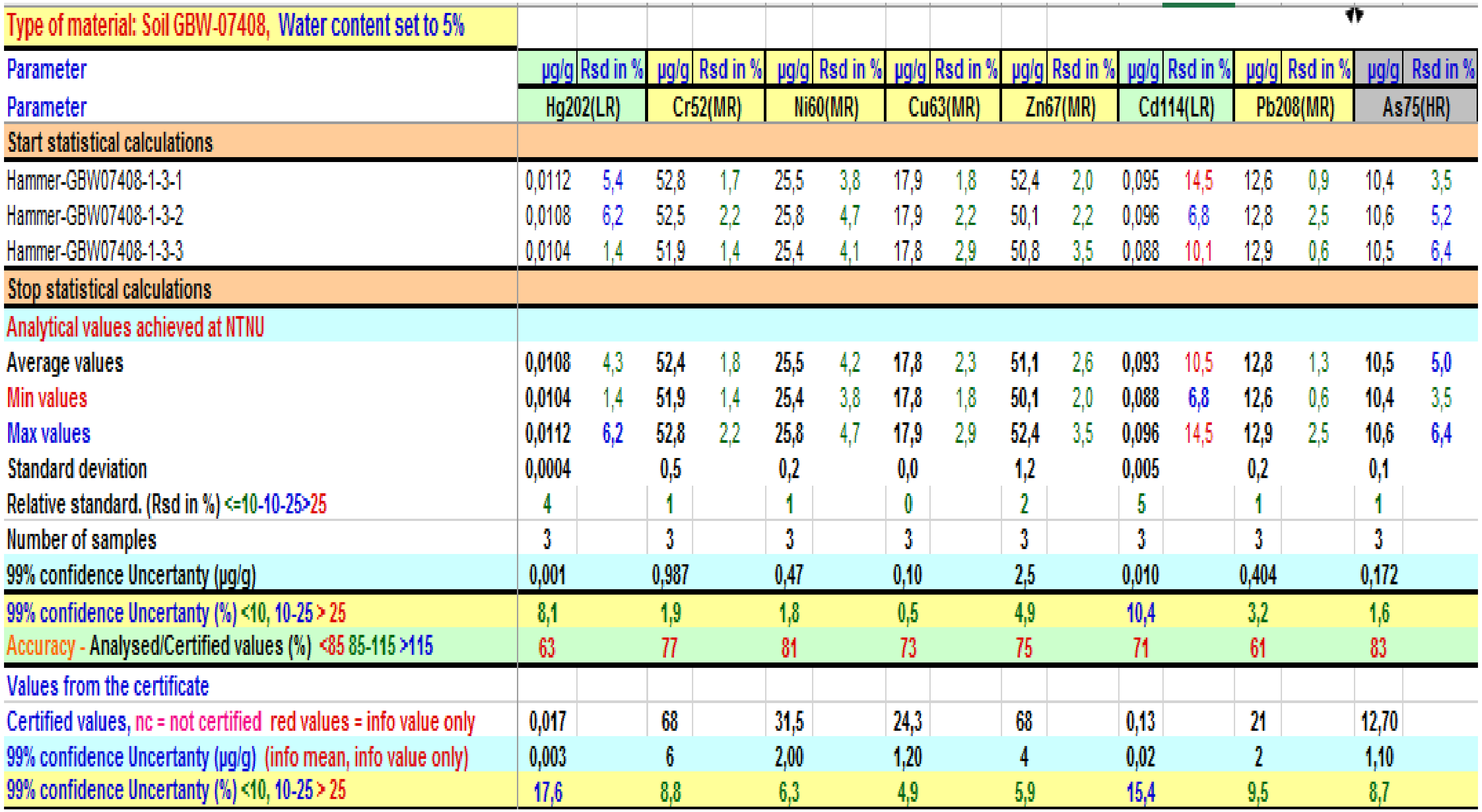
Cd111(MR) Conc. µg/g	Cd111(MR) RSD, %	Pb208(MR) Conc. µg/g	Pb208(MR) RSD, %	As75(HR) Conc. µg/g	As75(HR) RSD, %
0,0820	10,7	11,0	2,0	3,51	9,0

Reference material October:



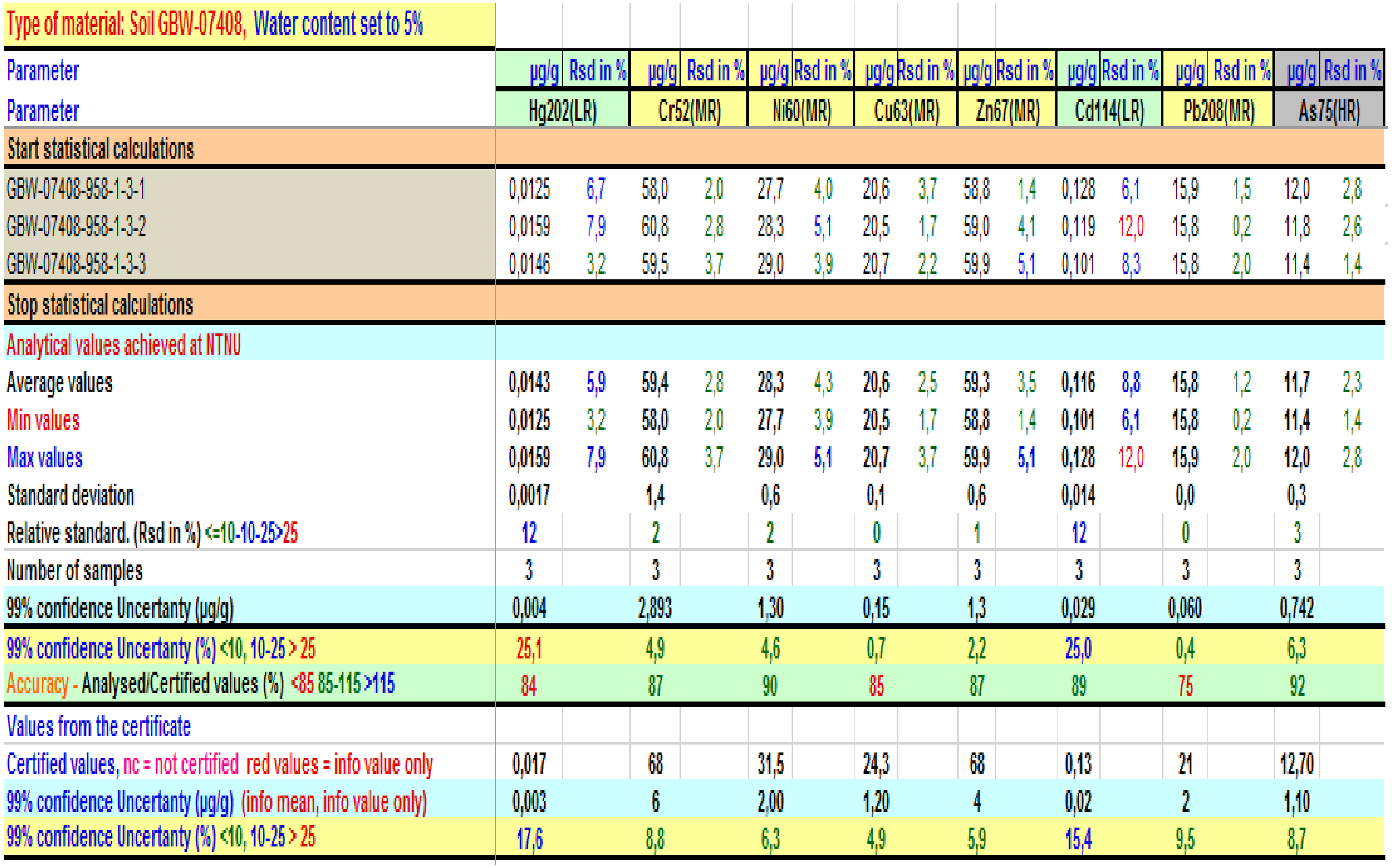
Type of material: Soil GBW-07408, Water content set to 5%																
Parameter	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %
Parameter	Hg202(LR)		Cr52(MR)		Ni60(MR)		Cu63(MR)		Zn67(MR)		Cd114(LR)		Pb208(MR)		As75(HR)	
Start statistical calculations																
Tony-GBW07408-886-1	0,0128	7,9	63,5	3,0	26,3	2,3	18,3	0,5	52,0	7,3	0,118	19,7	15,0	2,0	11,1	8,2
Tony-GBW07408-886-2	0,0137	13,4	68,3	0,6	27,7	4,8	20,0	0,6	53,9	5,3	0,138	10,4	15,8	1,0	11,9	15,4
Tony-GBW07408-886-3	0,0125	5,1	66,6	0,3	25,3	3,0	18,8	5,8	51,3	1,5	0,132	19,2	14,9	4,4	10,9	13,7
Tony-GBW07408-886-4	0,0161	4,7	66,4	0,6	25,8	8,4	19,0	1,3	52,7	6,1	0,119	3,9	14,6	1,9	11,5	10,4
Kvitrud-GBW07408-891-1	0,0136	5,1	62,6	2,4	25,7	2,7	18,5	3,0	54,2	3,9	0,107	13,8	15,1	2,1	11,5	11,1
Kvitrud-GBW07408-891-2	0,0131	10,7	61,2	0,3	26,3	3,4	18,9	1,0	53,1	2,8	0,118	12,6	14,9	1,2	11,5	11,4
Kvitrud-GBW07408-891-3	0,0120	6,3	63,1	2,6	24,2	0,1	18,4	2,4	53,8	6,6	0,114	6,2	14,9	1,6	11,1	14,4
Kvitrud-GBW07408-891-4	0,0122	4,3	60,8	2,1	23,5	2,6	18,1	0,3	52,8	5,7	0,115	16,7	14,2	1,1	11,3	13,5
Stop statistical calculations																
Analytical values achieved at NTNU																
Average values	0,0133	7,2	64,1	1,5	25,6	3,4	18,7	1,9	52,9	4,9	0,120	12,8	14,9	1,9	11,3	12,3
Min values	0,0120	4,3	60,8	0,3	23,5	0,1	18,1	0,3	51,3	1,5	0,107	3,9	14,2	1,0	10,9	8,2
Max values	0,0161	13,4	68,3	3,0	27,7	8,4	20,0	5,8	54,2	7,3	0,138	19,7	15,8	4,4	11,9	15,4
Standard deviation	0,0013		2,7		1,3		0,6		1,0		0,010		0,5		0,3	
Relative standard. (Rsd in %) <=10-10-25>25	10		4		5		3		2		9		3		3	
Number of samples	8		8		8		8		8		8		8		8	
99% confidence Uncertanty (µg/g)	0,001		3,102		1,49		0,66		1,1		0,012		0,527		0,350	
99% confidence Uncertanty (%) <10, 10-25 > 25	11,0		4,8		5,8		3,5		2,2		9,7		3,5		3,1	
Accuracy - Analysed/Certified values (%) <85 85-115 >115	78		94		81		77		78		92		71		89	
Values from the certificate																
Certified values, nc = not certified red values = info value only	0,017		68		31,5		24,3		68		0,13		21		12,70	
99% confidence Uncertanty (µg/g) (info mean, info value only)	0,003		6		2,00		1,20		4		0,02		2		1,10	
99% confidence Uncertanty (%) <10, 10-25 > 25	17,6		8,8		6,3		4,9		5,9		15,4		9,5		8,7	

Reference material May:



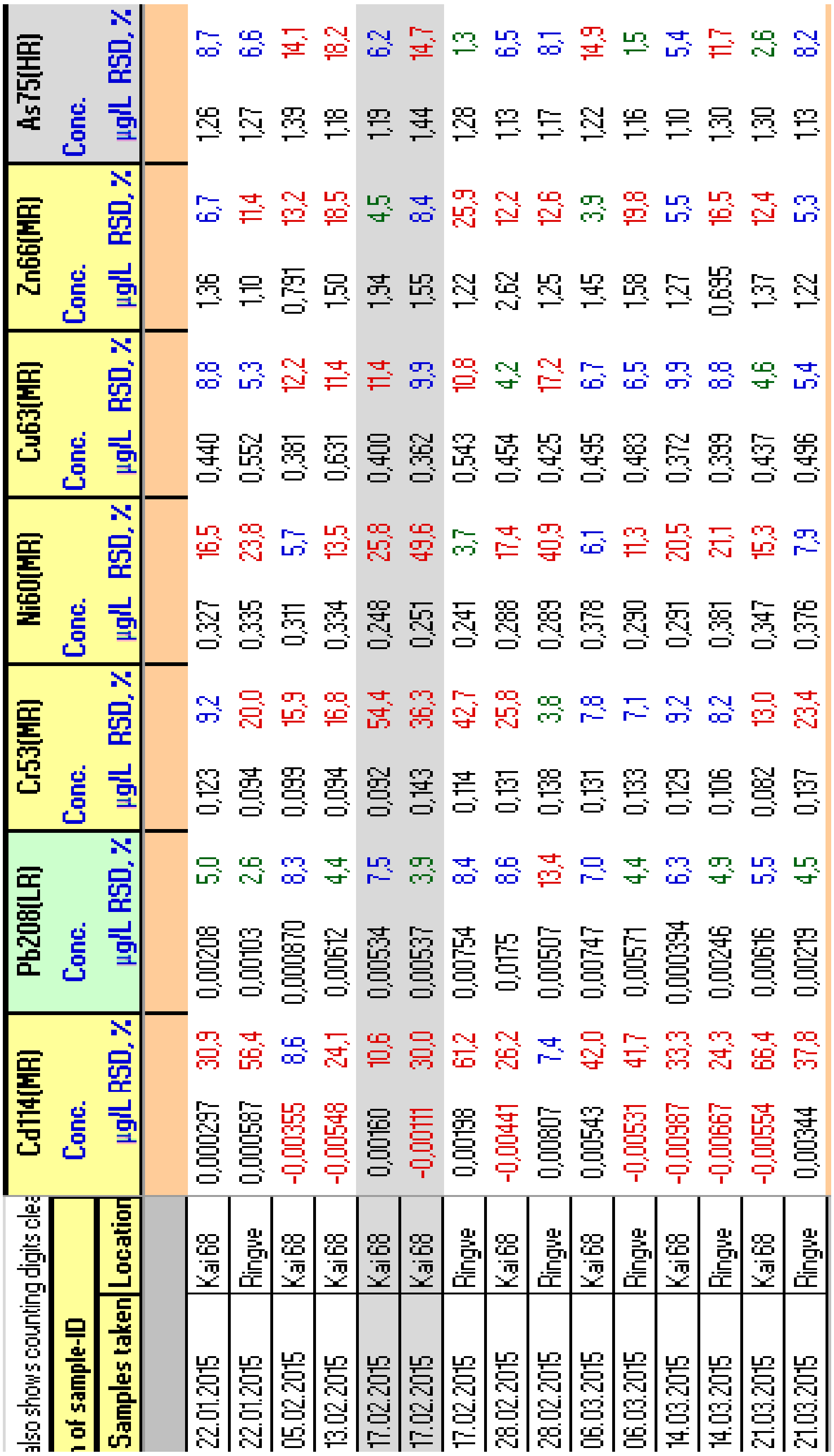
Type of material: Soil GBW-07408, Water content set to 5%																
Parameter	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %
Parameter	Hg202(LR)		Cr52(MR)		Ni60(MR)		Cu63(MR)		Zn67(MR)		Cd114(LR)		Pb208(MR)		As75(HR)	
Start statistical calculations																
Hammer-GBW07408-1-3-1	0,0112	5,4	52,8	1,7	25,5	3,8	17,9	1,8	52,4	2,0	0,095	14,5	12,6	0,9	10,4	3,5
Hammer-GBW07408-1-3-2	0,0108	6,2	52,5	2,2	25,8	4,7	17,9	2,2	50,1	2,2	0,096	6,8	12,8	2,5	10,6	5,2
Hammer-GBW07408-1-3-3	0,0104	1,4	51,9	1,4	25,4	4,1	17,8	2,9	50,8	3,5	0,088	10,1	12,9	0,6	10,5	6,4
Stop statistical calculations																
Analytical values achieved at NTNU																
Average values	0,0108	4,3	52,4	1,8	25,5	4,2	17,8	2,3	51,1	2,6	0,093	10,5	12,8	1,3	10,5	5,0
Min values	0,0104	1,4	51,9	1,4	25,4	3,8	17,8	1,8	50,1	2,0	0,088	6,8	12,6	0,6	10,4	3,5
Max values	0,0112	6,2	52,8	2,2	25,8	4,7	17,9	2,9	52,4	3,5	0,096	14,5	12,9	2,5	10,6	6,4
Standard deviation	0,0004		0,5		0,2		0,0		1,2		0,005		0,2		0,1	
Relative standard. (Rsd in %) <=10-10-25>25	4		1		1		0		2		5		1		1	
Number of samples	3		3		3		3		3		3		3		3	
99% confidence Uncertanty (µg/g)	0,001		0,987		0,47		0,10		2,5		0,010		0,404		0,172	
99% confidence Uncertanty (%) <10, 10-25 > 25	8,1		1,9		1,8		0,5		4,9		10,4		3,2		1,6	
Accuracy - Analysed/Certified values (%) <85 85-115 >115	63		77		81		73		75		71		61		83	
Values from the certificate																
Certified values, nc = not certified red values = info value only	0,017		68		31,5		24,3		68		0,13		21		12,70	
99% confidence Uncertanty (µg/g) (info mean, info value only)	0,003		6		2,00		1,20		4		0,02		2		1,10	
99% confidence Uncertanty (%) <10, 10-25 > 25	17,6		8,8		6,3		4,9		5,9		15,4		9,5		8,7	

Reference material February:



Type of material: Soil GBW-07408, Water content set to 5%																
Parameter	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %	µg/g	Rsd in %
Parameter	Hg202(LR)		Cr52(MR)		Ni60(MR)		Cu63(MR)		Zn67(MR)		Cd114(LR)		Pb208(MR)		As75(HR)	
Start statistical calculations																
GBW-07408-958-1-3-1	0,0125	6,7	58,0	2,0	27,7	4,0	20,6	3,7	58,8	1,4	0,128	6,1	15,9	1,5	12,0	2,8
GBW-07408-958-1-3-2	0,0159	7,9	60,8	2,8	28,3	5,1	20,5	1,7	59,0	4,1	0,119	12,0	15,8	0,2	11,8	2,6
GBW-07408-958-1-3-3	0,0146	3,2	59,5	3,7	29,0	3,9	20,7	2,2	59,9	5,1	0,101	8,3	15,8	2,0	11,4	1,4
Stop statistical calculations																
Analytical values achieved at NTNU																
Average values	0,0143	5,9	59,4	2,8	28,3	4,3	20,6	2,5	59,3	3,5	0,116	8,8	15,8	1,2	11,7	2,3
Min values	0,0125	3,2	58,0	2,0	27,7	3,9	20,5	1,7	58,8	1,4	0,101	6,1	15,8	0,2	11,4	1,4
Max values	0,0159	7,9	60,8	3,7	29,0	5,1	20,7	3,7	59,9	5,1	0,128	12,0	15,9	2,0	12,0	2,8
Standard deviation	0,0017		1,4		0,6		0,1		0,6		0,014		0,0		0,3	
Relative standard. (Rsd in %) <=10-10-25>25	12		2		2		0		1		12		0		3	
Number of samples	3		3		3		3		3		3		3		3	
99% confidence Uncertanty (µg/g)	0,004		2,893		1,30		0,15		1,3		0,029		0,060		0,742	
99% confidence Uncertanty (%) <10, 10-25 > 25	25,1		4,9		4,6		0,7		2,2		25,0		0,4		6,3	
Accuracy - Analysed/Certified values (%) <85 85-115 >115	84		87		90		85		87		89		75		92	
Values from the certificate																
Certified values, nc = not certified red values = info value only	0,017		68		31,5		24,3		68		0,13		21		12,70	
99% confidence Uncertanty (µg/g) (info mean, info value only)	0,003		6		2,00		1,20		4		0,02		2		1,10	
99% confidence Uncertanty (%) <10, 10-25 > 25	17,6		8,8		6,3		4,9		5,9		15,4		9,5		8,7	

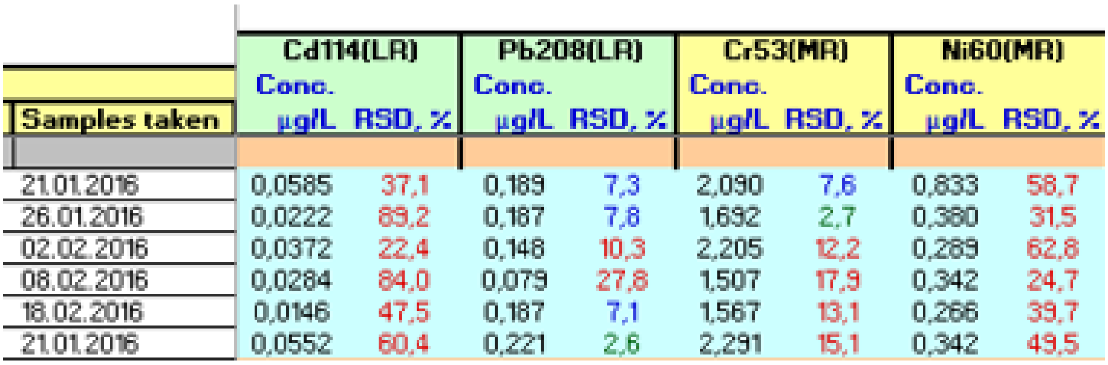
Surface water samples pier 68 and Ringve 2015:



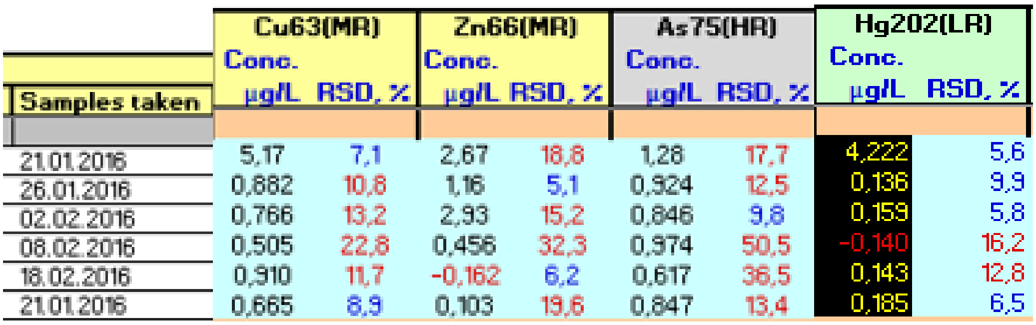
also shows counting digits clea		Cd114(MR)		Pb208(LR)		Cr53(MR)		Ni60(MR)		Cu63(MR)		Zn66(MR)		As75(HR)	
n of sample-ID		Conc.		Conc.		Conc.		Conc.		Conc.		Conc.		Conc.	
Samples taken	Location	µg/L	RSD, %	µg/L	RSD, %	µg/L	RSD, %	µg/L	RSD, %	µg/L	RSD, %	µg/L	RSD, %	µg/L	RSD, %
22.01.2015	Kai 68	0,000297	30,9	0,00208	5,0	0,123	9,2	0,327	16,5	0,440	8,8	1,36	6,7	1,26	8,7
22.01.2015	Ringve	0,000587	56,4	0,00103	2,6	0,094	20,0	0,335	23,8	0,552	5,3	1,10	11,4	1,27	6,6
05.02.2015	Kai 68	-0,00355	8,6	0,000870	8,3	0,099	15,9	0,311	5,7	0,381	12,2	0,791	13,2	1,39	14,1
13.02.2015	Kai 68	-0,00548	24,1	0,00612	4,4	0,094	16,8	0,334	13,5	0,631	11,4	1,50	18,5	1,18	18,2
17.02.2015	Kai 68	0,00160	10,6	0,00534	7,5	0,092	54,4	0,248	25,8	0,400	11,4	1,94	4,5	1,19	6,2
17.02.2015	Kai 68	-0,00111	30,0	0,00537	3,9	0,143	36,3	0,251	49,6	0,362	9,9	1,55	8,4	1,44	14,7
17.02.2015	Ringve	0,00198	61,2	0,00754	8,4	0,114	42,7	0,241	3,7	0,543	10,8	1,22	25,9	1,28	1,3
28.02.2015	Kai 68	-0,00441	26,2	0,0175	8,6	0,131	25,8	0,288	17,4	0,454	4,2	2,62	12,2	1,13	6,5
28.02.2015	Ringve	0,00807	7,4	0,00507	13,4	0,138	3,8	0,289	40,9	0,425	17,2	1,25	12,6	1,17	8,1
06.03.2015	Kai 68	0,00543	42,0	0,00747	7,0	0,131	7,8	0,378	6,1	0,495	6,7	1,45	3,9	1,22	14,9
06.03.2015	Ringve	-0,00531	41,7	0,00571	4,4	0,133	7,1	0,290	11,3	0,483	6,5	1,58	19,8	1,16	1,5
14.03.2015	Kai 68	-0,00987	33,3	0,000394	6,3	0,129	9,2	0,291	20,5	0,372	9,9	1,27	5,5	1,10	5,4
14.03.2015	Ringve	-0,00667	24,3	0,00246	4,9	0,106	8,2	0,381	21,1	0,399	8,8	0,695	16,5	1,30	11,7
21.03.2015	Kai 68	-0,00554	66,4	0,00616	5,5	0,082	13,0	0,347	15,3	0,437	4,6	1,37	12,4	1,30	2,6
21.03.2015	Ringve	0,00344	37,8	0,00219	4,5	0,137	23,4	0,376	7,9	0,496	5,4	1,22	5,3	1,13	8,2

Hg is not shown due to very uncertain results, below IDL.

Surface water samples pier 68 January and February 2016:

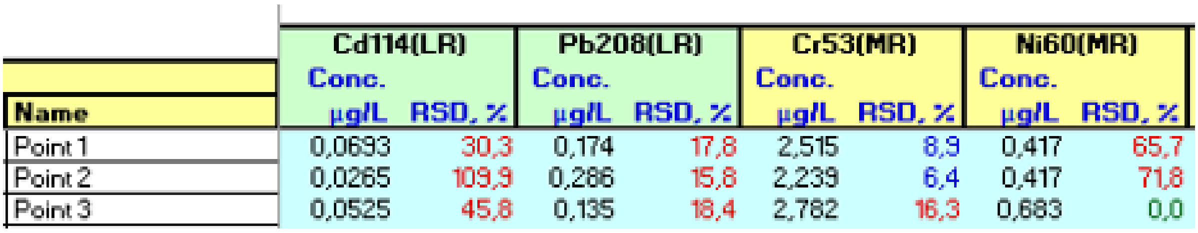


	Cd114(LR)		Pb208(LR)		Cr53(MR)		Ni60(MR)	
Samples taken	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %
21.01.2016	0,0585	37,1	0,189	7,3	2,090	7,6	0,833	58,7
26.01.2016	0,0222	89,2	0,187	7,8	1,692	2,7	0,380	31,5
02.02.2016	0,0372	22,4	0,148	10,3	2,205	12,2	0,289	62,8
08.02.2016	0,0284	84,0	0,079	27,8	1,507	17,9	0,342	24,7
18.02.2016	0,0146	47,5	0,187	7,1	1,567	13,1	0,266	39,7
21.01.2016	0,0552	60,4	0,221	2,6	2,291	15,1	0,342	49,5

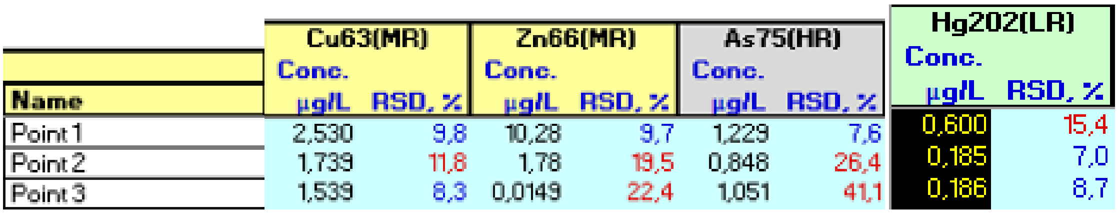


	Cu63(MR)		Zn66(MR)		As75(HR)		Hg202(LR)	
Samples taken	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %
21.01.2016	5,17	7,1	2,67	18,8	1,28	17,7	4,222	5,6
26.01.2016	0,882	10,8	1,16	5,1	0,924	12,5	0,136	9,9
02.02.2016	0,766	13,2	2,93	15,2	0,846	9,8	0,159	5,8
08.02.2016	0,505	22,8	0,456	32,3	0,974	50,5	-0,140	16,2
18.02.2016	0,910	11,7	-0,162	6,2	0,617	36,5	0,143	12,8
21.01.2016	0,665	8,9	0,103	19,6	0,847	13,4	0,185	6,5

Surface water samples taken out on the fjord:

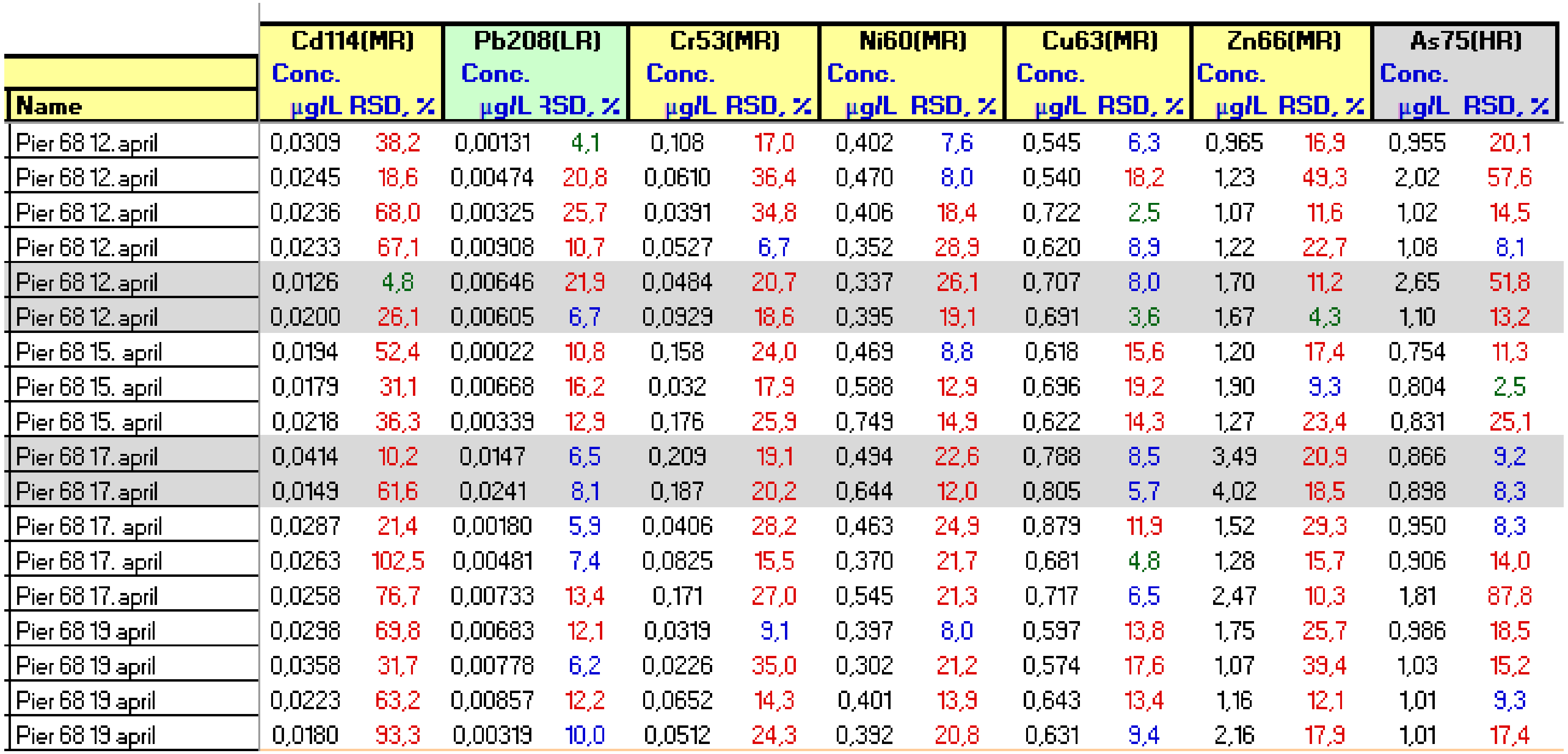


	Cd114(LR)		Pb208(LR)		Cr53(MR)		Ni60(MR)	
Name	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %
Point 1	0,0693	30,3	0,174	17,8	2,515	8,9	0,417	65,7
Point 2	0,0265	109,9	0,286	15,8	2,239	6,4	0,417	71,8
Point 3	0,0525	45,8	0,135	18,4	2,782	16,3	0,683	0,0



	Cu63(MR)		Zn66(MR)		As75(HR)		Hg202(LR)	
Name	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %	Conc. µg/L	RSD, %
Point 1	2,530	9,8	10,28	9,7	1,229	7,6	0,600	15,4
Point 2	1,739	11,8	1,78	19,5	0,848	26,4	0,185	7,0
Point 3	1,539	8,3	0,0149	22,4	1,051	41,1	0,186	8,7

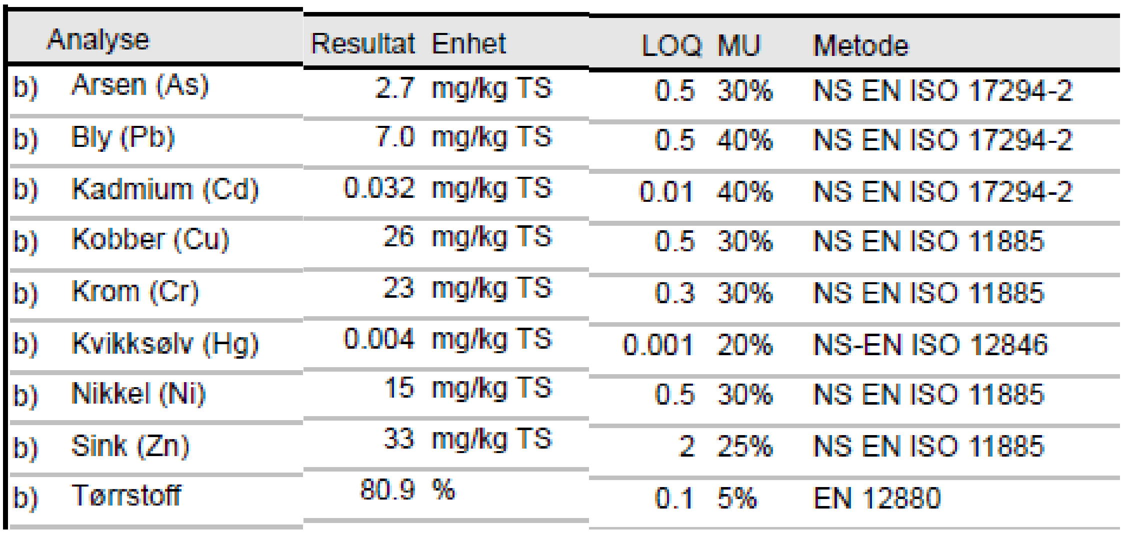
Surface water samples pier 68 April 2016:



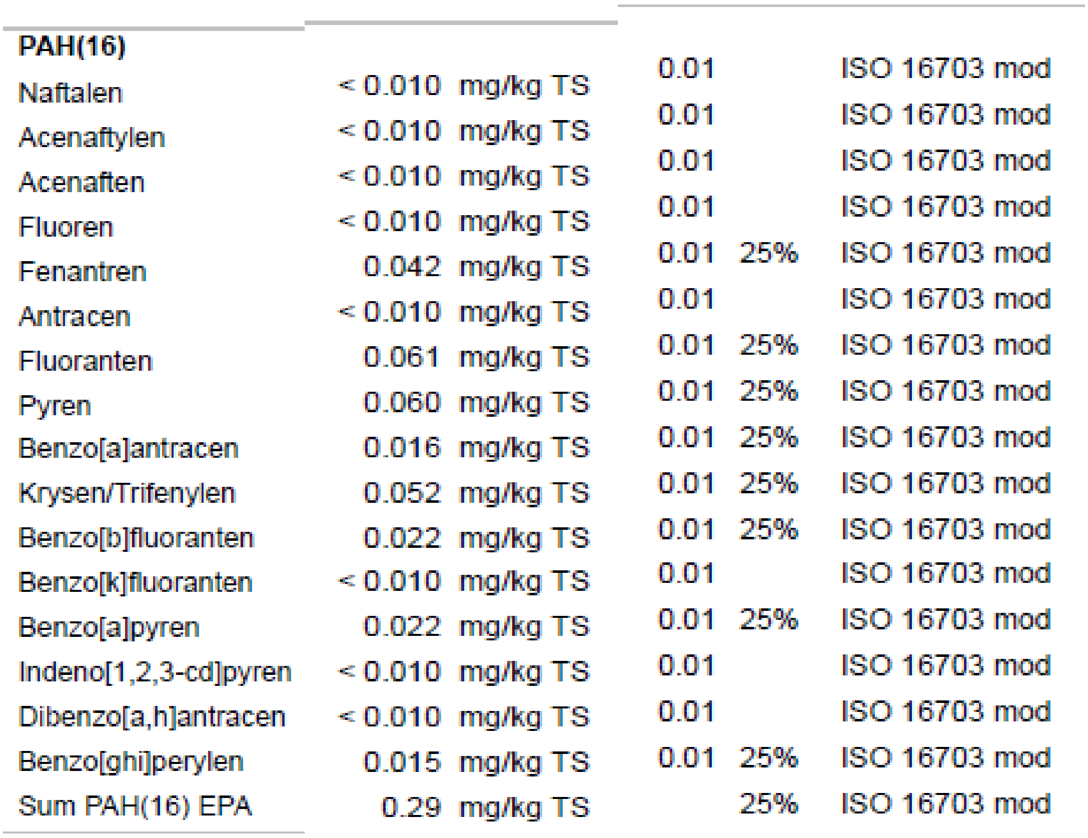
Name	Cd114(MR) Conc. µg/L	Cd114(MR) RSD, %	Pb208(LR) Conc. µg/L	Pb208(LR) RSD, %	Cr53(MR) Conc. µg/L	Cr53(MR) RSD, %	Ni60(MR) Conc. µg/L	Ni60(MR) RSD, %	Cu63(MR) Conc. µg/L	Cu63(MR) RSD, %	Zn66(MR) Conc. µg/L	Zn66(MR) RSD, %	As75(HR) Conc. µg/L	As75(HR) RSD, %
Pier 68 12.april	0,0309	38,2	0,00131	4,1	0,108	17,0	0,402	7,6	0,545	6,3	0,965	16,9	0,955	20,1
Pier 68 12.april	0,0245	18,6	0,00474	20,8	0,0610	36,4	0,470	8,0	0,540	18,2	1,23	49,3	2,02	57,6
Pier 68 12.april	0,0236	68,0	0,00325	25,7	0,0391	34,8	0,406	18,4	0,722	2,5	1,07	11,6	1,02	14,5
Pier 68 12.april	0,0233	67,1	0,00908	10,7	0,0527	6,7	0,352	28,9	0,620	8,9	1,22	22,7	1,08	8,1
Pier 68 12.april	0,0126	4,8	0,00646	21,9	0,0484	20,7	0,337	26,1	0,707	8,0	1,70	11,2	2,65	51,8
Pier 68 12.april	0,0200	26,1	0,00605	6,7	0,0929	18,6	0,395	19,1	0,691	3,6	1,67	4,3	1,10	13,2
Pier 68 15. april	0,0194	52,4	0,00022	10,8	0,158	24,0	0,469	8,8	0,618	15,6	1,20	17,4	0,754	11,3
Pier 68 15. april	0,0179	31,1	0,00668	16,2	0,032	17,9	0,588	12,9	0,696	19,2	1,90	9,3	0,804	2,5
Pier 68 15. april	0,0218	36,3	0,00339	12,9	0,176	25,9	0,749	14,9	0,622	14,3	1,27	23,4	0,831	25,1
Pier 68 17.april	0,0414	10,2	0,0147	6,5	0,209	19,1	0,494	22,6	0,788	8,5	3,49	20,9	0,866	9,2
Pier 68 17.april	0,0149	61,6	0,0241	8,1	0,187	20,2	0,644	12,0	0,805	5,7	4,02	18,5	0,898	8,3
Pier 68 17. april	0,0287	21,4	0,00180	5,9	0,0406	28,2	0,463	24,9	0,879	11,9	1,52	29,3	0,950	8,3
Pier 68 17. april	0,0263	102,5	0,00481	7,4	0,0825	15,5	0,370	21,7	0,681	4,8	1,28	15,7	0,906	14,0
Pier 68 17.april	0,0258	76,7	0,00733	13,4	0,171	27,0	0,545	21,3	0,717	6,5	2,47	10,3	1,81	87,8
Pier 68 19 april	0,0298	69,8	0,00683	12,1	0,0319	9,1	0,397	8,0	0,597	13,8	1,75	25,7	0,986	18,5
Pier 68 19 april	0,0358	31,7	0,00778	6,2	0,0226	35,0	0,302	21,2	0,574	17,6	1,07	39,4	1,03	15,2
Pier 68 19 april	0,0223	63,2	0,00857	12,2	0,0652	14,3	0,401	13,9	0,643	13,4	1,16	12,1	1,01	9,3
Pier 68 19 april	0,0180	93,3	0,00319	10,0	0,0512	24,3	0,392	20,8	0,631	9,4	2,16	17,9	1,01	17,4

Appendix J: results sediment traps

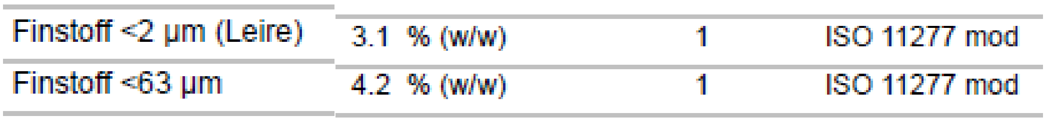
Trap 1



	Analyse	Resultat	Enhet	LOQ	MU	Metode
b)	Arsen (As)	2.7	mg/kg TS	0.5	30%	NS EN ISO 17294-2
b)	Bly (Pb)	7.0	mg/kg TS	0.5	40%	NS EN ISO 17294-2
b)	Kadmium (Cd)	0.032	mg/kg TS	0.01	40%	NS EN ISO 17294-2
b)	Kobber (Cu)	26	mg/kg TS	0.5	30%	NS EN ISO 11885
b)	Krom (Cr)	23	mg/kg TS	0.3	30%	NS EN ISO 11885
b)	Kvikksølv (Hg)	0.004	mg/kg TS	0.001	20%	NS-EN ISO 12846
b)	Nikkel (Ni)	15	mg/kg TS	0.5	30%	NS EN ISO 11885
b)	Sink (Zn)	33	mg/kg TS	2	25%	NS EN ISO 11885
b)	Tørrstoff	80.9	%	0.1	5%	EN 12880

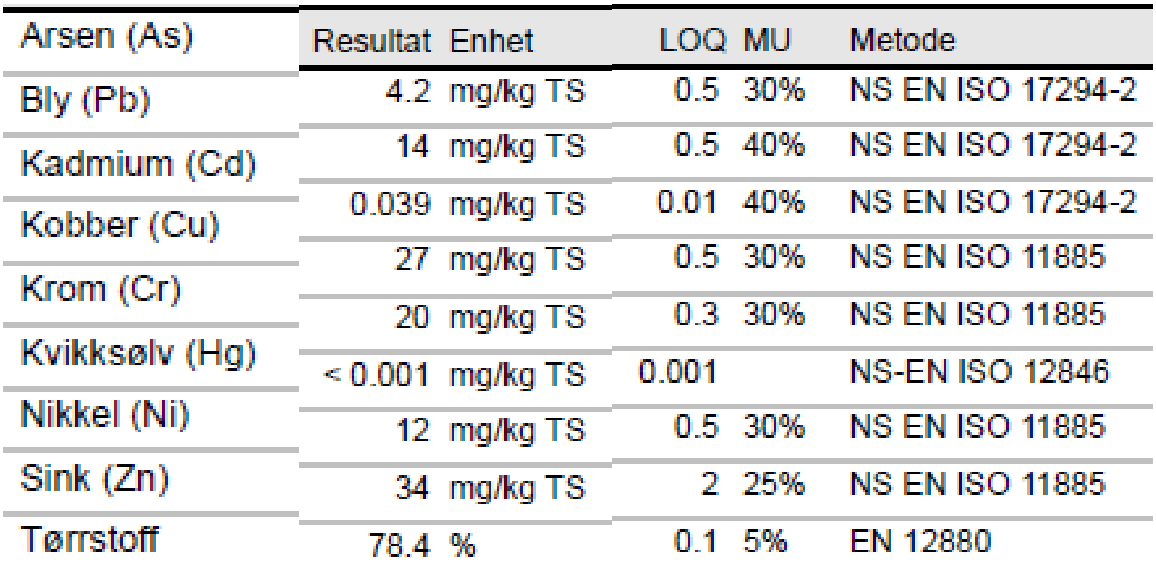


PAH(16)					
Naftalen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Acenaftylen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Acenaften	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fluoren	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fenantren	0.042	mg/kg TS	0.01	25%	ISO 16703 mod
Antracen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fluoranten	0.061	mg/kg TS	0.01	25%	ISO 16703 mod
Pyren	0.060	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[a]antracen	0.016	mg/kg TS	0.01	25%	ISO 16703 mod
Krysen/Trifenylen	0.052	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[b]fluoranten	0.022	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[k]fluoranten	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Benzo[a]pyren	0.022	mg/kg TS	0.01	25%	ISO 16703 mod
Indeno[1,2,3-cd]pyren	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Dibenzo[a,h]antracen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Benzo[ghi]perylen	0.015	mg/kg TS	0.01	25%	ISO 16703 mod
Sum PAH(16) EPA	0.29	mg/kg TS		25%	ISO 16703 mod

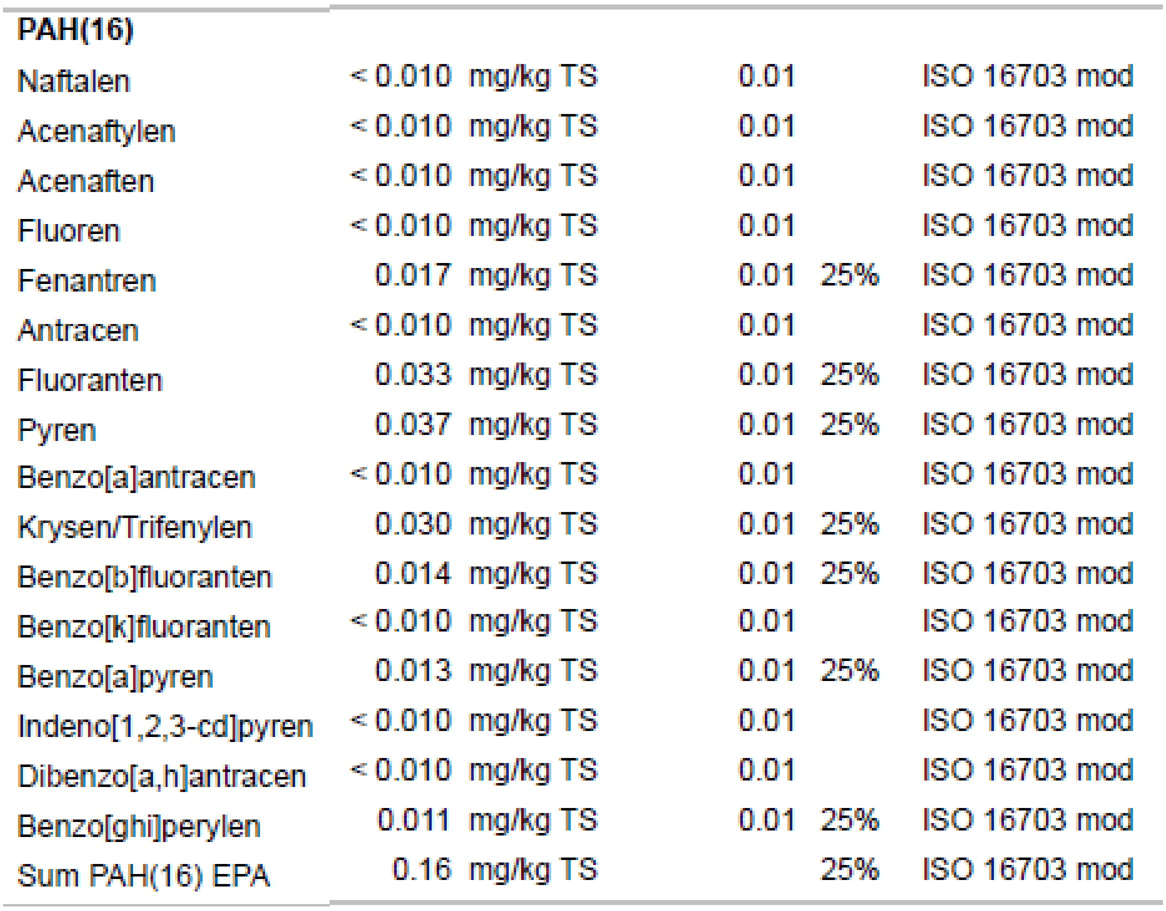


Finstoff <2 µm (Leire)	3.1	% (w/w)	1	ISO 11277 mod
Finstoff <63 µm	4.2	% (w/w)	1	ISO 11277 mod

Trap 2

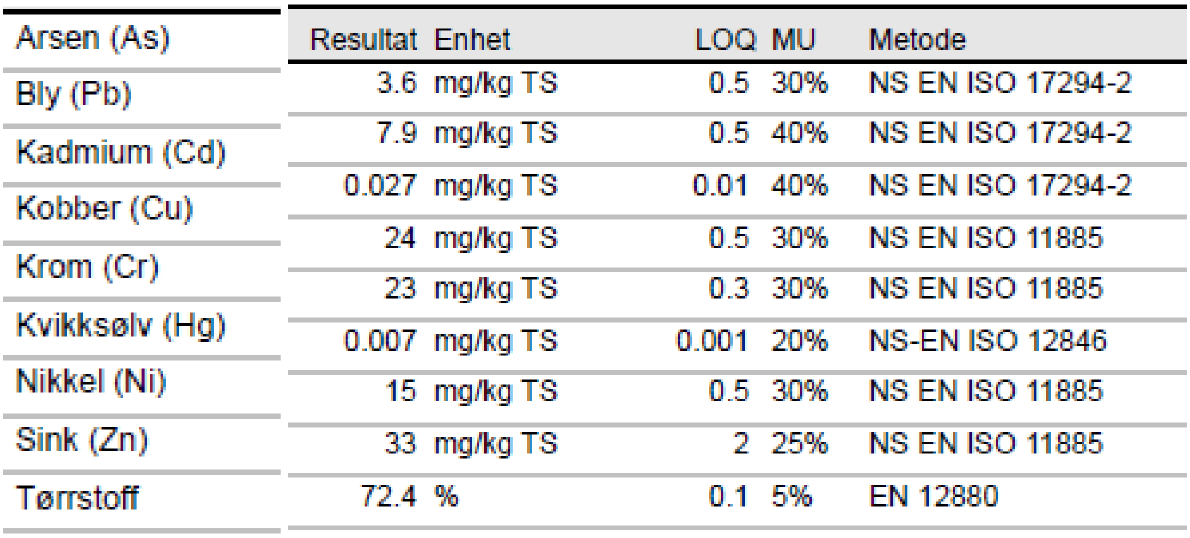


	Resultat	Enhet	LOQ	MU	Metode
Arsen (As)	4.2	mg/kg TS	0.5	30%	NS EN ISO 17294-2
Bly (Pb)	14	mg/kg TS	0.5	40%	NS EN ISO 17294-2
Kadmium (Cd)	0.039	mg/kg TS	0.01	40%	NS EN ISO 17294-2
Kobber (Cu)	27	mg/kg TS	0.5	30%	NS EN ISO 11885
Krom (Cr)	20	mg/kg TS	0.3	30%	NS EN ISO 11885
Kvikksølv (Hg)	< 0.001	mg/kg TS	0.001		NS-EN ISO 12846
Nikkel (Ni)	12	mg/kg TS	0.5	30%	NS EN ISO 11885
Sink (Zn)	34	mg/kg TS	2	25%	NS EN ISO 11885
Tørrstoff	78.4	%	0.1	5%	EN 12880

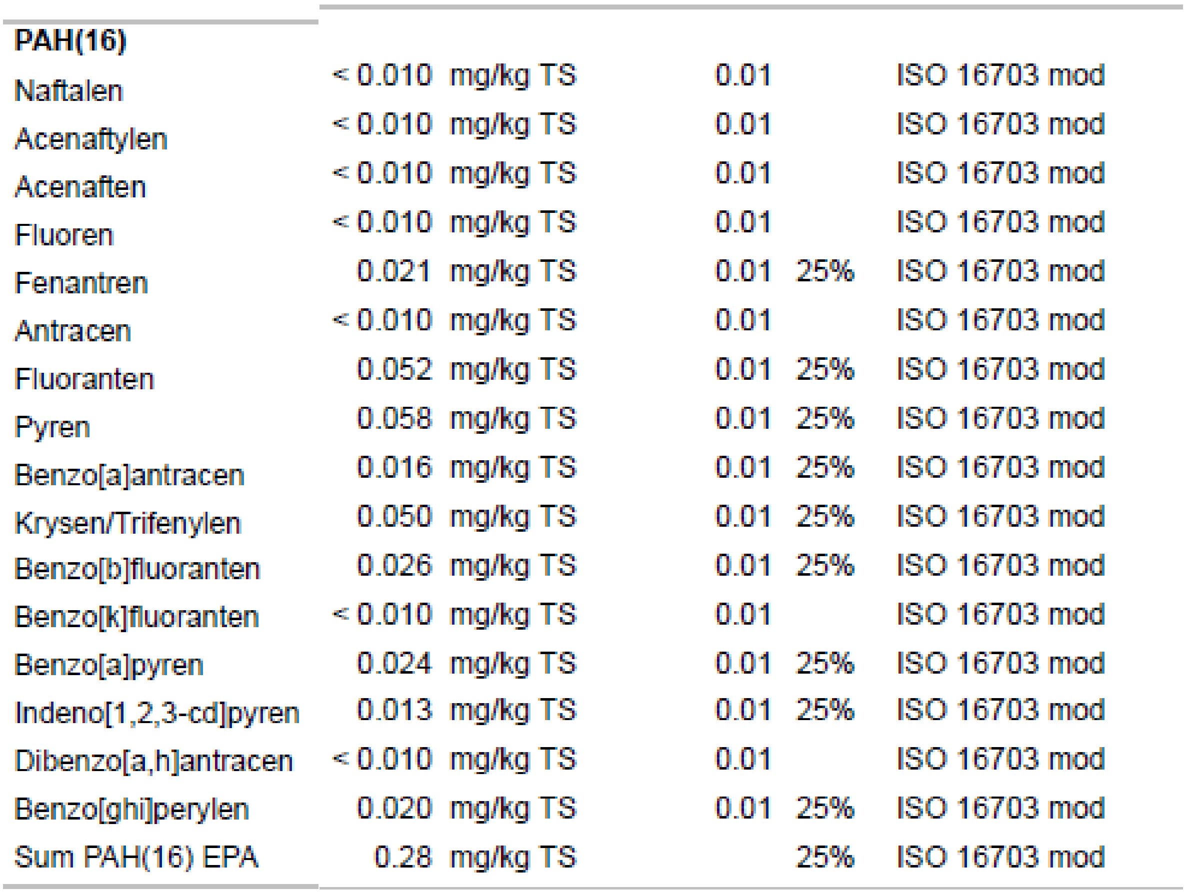


PAH(16)					
Naftalen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Acenaftylen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Acenaften	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fluoren	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fenantren	0.017	mg/kg TS	0.01	25%	ISO 16703 mod
Antracen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fluoranten	0.033	mg/kg TS	0.01	25%	ISO 16703 mod
Pyren	0.037	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[a]antracen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Krysen/Trifenylen	0.030	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[b]fluoranten	0.014	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[k]fluoranten	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Benzo[a]pyren	0.013	mg/kg TS	0.01	25%	ISO 16703 mod
Indeno[1,2,3-cd]pyren	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Dibenzo[a,h]antracen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Benzo[ghi]perylen	0.011	mg/kg TS	0.01	25%	ISO 16703 mod
Sum PAH(16) EPA	0.16	mg/kg TS		25%	ISO 16703 mod

Trap 3



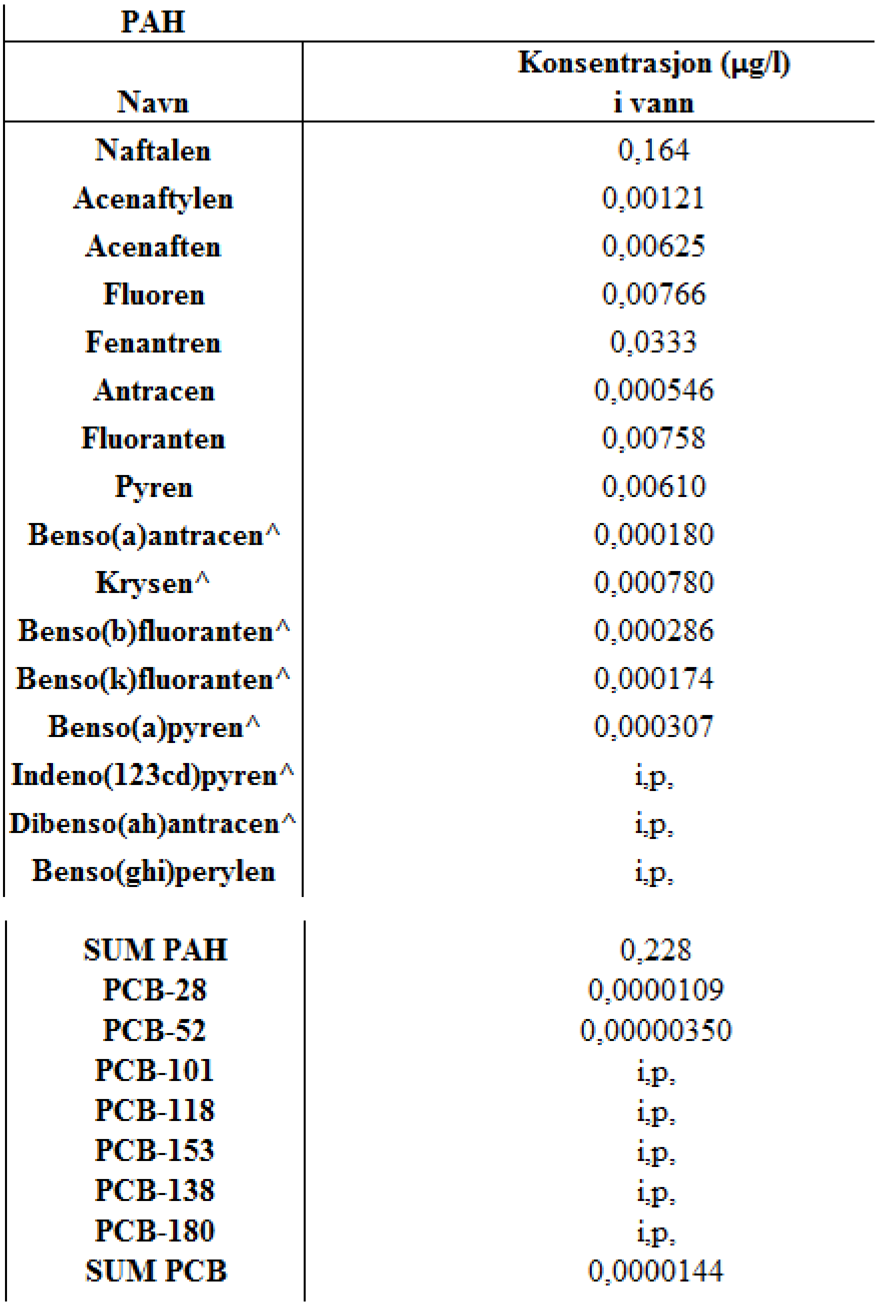
	Resultat	Enhet	LOQ	MU	Metode
Arsen (As)	3.6	mg/kg TS	0.5	30%	NS EN ISO 17294-2
Bly (Pb)	7.9	mg/kg TS	0.5	40%	NS EN ISO 17294-2
Kadmium (Cd)	0.027	mg/kg TS	0.01	40%	NS EN ISO 17294-2
Kobber (Cu)	24	mg/kg TS	0.5	30%	NS EN ISO 11885
Krom (Cr)	23	mg/kg TS	0.3	30%	NS EN ISO 11885
Kvikksølv (Hg)	0.007	mg/kg TS	0.001	20%	NS-EN ISO 12846
Nikkel (Ni)	15	mg/kg TS	0.5	30%	NS EN ISO 11885
Sink (Zn)	33	mg/kg TS	2	25%	NS EN ISO 11885
Tørrstoff	72.4	%	0.1	5%	EN 12880



PAH(16)					
Naftalen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Acenaftylen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Acenaften	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fluoren	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fenantren	0.021	mg/kg TS	0.01	25%	ISO 16703 mod
Antracen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Fluoranten	0.052	mg/kg TS	0.01	25%	ISO 16703 mod
Pyren	0.058	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[a]antracen	0.016	mg/kg TS	0.01	25%	ISO 16703 mod
Krysen/Trifenylen	0.050	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[b]fluoranten	0.026	mg/kg TS	0.01	25%	ISO 16703 mod
Benzo[k]fluoranten	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Benzo[a]pyren	0.024	mg/kg TS	0.01	25%	ISO 16703 mod
Indeno[1,2,3-cd]pyren	0.013	mg/kg TS	0.01	25%	ISO 16703 mod
Dibenzo[a,h]antracen	< 0.010	mg/kg TS	0.01		ISO 16703 mod
Benzo[ghi]perylen	0.020	mg/kg TS	0.01	25%	ISO 16703 mod
Sum PAH(16) EPA	0.28	mg/kg TS		25%	ISO 16703 mod

Appendix K: results POMs

POM1:



PAH

Navn	Konsentrasjon (µg/l) i vann
Naftalen	0,164
Acenaftylen	0,00121
Acenaften	0,00625
Fluoren	0,00766
Fenantren	0,0333
Antracen	0,000546
Fluoranten	0,00758
Pyren	0,00610
Benso(a)antracen^	0,000180
Krysen^	0,000780
Benso(b)fluoranten^	0,000286
Benso(k)fluoranten^	0,000174
Benso(a)pyren^	0,000307
Indeno(123cd)pyren^	i.p.
Dibenso(ah)antracen^	i.p.
Benso(ghi)perylen	i.p.
SUM PAH	0,228
PCB-28	0,0000109
PCB-52	0,00000350
PCB-101	i.p.
PCB-118	i.p.
PCB-153	i.p.
PCB-138	i.p.
PCB-180	i.p.
SUM PCB	0,0000144

POM2:

PAH

Navn	Konsentrasjon (µg/l) i vann
Naftalen	0,273
Acenaftylen	0,0122
Acenaften	1,39
Fluoren	0,671
Fenantren	1,52
Antracen	0,0423
Fluoranten	0,231
Pyren	0,111
Benso(a)antracen^	0,00209
Krysen^	0,00353
Benso(b)fluoranten^	0,000263
Benso(k)fluoranten^	0,000172
Benso(a)pyren^	0,000107
Indeno(123cd)pyren^	i.p.
Dibenso(ah)antracen^	i.p.
Benso(ghi)perylen	0,0000763
SUM PAH	4,26

Krysen^	0,00353
Benso(b)fluoranten^	0,000263
Benso(k)fluoranten^	0,000172
Benso(a)pyren^	0,000107
Indeno(123cd)pyren^	i.p.
Dibenso(ah)antracen^	i.p.
Benso(ghi)perylen	0,0000763
SUM PAH	4,26
PCB-28	0,00000626
PCB-52	0,0000187
PCB-101	i.p.
PCB-118	i.p.
PCB-153	i.p.
PCB-138	0,000000477
PCB-180	i.p.
SUM PCB	0,00000861

POM3:

PAH

Navn	Konsentrasjon (µg/l) i vann
Naftalen	0,148
Acenaftylen	0,00124
Acenaften	0,0570
Fluoren	0,0381
Fenantren	0,149
Antracen	0,00325
Fluoranten	0,0375
Pyren	0,0188
Benso(a)antracen^	0,000393
Krysen^	0,000881
Benso(b)fluoranten^	0,000306
Benso(k)fluoranten^	0,000158
Benso(a)pyren^	0,0000821
Indeno(123cd)pyren^	i.p.
Dibenso(ah)antracen^	i.p.
Benso(ghi)perylen	i.p.
SUM PAH	0,455

PCB-28	0,00000618
PCB-52	0,00000171
PCB-101	i.p.
PCB-118	i.p.
PCB-153	i.p.
PCB-138	i.p.
PCB-180	i.p.
SUM PCB	0,00000788

Appendix L: detection limits ICP-MS NTNU

Instrument detection limit (IDL) ICP-MS NTNU:

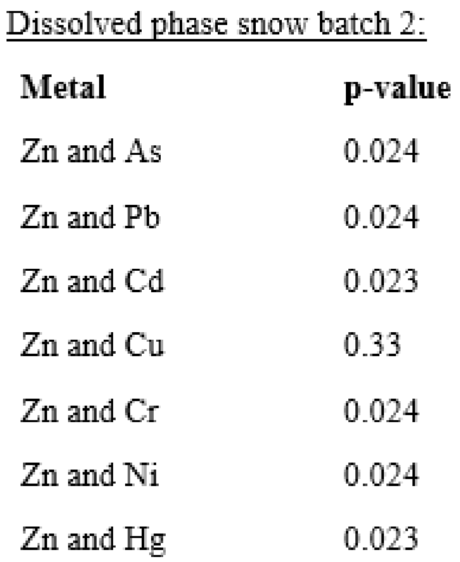
	Undiluted samples (DGTs) μg/L	Sea water samples μg/L	Sediment samples mg/kg dry weight
As	0.025	0.25	0.050
Pb	0.002	0.02	0.004
Cd	0.002	0.02	0.004
Cu	0.03	0.30	0.04
Cr	0.005	0.05	0.01
Hg	0.001	0.01	0.002
Ni	0.015	0.15	0.03
Zn	0.025	0.25	0.08

Appendix M: all DGTs January and February

Period	**DGT no:**	**Pb**	**Cd**	**Cu**	**Cr**	**Ni**	**Zn**
		µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
21.01-26.01	1	0,0376	0,0095	1,03	0,0602	0,155	0,901
	2	0,0262	0,0114	8,13	0,0485	0,172	1,09
	3	0,0209	0,0104	15,9	0,0495	0,172	1,42
26.01-02.02	4	0,0162	0,0097	0,585	0,0419	0,160	0,765
	5	0,0268	0,0111	1,44	0,0361	0,476	0,847
	6	0,0220	0,0112	0,708	0,0450	0,163	0,806
02.02-08.02	7	0,0337	0,0134	5,25	0,0465	0,869	2,11
	8	0,0291	0,0133	1,26	0,0379	0,175	0,805
	9	0,0438	0,0130	10,8	0,0597	0,213	1,38
08.02-18.02	10	0,27	0,0105	5,57	0,161	0,176	0,820
	11	0,0432	0,00918	5,26	0,0659	0,167	0,777
	12	0,0412	0,00919	6,28	0,0576	0,147	0,729
18.02-21.02	13	0,0314	0,0104	3,23	0,0705	0,149	0,965
	14	0,0581	0,0115	4,80	0,0818	0,167	0,871
	15	0,0394	0,0117	3,22	0,0811	0,206	0,969

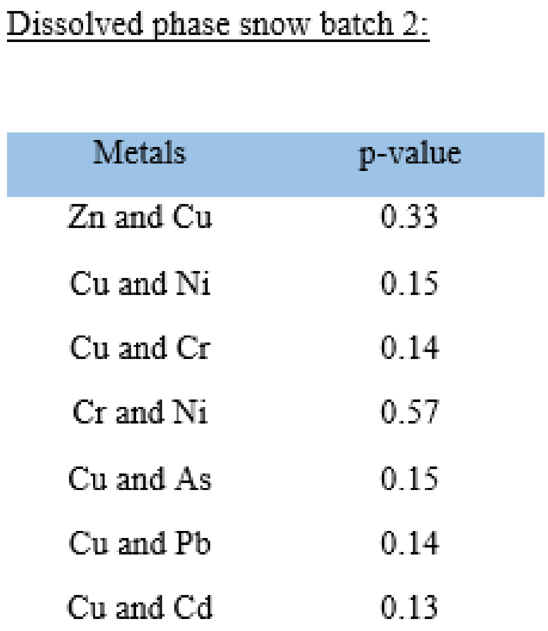
Appendix N: p-values

The p-values found using t-test in Excel.



Dissolved phase snow batch 2:

Metal	**p-value**
Zn and As	0.024
Zn and Pb	0.024
Zn and Cd	0.023
Zn and Cu	0.33
Zn and Cr	0.024
Zn and Ni	0.024
Zn and Hg	0.023

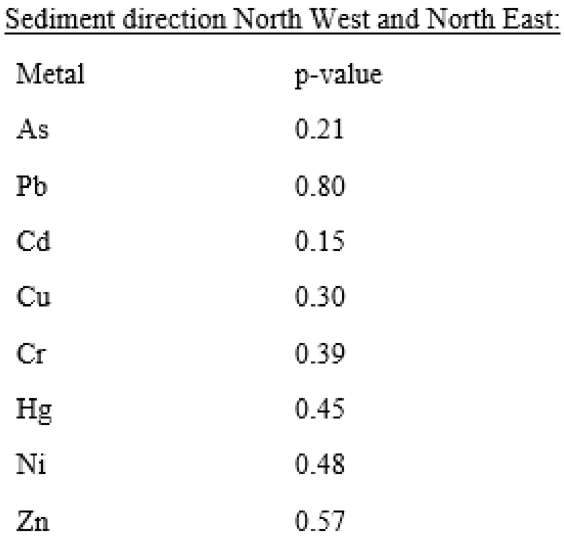


Dissolved phase snow batch 2:

Metals	p-value
Zn and Cu	0.33
Cu and Ni	0.15
Cu and Cr	0.14
Cr and Ni	0.57
Cu and As	0.15
Cu and Pb	0.14
Cu and Cd	0.13

Snow samples particulate material:

Metals	p-value
Zn and Cu	0.015
Zn and Cr	0.011
Cu and Cr	0.22
Cu and Ni	0.0040
Cr and Ni	0.013
Ni and Pb	0.021
Pb and As	0.0031
As and Cd	0.017
Cd and Hg	0.015



Sediment direction North West and North East:

Metal	p-value
As	0.21
Pb	0.80
Cd	0.15
Cu	0.30
Cr	0.39
Hg	0.45
Ni	0.48
Zn	0.57

Sediment direction North West and North East:

Metal	p-value
As	0.21
Pb	0.80
Cd	0.15
Cu	0.30

Cr	0.39
Hg	0.45
Ni	0.48
Zn	0.57

Sediment Feb and May:

Metal	p-value
As	1
Pb	0.93
Cd	0.85
Cu	0.31
Cr	0.21
Hg	0.30
Ni	0.54
Zn	0.58

Snow samples particulate material and sediment:

Metals	p-value
As	0.11
Pb	0.00082
Cd	0.53
Cu	0.0054
Cr	0.26
Hg	0.00010
Ni	0.095
Zn	0.0061

Surface water Ringve and pier 68 2015:

Metal	p-value
As	0.95
Pb	0.36
Cd	-
Cu	0.43
Cr	0.35
Hg	-
Ni	0.91
Zn	0.14

Surface water pier 68 2015 and during snow dumping.

Metal	p-value
As	0.02
Pb	0.0005
Cd	0.02
Cu	0.2
Cu (without value 5.17)	0.01
Cr	5E-05
Hg	
Ni	0.3
Zn	0.6

Surface water pier 68 during and after snow dumping:

Metal	p-value
As	0.31
Pb	0.00054
Cd	0.22
Cu	0.32
Cu without value (5.17 µg/L)	0.36
Cr	4.0014E-05
Ni	0.59
Zn	0.52

Surface water pier 68 during snow dumping and out on the fjord:

Metals	p-value
As	0.41
Pb	0.59
Cd	0.39
Cu	0.59
Cr	0.030
Ni	0.47
Zn	0.47

Surface water pier 68 2015 and after snow dumping.

Metal	p-value
Cu	0.0027

Surface water and water column during snow dumping

Metal	p-value
Pb	0.0016
Cd	0.026
Cu	0.051
Cr	4.42E-05
Ni	0.13
Zn	0.69

Water column during and after snow dumping

Metals	p-value
Pb	0.23
Cd	0.048
Cu	0.58
Cr	0.010
Ni	0.066
Zn	0.0023

Sediment 100 m oktober vs. 150 m:

Metals	p-value
As	0.27
Pb	0.047
Cd	0.21
Cu	0.0086
Cr	0.024
Hg	0.065
Ni	0.0077
Zn	0.77

Snow samples dissolved phase (batch 1)

Metals	p-value
Cu and Zn	0.45
Zn and Ni	0.052
Cu and Ni	0.00013
Ni and Cr	0.011
Zn and Cr	0.037
Zn and Cd	0.023

Average concentrations sediment all directions (except 500 m out)

Metals	p-value
Cr and Cu	$5.8*10^{-10}$

Appendix O: results deeper layers Østmarka point 1, 3 and 6

Point 1

Depth cm	Hg mg/kg DW	Cr mg/kg DW	Ni mg/kg DW	Cu mg/kg DW	Zn mg/kg DW	Cd mg/kg DW	Pb mg/kg DW	As mg/kg DW
0-2	0.0593	69.5	25.6	17.6	47.6	0.0732	13.4	3.08
2-4	0.0621	61.1	23.2	20.8	59.8	0.103	17.0	3.12
4-6	0.122	83.7	30.1	25.2	75.5	0.153	25.6	3.72
6-8	0.198	75.7	29.7	26.6	255	0.410	40.3	8.65

Point 3

Depth cm	Hg mg/kg DW	Cr mg/kg DW	Ni mg/kg DW	Cu mg/kg DW	Zn mg/kg DW	Cd mg/kg DW	Pb mg/kg DW	As mg/kg DW
0-2	0.0672	78.2	25.6	20.1	69.7	0.0827	0.0827	2.71
2-4	0.141	69.3	27.5	33.2	66.8	0.167	0.167	4.12
4-6	0.110	77.8	25.9	25.9	76.6	0.112	0.112	3.74
6-8	0.254	89.2	36.6	26.2	71.7	0.100	0.100	4.86

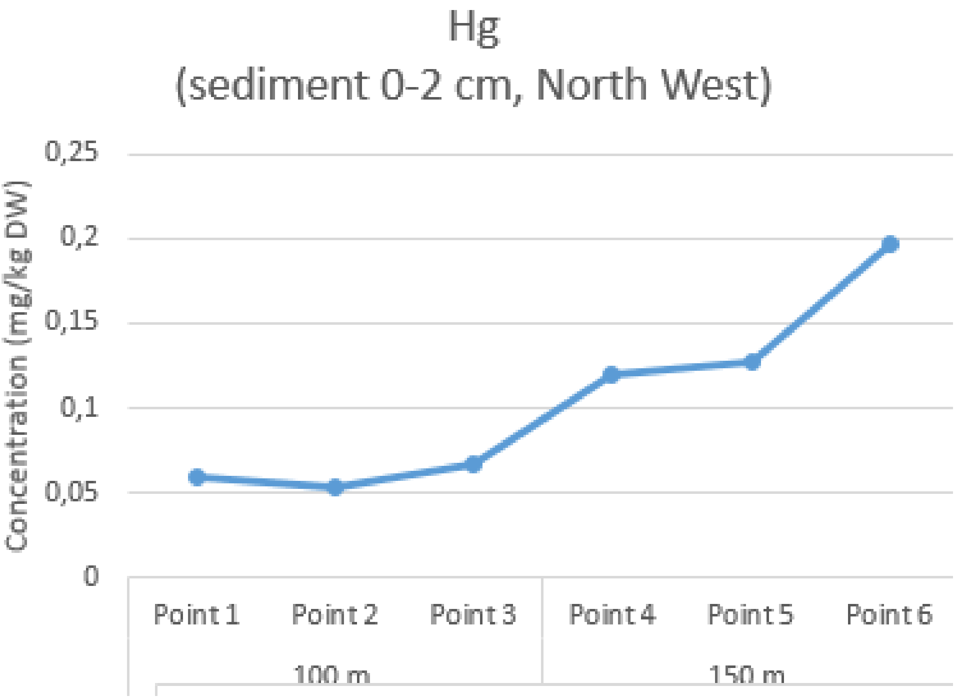
Point 6

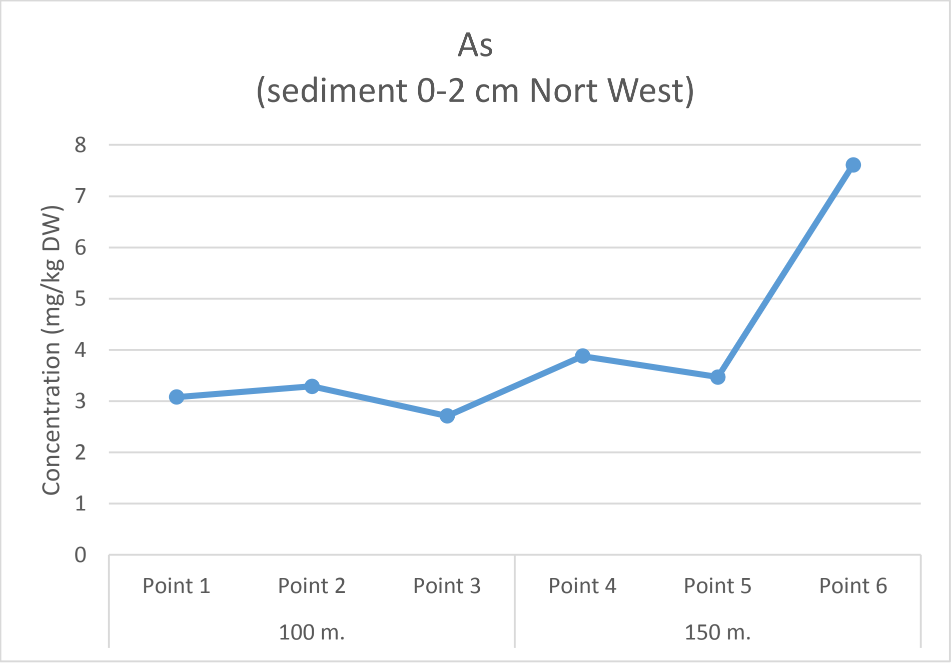
Depth cm	Hg mg/kg DW	Cr mg/kg DW	Ni mg/kg DW	Cu mg/kg DW	Zn mg/kg DW	Cd mg/kg DW	Pb mg/kg DW	As mg/kg DW
0-2	0.197	87.5	29.7	28.1	82.5	0.191	27.4	7.61
2-4	0.299	81.5	27.9	21.9	92.4	0.233	51.4	3.48
4-6	0.283	90.9	31.8	36.0	96.7	0.054	54.5	10.1
6-8	0.215	70.0	29.5	37.6	90.4	0.232	31.6	4.82
8-10	0.320	94.1	38.0	43.5	122	0.429	54.7	8.88

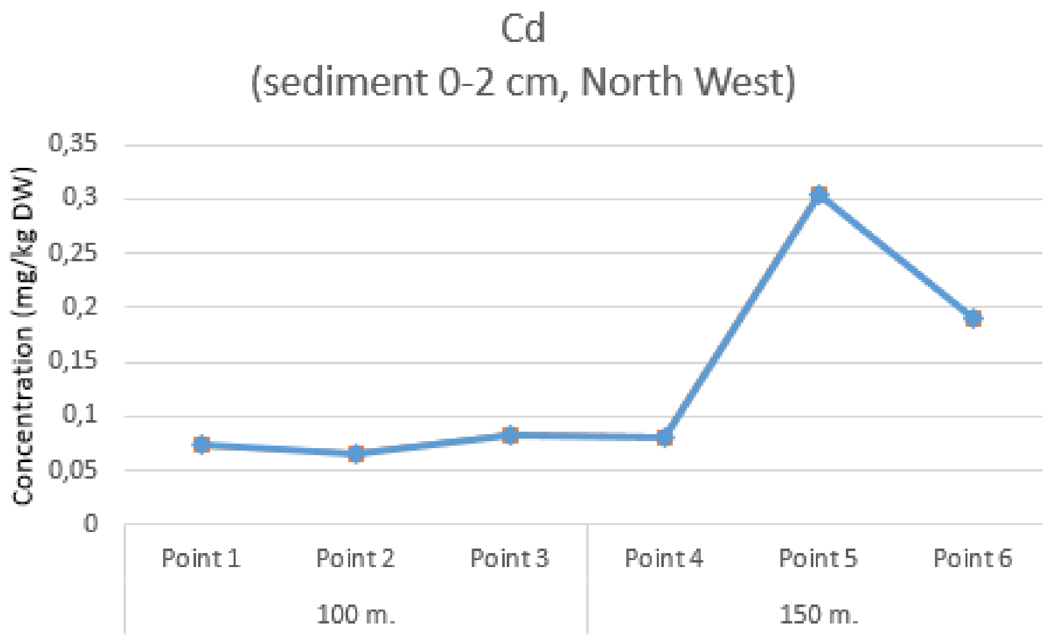
Appendix P: results all water samples April 2016

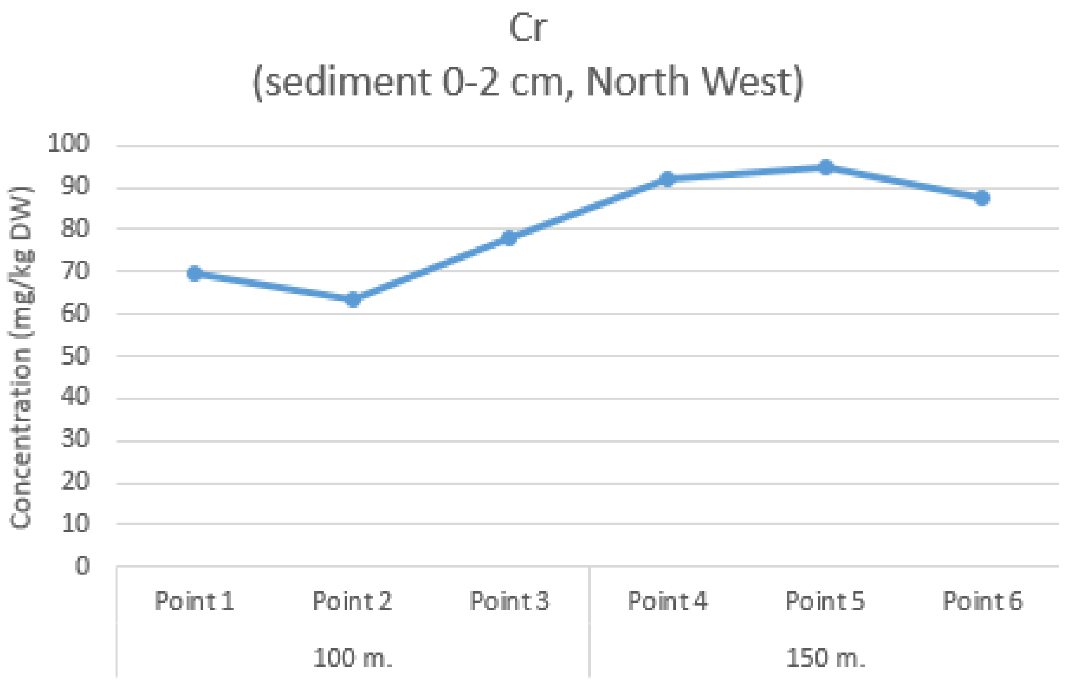
	As	**Pb**	**Cu**	**Cr**	**Ni**	**Zn**
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
April 12th, sample 1	0,955	< 0,02	0,545	0,108	0,402	0,965
April 12th, sample 2	2,02	< 0,02	0,540	0,0610	0,470	1,23
April 12th, sample 3	1,02	< 0,02	0,722	0,0391	0,406	1,07
April 12th, sample 4	1,08	< 0,02	0,620	0,0527	0,352	1,22
April 12th, sample 5	1,88	0,01	0,699	0,0707	0,366	1,69
April 15th, sample 1	0,754	< 0,02	0,618	0,158	0,469	1,20
April 15th sample 2	0,804	< 0,02	0,696	0,032	0,588	1,90
April 15th sample 3	0,831	< 0,02	0,622	0,176	0,749	1,27
April 17th, sample 1	0,882	0,0194	0,797	0,198	0,569	3,76
April 17th, sample 2	0,950	< 0,02	0,879	0,0406	0,463	1,52
April 17th, sample 3	0,906	< 0,02	0,681	0,0825	0,370	1,28
April 17th sample 4	1,81	< 0,02	0,717	0,171	0,545	2,47
April 19th, sample 1	0,986	< 0,02	0,597	0,0319	0,397	1,75
April 19th, sample 2	1,03	< 0,02	0,574	0,0226	0,302	1,07
April 19th, sample 3	1,01	< 0,02	0,643	0,0652	0,401	1,16
April 19th, sample 4	1,01	< 0,02	0,631	0,0512	0,392	2,16

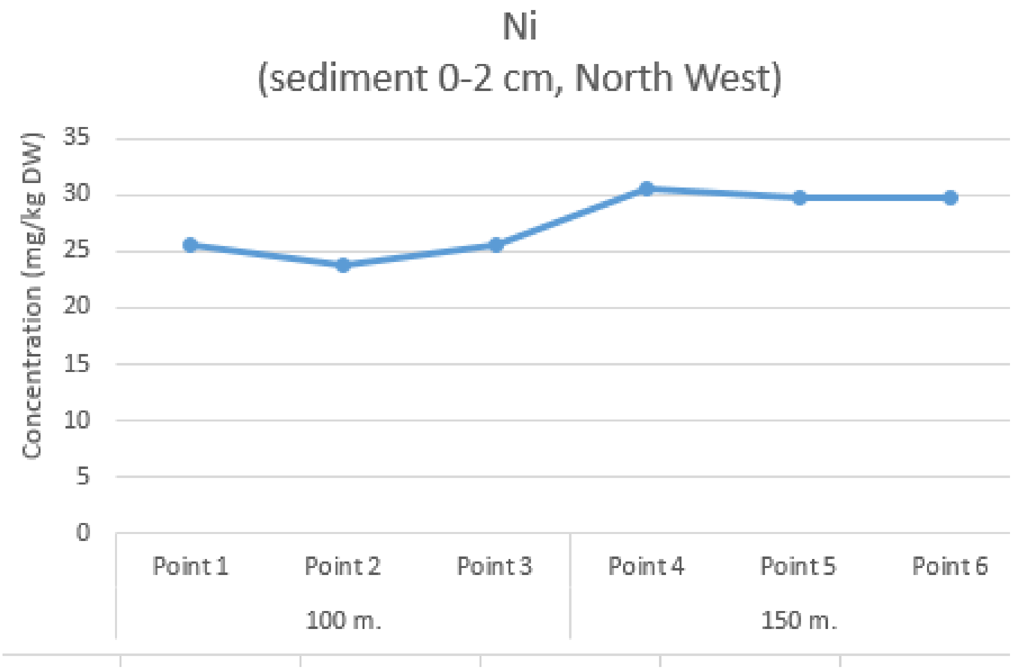
Appendix Q: sediment graphs

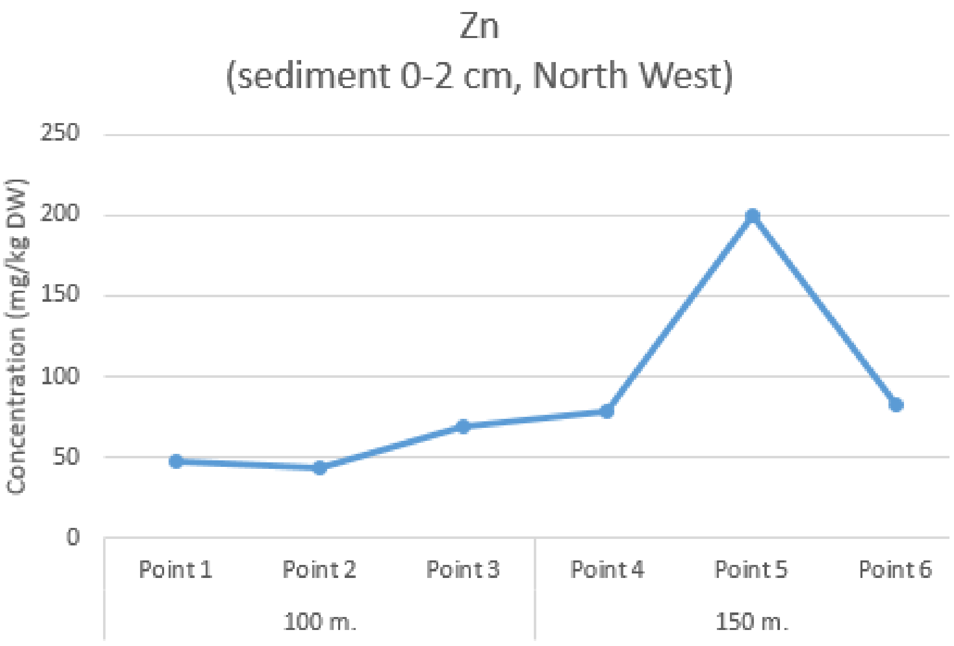


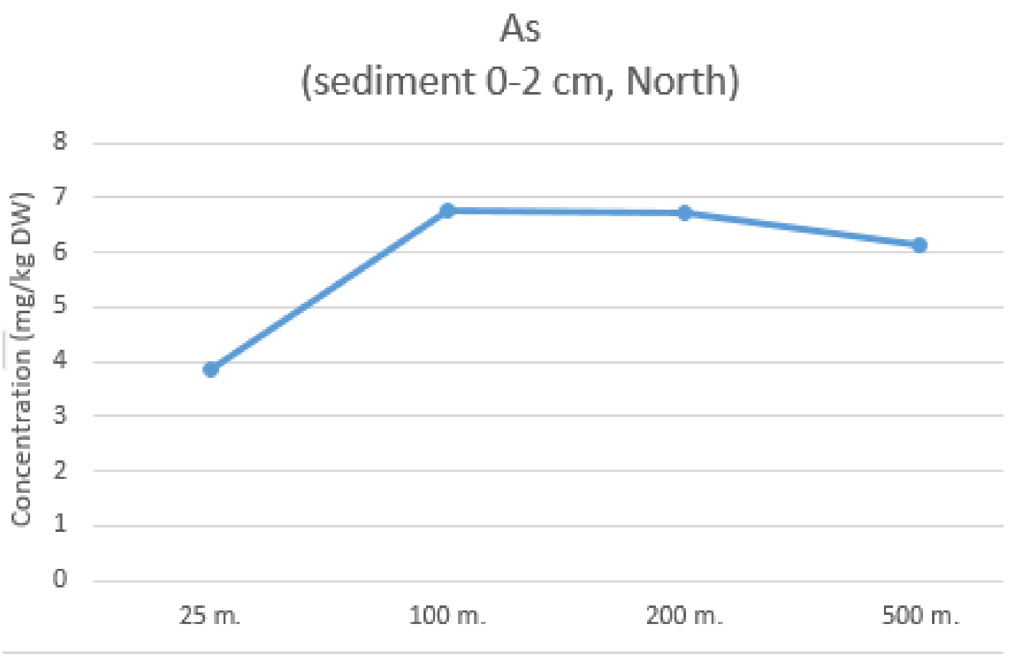


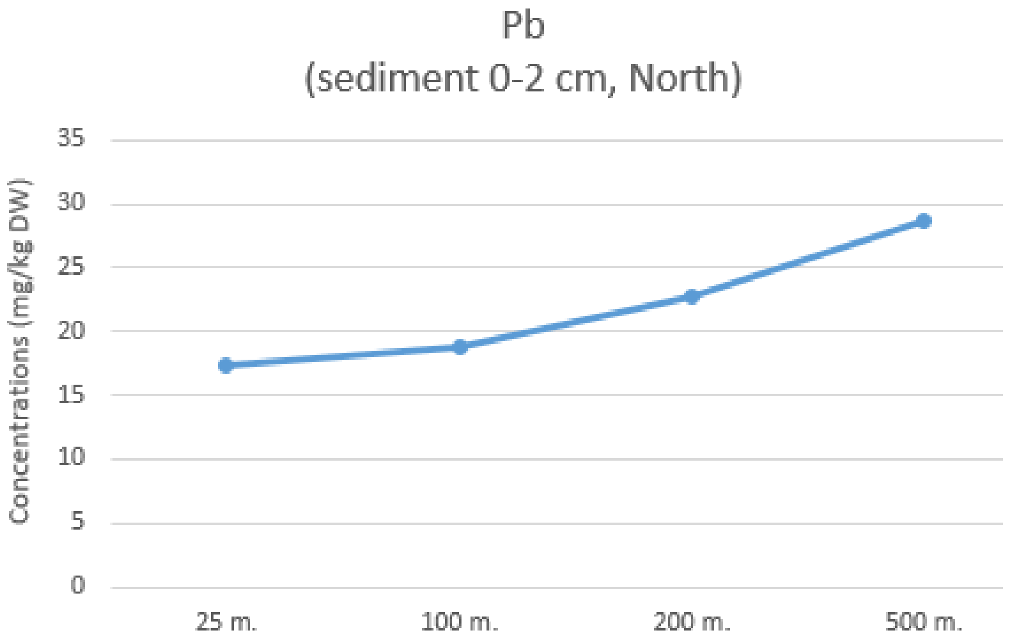

Cd
(sediment 0-2 cm, North West)
Concentration (mg/kg DW)
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
100 m.
150 m.

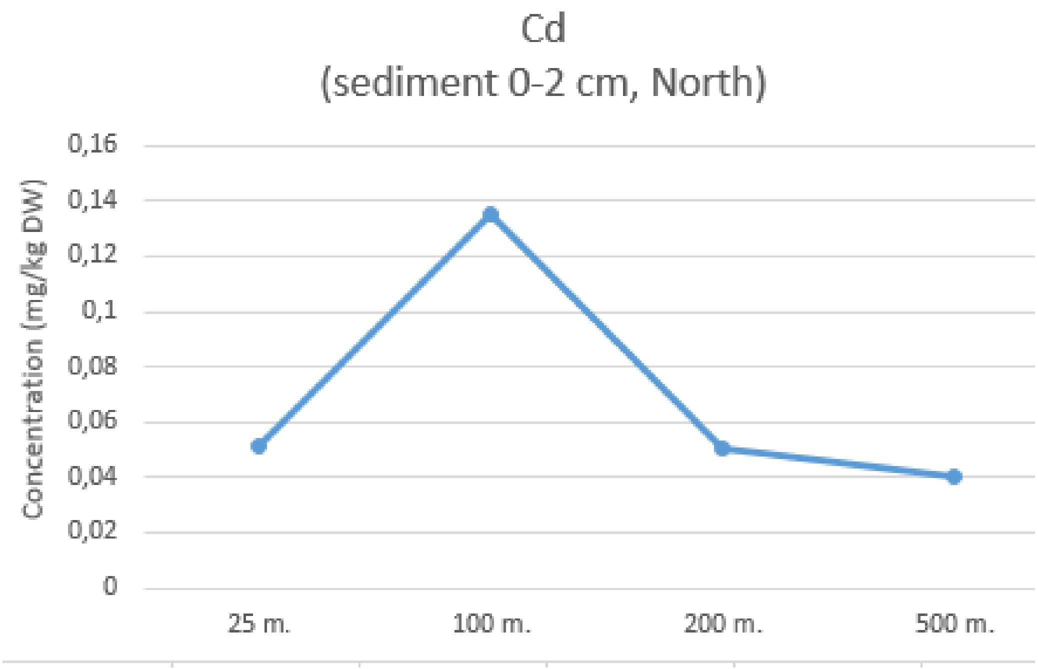

Cr
(sediment 0-2 cm, North West)
Concentration (mg/kg DW)
100
90
80
70
60
50
40
30
20
10
0
Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
100 m.
150 m.

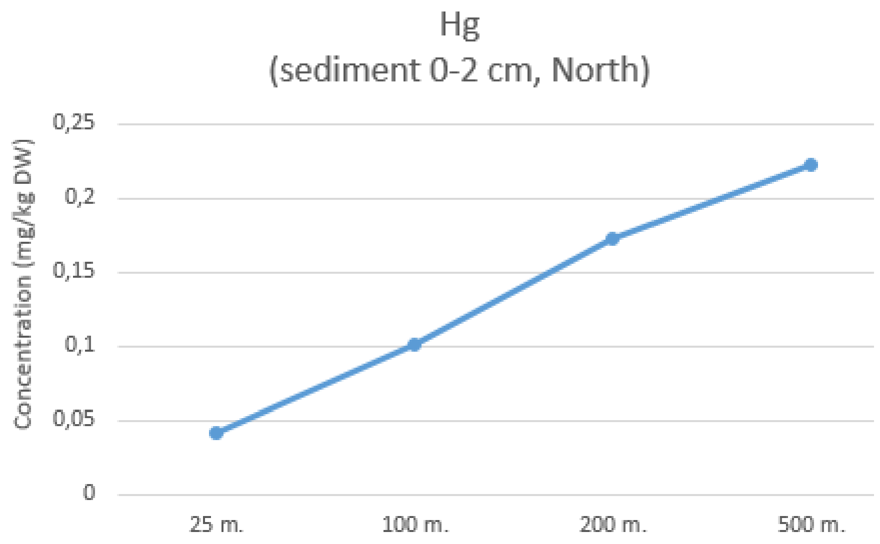

Ni
(sediment 0-2 cm, North West)
Concentration (mg/kg DW)
35
30
25
20
15
10
5
0
Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
100 m.
150 m.

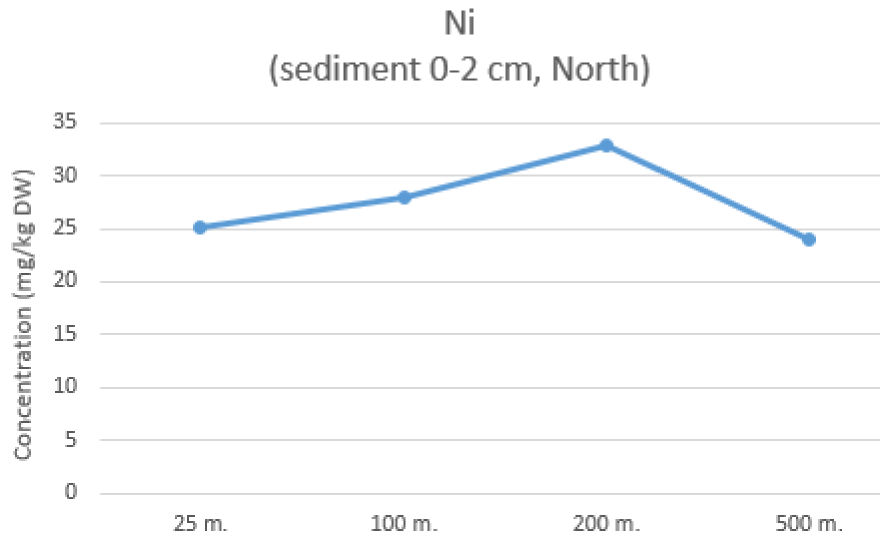

Zn
(sediment 0-2 cm, North West)
Concentration (mg/kg DW)
250
200
150
100
50
0
Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
100 m.
150 m.

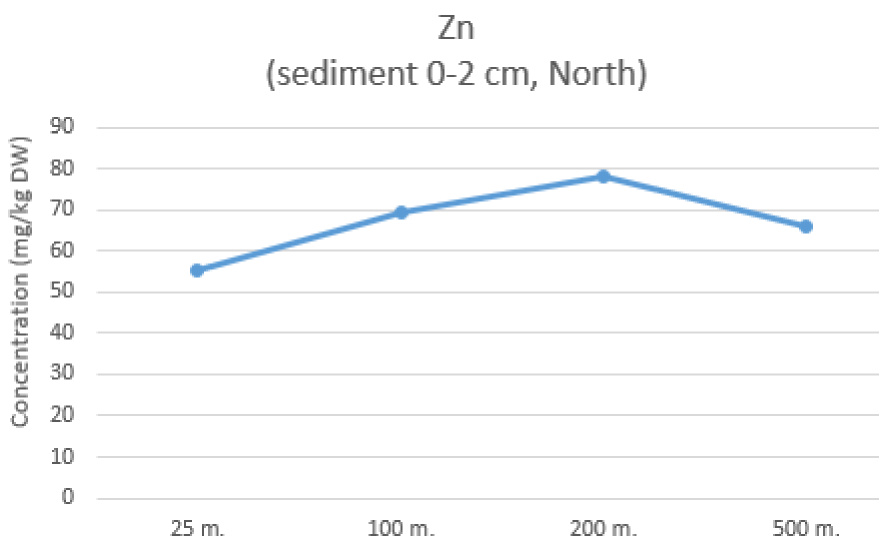

As
(sediment 0-2 cm, North)
Concentration (mg/kg DW)
8
7
6
5
4
3
2
1
0
25 m.
100 m.
200 m.
500 m.

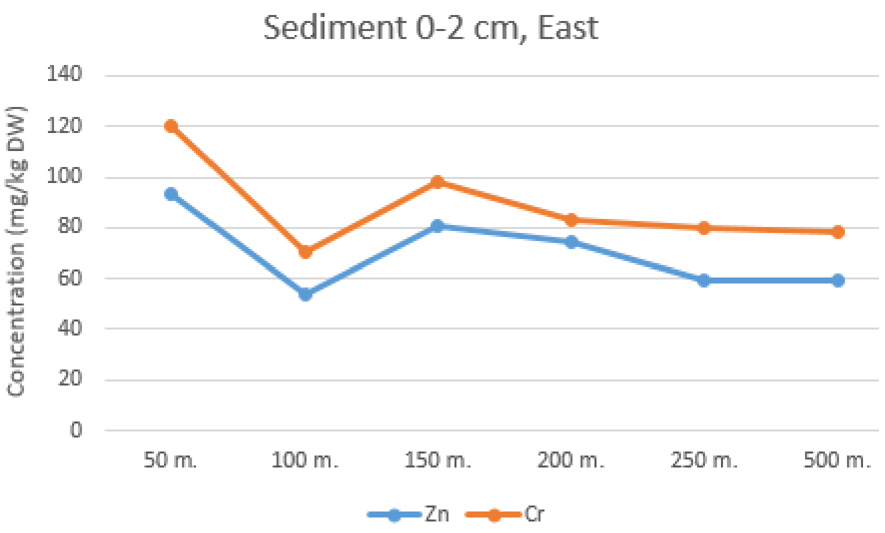

Pb
(sediment 0-2 cm, North)
Concentrations (mg/kg DW)
35
30
25
20
15
10
5
0
25 m.
100 m.
200 m.
500 m.

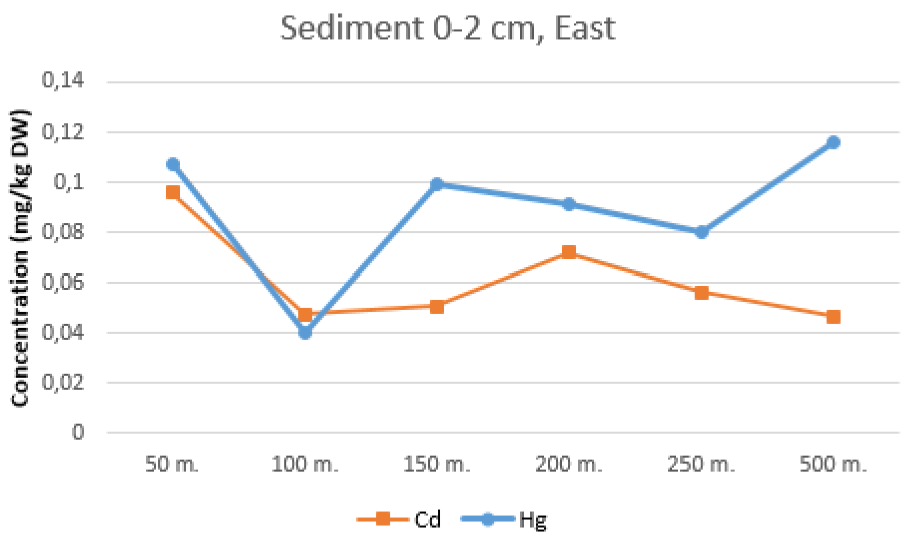

Cd
(sediment 0-2 cm, North)
Concentration (mg/kg DW)
0,16
0,14
0,12
0,1
0,08
0,06
0,04
0,02
0
25 m.
100 m.
200 m.
500 m.

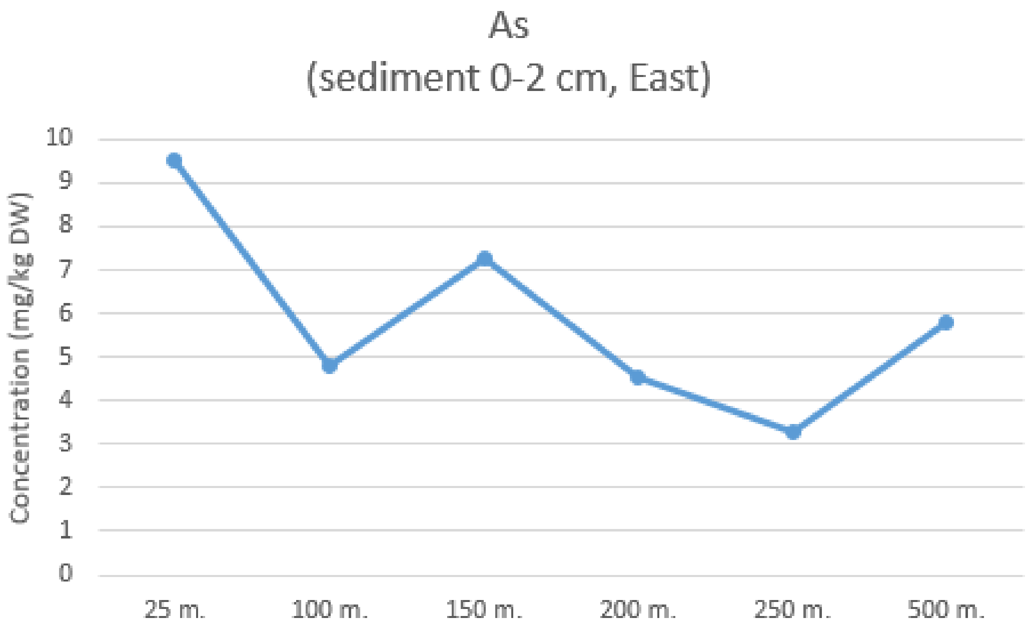

Hg
(sediment 0-2 cm, North)
Concentration (mg/kg DW)
0,25
0,2
0,15
0,1
0,05
0
25 m.
100 m.
200 m.
500 m.


Ni
(sediment 0-2 cm, North)
Concentration (mg/kg DW)
35
30
25
20
15
10
5
0
25 m.
100 m.
200 m.
500 m.


Zn
(sediment 0-2 cm, North)
Concentration (mg/kg DW)
90
80
70
60
50
40
30
20
10
0
25 m.
100 m.
200 m.
500 m.

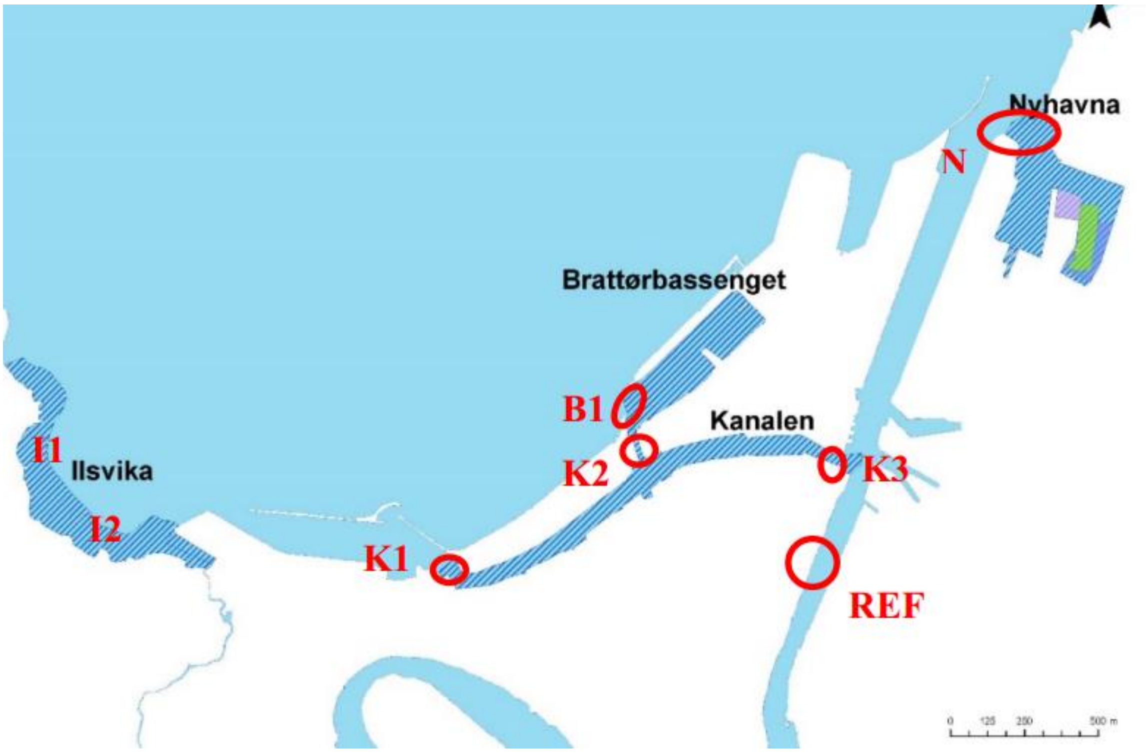

Sediment 0-2 cm, East
Concentration (mg/kg DW)
140
120
100
80
60
40
20
0
50 m.
100 m.
150 m.
200 m.
250 m.
500 m.
Zn
Cr


Sediment 0-2 cm, East
Concentration (mg/kg DW)
0,14
0,12
0,1
0,08
0,06
0,04
0,02
0
50 m.
100 m.
150 m.
200 m.
250 m.
500 m.
Cd
Hg


As
(sediment 0-2 cm, East)
Concentration (mg/kg DW)
10
9
8
7
6
5
4
3
2
1
0
25 m.
100 m.
150 m.
200 m.
250 m.
500 m.

Appendix R: locations sediment traps NGI

January and February 2015



(NGI, 2015)