

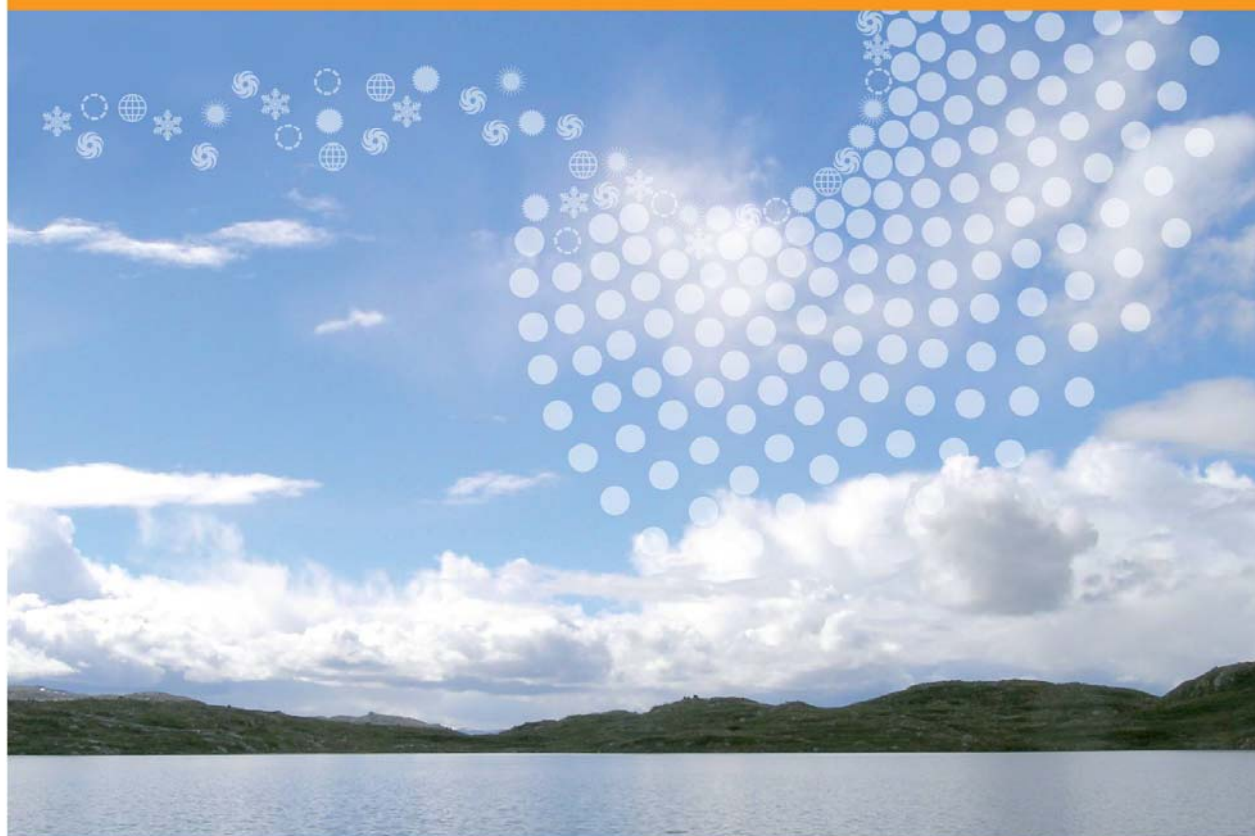


Statlig program for forurensningsovervåking

SCREENING OF SELECTED METALS AND NEW ORGANIC CONTAMINANTS 2007

2367

2008





**Norwegian Pollution Control Authority**

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• **Screening of selected metals and  
new organic contaminants 2007**

Rapport  
1014/2008

Phosphorus flame retardents, polyfluorinated organic compounds, nitro-PAHs, silver, platinum and sucralose in air, wastewater treatment facilities, and recipients

Authors: Norman Green (project leader), Martin Schlabach, Torgeir Bakke, Einar M. Brevik, Christian Dye, Dorte Herzke, Sandra Huber, Benedek Plosz, Mikael Remberger, Merete Schøyen, Hilde Thelle Uggerud, Christian Vogelsang

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## Foreword

On behalf of the Norwegian Pollution Control Authority (SFT) the Norwegian Institute for Water Research (NIVA), Norwegian Institute for Air Research (NILU), and Swedish Environmental Research Institute (IVL) have analyzed selected metals and new organic contaminants. These include silver, platinum, polyfluorinated organic compounds (PFCs), nitro-PAHs, phosphorous flame retardants (PFRs), and sucralose in samples from wastewater/sludge, sediment, blue mussel and cod taken in 2007 from selected wastewater treatment plants (WWTP), and atmosphere, freshwater and marine sites. In addition, sucralose was analyzed in samples from wastewater/sludge and seawater, and silver and platinum were analyzed in samples of atmosphere and wastewater/sludge.

Thanks are due to all who have participated in this project and especially to:

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Marit Vadset: metal analyses

Hans Gundersen, Anders Borgen and Mebrat Gebremeskel: GC/MS analyses

Christian Dye: LC/MS, background information on sucralose and assessment of these in seawater, and samples from wastewater treatment facilities.

Hans Gundersen: LC/MS analyses

Martin Schlabach: contact person for NIVA, background information on nitro-PAHs.

Dorte Herzke and Sandra Huber: background information on polyfluorinated organic compounds

Hilde Thelle Uggerud: background information on silver and platinum.

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Benedek Plosz: assessment of results from wastewater treatment plants and freshwater.

Jarle Håvardstun, Lise Tveiten, and Sigurd Øxnevad: sampling and handling of samples from the marine environment

Åse Rogne: handling of samples from WWTP, freshwater and marine environment

Merete Schøyen: sampling and handling of samples from the marine environment and responsible for all tables and figures.

Norman Green: project coordinator and responsible for assessment of results from the marine environment

Torgeir Bakke: assessment of results from the marine environment

Bent Skaare and Einar Brevik: background information on metals and organic compounds involved.

Norwegian Pollution Control Authority (SFT)

Bård Nordbø: – project coordinator at SFT.

NIVA, Oslo, 3 March 2008

Norman Green

Research Scientist, Project leader

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## Extended summary

On behalf of the Norwegian Pollution Control Authority (SFT) the Norwegian Institute for Water Research (NIVA), the Norwegian Institute for Air Research (NILU), and Swedish Environmental Research Institute (IVL) have monitored phosphorus flame retardants (PFRs), polyfluorinated organic compounds (PFCs), nitro-PAHs, silver, platinum, and sucralose in air, samples from wastewater treatment facilities, seawater, marine and freshwater sediment, blue mussel and cod liver taken in 2007 (with the exception of 2 sediment samples from 2003). The survey covers 54 individual compounds and 2 metals from 59 sites, of which 5 are for air sampling, 22 for wastewater treatment facilities, 3 for freshwater sediment and 29 for the marine environment. Samples of air also included dust and road dust. Waste treatment facilities included domestic wastewater treatments plants, a landfill, a car demolishing site and a fire fighting test site. The report should be a guideline in the planning of environmental monitoring where these substances are concerned.

### Phosphorus Flame Retardants (PFRs)

The analysis covered 9 compounds, and TIBP dominated. Except for samples from wastewater treatment facilities, most samples had compound concentration below the detection limit.

#### *Air*

Highest concentrations were found in indoor samples. There was a dominance of TPhP and to a lesser degree TBEP, TCPP, TBP and TCEP. It is uncertain what reason is behind the large difference found between the two samples taken in each of the two indoor localities.

#### *Wastewater*

All samples contained PFRs, ranging from 9.57-28.1 µg/l in the water samples (highest at Solumstrand WWTP), 3.85-4.86 mg/kg loss of ignition weight (LOI.weight) in the sludge samples (highest at Bekkelaget WWTP) and 7.46-33.2 mg/kg LOI.w. in the sediment samples (highest at the car demolishing site Hellik Teigen AS). The overall PFR removal ratio (influent vs. effluent) was about 60 % at Bekkelaget WWTP and Saulekilen WWTP, while a somewhat lower removal ratio was obtained at Solumstrand WWTP (about 30 %). In sludge, TBEP, EHDPP and TCPP dominated the PFR content constituting ca.90 % of the total 4856 µg/kg LOI weight; 2222, 1222 and 944 µg/kg LOI weight. It should be noted that the comparison of influent-effluent water samples indicated that neither EHDPP nor TCPP would be removed from water. While TPhP, TBP and TDCP dominated the sediment samples from Lindum landfill with concentrations of 1.1-5.0, 0.76-4.3 and 1.5-3.3 mg/kg LOI weight, respectively, TCPP was the dominating PFR in all sediment samples from Hellik Teigen car demolishing site (9.5-23.5 mg/kg LOI weight).

#### *Recipient*

The most common compound in most samples was TCPP, followed by TCEP and TIBP. TPhP was only quantifiable in 2 of the samples, Bekkelaget station 1 and Loselva station 3. The by far highest levels of PFRs was found in the Loselva station 3 sediments. This station is closest to the Hellik Teigen car destruction site, and the dominance of TCPP, TBEP and TCEP reflected the pattern found in the Hellik Teigen samples.

## **Polyfluorinated organic compounds (PFCs)**

### *Air*

No volatile PFCs were detected in air collected at the remote locations Birkenes and New Ålesund. However, in 8 out of 10 samples from the urban location, volatile PFCs could be found. The 8:2 FTOH dominated the compound pattern in all samples. The indoor samples were up to 100 times higher contaminated compared to the outdoor samples (up to 60 pg/m<sup>3</sup> outdoor and 9500 pg/m<sup>3</sup> 8:2 FTOH indoor). A broad variety of ionic compounds (less volatile) could be detected in all samples, but at very low concentrations close to the detection limit. However, PFOS was ubiquitous in all air samples analyzed.

### *Wastewater*

Only the sludge samples at Solumstrand WWTP contained appreciable concentrations of volatile PFCs: 6:2 FTOH, 8:2 FTOH, 10:2 FTOH and 12:2 FTOH summarized to 0.07 ng/g dry weight sludge. The sediment sample with the highest total volatile PFC concentration was found at the fire drill site Res-Q (0.19 ng/kg dry weight).

For the ionic PFCs, all 18 samples contained appreciable concentrations amounting to a total of 0.74-2.17 ng/l in water samples, 1.55-12.1 µg/kg dry weight in sludge samples and 5.17-157 µg/kg dry weight in sediment samples. 14 out of the 27 selected PFCs compounds were found in one or more of the collected samples, with PFOS being the only compound found in all samples: 0.67-1.47 ng/l in water samples, 1.20-5.16 µg/kg dry weight in sludge samples and 0.72-59 µg/kg dry weight in sediment samples. The highest sludge concentration was found at Bekkelaget WWTP, while the highest sediment concentration was found at the fire drill site Res-Q in the sample taken from the last manhole on the transfer line before discharge to the sea. PFOS and PFDS (only Bekkelaget WWTP) being the only ionic PFC found at appreciable concentrations. PFOS was lower than what was found in the effluents from Bekkelaget and Saulekilen WWTPs in the 2004 screening. At Solumstrand WWTP PFTrA and PFTA dominated the influent water with concentrations of 25-26 ng/l. The value of total ionic PFC concentrations in the Bekkelaget and Saulekilen WWTP sludge samples were measured to be 12.1 and 8.3 µg/kg sludge, respectively, which is about a magnitude higher than in the Solumstrand sample and 4 times higher than the levels found in the respective sludge samples in the 2004 screening. In the samples taken from the fire drill sedimentation basins, PFOS dominated (28.7-31.5 µg/kg) with also an elevated concentration of PFNS (11.3 µg/kg) in one of these samples. PFOSA, PFHxS, PFHpS and PFDS were also detected at appreciable concentrations, but the dominating compounds found in the samples from the ditch on the test site (i.e. PFHxA and PFDoA) were not detected. All the landfill samples (Lindum) PFOS (3.8-7.5 µg/kg) and PFHxS (0.4-0.9 µg/kg) were found in all samples. Concentrations of PFCs were within the concentration range found in the 2004 screening, but the PFC composition appeared to be somewhat different.

### *Recipient*

Of the 19 recipient samples analyzed only 8 had levels of one or more volatile PFCs above the detection limits; the quantifiable concentrations being within the range of the detection limits for other comparable samples. PFOS varied in the range 0.1-6.7 µg/kg dry weight among the 9 sediment samples analyzed. The corresponding ranges in the 2004 and 2006 screening surveys were reasonably similar. Concentrations are well below the potential no effect concentration (PNECs) for PFOS in marine sediments in the revised SFT risk assessment tool (SFT 2007) and should therefore pose no risk to the environment. This may also apply to the three sediment samples from Loselva. PFOS in mussels varied in the range 0.2-1.9 µg/kg wet weight among the 7 samples analyzed. Highest level was found outside the Res-Q fire

fighting facility at Haugesund. Results from previous investigation suggests that there is an increase in PFOS in mussels from 2004 to 2006 that continues into 2007. The overall trend should still be an argument for continued monitoring of PFOS in blue mussel. With concentrations of PFOS found in the two samples cod liver from Bekkelaget (19.8 and 28.0 µg/kg wet weight) there is also an indication of an increase in PFOS in cod liver from the inner Oslofjord.

### **Nitro-PAHs**

#### *Air*

1-NPY is detected in 16 of 19 samples and shows with one exception the highest concentration of all measured nitro-PAHs. The indoor air samples and the traffic related samples showed in general the highest concentration of nitro-PAHs.

### **Silver and platinum**

#### *Air and road dust*

The platinum content measured in air (2-5 pg/m<sup>3</sup>) and road dust (up to 225µg/kg dry weight) is comparable to corresponding samples from other European major roads and cities with high traffic density. New measurements of platinum are recommended in order to optimize the analytical method.

#### *Wastewater*

All samples except the effluent samples from the WWTPs contained appreciable concentrations of silver; 180-530 ng/l in influent WWTP samples, 482-7640 µg/kg dry weight in sludge samples and 319-7427 µg/kg dry weight in sediment samples. The platinum concentrations were much lower.

Sludge samples from Bekkelaget, Saulekilen and Solumstrand WWTPs would be classified as strongly contaminated (SFT environmental Class IV: 5-10 mg Ag/kg), markedly contaminated (Class III: 1.5-5 mg Ag/kg) and moderately contaminated (Class II: 0.3-1.3 mg Ag/kg), respectively.

Using the marine classification criteria for sediments, all sediment samples from Lindum would be characterized as moderately or markedly contaminated and all sediment samples from Hellik Teigen would be characterized as markedly or strongly contaminated.

### **Sucralose**

#### *Wastewater treatment*

The highest effluent concentration was found at Saulekilen WWTP with 5876 ng/l. In the effluent samples the sucralose concentration was either similar or somewhat higher than in the influent, and only the sludge from Saulekilen WWTP showed quantifiable traces of sucralose (22 µg/kg dry weight). Hence, sucralose appeared to go straight through all treatment steps in all plants in the study.

#### *Sea water*

Samples from Bekkelaget basin were 3 to 4 times higher than in the samples from Arendal. This may be explained both by the higher total sewage discharge for the WWTP at Bekkelaget and by the fact the Bekkelaget basin is a much more enclosed recipient than outside Arendal. Outside Bekkelaget the concentration range was 18-30 ng/l and with no systematic change with distance from the point of discharge.



## **Sammendrag**

**Tittel:** Kartlegging av utvalgte metaller og nye organiske miljøgifter. Fosfor flammehemmere, polyfluorerte organiske stoffer, nitro-PAHer, sølv, platina og sukralose i luft, avløpsvann og resipienter.

**År:** 2008

**Forfattere:** Norman Green (prosjektleder), Martin Schlabach, Torgeir Bakke, Einar M. Brevik, Christian Dye, Dorte Herzke, Sandra Huber, Benedek Plosz, Mikael Remberger, Merete Schøyen, Hilde Thelle Uggerud, Christian Vogelsang.

**Kilde:** Statens forurensningstilsyn, SFT SPFO rapport 1014/2008, TA-2367/2008. ISBN 978-82-577-5304-7.

På oppdrag fra Statens forurensningstilsyn (SFT) har Norsk institutt for vannforskning (NIVA), Norsk institutt for luftforskning (NILU) og Svenska Miljöinstitutet (IVL) analysert fosfor flammehemmere (PFRer), polyfluorerte organiske-forbindelser (PFCer), nitro-PAHer, sølv, platina og sukralose i prøver fra luft, avløpsvann, sjøvann, marint- og ferskvannssediment, blåskjell og torskelerver innsamlet i 2007 (samt to sedimentprøver samlet i 2003). Undersøkelsen dekker 54 individuelle enkeltforbindelser og to metaller fra 59 lokaliteter. Av disse er fem fra luft, 22 fra avløpsvann, tre fra ferskvannssediment og 29 fra marint miljø. Luftprøver inkluderer også støvpartikler og veistøv. Avløpsbehandling inkluderte avfallsvann, en landfylling, et sted for bilopphugging og et øvelsessted for brannslukning. Rapporten bør fungere som veileder for planleggingen av overvåking av de involverte stoffene.

### **Fosforflammehemmere (PFRer)**

Analysen dekket ni forbindelser hvor TIBP dominerte. Bortsett fra prøver tatt i forbindelse med avløpsvann, hadde de fleste forbindelsene konsentrasjoner under deteksjonsgrensen.

### **Luft**

De høyeste konsentrasjonene ble funnet i prøver tatt innendørs. Det var en dominans av TPhP og i mindre grad TBEP, TCPP, TBP og TCEP. Årsaken til den store forskjellen funnet mellom de to prøvene tatt ved hver lokalitet innendørs er uklar.

### **Avløpsvann**

Alle prøver inneholdt PFRer, rangert fra 9.57-28.1 µg/l i vannprøver (høyest ved Solumstrand Renseanlegg), 3.85-4.86 mg/kg gløderest (LOI vekt) i slamprøvene (høyest ved Bekkelaget Renseanlegg) og 7.46-33.2 mg/kg LOI vekt i sedimentprøvene (høyest ved bilopphuggeriet Hellik Teigen AS). Den samlede PFR-fjerningen (innløp i forhold til utløp) var på ca 60 % ved Bekkelaget Renseanlegg og Saulekilen Renseanlegg, mens en noe lavere fjerning ble oppnådd ved Solumstrand Renseanlegg (ca 30 %). TBEP, EHDPP og TCPP dominerte PFR-innholdet i slam og inneholdt ca.90 % av totalt 4856 µg/kg LOI vekt; 2222, 1222 og 944 µg/kg LOI vekt. Det bør nevnes at forholdet mellom innløps-utløpsvannet indikerte at verken EHDPP eller TCPP blir fjernet fra vannet. Mens TPhP, TBP og TDCP dominerte sedimentprøvene fra Lindum landfylling med konsentrasjoner på 1.1-5.0, 0.76-4.3 og 1.5-3.3 mg/kg LOI vekt, var TCPP det dominerende PFR i alle sedimentprøvene fra Hellik Teigen bilopphuggingssted (9.5-23.5 mg/kg LOI vekt).

## Resipient

*Den mest alminnelige forbindelsen i de fleste prøvene var TCPP, etterfulgt av TCEP og TIBP. TPhP var bare målbar i to prøver, Bekkelaget stasjon 1 og Loselva stasjon 3. De til nå høyeste verdiene av PFRer ble funnet i Loselva sedimentstasjon 3. Denne stasjonen er nærmest Hellik Teigen biloppbyggingssted, og dominansen av TCPP, TBEP og TCEP reflekterte mønsteret funnet i Hellik Teigen prøvene.*

## **Polyfluorerte forbindelser (PFCer)**

### Luft

*Ingen flyktige PFCer ble funnet i luft innsamlet ved de fjerntliggende stasjonene Birkenes og Ny-Ålesund. Imidlertid, i åtte av 10 prøver fra urban lokalisasjon ble flyktige PFCer funnet. 8:2 FTOH dominerte sammensetningen i alle prøvene. Prøvene tatt innendørs var opptil 100 ganger høyere kontaminert sammenliknet med utendørsprøvene (opptil 60 pg/m<sup>3</sup> utendørs og 9500 pg/m<sup>3</sup> 8:2 FTOH innendørs). En bred variasjon av ioniske forbindelser (mindre flyktige) kunne oppdages i alle prøvene, men med veldig lave konsentrasjoner nær deteksjonsgrensen. PFOS var tilstedeværende i alle de analyserte prøvene.*

### Avløpsvann

*Bare slamprøver fra Solumstrand Renseanlegg inneholdt vesentlige konsentrasjoner av flyktige PFCer: 6:2 FTOH, 8:2 FTOH, 10:2 FTOH og 12:2 FTOH summert til 0.07 ng/g tørrvekt slam. Sedimentprøven med den høyeste totale flyktige PFC-konsentrasjonen ble funnet ved brannøvelsesstedet Res-Q (0.19 ng/kg tørrvekt).*

*For ioniske PFCer inneholdt alle de 18 prøvene vesentlige konsentrasjoner summert til totalt 0.74-2.17 ng/l i vannprøver, 1.55-12.1 µg/kg tørrvekt i slamprøver og 5.17-157 µg/kg tørrvekt i sedimentprøver. 14 av de 27 utvalgte PFAS-prøvene ble funnet i en eller flere av de innsamlede prøvene, hvor PFOS var den eneste forbindelsen som ble funnet i alle prøvene: 0.67-1.47 ng/l i vannprøver, 1.20-5.16 µg/kg tørrvekt i slamprøver og 0.72-59 µg/kg tørrvekt i sedimentprøver. Den høyeste slamkonsentrasjonen ble funnet ved Bekkelaget Renseanlegg, mens den høyeste sedimentkonsentrasjonen ble funnet ved brannøvelsesområdet Res-Q i prøven tatt fra den siste kummen på transportlinjen før uttømming til sjøen. PFOS og PFDS (bare Bekkelaget Renseanlegg) var de eneste ioniske PFC-forbindelsene funnet med vesentlige konsentrasjoner. PFOS var lavere enn det som var funnet ved utløpet til Bekkelaget Renseanlegg og Saulekilen Renseanlegg ved 2004-screeningen. Ved Solumstrand Renseanlegg dominerte PFTrA og PFTA innløpsvannet med konsentrasjoner på 25-26 ng/l.*

*Verdien til total ionisk PFC-konsentrasjon av slam ved Bekkelaget Renseanlegget og Saulekilen Renseanlegg var målt til 12.1 og 8.3 µg/kg slam, som henholdsvis er en størrelsesorden høyere enn prøven ved Solumstrand og 4 ganger høyere enn nivåene funnet ved de respektive slamprøvene ved 2004-screeningen.*

*Ved sedimentene innsamlet ved sedimentasjonsbassenget på brannøvelsesområdet dominerte PFOS (28.7-31.5 µg/kg) med også forhøyet konsentrasjon av PFNS (11.3 µg/kg) ved en av prøvene. PFOSA, PFHxS, PFHpS og PFDS var også funnet med vesentlige konsentrasjoner, men den dominerende forbindelsen i prøven tatt fra avrenningsgrøften på øvelsesområdet (dvs. PFHxA og PFDoA) ble ikke funnet.*

*Ved alle landbaserte prøver (Lindum) ble PFOS (3.8-7.5 µg/kg) and PFHxS (0.4-0.9 µg/kg) funnet i alle prøvene. Konsentrasjoner av PFAS var innenfor konsentrasjonsskalaen funnet ved 2004-screeningen, men PFAS-sammensetningen var noe forskjellig.*

## Resipient

Av alle de 19 analyserte resipientprøvene hadde bare åtte av disse nivåer over deteksjonsgrensen for en eller flere flyktige PFAS: de kvantifiserte konsentrasjonene var innenfor intervallene for deteksjonsgrensen for andre sammenliknbare prøver. PFOS varierte innenfor skalaen 0.1-6.7 µg/kg tørrvekt mellom de ni analyserte sedimentprøvene. De korresponderende skalaene i screeningundersøkelsene i 2004 og 2006 var noenlunde like. Konsentrasjonene er godt under den potensielle ingen-effekt-konsentrasjonen (PNECs) for PFOS i marine sedimenter i den reviderte SFT-risikoveilederen (SFT 2007) og bør derfor ikke utgjøre noen risiko for miljøet. Dette gjelder også for de tre sedimentundersøkelsene fra Loselva.

PFOS i blåskjell varierte mellom 0.2-1.9 µg/kg våtvekt mellom de syv analyserte prøvene. Det høyeste nivået ble funnet utenfor Res-Q i Haugesund. Resultater fra tidligere undersøkelser antyder at økningen i PFOS i blåskjell fra 2004 til 2006 fortsetter i 2007. Den generelle trenden bør fortsatt være et argument for å fortsette overvåkingen av PFOS i blåskjell. Med konsentrasjoner av PFOS funnet i to prøver av torskelever fra Bekkelaget (19.8 og 28.0 µg/kg våtvekt), er det også indikasjoner på en økning i PFOS i torskelever fra indre Oslofjord.

## Nitro-PAHer

### Luft

1-NPY er funnet i 16 av 19 prøver og viser, med ett unntak, den høyeste konsentrasjonen av alle målte nitro-PAHer. Innendørs luftprøver og de trafikkrelaterte prøvene viser generelt de høyeste målingene av nitro-PAHer.

## Sølv og platina

### Luft og veistøv

Platinainnholdet målt i luft (2-5 pg/m<sup>3</sup>) og veistøv (opp til 225 µg/kg tørrvekt) er sammenliknbare med korresponderende prøver funnet fra andre europeiske store veier og byer med høy trafikk tetthet. Nye målinger av platina er anbefalt for å optimalisere den analytiske metoden.

### Avløpsvann

Alle prøvene unntatt prøvene av avløpsvann fra renseanleggene inneholdt vesentlige sølvkonsentrasjoner; 180-530 ng/l i innløpsvann fra renseanleggprøver, 482-7640 µg/kg tørrvekt i slamprøver og 319-7427 µg/kg tørrvekt i sedimentprøver. Platinakonsentrasjonen var mye lavere.

Slamprøver fra renseanleggene ved Bekkelaget, Saulekilen og Solumstrand ble klassifisert som henholdsvis sterkt forurenset (SFT miljøklassifiseringssystem IV: 5-10 mg Ag/kg), markert forurenset (klasse III: 1.5-5 mg Ag/kg) og moderat forurenset (klasse II: 0.3-1.3 mg Ag/kg).

Ved å bruke det marine klassifiseringssystemet for sedimenter ble alle sedimentene fra Lindum karakterisert som moderat til markert forurenset og alle sedimentprøvene fra Hellig Teigen ble karakterisert som markert til sterkt forurenset.

### **Sukralose**

#### Avfallsbehandling

*Den høyeste konsentrasjonen av sukralose i utløpsvann ble funnet ved Saulekilen Renseanlegg med 5876 ng/l. Sukralosekonsentrasjonen var enten lik eller noe høyere ved utløpsvann enn ved innløpsvann, og kun slammet fra Saulekilen Renseanlegg viste målbare spor av sukralose (22 µg/kg tørrvekt). Sukralose ser derfor ut til å gå rett gjennom alle behandlings-trinn i undersøkelsen.*

#### Sjøvann

*Prøver fra Bekkelagsbassenget var 3 til 4 ganger høyere enn i prøver fra Arendal. Dette kan muligens forklares ved både høyere totalt utslipp fra Bekkelaget Renseanlegg og ved det faktum at Bekkelagsbassenget er en mer innelukket resipient enn den utenfor Saulekilen Renseanlegg ved Arendal. Utenfor Bekkelaget var konsentrasjonen 18-30 ng/l uten systematisk avstandsvariasjon fra avløpet.*

# 1. Background and purpose

## 1.1 General

The purpose of this national screening survey is to obtain an overview of the occurrence of selected new and little known contaminants in the Norwegian environment. This is the 6th annual screening survey performed and covers analysis of samples primarily taken during 2007. Previous screening surveys have covered contaminants such as metals, brominated flame retardants, polyfluorinated organic compounds (PFCs), chlorinated organic compounds, biocides, pharmaceutical, cosmetics. The 2007 screening survey covers phosphorous flame retardants (PFRs), polyfluorinated organic compounds (PFCs), nitro-PAHs, silver, platinum, and sucralose, in samples from air, wastewater/sludge, road dust, seawater, freshwater and marine sediment, blue mussel and cod. Some compounds previously covered, such as PFCs, have also been included in this survey. The report should be of value as a guide for establishment of national and regional environmental monitoring programmes on prioritized contaminants.

## 1.2 Elements and compounds

A total of 56 metals and organic compounds covered in the screening survey (*Table 1*). In the following a brief overview is given on these compounds with focus on their potential as environmental risk factors and occurrence in air, wastewater treatment facilities and natural recipients. The structure of some of these compounds is presented (Annex 1).

*Table 1. Overview of the compounds and metals investigated. (See also Annex 1 for more information on molecular structure of selected compounds).*

Compound	Abbreviation	CAS-no. <sup>1</sup>
<b>Phosphorus Flame Retardants</b>		
tri- <i>iso</i> -butylphosphate	TIBP	126-71-6
tributylphosphate	TBP	126-73-8
tri(2-chloroethyl)phosphate	TCEP	115-96-8
tri(1-chloro-2-propyl)phosphate	T CPP	13674-84-5
tri(1,3-dichloro-2-propyl)phosphate	TDCP	13674-87-8
tri(2-butoxyethyl)phosphate	TBEP	78-51-3
triphenylphosphate	TPhP	115-86-6
2-ethylhexyl-di-phenylphosphate	EHDPP	1241-94-7
tetrekis(2-chlorethyl)dichloroisopentyldiphosphate	V6	38051-10-4
<b>Volatile PFCs</b>		
3,3,4,4,5,5,6,6,6-nonafluorohexan-1-ol	4:2 FTOH	
3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctan-1-ol	6:2 FTOH	647-42-7
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptafluorodecan-1-ol	8:2 FTOH	865-86-1
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-henicosafuorododecan-1-ol	10:2 FTOH	678-39-7
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,13,13,14,14,14-pentacosafuorotetradecan-1-ol	12:2 FTOH	39239-77-5
<i>n</i> -methyl perfluorooctane sulfonamide	N-Me-FOSA	31506-32-8
<i>n</i> -ethyl perfluorooctane sulfonamide	N-Et-FOSA	4151-50-2
<i>n</i> -methyl perfluorooctane sulfonamidoethanol	N-Me-FOSE	24448-09-7

<sup>1</sup> For some compounds CAS-no. were not available

Compound	Abbreviation	CAS-no. <sup>1</sup>
n-ethyl perfluorooctane sulfonamidoethanol	N-Et-FOSE	1691-99-2
<b>Ionic PFCs</b>		
fluorotelomer sulfonate	6:2 FTS	
fluorotelomer sulfonate	8:2 FTS	
sulfuramid or N-ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-1-octanesulfonamide	PFOSA	4151-50-2 754-91-6
perfluorobutane sulfonate	PFBS	2795-39-3
perfluoropentane sulfonate	PFPS	29420-49-3
perflurohexanoic sulfonate	PFHxS	432-50-7
perfluroheptanoic sulfonate	PFHpS	
perfluorooctanoic sulfonate /perfluorooctane sulfonate	PFOS	2795-39-3
perfluorononanoic sulfonate	PFNS	
perfluorodecanoic sulfonate	PFDS	67906-42-7
perfluorundecanoic sulfonate	PFUnS	
perfluorododecanoic sulfonate	PFDoS	
perfluorotridecanoic sulfonate	PFTTrS	
perfluorotetradecanoic sulfonate	PFTS	
perfluoropentadecanoic sulfonate	PFPeS	
perflurobutanoic acid	PFBA	
perfluropentanoic acid	PFPA	
perflurohexanoic acid	PFHxA	307-24-4
perfluroheptanoic acid	PFHpA	375-85-9
perfluorooctanoic acid	PFOA	335-67-1
perfluorononanoic acid	PFNA	375-95-1
perfluorodecanoic acid	PFDA	335-76-2
perfluorundecanoic acid	PFUnA	2058-94-8
perfluorododecanoic acid	PFDoA	
perfluorotridecanoic acid	PFTTrA	
perfluorotetradecanoic acid	PFTA	
perfluoropentadecanoic acid	PFPeA	
<b>Nitro-PAH</b>		
3-nitrobenzanthrone	3-NBA	17117-34-9
9-nitroanthracene	9-NAA	602-60-8
7-nitrobenz[a]anthracene	7-NBAA	20268-51-3
2+3-nitrofluoranthene	2+3-NFA	13177-29-2, 892-21-7
1-nitropyrene	1-NPY	5522-43-0
4-nitropyrene	4-NPY	57835-92-4
1,3-dinitropyrene	1,3-dNPY	75321-20-9
1,6-dinitropyrene	1,6-dNPY	42397-64-8
<b>Metals</b>		
silver	Ag	7440-22-4, 7783-90-6, 7785-23-1, 7761-88-8
platinum	Pt	7440-06-4
<b>Sucralose</b>	Sukr	56038-13-2

<sup>1</sup> For some compounds CAS-no. were not available

### 1.2.1 Phosphorous Flame Retardants (PFRs)

#### General

The world wide use of phosphorous based flame retardants was in 2001 186 000 tons. In recent years, the consumption in Western Europe has rapidly increased from 53000 in 1998 to 83000 tons 2001 (Marklund *et al.* 2005b). The amount of organic phosphates esters imported in products of plastic is unknown.

Organic phosphates are used as flame retardants in polymeric materials such as polyphenyloxide (PPO), polyurethane foam (PUF) and polyvinylchloride (PVC). Organic

phosphates are also used in plasticizer, paint, paper, surface treatment and as additive in different lubricant and transmission oils and hydraulic fluid in aircrafts (Marklund 2005a).

Arylphosphates are mostly used as flame retardants and plasticizer in PVC but also in polycarbonate, ABS (a copolymer made of acrylnitril, butadien and styrene and other plastic polymers). Arylphosphates with short alkyl chain are used as flame retardant in different hydraulic oils and lubricants and phosphate esters with long carbon chain are more suitable in plastic as plasticizer.

Alkyl diakrylphosphates have better properties compared to akrylphosphates as plasticizer in PVC at low temperatures. On the other hand are these compounds less good as flame retardants.

Chlorinated trialkyl phosphates are mostly used in both flexible and rigid polyurethane foams, rubber and textile coatings.

The organic phosphate esters included in this report are in its pure state exists in the form of colourless viscous oils with low vapour pressure and water solubility making them excellent additives in *e.g.* plastic polymers.

It is well-known that organic phosphorus esters are highly toxic since many low molecular phosphor esters have been used as chemical nerve gas. These compounds block the enzyme acetyl cholinesterase (ACh) in the nerves. Even the organic phosphorus chemicals examined in this investigation may have effects on the nerve system *e.g.* triphenylphosphate and tri-cresyl-phosphates (ECETOC, 1998). Generally, recent toxicological data on phosphate esters are scarce and most of the data are from 1980s. These data concern acute toxicity (LD-50) studies. TBP data on LD-50 for Killfish (*Oryzias latipes*) and Goldfish (*Carassius auratur*) were 9.6 and 8.8 mg/l respectively (Sasaki *et al.* 1981). The toxicity to rainbow trout was determined to 4.2-12 mg/l (96 h LC50; WHO, 1991a).

Toxicological data for TBEP are available for goldfish and was determined to 90 mg/l (96 h LC50; WHO, 2000). 96 h LC50 for TPhP to rainbow trout was 0.36 mg/l (WHO, 1991b). EHDPP is considered highly toxic to fish and aquatic plants and has potential to bioaccumulate (Bolag 2007).

#### *TIBP: Tris-iso-butylphosphate*

Tris-*iso*-butylphosphate (TIBP) is a colourless viscous liquid with a density slightly less than water. The use in Norway 2005 was 0.7 tonnes, and used in 22 products (SPIN). TIBP is used in the same products as TBP.

#### *TBP: Trisbutylphosphate*

Trisbutylphosphate (TBP) is a colourless viscous liquid with a density slightly less than water. Use in Norway 2005 as 33.8 tonnes and was used in 28 products (SPIN<sup>2</sup>). Mixtures of TBD and tri-*iso*-butyl phosphate (TIBP) are used in aircraft hydraulic fluids wherein the amount of TIBP ranges from about 35 to about 50 weight percent based on the total weight. Other application are construction materials, paint, plaques, varnishes and different consumer preparations (SPIN).

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<sup>2</sup> A database of the use of chemical substances in the nordic countries.

*TCEP: Tri(2-chloroethyl)phosphate*

Currently replaced by other flame retardants, primarily TCPP, and is no longer produced in Europe. Use in Norway 2003 was 1286 tonnes mainly related to production of rubber and plastic products.

TCEP is detected in all precipitation samples collected in Ireland, Poland and Sweden in concentrations up to 20 ng/L. TCEP was present in 85% of a total of 983 domestic dust samples and results show that soft foam, paints and wallpapers contained TCEP.

TCEP is considered as very stable both for oxidation and degradation by chlorine attack. No degradation in sewage waster water treatment plants. It is considered as non biodegradable by EU (EU, 2005). TCEP may be emitted by sewage treatment plants since methodology removing PFRs from effluents are missing (Andersen *et al.*, 2004).

TCEP concentrations around 10 ml/L are suspected as a threshold level for trout and LC50: 170mg/L (EU, 2005). TCEP was one of the most frequent detected compounds in water samples from steams across USA in 1999 and 2002 (EU, 2005). In Germany the levels in the river Oder showed mean values between 30 to 282 ng/L (EU, 2005). The main source was effluents from sewage treatment plants.



*TCPP: Tri(1-chloro-2-propyl)phosphate*

TCPP is a colourless liquid used mainly as an additive to polyurethane foams. Annual worldwide demand exceeds 40000 tonnes in 1997. 50 tonnes was used in Norway in 2001 for manufacture of chemicals, rubber and plastic.

The EU calculated a loss to air of 0.75% for outdoor use associated with volatile release from the articles themselves accounting that 40% of TCPP is available for release which is much higher than for TDCP (EU, 2006a). TCPP was found in 60-90% of 436 domestic dust samples with levels ranging from 0.1 to 375 mg/kg. Traffic is assumed to be a general source for contamination of the outdoor environment. In Sweden TCPP dominated in the snow samples with levels up to 170 ng/kg at 2 m from the road with levels decreasing with increasing distance from the road.

TCPP is considered as very stable both for oxidation and degradation by chlorine attack. No degradation in sewage treatment plants is detected. It is considered to meet the screening criteria as persistent/ very persistent (EU, 2006a).

The EU risk assessment 2006 states that it is unlikely for TCPP to exhibit a chronic toxicity to fish at <1 mg/L and suggest no classification for the compound. TCPP is found to be readily metabolised in fish (WHO, 1998) and due to lack of bioaccumulation of TCPP, the EU concluded that there were no risks for secondary poisoning of the marine environment. TCPP has been analysed in several rivers and sewage treatment plant effluents in Germany and the levels in the river Ruhr range from 20 to 200 ng/L TCPP. The sewage treatment plants effluents had concentrations up to 400 ng/L TCPP.

*TDCP: Tri(1,3-dichloro-2-propyl)phosphate*

TDCP is a viscous colourless liquid used in a range of plastic foams, reins and latexes. The annual world-wide demand exceeded 8000 tonnes in 1997 and total EU production in 2000 was about 10000 tonnes. No data available for use in Norway.

Since TDCP is applied as an additive it may be subject to volatilisation or leaching from the polymer matrix. An annual rate of release to air of 0.001% accounting that only 10% of TDCP is available for release (EU, 2006b). In snow samples up to 230 ng/kg TDCP is found along a road in northern Sweden indicating road traffic as point source for TDCP into the environment.

TDCP is considered as very stable both for oxidation and degradation by chlorine attack. No degradation in sewage treatment plants is detected. A general lack of ready biodegradability was noted by the EU risk assessment (EU, 2006b).

The aquatic toxicity of TDCP is approximately 1 mg/L for rainbow trout and 5 mg/L for *Daphnia magna*. The EU risk assessment confirms the classification N R51-53-toxic to aquatic organisms and may cause long term effects in the aquatic environment. A bioconcentration factor of 45 L/kg for fish is suggested implying rapid metabolism (EU, 2006b). TDCP has been analysed in several rivers and sewage treatment plants in Germany and the concentrations in River Ruhr were about 50 ng/L and a sewage treatment plant effluents have up to 120 ng/L TDCP. In Japan up to 5599 ng/L TDCP was detected in the leachate from a landfill site.

*TBEP: Tri(2-butoxyethyl)phosphate*

The use of trisbutoxyphosphate (TBEP) in Norway has decreased from 1.3-1.5 tonnes in 2003-2004 to 0.6 tonnes in 2005. The chemical was used in 12 different products 2005 (SPIN). TBEP is for example applied in paint, lacquers and varnishes.

*TPhP: Triphenylphosphate*

The use of triphenylphosphate (TPhP) have in Norway decreased from 55 ton 2004 to 6.7 ton in 2005 but still used in the same numbers of products (29 products 2005; SPIN). TPP is used as flame retardant in cellulose acetate, vinyl copolymers used in vacuum cleaner parts, Christmas tree lighting set ([www.PAC-india.com](http://www.PAC-india.com)).

*EHDPP: 2-ethylhexyl-di-phenylphosphate*

The use of 2-ethylhexyl-di-phenylphosphate (EHDPP) has in Norway increased from 2.8 tonnes year 2002 to 30.1 tonnes in 2005 but appears to level off from 2004-2005.

*V6: Tetrekis(2-chlorethyl)dichloroisopentyldiphosphate*

The main use of V6 is as a flame retardant in flexible polyurethane foam and has the potential for migration. One of the main impurities in V6 is TCEP (4.5-7.5%). Annual production in Europe was less than 5000 tonnes in 2000 (SPIN). No data available for use in Norway.

Since V6 is applied as an additive it may be subject to volatilisation or leaching from the polymer matrix. An annual rate of release to air of 0.001% accounting that 10% of V6 is available for release (EU, 2006).

V6 is considered as very stable both for oxidation and degradation by chlorine attack. No degradation in sewage treatment plants was detected. Biological degradation of 37% in 28 day has been reported (EU, 2006). On the other hand in the same report V6 was characterised as persistent in the marine environment.

Measured V6 toxicity to fish and invertebrates is higher than for TCEP by a factor of 2 and 8, respectively. The EU risk assessment confirms the classification N R51-53 – toxic to aquatic organisms and may cause long term effects in the aquatic environment. LC50 for fish, *Daphnia* and algae all fall in the range 10 to 100 mg/L. Long term NOEC values for *Daphnia* and algae are greater than 1 mg/L, however no value is available for fish. V6 is characterised as persistent in the marine environment (EU, 2006). No monitoring data is available.

**Use and application**

**(No information)**

**Emissions and discharges**

**(No information)**

**Distribution and affects**

**(No information)**

**Remedial action**

**(No information)**

## 1.2.2 Polyfluorinated organic compounds (PFCs), including some volatile forms

### General

Polyfluorinated organic compounds (PFCs) are a group of compounds where the hydrogen in the alky-chain is exchanged completely by fluoride. In addition, there is a polar aspect to the chemical structures that make them partly soluble, hence surface active. Unique chemical properties of PFCs make them important ingredients in numerous industrial and consumer products. PFCs repel both water and oil, and are therefore ideal chemicals for surface treatment of for example textiles. Polytetrafluoroethylene (PTFE)-based membranes are often used due to their water, fat and stain resistance and ability to “breathe”.

Polyfluorinated organic compounds (PFCs) are acknowledged widespread environmental contaminants, due to their manufacture over a period of decades, and release into the environment after use and disposal. The different toxicological, chemical and physical behaviour of PFCs, some of which are used as technical mixtures (formulations) containing a number of individual compounds, makes it difficult to fully assess their impact on humans and the environment. Currently, worldwide research is mainly focused on the perfluorinated alkyl sulphonates and carboxylates (PFAS, PFCA), but sulphonates (FTS) and the more volatile compound groups, fluorotelomer alcohols (FTOH), are also studied.

The present screening survey includes four groups of PFCs (**Table 2**).

*Table 2. Overview of polyfluorinated organic compounds (PFCs) included in this study.*

Parameter	
<b>FTOH</b> (4:2, 6:2, 8:2, 10:2, 12:2)	fluorotelomer alcohols
<b>FOSA/FOSE</b> (N-Me-FOSA, N-Et-FOSA, N-Me-FOSE, N-Et-FOSE)	fluorooctan sulfonamides and sulfonamidetanoles
<b>FTS</b> (6:2, 8:2)	fluorotelomer sulfonates
<b>PFS (C4-C15)</b> : PFOSA, PFBS, PFPS, PFHxS, PFHpS, PFOS, PFNS, PFDS, PFUnS, PFDoS, PFTrS, PFTS, PFPeS	perfluoro alkyl sulfonates and perfluoro sulfonamides
<b>PFCA (C4-C15)</b> : PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFTrA, PFTA, PFPeA	perfluoro alkyl carboxylates

### Use and application

Pursuant to the SFT review material-flow (SFT 2004) there is no production of PFCs in Norway. Therefore what is marketed nationally is imported, and this is in the form of chemical-technical products or components in manufactured goods.

Fire extinguishers (Aqueous Film Forming Foams, AFFF) and personal products like coated paper, carpets and furniture as well as all-weather clothing are the most important source of PFCs in Norway. AFFF is used for extinguishing fires associated with petroleum-products (e.g., oil, petrol) or flammable water-soluble liquids (e.g. acetone, alcohol). It is used primarily in connection with offshore installations, airports, oil refineries, tanker ships. PFCs are also used to treat clothing and other textile products in order to enhance their dirt- and water repelling quality. Hence, PFCs can be imported or applied to these items. Treatments that involve PFCs are primarily connected to clothing that is water-tight or similar products with breathable fabrics (e.g. Gore-Tex) and to achieve dirt-repellent characteristics. For other imports, PFCs are mainly found in manufactured products. The quantity of PFCs that is imported is uncertain. (Fjeld *et al.* 2005). In the present report a distinction is made between the volatile PFCs (FTOH) and the ionic PFCs (PFS, PFCA, FTS).

### ***FTOH (volatile PFCs)***

These compounds are manufactured as raw material used in the synthesis of fluorotelomer-based surfactants and polymeric products. The manufacture usually results in a mixture containing six to twelve fluorinated carbon congeners; 8:2 FTOH being the dominant one. Estimated global production of 13000 tonnes/yr and increasing (2006-data). No data available for use in Norway. FTOH can act as a precursor for stable PFCs. For example, oxidation of 8:2 FTOH yields the highly stable PFOA, both after atmospheric and biodegradation. On the basis of their volatility FTOHs are expected to occur predominantly in the atmospheric gas phase. Water solubility 0.012g/L (6:2 FTOH) and 0.00014 g/L (8.2 FTOH).

Atmospheric lifetime of short chain FTOHs was determined to be 20 days enabling the molecules to be transported up to 7000 km by air. Oxidation in the atmosphere lead quantitatively to the corresponding polyfluorinated aldehyde being further degraded to PFCA. Monitoring data for FTOHs in the North America atmosphere are available and modelling focus on quantitative explanation for the presence of PFCAs in remote regions.

Biological transformation may be a major degradation pathway for fluorinated telomere alcohols in aquatic systems (Dinglasan *et al.* 2004).

### ***FOSA/FOSE (volatile PFCs)***

Fluorooctane sulfonamides (FOSA) and sulfonamide etanoles (FOSE) contain the same perfluorinated C8-carbonchain like PFOS and PFOA. They differ in the functional group (sulfonamide or sulfonamide ethanoles) connected to this chain. Different aliphatic groups can be connected to the nitrogen. The most important compound in this group is the perfluorinated sulfonamide (PFOSA).

FOSAs and FOSEs are used in the surface coating of paper and textiles. FOSAs can also occur as intermediates in the synthesis of other PFCs. They are volatile and can get airborne in the gas phase but adsorbed to particles as well. They are not stable in the environment and degrade to PFOSA and PFOS.

### ***PFCA***

Direct sources of PFCA result from their manufacture and use. PFCA have been used as processing aids in the manufacture of fluoropolymers such as Teflon since the 1950s. Commercial PFCA products consists mainly of linear C8- and C9-PFCA. Homologues with a chain length between C4 and C13 can also be found.

### ***PFS***

PFOS is considered as the most important PFS because of its intentional industrial production and global distribution. PFOS and its homologues are used commercially for numerous applications.

### ***FTS***

The fluorotelomerisation process, used by the industry to manufacture fluorotelomer compounds, results in an ethyl group being inserted between the fluoroalkyl chain and the end-group. Fluorotelomer sulphonates are commercial surfactants mainly applied in aqueous formulations. They lower surface tension and improve wetting and levelling. The fluorotelomer sulphonate (6:2 FTS, also known as THPFOS) has been found in the abiotic environment (de Voogt, 2006).

### **Emissions and discharges**

Direct discharge of PFCs is not considered relevant because there is no production of PFCs in Norway (SFT 2004). In Norway, a considerable number of manufactures use PFC containing products for the production of personal products (clothing, carpets, furniture, impregnation fluids, paints, coated paper etc.) (SFT; PFOA Study, 2007). In addition, the release of PFCs to environment can occur under application, use and disposal of PFC-containing products.

The annual total discharge of PFCs from Norway has been estimated to be (SFT 2004):

- 7-8 tons from the North Sea offshore industry
- 7-8 tons to water or groundwater from municipal pipelines, airports, industry, etc, of which <1 tonne can be attributed to refuse-sites.

### **Distribution and effects**

A Nordic screening investigation (Kallenborn *et al.* 2004) has indicated the presence of PFC in all sample types with highest levels in marine mammals. The report concluded that significant concentrations of PFCs are found in the Nordic environment. In the screening survey of 2004 and 2006 some PFCs were found both in freshwater and marine ecosystems including PFOS, PFOA, PFNS, PFNA and PFUnA (Fjeld *et al.* 2005, Bakke *et al.* 2007). These compounds are environmentally stable and degrade slowly. PFOS, the dominating compound in most samples, is toxic to aquatic organisms, birds and insects.

### **Remedial action**

Discharges of PFCs are expected to be reduced significantly in Norway within 2010 (Fjeld *et al.* 2005). SFT has an action plan to reduce the risk to human health and to the environment.

For PFS, because of its potential toxicity, extreme persistence and accumulation potential have resulted in PFOS-containing products being prohibited for new use or importation by chemical regulatory authorities in the USA. and elsewhere, 3M, the major manufacturing company of PFOS, voluntarily began phase out of the PFOS chemistry in 2001 (3M, 2000; US EPA, 2001).

## **1.2.3 Nitro-PAHs**

### **General**

Unsubstituted polycyclic aromatic hydrocarbons (PAH) are one of the most abundant sub-classes of polycyclic aromatic compounds and since many PAHs are carcinogenic they contribute to cancer risk. It is now clear that PAH alone cannot explain all of the risk associated with ambient particles and especially nitrated polycyclic aromatic hydrocarbons (nitro-PAH) has been proposed to contribute significantly to the carcinogenicity of airborne particles. In recent years, other more polar and very potent nitro-compounds have been detected and suggested to partly explain the remaining mutagenic activity. For example, Sera (Sera *et al.*, 1994) detected heterocyclic nitro-azaarenes in ambient air and diesel exhaust and Enya *et al.* (1997) detected 3-nitrobenzanthrone (3-NBA) in ambient air and diesel exhaust.

3-NBA and other nitro- and nitro-oxy-PAH have caused environmental concern due to their potent mutagenic activity and carcinogenicity. They abundantly exist in the particulate matters emitted from diesel and gasoline engines and also on the surface of airborne particulates and are most likely be formed during the combustion of fossil fuels as well as by the photoreaction of parent PAH with nitrogen oxides in ambient air (Enya *et al.* 1997).

Formation of nitro-PAH compounds has also been reported in fish contaminated with PAH and exposed to nitrite ( $\text{NO}_2^-$ ) in the ambient water.

### **Use and application**

PAH and their nitro- and oxy-analogues are with few exceptions, like naphthalene, unintentional bi-products of the incineration of carbon-containing fuels.

### **Emissions and discharges**

In contrast to PAHs the concentration of nitro- and oxy-analogues are not measured in urban air in Norway and there are no knowledge about the emissions of these compounds.

### **Distribution and effects**

PAHs and their nitro- and oxy-analogues are by-products of the incineration of carbon-containing fuels. In addition to the direct formation during incineration nitro- and oxy-PAHs can also be photochemically formed from their PAH analogues. Statistics Norway (SSB, 2008) estimates the total Norwegian PAHs emission to air to about 154 t per year (2005). Aluminium production together with household wood-firing is the major sources for PAHs. There are no Norwegian measurements of nitro- and oxy-PAHs. However, measurements from other countries suggest the same sources as for PAHs but maybe with a lower concentration levels (Naturvårdsverket, 2007). Traffic emissions and especially emissions from diesel engines can locally contribute significantly to the contamination of urban air with PAHs and their nitro- and oxy-analogues.

According to WHO-IARC diesel exhaust is regarded as probably carcinogenic to humans (IARC 1989). Several nitro- and nitro-oxy-PAHs are shown to be possible carcinogens (IARC 1989, WHO 2003). 3-NBA is found in diesel, and there are studies showing that it is carcinogenic in rats (Arlt 2005). But even though it is highly mutagenic there are few evidences for it to be a human carcinogen (WHO 2003, Arlt 2005). WHO, however, emphasize that this chemical should be attributed to increased attention and that proper data is missing to make certain conclusions about its potential as a carcinogen. No data was found on the persistence of nitro-PAHs, but 3-NBA seems to be more persistent than unsubstituted PAHs (Feilberg *et al.*, 2002).

## **1.2.4 Metals – silver and platinum**

### **General**

Silver and silver salts have a wide range of applications. Silver is an element with atomic weight 107.870 Da, boiling point 2212 °C melting point 961.8 °C. Platinum is an element with atomic weight 195.09 Da, boiling point 3827 °C melting point 1768 °C. Both silver and platinum do not corrode in air and do not dissolve in 1 molar mineral acids, which places them among the noble metals.

### **Use and application**

Silver shows the best electric conductivity of all metals, and hence is commonly used in electrical and electronic products, including batteries. Silver is also used in dental alloys, e.g. with Hg. Silver containing compounds are further used as a bactericide, e.g. in Flamazin lotion used to prevent infections of complex burns. Recently this ability has been utilised in production of e.g. fridges, washing machines, cosmetics, and clothing to prevent bacterial growth. Earlier one of the most common use of silver salts was in photographic films and papers, but this use is declining. In 2005 the total use of silver (CAS 7440-22-4) in Norway was 7.2 tonnes/yr (SPIN).

Platinum is used in catalytic converters, sensors and spark plugs, as catalyst in chemical processing, in high temperature and no corrosive wires and contacts, in dental/medical equipment and reconstructives and in cytostatica (cisplantin, carboplantin). There is no available data for the total use of platinum (CAS 7440-06-4) in Norway.

### **Emissions and discharges**

Data on total emissions of silver or platinum are not available, but there is a risk that considerable amounts of silver enter the environment through deposited household waste and wastewater. Particulate silver may also enter through sludge from treatment plants used as soil addition.

The emission of platinum has increased markedly during the last two decades due to introduction of catalyst in vehicles thus traffic is the main source of platinum-group elements (PGE) contamination to the environment in urban areas. The emission of fine PGE-containing particles and their occurrence in urban areas suggest the possibility for long-range transport. Platinum may also be found the surroundings of car demolition plants. Possible discharges of platinum containing compounds from medical and dental applications may be discovered in municipal wastewater.

### **Distribution and effects**

Background concentration of silver and platinum found in Norway (SFT, 2005) are per se relatively low. With occasional monitoring through a moss survey, as has been done since 1977, possible changes in concentration levels will be revealed.

Results from a moss survey around a selection of seven Norwegian industrial sites, shows results for silver that are more than ten times background levels in Kristiansand, Odda and Mo i Rana (SFT, 2007). The measured concentration of platinum mainly equals the background level.

Metallic silver and insoluble silver compounds appear to pose minimal risk to human health (WHO, 1977; Drake & Hazelwood, 2005) Silver in any form is not thought to be toxic to the immune, cardiovascular, nervous or reproductive systems, and there is no scientific evidence of silver to be carcinogenic (Drake & Hazelwood, 2005). The most prominent effect of prolonged ingestion, inhalation or dermal absorption of silver is discoloration of skin and eyes.

Silver in its ionic form is highly toxic to aquatic bacteria, animals and plants (WHO, 2002). Some acute toxicity data on mammals is available (WHO, 1977, WHO, 2002). Freshwater fish and amphibians are the most sensitive vertebrates to dissolved silver.

Elevated silver concentrations in biota may occur in the vicinities of sewage outfalls, electroplating plants, mine waste sites, and silver iodide-seeded areas. Scientific literature is not conclusive on the inhibitory impacts of Ag and Pt on mixed autotrophic and heterotrophic bacteria population typical to activated sludge, and it thus warrants further research.

Human health effects of metallic platinum are primarily confined to occupational exposure as in for example platinum metal refineries and catalyst manufacture plants (WHO, 1991c). Some platinum drugs exert considerable toxicity, especially on the peripheral nervous system and on the kidney (Safirenstein *et al.*, 1986, Hartmann *et al.*, 1999, Screnci & McKeage,

1999, Markman, 2003). These drugs are used as therapeutic agents and are designed to be bioactive.

According to the WHO report, platinum compounds at concentrations in the mg/l and mg/kg range affect aquatic and terrestrial plants, and several studies have shown that Platinum can bioaccumulate and is bioavailable (WHO, 1991c; Ravindra *et al.*, 2004; Zimmermann *et al.*, 2005).

**Remedial action**  
**(No information)**

**1.2.5 Sucralose**

**General**

1,6-Dichlor-1,6-dideoxy-  $\beta$ -D-fructofuranosyl-4-chlor- 4-deoxy- $\alpha$ -D-glucopyranosid (C<sub>12</sub>H<sub>19</sub>Cl<sub>3</sub>O<sub>8</sub>) or shorter sucralose is a triple chlorinated analogue of the disaccharide sucrose which is the normal household sugar used as an artificial sweetener. In the European Union, it is also known under the E number (additive code) E955. Sucralose is approximately 600 times sweeter than sucrose (table sugar), twice as sweet as saccharin, and four times as sweet as aspartame. Unlike aspartame, it is stable under heat and over a broad range of pH conditions and can be used in baking or in products that require a longer shelf life.

The molecule is a tri-chlorinated disaccharide. The human excretion is not able to utilize the molecular energy, and more than 85 % is excreted unchanged while a minor fraction conjugates with glucuronic acid. The environmental lifetime in Norwegian waters is expected to be 5-10 years. Sucralose has a low human toxicity and it does not bio-accumulate. However, the environmental persistence is of concern due to the lack of knowledge on how sucralose interact with the aquatic environment.

**Use and application**

Sucralose has been used as an artificial sweetener for nearly 30 years, and today the compound is approved as sweetener in more than 80 countries. Norway approved sucralose in June 2005, and the sweetener is now used in various low-calorie food and soft drinks and can also be obtained commercially as sugar substitute (Splenda) in food stores.

**Emissions and discharges**

Sucralose is used in a lot of different “light” products for consumption. As mentioned above, little of the sucralose consumed by humans is assimilated. The sewage treatment plants are not able to remove sucralose from the wastewater, and most of the used sucralose will therefore find its way to the environment.

**Distribution and effects**

Sucralose has earlier been found in some wastewater samples in the range from tens of ng/L to several  $\mu$ g/L. The environmental lifetime in Norwegian waters is expected to be 5-10 years. Sucralose has a low human toxicity and it does not bio-accumulate. However, the environmental persistence is of concern due to the lack of knowledge on how sucralose interact with the aquatic environment.

**Remedial action**  
**(No information)**



## 2. Materials and methods

### 2.1 Description of sampling sites

The screening survey covered 45 sites for sampling of air (5), sampling in freshwater (3) and the marine environment (26) and for taking samples in wastewater and solid waste treatment plants (12) (**Table 3, Figure 1, Figure 2**). A total of 119 samples were analysed, including samples of air or airborne-particles (64), samples from wastewater treatment plants (9), seawater (14), sediment (22), blue mussel (7) and cod liver (3). A wider description of the station selection is given in Chapter 2.1.

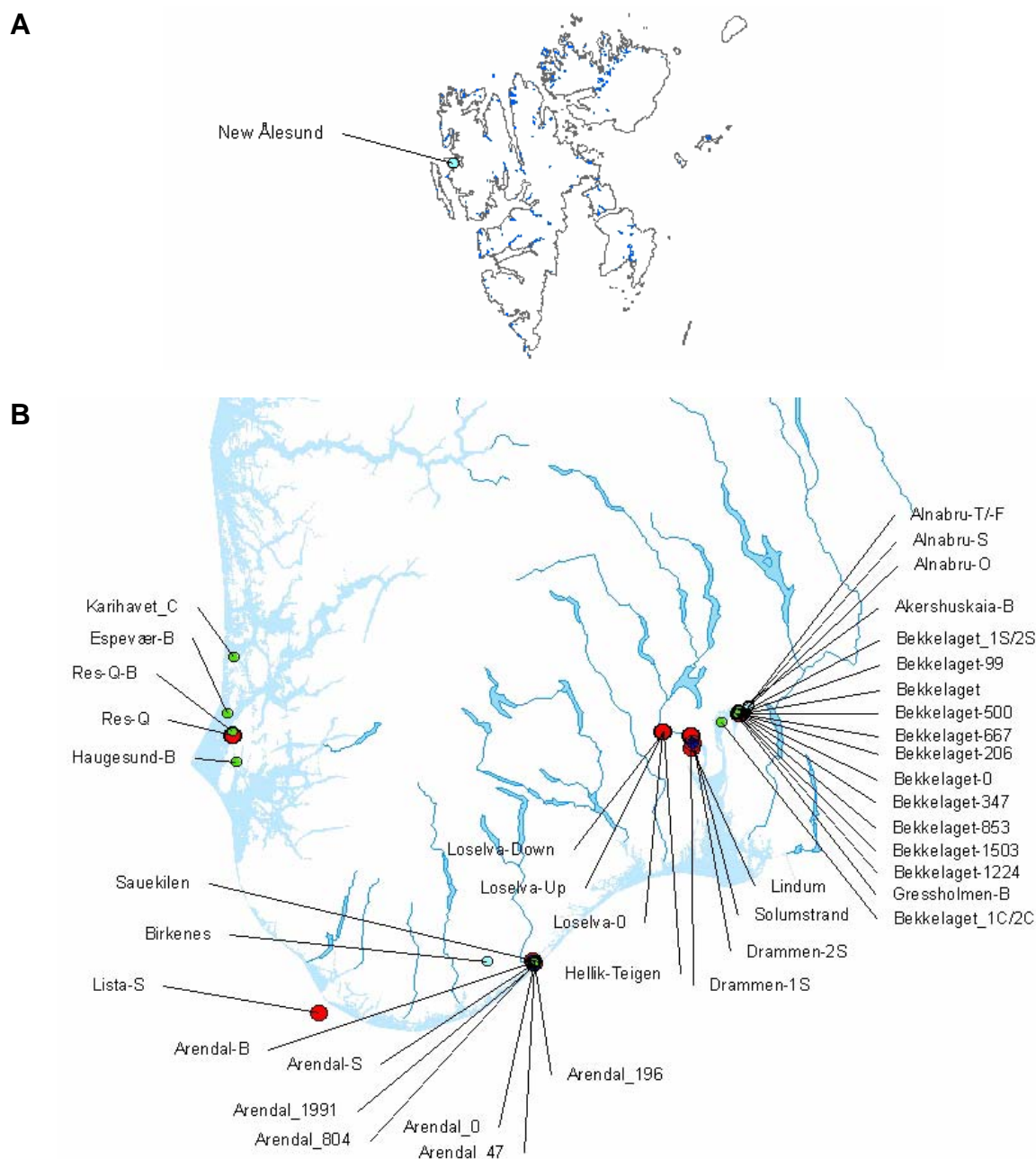


Figure 1. Map of sampling sites at Svalbard (**A**) and southern part of Norway (**B**) (see also Table 3 and Annex 2 for code description).

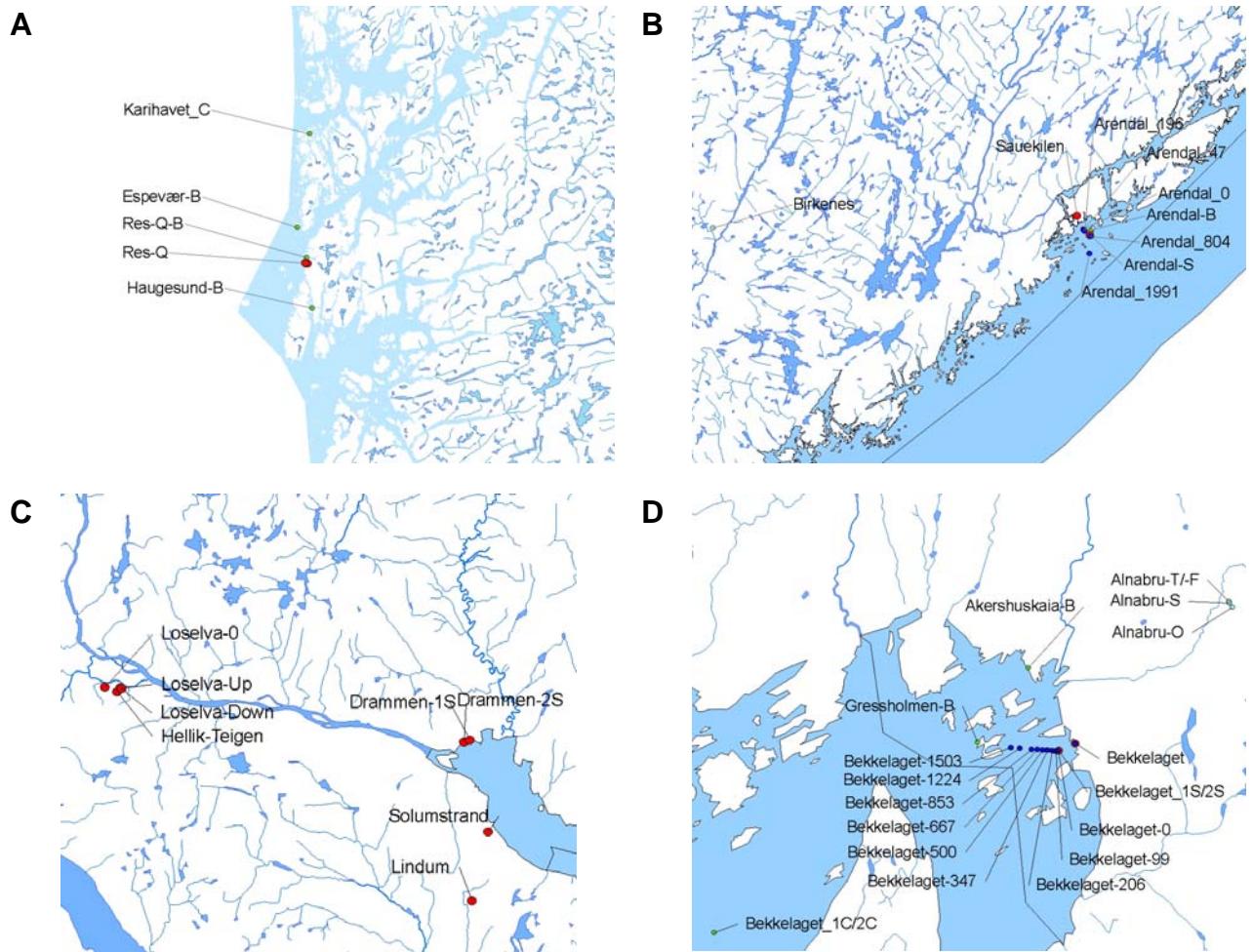


Figure 2. Map of sampling sites in the Haugesund area (A), Arendal area (B), Drammen area (C) and Inner Oslofjord area (D) (see also Table 3 and Annex 2 for code description).

Table 3. Overview of sample location and type (see also Figure 1, Figure 2 and Annex 2). Category (C) has three groupings: air (A), effluent (E) and recipient (R). Sample count (N) is also indicated.

Site/Map ID	Area	Area specification	Latitude°	Longitude°	C	Sample type	N
Alnabru-T/-F	Alnabru	Metering station	59° 55.664	10° 50.793	A	Air	18
Alnabru-T/-F	Alnabru	Metering station	59° 55.664	10° 50.793	A	Dust	6
Alnabru-T/-F	Alnabru	Metering station	59° 55.664	10° 50.793	A	Road dust	12
Alnabru-O	Alnabru	Shopping centre	59° 55.567	10° 50.942	A	Air	6
Alnabru-S	Alnabru	Shopping centre	59° 55.638	10° 50.829	A	Air	6
Birkenes	Birkenes	Metering station	58°23.407	8°15.175	A	Air	13
New Ålesund	Svalbard	Zeppelin Obs. Metering st.	78°54.383	11°53.276	A	Air	15
Bekkelaget	Oslo	Bekkelaget WWTP	59°53.100	10°45.960	E	Water-influent	1
Bekkelaget	Oslo	Bekkelaget WWTP	59°53.100	10°45.960	E	Water-effluent	1
Bekkelaget	Oslo	Bekkelaget WWTP	59°53.100	10°45.960	E	Sediment-sludge	1
Saulekilen	Arendal	Saulekilen WWTP	58°25.440	8°44.580	E	Water-influent	1
Saulekilen	Arendal	Saulekilen WWTP	58°25.440	8°44.580	E	Water-effluent	1
Saulekilen	Arendal	Saulekilen WWTP	58°25.440	8°44.580	E	Sediment-sludge	1
Solumstrand	Drammen	Solumstrand WWTP	59°42.394	10°16.089	E	Water-influent	1
Solumstrand	Drammen	Solumstrand WWTP	59°42.394	10°16.089	E	Water-effluent	1
Solumstrand	Drammen	Solumstrand WWTP	59°42.394	10°16.089	E	Sediment-sludge	1
Res-Q	Haugesund	Res-Q 1	59°28.190	5°14.543	E	Sediment	1
Res-Q	Haugesund	Res-Q 2	59°28.190	5°14.543	E	Sediment	1
Res-Q	Haugesund	Res-Q FTS 1	59°28.196	5°15.036	E	Sediment	1
Res-Q	Haugesund	Res-Q FTS 2	59°28.196	5°15.036	E	Sediment	1
Res-Q	Haugesund	Res-Q/ effluent Sveio. WWTP	59°28.177	5°14.114	E	Sediment	1
Lindum	Drammen	Lindum Resource and Recycling	59°40.540	10°15.509	E	Sediment	41
Hellik Teigen	Hokksund	Hellik Teigen, car breaker	59°45.351	9°56.332	E	Sediment	4
Loselva-1	Hokksund	Loselva st.1 (Hellik Teigen area)	59°45.469	9°56.496	R	Sediment	1
Loselva-2	Hokksund	Loselva st.2 (Hellik Teigen area)	59°45.454	9°56.542	R	Sediment	1
Loselva-3	Hokksund	Loselva st.3 (Hellik Teigen area)	59°45.442	9°55.691	R	Sediment	1
Akershuskaia-B	Inner Oslofjord	Akershuskaia, I301	59°54.320	10°44.202	R	Blue mussels	1
Gressholmen-B	Inner Oslofjord	Gressholmen, 30A	59°53.014	10°42.659	R	Blue mussels	1
Arendal-B	Sørlandet	Arendal, Ærøya	58°24.888	8°45.818	R	Blue mussels	1
Espevær-B	Vestlandet	Espevær, 22A	59°35.021	5°08.749	R	Blue mussels	1
Res-Q-B	Vestlandet	Haugesund Res-Q, manhole	59°29.326	5°14.197	R	Blue mussels	1
Haugesund-B	Vestlandet	Høgevarde, 227A	59°19.341	5°19.127	R	Blue mussels	1
Bekkelaget_1C	Inner Oslofjord	Bekkelaget 30B	59°49.509	10°34.237	R	Cod	1
Bekkelaget_2C	Inner Oslofjord	Bekkelaget 30B	59°49.509	10°34.237	R	Cod	1
Karihavet_C	Vestlandet	Karihavet, 23B	59°54	5°08	R	Cod	1
Bekkelaget_1S	Bekkelaget	Bekkelaget WWTP, outside	59°52.969	10°45.418	R	Sediment	1
Bekkelaget_2S	Bekkelaget	Bekkelaget WWTP, outside	59°52.969	10°45.418	R	Sediment	1
Drammen-1S	Drammen	Teigen	59°44.70	10°14.520	R	Sediment	1
Drammen-2S	Drammen	Leirterminal	59°44.76	10°14.820	R	Sediment	1
Arendal-S	Arendal	Local monitoring programme, st.U-10	58°24.663	8°45.796	R	Sediment	1
Lista-S	Lista/ Farsund	Coastal monitoring, st.15S/C-380	58°00.10	6°34.30	R	Sediment	1
Bekkelaget-0	Bekkelaget	Bekkelaget WWTP, outside, st.1 and 2	59°52.967	10°45.402	R	Water	1
Bekkelaget-99	Bekkelaget	Bekkelaget WWTP, outside, st.3	59°52.950	10°45.318	R	Water	1
Bekkelaget-206	Bekkelaget	Bekkelaget WWTP, outside, st.4	59°52.960	10°45.197	R	Water	1
Bekkelaget-347	Bekkelaget	Bekkelaget WWTP, outside, st.5	59°52.960	10°45.044	R	Water	1
Bekkelaget-500	Bekkelaget	Bekkelaget WWTP, outside, st.6	59°52.960	10°44.880	R	Water	1
Bekkelaget-667	Bekkelaget	Bekkelaget WWTP, outside, st.7	59°52.959	10°44.700	R	Water	1
Bekkelaget-853	Bekkelaget	Bekkelaget WWTP, outside, st.8	59°52.960	10°44.500	R	Water	1
Bekkelaget-1224	Bekkelaget	Bekkelaget WWTP, outside, st.9	59°52.958	10°44.100	R	Water	1
Bekkelaget-1503	Bekkelaget	Bekkelaget WWTP, outside, st.10	59°52.958	10°43.800	R	Water	1
Arendal_0	Sørlandet	Arendal, U-5	58°24.905	8°45.224	R	Water	1
Arendal_47	Sørlandet	Arendal, U-5-50	58°24.883	8°45.249	R	Water	1
Arendal_196	Sørlandet	Arendal, U-5-200	58°24.825	8°45.357	R	Water	1
Arendal_804	Sørlandet	Arendal, U-10	58°24.619	8°45.848	R	Water	1
Arendal_1991	Sørlandet	Arendal, U-12	58°23.89	8°45.90	R	Water	1

### 2.1.1 Air and road dust sampling stations

Six sampling sites were used; all but New Ålesund (Svalbard) were located in southern Norway (*Table 4*).

*Table 4. Air and dust/road dust sampling and sample count (N).*

Station/ sample no.	Sample	Date (2007)	Issue	N
Alnabru, metering station	Air, high volume	Aug/ Sept 07	Heavy traffic	9
Alnabru, metering station	Air, high volume	May 07	Heavy traffic	9
Alnabru, shopping centre	Air, low volume	Oct 07	Offices	6
Alnabru, shopping centre	Air, low volume	Oct/ Nov 07	Offices	6
Birkenes	Air, high volume	June/ Sept 07	Long range transport (LRT)	13
New Ålesund	Air, high volume	June/ Sept 07	Long range transport (LRT)	15
Alnabru, metering station	Dust	Aug/ Sept 07	Heavy traffic	6
Alnabru, metering station	Road dust	May/ Oct 07	Heavy traffic	12

#### New Ålesund

The Zeppelin Observatory (474 m above sea level) is situated at Svalbard, in an undisturbed Arctic environment far away from major pollution sources. The remote location on "top of the world" combined with the well developed infrastructure in New Ålesund and the accessibility for scientists, is unique among monitoring stations world wide.

The observatory receives air masses from all continents on the northern hemisphere, making the location ideal for obtaining information concerning global pollution and climate change. As a result, the Zeppelin Observatory has become a major contributor of data on a global as well as a regional scale. The activities at the observatory are mainly based on the monitoring of long range transported air pollution. This includes greenhouse gases, persistent organic pollutants (POPs), particles, heavy metals, ozone, sulphur and nitrogen compounds. The Zeppelin Observatory contributes to numerous international monitoring networks and is also an important contributor to several EU-projects.

#### Birkenes

The Birkenes Observatory (190 m above sea level) is located in southern Norway, to the south-east of the Scandinavian mountain chain. Due to the location of the site away from local pollution sources, long-range transport exerts a large influence on the pollution climatology of the site. The site is well-suited for e.g. trend analysis.

#### Alnabru

The Alnabru air quality measurement station (ca. 90 m above sea level) which is operated by Oslo Community for regular air pollution monitoring, is located close to two main roads (Stømsveien, 3 m distant, and the freeway E6, 250 m away) in Oslo. This station is one of the urban air stations in Norway with the highest load of dust and other traffic related air pollution components. The high load is due to the heavy traffic during the whole day and due the topographic conditions forming a bowl. The Alnabru area is like a pot with the inversions acting like a lid, capturing the local air masses which have a high and continues load of traffic pollutions.

The road dust samples were taken on a parking lot close to this station. The indoor store samples were taken in an office and sporting goods store not more than 200 m away from the Alnabru air quality measurement station.

The office was located in a building close to a very busy street a little northeast of central Oslo (*Figure 3*). The sampler was placed inside an office facing the street right opposite of an



air quality monitoring site. The traffic consists mainly of heavy trucks during the day with addition of smaller vehicles during the rush hours. Another sampler located in a sporting goods equipment store farther away from the traffic. The sampler in the sporting goods store was placed on a pillar inside the shop.

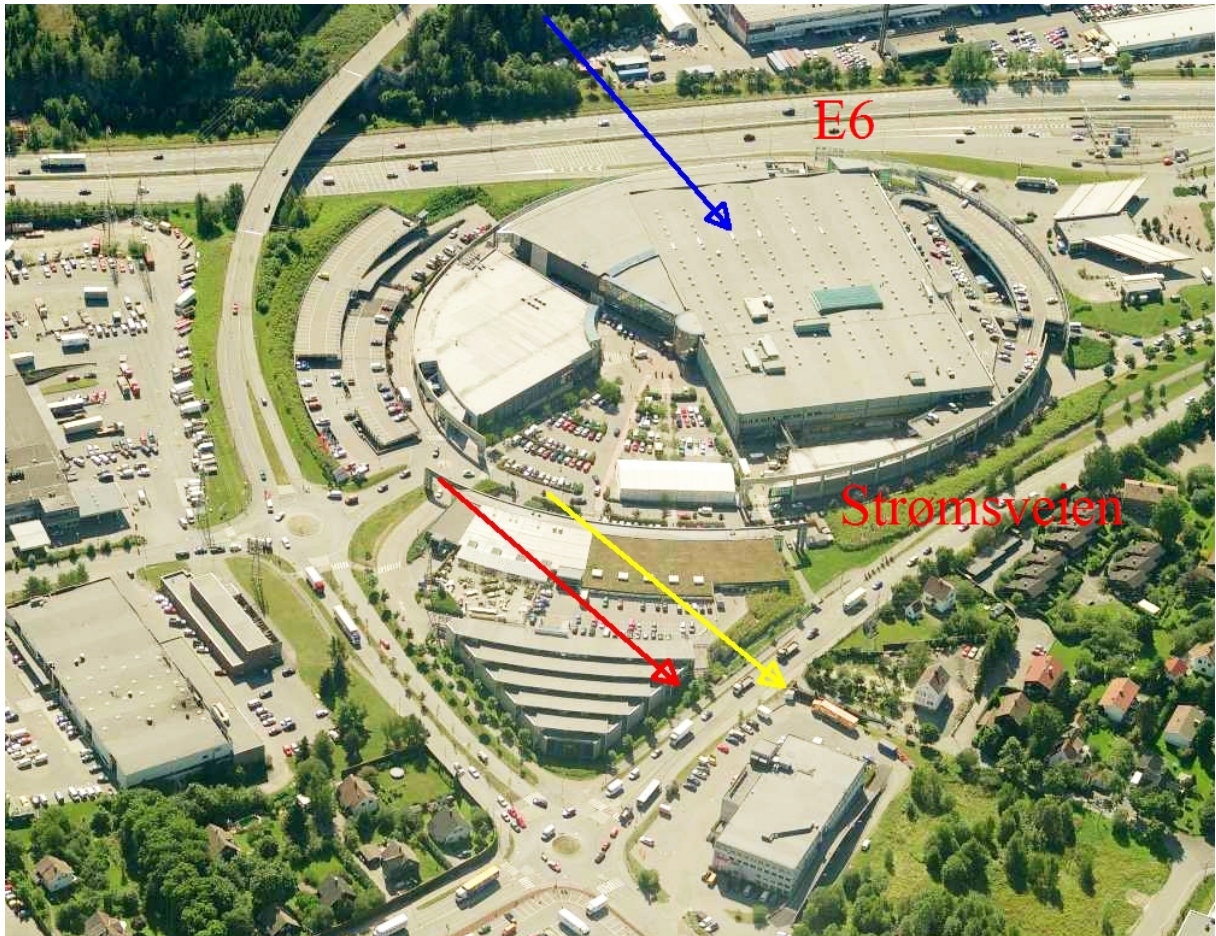


Figure 3. Air sampling sites; outdoor air quality monitoring site (yellow arrow), office (red arrow) and sporting goods store (blue arrow). (Source: [www.gulesider.no](http://www.gulesider.no))

### 2.1.2 Waste treatment facilities

Effluent related samples (*Table 5*) were taken from 6 wastewater treatment and waste recycling plants situated in Oslo (Bekkelaget), Drammen (Solumstrand, Lindum, Hellik Teigen), Arendal (Saulekilen), and from one fire fighting test facility at Haugesund (Res-Q).

*Table 5. Samples and count (N) in close proximity to waste treatment facilities.*

Station/ sample no.	Date	N	Instrument
<b>Surface sediments</b>			
Haugesund, Res-Q Fire Drill Site	02.07.07	5	van Veen grab
Drammen, Lindum (landfill)	21.06.07	2	van Veen grab
Drammen, Lindum (landfill)	29.08.07	2	van Veen grab
Hokksund, Hellik Teigen (car demolition)	25.10.07	2	van Veen grab
Hokksund, Hellik Teigen (car demolition)	01.11.07	2	van Veen grab
Hokksund, Hellik Teigen (Loselva)	05.05.07	3	van Veen grab
<b>Water</b>			
Oslo, Bekkelaget, treatment plant	18.06 – 25.06.07	2	composite flow-proportional
Arendal, Saulekilen, treatment plant	25.09 – 02.07.07	2	composite flow-proportional
Drammen, Solumstrand, treatment plant	22.06 – 29.06.07	2	composite flow-proportional
<b>Sludge</b>			
Oslo, Bekkelaget, treatment plant	25.06.07	1	grab
Arendal, Saulekilen, treatment plant	02.07.07	1	grab
Drammen, Solumstrand, treatment plant	22.06 – 29.06.07	1	composite grab

### Wastewater treatments facilities

#### *Bekkelaget WWTP (ca. 290 000 p.e.)*

The plant is located at Bekkelaget in Oslo municipality and treats wastewater mainly from the eastern parts of Oslo. Bekkelaget WWTP treats annually ca.40 mill m<sup>3</sup> wastewater and produces 4270 tons dry weight (2006) of sludge. The wastewater is primarily household water and light industrial wastewater (ca. 30 %). The landfill site Grønmo (no longer in use) is connected to Bekkelaget WWTP. The main water treatment is based on activated sludge (pre-denitrification) combined with simultaneous precipitation with iron sulphate. The wastewater is pre-treated by sieving (3 mm screen), sand and fat trap and pre-sedimentation and a two-media down-flow sand filter is used as a polishing step before discharge to the Bekkelag basin at 50 m depth. At water flows exceeding 1900 l/s the excess water is treated chemically with iron chloride or PAX in a bypass line. At water flows exceeding 3000 l/s the excess water is only treated mechanically (sieving, sand and fat trap) and flows exceeding 6000 l/s is discharged untreated at 25 m depth in the Bekkelaget basin. The produced sludge in the pre-sedimentation tanks, in the bioreactors and on the sand filter is undergone thermophilic anaerobic digestion at 55 °C and dewatering by centrifugation to 30-35 % solids. The dryers are no longer in use.

#### *Saulekilen WWTP (ca. 45 000 p.e.)*

The plant is located at Hisøya in Arendal municipality (on the South Coast of Norway) and treats wastewater from households, some industry (brewery) and from the inter-municipal landfill site in Heftingsdalen. In 2007 the plant treated 4.7 mill m<sup>3</sup> wastewater and produced

approximately 660 tons dry weight of sludge. The main treatment is based on chemical precipitation with PAX18. As pre-treatment the wastewater goes through a sieve (3 mm) and a fiber strainer (0.2 mm). The produced sludge undergo anaerobic digestion (2-3 weeks) followed by hyper pressing and drying. The final sludge has a solids content of 5 %.

#### *Solumstrand WWTP (ca. 80 000 p.e.)*

Solumstrand WWTP is located in Drammen municipality (west of Oslo) and receives spill water from households (ca. 70 %) and industry including the landfill site *Lindum Ressurs og Gjenvinning*. The plant treats annually ca. 8 mill m<sup>3</sup> wastewater and produces approximately 4000 tons dry weight of sludge. The main treatment is based on chemical precipitation with lime and seawater and sedimentation. As pre-treatment the wastewater goes through a sieve (3 mm) and a sand trap. The treated water is discharged to the inner parts of Drammenfjord 195 m from the shore and at 27 m depth outside Solum. The collected sludge is dewatered by pressing to a final dry weight content of ca. 30 %.

#### **Landfill site**

Lindum Ressurs og Gjenvinning as (Lindum) is located in Drammen municipality and receives solid waste from the Drammen region. Waste that may contribute to leachate content from the landfill is; residual waste, screening and sand trap wastes, asbestos containing waste, blow sand, compost, waste permanently deposited in biocell and waste to industrial biocell (degradable waste and sludge). The leachate goes through an aerated lagoon and a sedimentation basin before discharge to Solumstrand WWTP. The average annual leachate discharge for the years 2003-2006 was 480000 m<sup>3</sup>.

#### **Fire drill site**

Res-Q is located in Bleivik north of Haugesund on the West Coast of Norway. It conducts fire safety and emergency preparedness courses for landbased, offshore and maritime operations, primarily for the oil industry. Res-Q is the only fire drill site in Norway where they on a regular basis use foam with FTS; ca. three to five 9-litre extinguishers per week. The run-off from the test site is collected in two consecutive sub-surface basins for sedimentation of solids followed by an oil skimmer and centrifugation. The treated effluent is discharged to Bleivika at ca.15 m depth. Collected sediments in the sedimentation basins are removed annually and delivered as special waste for incineration. In July 2007 12.5 tons of sediments with unknown dry weight content were delivered for incineration.

#### **Car demolishing site**

Hellik Teigen as is located at Losmoen in Hokksund. It receives and recycles iron and other metals from scrapped cars, household appliances and metal raw materials; steel, cast iron, stainless steel and copper, aluminium, brass and different types of alloys, computer and electronic waste, wood and rubber. According to staff members it primarily receives the cars after that the main environmental contaminants have been removed. All water run-off from the site is collected and treated (sand trap, oil skimmer, flotation, venturi scrubber) before discharge to the small river Loselva. At low water levels in the river (which is influenced by the tidal amplitude) the discharge pipe is well above the water level.

### 2.1.3 Recipient samples (water, sediments, organisms)

#### *Freshwater sediment - Loselva*

Discharge from the Hellik Teigen car demolition plant empties into the Loselva river. From here 3 sediment samples were taken, one close to the main outlet from the plant, one upstream of this, and one downstream the outlet (**Table 6**).

#### *Marine samples*

Most of the samples from the marine recipients were taken close the point of discharge from the wastewater treatment facilities described above (cf. section 2.1.2), i.e. Bekkelaget WWTP in the inner Oslofjord, Saulekilen WWTP at Arendal in the South of Norway, Solumstrand WWTP (as recipient of discharge from the landfill site at Lindum) in the Drammensfjord area, and the Fire drill site Res-Q on the West Coast.

The discharge from Bekkelaget WWTP empties at 25-50m depth into the shallow Bekkelaget basin (maximum depth is 68 m) in the inner Oslofjord. The basin has a sill depth of about 50m which hinders turnover of the deepwater mass in the basin. Surface waters are better mixed with the waters outside the basin. From the Bekkelaget recipient the program covers sediment samples from 2 stations and seawater outside the plant outlet (**Table 7**) and samples of blue mussel (**Table 8**) and cod liver (**Table 9**) further out in the main fjord (Vestfjord, **Figure 2D**). Mussel samples were taken at Akershuskaia and Gressholmen, both in the vicinity of the plant outlet.

Discharge from Solumstrand empties at 27 m depth into the Drammensfjord, a branch of the Oslofjord. This arm of the fjord is about 120 m deep and has a sill-depth of 10 m which hinders easy exchange of watermasses with the fjord area outside. Drammensfjord For pragmatic reasons sediment samples from 2003 were used (**Table 7**). These were taken at 2 stations located about 3 km from Solumstrand (**Figure 2C**).

The discharge from Saulekilen WWTP is at about 30 m depth and unlike Bekkelaget and Solumstrand is in an area where there is relatively rapid exchange of watermass (**Figure 2B**). Seawater and sediment (**Table 7**) as well as blue mussel samples (**Table 8**) were taken in the vicinity of the point of discharge.

The discharge from Res-Q empties into Bleivika at about 15 m depth. There is relatively good exchange of the watermass in this area. Blue mussels were sampled at one station outside the Res-Q plant north of Haugesund, and at Høgevarde south of Haugesund.

In addition reference samples of marine sediments were taken from Lista (station 15S in the Coastal Monitoring Program), reference samples of blue mussels from Espevær and reference samples of cod liver from Karihavet, the latter two at Bømlo, west Norway. Several of the marine stations are also included in the CEMP monitoring program (indicated in **Table 3**).



Table 6. Freshwater sediments analyzed and sample count (N).

Station	Date	Depth (m)	Layer (cm)	Instrument	N
Loselva st.1 (Hellik Teigen area), Hokksund	25.06.07	0.2	surface	Hand held steel corer	1
Loselva st.2 (Hellik Teigen area), Hokksund	25.06.07	0.5	surface	Hand held steel corer	1
Loselva st.3 (Hellik Teigen area), Hokksund	25.06.07	0.5	surface	Hand held steel corer	1

Table 7. Marine sediments and water analyzed and sample count (N).

Station	Date	Depth (m)	Layer (cm)	Instrument	N
<b>Sediment</b>					
Inner Oslofjord, Bekkelaget	15.08.07	52	0-2	van Veen grab	2
Drammen, Lierterminalen	25.09.03	7.5	0-2	van Veen grab	1
Drammen, Teigen dock area	25.09.03	4.5	0-2	van Veen grab	1
Arendal	06.06.07	41	0-2	van Veen grab	1
Lista/ Farsund	05.06.07	386	0-2	van Veen grab	1
<b>Water</b>					
Inner Oslofjord, Bekkelaget st 0, 3, 4, 5, 6, 7, 8, 9, 10	15.08.07	0		flask	9
Arendal, st U-5-50, U-5-200, U-10, U-12	06.06.07	0		flask	5

Table 8. Blue mussel (*Mytilus edulis*) analyzed and sample count (N).

Station	Station no. (CEMP)	Date	Number mussels in bulk	Shell-size (mm) (min-max)	N
Inner Oslofjord, Akershuskaia	I301	15.08.07	20	33-48	1
Inner Oslofjord, Gressholmen	30A	22.08.07	20	35-49	1
Arendal, Ærøya		12.10.07	20	34-49	1
Bømlo, Espevær	22A	21.09.07	20	31-49	1
Haugesund, Res-Q by effluent tank		22.09.07	20	21-34	1
Haugesund, Høgevarde	227A	22.09.07	20	29-44	1

Table 9. Atlantic cod (*Gadus morhua*) analyzed and sample count (N).

Main area	Sample type	Station no. (CEMP)	Date	Number of fish in bulk	Fish length (cm) (min- max)	Fish weight (g) (min- max)	N
Inner Oslofjord	Cod/liver	30B	24.10.06	5	47.0 - 61.0	887 – 2190	1
Inner Oslofjord	Cod/liver	30B	24.10.06	5	62 - 78	2467 – 4640	1
Karihavet	Cod/liver	23B	16.09.06	5	59.5 - 73.0	2029 – 3934	1

## 2.2 Sampling and sample treatment

### 2.2.1 Air and dust sampling

#### High volume air sampling

For high volume sampling at New Ålesund (*Ny Ålesund*), Birkenes and Alnabru metering site a DIGITEL high volume air sampler (DHA-80) was used. The air samples were collected with different combinations of a glass fibre particle filter (collecting airbourne particles) followed by PUF adsorbents or PUF/XAD2-adsorbents (collecting airbourne particles) (**Table 10**)

Table 10. Compound group and high volume air-sampling equipment. (See also Table 4):

Compound group	Sampling equipment
PFRs	Filter + 2 PUF plugs
PFCs	Filter (ionics) + PUF/XAD2/PUF (volatiles)
Nitro/oxy-PAH	Filter + 2 PUF plugs
Ag/Pt	Filter

The glass fibre filter was cleaned by heating to 450 for 8 h. The PUF and XAD2 adsorbent were pre-extracted with acetone and toluene for 8 h using Soxhlet extraction and then dried under vacuum. The flow rate was about 20 m<sup>3</sup>/h. A sample volume of about 1000m<sup>3</sup> was taken using a high volume sampler for 48 hours. After sampling the exposed filter and PUFs were sent to the laboratory for analysis.

#### Low volume air sampling

For low volume sampling (indoor air samples) a NILU air sampler (MiniPUR) was used. The air samples were collected with different combinations of a glass fibre particle filter followed by PUF adsorbents or PUF/XAD2-adsorbents a glass fibre particle filter (collecting airborne particles) followed by PUF adsorbents or PUF/XAD2-adsorbents (collecting gaseous compounds) (**Table 11**).

Table 11. Compound group and low volume air-sampling equipment.

Compound group	Sampling equipment
PFRs	Filter + 2 PUF plugs
PFCs	Filter (ionics) + PUF/XAD2/PUF (volatiles)
Nitro/oxy-PAH	Filter + 2 PUF plugs

The glass fibre filter was cleaned by heating to 450 for 8 h. The PUF and XAD2 adsorbent were pre-extracted with acetone and toluene for 8 h using Soxhlet extraction and then dried under vacuum. The flow rate was about 1,5 m<sup>3</sup>/h. A sample volume of about 12 m<sup>3</sup> was taken using a high volume sampler for 48 hours. After sampling the exposed filter and PUFs were sent to the laboratory for analysis.

#### Road dust sampling

Samples of road dust was collected with a brush and transferred into a zip-lock bag. All material in contact with the dust were made of polyethylene.

## 2.2.2 Wastewater treatment facility sampling

### Wastewater treatments facilities

Flow proportional composite water samples were collected over a 7 days period from the influent and effluent at Bekkelaget, Arendal and Solumstrand municipal wastewater treatment plants. The samples were collected using the plant's stationary automatic samplers set at collecting a sub-sample every 30-60 min which was immediately refrigerated for storage. Every 24 hours a fraction of the collected water was transferred to the final sample bottles, the volume being determined by the actual amount of wastewater being treated within that period. 1 litre samples for each of PFC, PFR, Pt/Ag and sucralose analyses were collected in four separate 2-litre polypropylene bottles that were stored cold. At the end of the sampling period at Bekkelaget and Saulekilen WWTPs a 100 g van Veen grab sludge sample was collected of the final dewatered/dried sludge and transferred to an annealed glass bottle. At Solumstrand WWTP the sludge sample was collected as a daily composite van Veen grab sample during the sampling period that was transferred to an annealed glass bottle and kept refrigerated. Both water and sludge samples were immediately sent to NILU with express delivery for analysis when the final sample fraction was collected.

It was tried to conduct sampling in a predominantly dry period (**Table 12**). As can be seen from Table 1, showing the amount of rain the last two weeks before sampling and during sampling as well as the average incoming flow rate to each WWTP, this was actually not the case for any of the WWTPs. At Bekkelaget WWTP the capacity of the biological part of the treatment plant (1900 litres/s) was significantly exceeded the two last days of the sampling period (3000 litres/s).

*Table 12. Total precipitation and average and maximum 24-hour rainfall the week before sampling and during sample collection measured at the weather station closest to each WWTP (gathered from eKlima, [www.met.no](http://www.met.no)), and average influent flow during sampling and estimated ratio surface runoff calculated from normal dry-weather flows.*

WWTP	Week	Rainfall 14 days prior to sampling			Rainfall during sampling			Influent flow		Sludge prod. ton d.w./d
		total	average	max	total	average	max	During sampling	Ratio surface runoff	
		(mm)	(mm/d)	(mm/d)	(mm)	(mm/d)	(mm/d)	m <sup>3</sup> /d	%	
Bekkelaget	18-25 June	0.8	0.3	0.5	75	12.5	38	1129376	ca.50	104
Arendal	5 June – 2 July	27	4.5	18	78	15.5	50	138108	ca.50	352
Solumstrand	22-29 June	5.0	0.6	2.8	102	14.6	46	247001	-	68
Res-Q	2.July	22	3.7	8.8	0.7	0.7	0.7	-	-	-

### Fire drill site Res-Q AS

Two sediment samples (Res-Q Firedrill-1 and Res-Q Firedrill-2) were collected in connection with a drill using FTS foam and taken from the sediments in the two primary run-off ditches from that area. The next two samples were collected at the end of the primary sedimentation basin (Res-Q Sedim-1) and in the last of the sedimentation basins before discharge (Res-Q Sedim-2) using a small (12.5x15 cm) van Veen grab sampler. The sediments were too fluffy for using a core sampler. Sampling was done right before the annual emptying and disposal of sediments in the two basins. The fifth sediment sample was collected with the van Veen grab sampler through the last manhole on the transfer line before discharge to sea (Res-Q out.d). This was downstream the connection point with domestic wastewater effluent from the Res-Q WWTP (see Table 1 above). This is a small (68 p.e.) mechanical WWTP with only a 6 mm screen to sieve of larger waste fractions.

### **Landfill site Lindum Ressurs og Gjenvinning AS**

At the landfill site Lindum Ressurs og Gjenvinning AS all sediment samples were collected as duplicates from the upper sediments in the pump pit before leachate discharge to the WWTP Solumstrand using a small (12.5x15 cm) van Veen grab sampler. It was tried to sample during a typical dry period (22 June) and a typical wet period (29 August). The daily average leachate flows were relatively low in the two weeks periods preceding both sampling times; 726 m<sup>3</sup>/d (560 m<sup>3</sup>/d at sampling day) and 1093m<sup>3</sup>/d (660 m<sup>3</sup>/d at sampling day), respectively. The average daily leachate flow from Lindum is approximately 1300 m<sup>3</sup>/d (1417 m<sup>3</sup>/d in 2007).

### **Car demolishing company Hellik Teigen AS**

At the car demolishing company Hellik Teigen AS the two first sediment samples were collected from inside the discharge pipeline to the recipient stream Loselva using a thin plexi glass sediment core slicer and the next two samples were collected from the bank sediments right outside the same discharge pipeline using a small (12.5x15 cm) van Veen grab sampler. It was tried to sample during a typical dry period and a typical wet period, however, at the intended time of collecting the wet period sample the whole area was flooded. Hence, both periods were rather dry but on each side of the flooding period.

## **2.2.3 Recipient sampling**

### **Freshwater sediment**

Surface sediment samples (0-2cm) were collected using a modified Kajak-Brinkhurst sediment corer. At each station five replicate samples were pooled and stored in glass jar sealed with aluminium foil that had been pre-treated by heating to 400 °C. The samples were stored in the dark and cool (4 °C) before delivery to NILU.

### **Marine sediment, seawater, blue mussel and cod**

Surface sediment (0-2cm) was collected either using a modified Kajak-Brinkhurst sediment corer (Drammensfjord) or van Veen grab. With the Kajak-Brinkhurst sampler five replicate samples were pooled. For the van Veen grab, 1-2 replicates were pooled. The samples were stored in the dark and cool (4 °C) before delivery to NILU.

Seawater was collected from the surface using 10 litre plastic containers that NILU had pre-cleaned.

Blue mussel and cod samples were derived from Coordinated Environmental Monitoring Programme (CEMP), a part of the Joint Assessment and Monitoring Programme (JAMP), OSPAR guidelines (1997) are used for collecting and pre-treating CEMP samples prior to analyses.

## 2.3 Chemical analyses

A selection was made as to which element / compounds group would be analyzed in which sample type (*Table 13*).

*Table 13. Overview of sample count for the element and compound groups analyzed in the different sample type.*

<b>Sample type</b>	<b>PFR</b>	<b>PFC</b>	<b>Nitro-PAHs</b>	<b>Pt/Ag</b>	<b>Sucralose</b>
Air – trafficated area	6	6	6	6	
Air – office area	2	2	2		
Air – sportings goods store	2	2	2		
Air – long rang transport station(s)	7	6	9	5	
Road dust				12	
Water treatment facilities – water	6	6		6	6
Water treatment facilities – sludge	3	3		3	3
Landfill – sediment	4	4			
Firedrill testing area - sediment		4			
Automobile demolishing/ – sediment	4			8	
Freshwater – sediment	3	3			
Marine – seawater					14
Marine – sediment	5	6			
Marine – blue mussel	6	7			
Marine – Atlantic cod	3	3			

### 2.3.1 PFRs

#### Chemicals and equipment

All glass equipment was thermally cleaned before they were used in the analytical work (400°C for 4 hours wrapped in aluminium foil). To avoid contamination from the laboratory air during the Soxhlet extraction of air samples the outlet of the cooler was protected by an activated charcoal column. All equipment of Teflon and metal was washed by solvent before used. Solvents used for extraction were delivered from Rathburn (Chemical Ltd., Peeblesshire, Scotland). The ethylenediamine-N-propyl column (PSA) was delivered from IST (International Sorbent Technology, Mid Glamorgan, U.K).

#### Sample preparation

##### *Air/aerosol samples*

Air samples collected on PUF-column, were spiked with recovery standards (tri-n-pentylphosphate, TAP) and extracted with methyl-*tetr*-butyl ether (MTBE, 200 ml) in a Soxhlet apparatus for 6 hours (8 cycles/hour). The extract was concentrated, and cleaned up on a PSA-column before GC-MS analysis.

##### *Sludge and sediment samples*

Sediment and sludge samples were freeze dried before extraction. The dry sample was fortified with a recovery standard (TAP) and mixed carefully. The sample was subsequently extracted with a mixture of methanol and MTBE in an ultrasonic bath for 5 min and thereafter on a shaking board for 30 min. After centrifugation the extract was safeguarded. The extraction was repeated twice with MTBE. The pooled extract was extracted with water to remove the methanol. The organic extract was transferred to a new test tube and concentrated by the aid of a stream of nitrogen gas. The combined extract from the sediment sample was subjected to clean up on a PSA-column before GC-MS analysis. Sludge samples needed a more careful clean up in two steps: first on a silica gel column followed by a PSA-column.

##### *Biota samples*

Biota samples (10 g) were homogenised in acetone:MTBE and spiked with the recovery standard (TAP). The extraction was carried out on a shaking machine for 1 hour. The extract was safeguarded and the samples were extracted again with MTBE for one hour. The extracts were combined and the acetone was removed by shaking the extract with water. The extracts were dried. The lipid in the extracts was separated through partition extraction of the extract (hexane) and acetonitrile according to Jensen *et al.*, (1977).

### Instrumentation

All organic phosphate esters except for V6 were analysed on a 6890N gas chromatograph coupled to a 5973N mass selective detector (Agilent Technologies, Inc. Santa Clara, CA USA). The injection, 1 µl, was done in split-less mode at 240°C. The fused silica capillary column (VF-5MS 30 m x 0.25 mm i.d. x 0.25 µm film thickness, Varian) was held at 45°C for 2 min, ramped 12°C/min to 290°C, and isothermal at 290°C for 2 min. Helium was used as carrier gas. The detector was used in selected ion monitoring mode (SIM) with electron ionisation at energy of 70 eV. The analytes were identified by their characteristic retention times and one target ion (Rrg-ion) used for quantification. In most cases two qualifier ions (Q-ion) were recorded to increase specificity (**Table 14**). Quantification was based on comparison of peak abundance to the known response of the internal standard (biphenyl). The reported analyte concentrations were corrected according to the determined surrogate (TAP) standard losses.

Table 14. Summary of target- and qualifier ions used to identify and quantify the target analytes

Compound	Tgt-ion*	Q1-ion*	Q2-ion*
tris- <i>iso</i> -butylphosphate	99	155	-
trisbutylphosphate	99	155	-
trischloroethylphosphate	249	251	205
tris-chloropropylphosphate	277	279	201
trisamylphosphate, recoverystandard	99	239	-
tris-(1,3-dichloropropyl) phosphate	191	209	381
trisbutoxyphosphate	125	299	-
trisphenylphosphate	326	235	215
2-ethylhexyl-di-phenylphosphate	251	250	-
tetrekis(2-chlorethyl)dichloroisopentyldiphosphate (V6)	-	-	-

\*) Explanations: Target ion (T-ion). Qualifier ion (Q<sub>1</sub> och Q<sub>2</sub>-ion). Injection standard (IS).

The compound V6 was analysed on an Agilent 5890 II GC fitted with a short column (RXI-5MS, 15 m, 0.25 mm ID med 0.25 µm phase; Restek Corporation, Bellefonte, PA) connected to a Nitrogen-Phosphor Detector (NPD). The injection, 1 µl, was done in column mode at 48°C. The column was held at 45°C for 1 min, ramped 25°C/min to 150°C, and by 5°C/min until 295°C. Helium was used as carrier gas.

### 2.3.2 PFCs

#### Sample preparation

##### Air samples

The particulate phase was collected on filters. The gas phase was collected on a sandwich column with PUF-XAD-PUF. Prior extraction, internal standard was added to all samples. Filter samples were extracted with methanol for ionic PFCs in an ultrasonic bath, ethylacetate was used for extracting volatile PFCs from the gas phase by liquid extraction. The extracts were concentrated and further cleaned using EnviCarb. After centrifugation, recoverystandard was added.

#### *Biota, sediment and sewage sludge*

Sediment and sludge samples were treated with acid and neutralized again prior extraction with methanol for ionic PFCs and with ethylacetate for volatile PFCs in an ultrasonic bath. Biota samples were homogenised and extracted likewise. Prior extraction, internal standard was added to all samples. Sediment and sludge samples were freeze dried prior analyses of ionic PFCs. The extracts were concentrated and further cleaned using EnviCarb. After centrifugation, recovery standard was added.

#### *Water*

Water samples were filtered in order to collect the particles. Particles were weight and treated similar to sediments.

### **Analytical determination**

Volatile PFCs were analysed using a GC-MS system in PCI-mode for identification and quantification. For compound verification measurements in NCI-mode were applied. Ionic PFCs were analysed using a high resolution LC/MS-TOF in ESI-mode.

### **2.3.3 Nitro-PAHs in air samples**

#### **Sample preparation**

The particulate phase was collected on filters. The gas phase was collected on 2 PUF-plugs. The filter and PUF-plugs were extracted ultrasonically twice with dichloromethane and once with acetone. Each extraction lasted 30 min. NPAH internal standard (1-Nitropyrene d10) were added to each sample before extraction. The extracts were elutes through a silica column using 40 ml of 40% DCM/hexane solution, concentrated under N<sub>2</sub> and exchanged to hexane.

#### **Analytical determination**

Nitro-PAHs were analysed by high resolution gas chromatography (HRGC) combined with high resolution mass spectrometry in EI-mode. A 30mx 0.25mmx0.1µm Zebron ZB-5 capillary column was used in the Nitro-PAH quantification. The initial oven temperature (40°C) was ramped to 150°C at 20°C min<sup>-1</sup>, then ramped to 300°C at 50°C min<sup>-1</sup> and hold for 10 min and injector temperature was 250°C.

### **2.3.4 Silver and Platinum**

#### **Sample preparation**

For air samples, particles were collected on filters. The filters were extracted in aqua regia using microwave oven. For sediments and sewage sludge, dried sediments and semi-dried sludge were extracted in aqua regia using microwave oven. For samples of water, aliquots of influent water were evaporated to dryness. The solid residues were treated like sediments. Effluent water samples were conserved to 1 (v/v)% nitric acid.

<sup>185</sup>Re was added to all standards and samples as internal standard.

#### **Analytical determination**

The concentration of silver and platinum for all matrices were determined using a high-resolution plasma mass spectrometer (ELEMENT2, Thermo Inc, Germany). The plasma generator was operated at 1250 W. The silver isotope <sup>107</sup>Ag was determined in low resolution mode (R<sub>z</sub>~300) and the platinum isotope <sup>195</sup>Pt was determined in high resolution mode (R<sub>z</sub>~11000). The flow rate of plasma gas and auxiliary gas used were 15 l min<sup>-1</sup> and 1 l min<sup>-1</sup>, respectively. Nebulizer gas flow was around 0.9 l min<sup>-1</sup> and optimised daily. The spray

chamber assembly consisted of a Meinhard concentric nebulizer and a glass spray chamber of type Scott. Nickel-tipped cones were used for both sampler and skimmer. The data processing and instrument control were performed by the ELEMENT software.

### **2.3.5 Sucralose**

#### **Sample preparation**

For each sample, a solid-phase extraction (SPE) cartridge (Oasis HLB-Plus, Waters Corp., Milford, MA, USA) was preconditioned by sequential washing with methanol, and Milli-Q water after which the water sample was slowly passed through the cartridge.

Sludge samples were extracted with Milli-Q water. The extracts were then treated as described above.

#### **Clean-up of sample extracts**

Sucralose was eluted from the sorbent with acetone:methanol. To remove matrix compounds the extract was cleaned by passing through a mixed-mode ionexchange SPE-cartridge (Isolute-MM, IST, Mid Glamorgan, UK). Any sucralose remaining in the SPE-resin was washed out with additional acetone:methanol, which were pooled with the extract. The extract volume was then reduced to 1 ml with a Zymark TurboVap II, Concentration Workstation (Caliper Life Sciences, Hopkinton, MA, USA). Further extract clean up was performed by passing the extract through another mixed mode ionexchange SPE cartridge (Oasis MAX, Waters Corp., Milford, MA, USA) with subsequent extract volume reduction.

#### **HPLC/HRMS analysis**

Liquid chromatography was performed with an Agilent 1100 liquid chromatography system (Agilent Technologies, Waldbronn, Germany), equipped with an autosampler, a quaternary pump, an on-line degassing system and a diode array detector (UV). The compound separation was performed with a reversed phase C<sub>18</sub> column (Atlantis dC18, 2.1 mm ID x 150 mm length, 3 μm, Waters, Milford USA). A stainless steel inlet filter (Supelco, 0.8 μm) was used in front of a pre-column with the same stationary phase as the separation columns. Water was used as solvent A and acetonitrile as solvent B. The binary gradient had a flow rate of 0.2 ml min<sup>-1</sup> and started with 95 % A. From 0.1 minute solvent B was introduced linear up to 90% at 10 minutes and kept isocratic until 16 minutes. At 16.5 minutes solvent B was ramped up to 100% and kept isocratic up to 19.5 minutes. At 19.6 minutes B was set to 5% and the column were equilibrated up to a total runtime of 30 minutes. The analytical detector was a Micromass LCT orthogonal-acceleration time-of-flight (TOF) mass spectrometer (MS) equipped with a Z-spray electrospray ion source and a 4 GHz time to digital converter (TDC) (Micromass Ltd., Wythenshawe, Manchester, UK). The electrospray source parameters were optimised to the following values: Negative mode: sample cone 20 V, capillary voltage 2.7 kV, extraction cone 3 V, source temperature 120 °C, desolvation temperature 350 °C, cone gas flow 4 l h<sup>-1</sup> and desolvation gas flow 632 l h<sup>-1</sup>. The pusher frequency was operated in automatic mode. The data processing and instrument (HPLC/HRMS) control were performed by the MassLynx software, and quantification was performed with signal extraction of a peak width of 90 amu (typical).



### 2.3.6 General remarks to chemical analyses

The Limit of Detection (LoD) of an analytical detection method is driven by the following factors:

1. Total sample amount extracted
2. Purity of the sample extract after sample clean-up
3. Proportion of the total sample extract injected into the analytical instrument
4. Chromatographic resolution and peak shape
5. Instrumental sensitivity

These factors vary from sample type to sample type and also within the same type of samples. A typical example for the variation of factor (1), also valid for other samples than air samples, is the difference between outdoor air samples or high volume air sample with a volume of 500 to 1000 m<sup>3</sup>, whereas a typical indoor air sample or low volume air sample is from 10 to 20 m<sup>3</sup>. This means that with all other factors unchanged the LoD will be about 50 times higher for indoor air samples compared to outdoor air samples. Factor (2), purity of the final sample extract, can vary due to differences in sample matrix and to batch-to-batch variation of the clean-up system and often explain the difference in LoD of apparently identical samples. Due to the varying character of the samples with only a few spot check samples from each sampling site and type the LoD is estimated individually for each single sample.

A thorough evaluation of the measurement uncertainty requires laboratory intercalibration exercises for each analytical method and all measured sample types/matrices. This is far beyond what is affordable in a screening study of this nature, and in many cases not possible at all. However, a rough estimate on the measurement uncertainty varies between 10 and 60 % (*Table 15*).

*Table 15. A rough estimate on the analytical measurement uncertainty.*

<b>Compound group</b>	<b>Analytical measurement uncertainty in %</b>
PFRs	20-40
PFCs (volatiles)	40-60
PFCs (ionics)	30-50
Nitro/oxy-PAH	40-60
Ag	10-30
Pt	30-50

In this report the concentration of an analysed compound (analyte) in a solid sample is defined as the mass of the analyte divided by the total sample mass and normally expressed as µg/kg or ng/kg. As the water content of soil, sediment and sewage sludge samples can vary quite heavily the concentration unit is normally given based on the dry weight of the analyzed sample (µg/kg d.w.). For biological material as fish or mussel samples with a more stable water content the concentration is normally given on a wet weight base (µg/kg w.w.). The concentration of an analyte in a liquid or gaseous sample is defined as the mass of the analyte divided by the total sample volume and expressed as µg/l, ng/l, ng/m<sup>3</sup> or pg/m<sup>3</sup>.

For lipophilic analytes (analytes with high octanol-water partitioning coefficient  $K_{ow} > 1$ ) like PCBs or PFRs we can assume binding to organic particles in sediment/sludge or to the lipids in the biological tissue. For comparison of samples with varying organic content or lipid content, concentrations can be normalized to the organic content (total organic carbon = TOC or loss of ignition = LoI) or the fat content (lipid weight = l.w.). In contrast to other organic pollutants most PFCs can neither be described as hydrophilic nor as lipophilic and thus cannot

be characterized by a  $K_{ow}$ . A normalization of the concentration based on organic content or lipid content seems therefore not useful and is not normal practice.

To allow the conversion of concentrations given as  $\mu\text{g}/\text{kg}$  LoI w. to  $\mu\text{g}/\text{kg}$  d.w. the LoI is listed in the relevant tables.

### 3. Results and discussion

#### 3.1 Phosphorous flame retardants (PFRs)

For this group of 9 compounds a total of 50 samples were analyzed, where relatively more were detected in samples from wastewater treatment facilities (88%) compared to air samples and recipient samples (sediments, seawater, blue mussel, cod) (<50%) (**Table 16**).

*Table 16. Phosphorus Flame Retardants (PFRs) compounds analysed and number of samples above detection limit (shaded in result tables). Total indicates total number of samples and % indicates percent of total number with concentration above the detection limit.*

Sample type	TIBP	TBP	TCEP	TCPP	TDCP	TBEP	TPhP	EHDPP	V6	Total	%
Air samples	15	10	11	11	8	8	6	5	1	17	49
WWT-facilities	15	16	14	16	15	16	16	16	2	16	88
Recipient	8	9	8	8	8	5	2	9	0	17	37

##### 3.1.1 Air samples

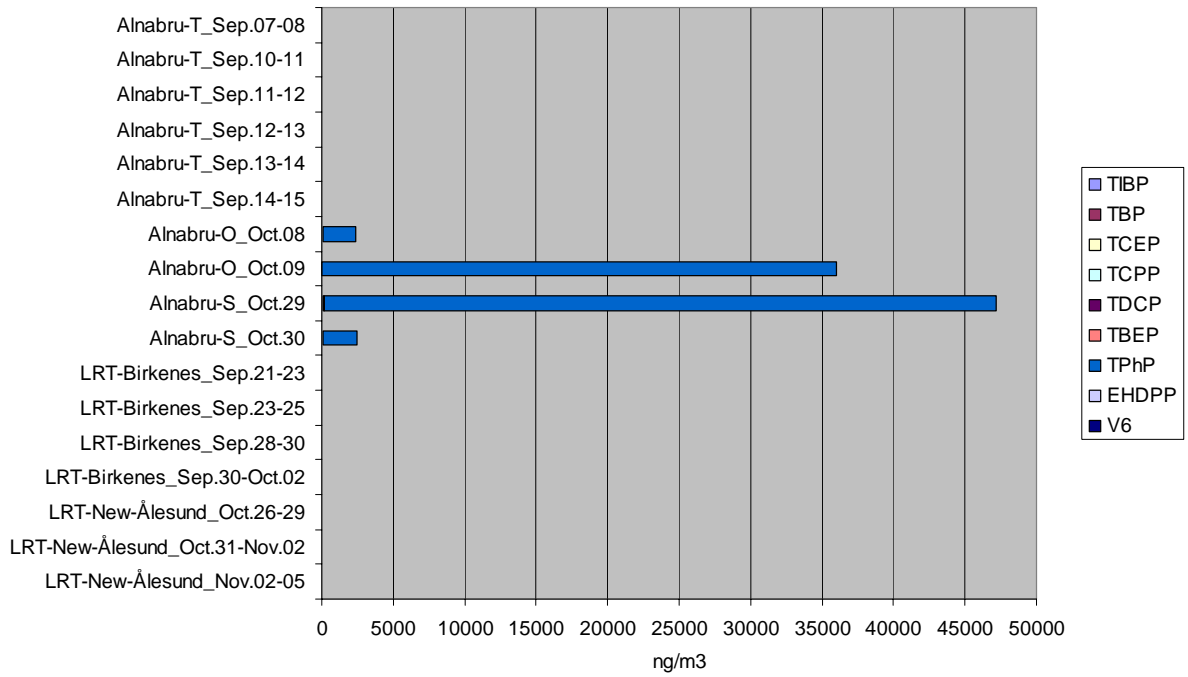
###### Results

Air samples were collected assessing differences between urban (10 samples) and remote locations (7 samples) as well as between indoor (4 samples) and outdoor location in an urbanized area (**Table 17**). About 650 m<sup>3</sup> air were collected at the urbanized outdoor location on three days, 12 m<sup>3</sup> at the urbane indoor location and about 1000 m<sup>3</sup> at the remote locations.

*Table 17. Phosphorus Flame Retardants (PFRs) compounds in air (ng/m<sup>3</sup>). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)*

Sample ID	TIBP	TBP	TCEP	TCPP	TDCP	TBEP	TPhP	EHDPP	V6
Alnabru-T_Sep.07-08	0.44	0.55	1.9	0.53	<0.04	0.34	<0.06	<0.2	<0.2
Alnabru-T_Sep.10-11	0.37	0.39	0.74	0.42	0.04	<0.1	<0.07	<0.2	<0.2
Alnabru-T_Sep.11-12	0.37	0.59	1	0.45	0.072	<0.1	<0.08	<0.2	<0.2
Alnabru-T_Sep.12-13	0.32	0.3	0.51	0.24	<0.04	<0.1	<0.05	<0.2	<0.2
Alnabru-T_Sep.13-14	4.4	3.7	6.2	3.7	<0.04	0.2	1	1.1	5.2
Alnabru-T_Sep.14-15	1.6	2.1	4	2.6	<0.04	0.11	0.77	0.78	<0.2
Alnabru-O_Oct.08	3.6	16	23	21	<0.04	51	2300	<0.2	<0.2
Alnabru-O_Oct.09	<0.01	8.2	2.7	10	7.1	10	36000	0.42	<0.2
Alnabru-S_Oct.29	7.9	14	5.8	49	18	55	47000	<0.2	<0.2
Alnabru-S_Oct.30	5.9	9.8	3.5	27	<0.04	8	2400	<0.2	<0.2
LRT-Birkenes_Sep.21-23	0.23	<0.2	<0.2	<0.2	<0.04	<0.1	<0.05	<0.2	<0.2
LRT-Birkenes_Sep.23-25	0.14	<0.2	<0.2	<0.2	0.14	<0.1	<0.05	<0.2	<0.2
LRT-Birkenes_Sep.28-30	0.16	<0.2	<0.2	<0.2	<0.04	<0.1	<0.05	<0.2	<0.2
LRT-Birkenes_Sep.30-Oct.02	0.19	<0.2	<0.2	<0.2	<0.04	<0.1	<0.05	<0.2	<0.2
LRT-New-Ålesund_Oct.26-29	<0.01	<0.2	0.27	0.33	0.25	<0.1	<0.05	0.26	<0.2
LRT-New-Ålesund_Oct.31-Nov.02	0.14	<0.2	<0.2	<0.2	0.23	0.15	<0.05	0.26	<0.2
LRT-New-Ålesund_Nov.02-05	0.032	<0.2	<0.2	<0.2	0.087	<0.1	<0.05	<0.2	<0.2

**A**



**B**

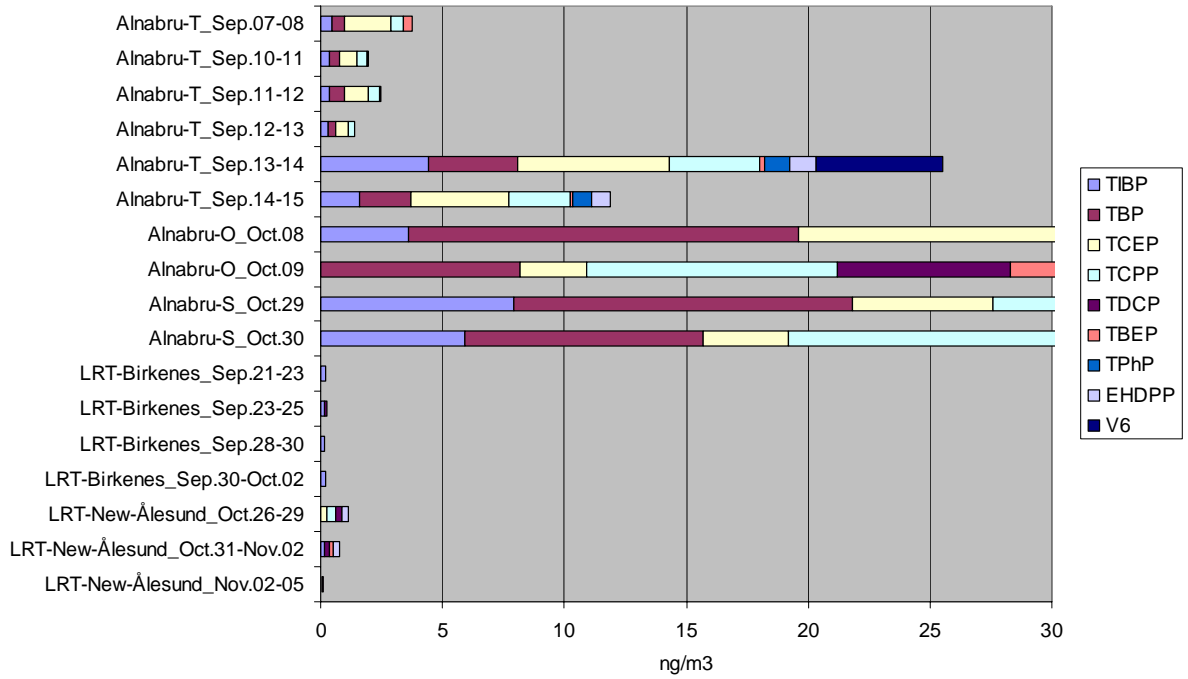


Figure 4. Phosphorus Flame Retardants (PFRs) compounds in air (ng/m<sup>3</sup>). Note two scales: overview (A) and detail of low concentrations (B). (See Annex 2 for sample ID description.)

The two highest concentrations were found in indoor samples, one from the office locality and one from the sporting goods store. There was a dominance of TPhP and to a lesser degree TBEP, TCPP, TBP and TCEP. Concentrations from the two remote sites (Birkenes and New Ålesund) were not quantifiable or very close to the detection limit.

## Discussion

Including all samples, the most frequently detected organophosphorus compounds (OP) were TIBP (15 out of 17) followed by TCEP, TCPP and TBP (**Table 16**).

Data on OPs in outdoor air are scarce, but results are presented here (cf. **Table 18 - Table 22**). The results from the Birkenes and New Ålesund samples indicates that TIBP, EHDPP and the chlorinated BFRs may be stable enough to reach long range transport (**Table 17**).

The samples collected at Alnabru-T represent air from a nearby main road in Oslo (se 2.1.1). Compared to samples collected from background areas, representing “global pollutions” (e.g. Birkenes, a “remote” area in the southern Norway), the measured concentrations at Alnabru-T were elevated. The OPs detected at the highest concentrations were TCEP (1-6.2 ng/m<sup>3</sup>) and TCPP (0.24-7.72 ng/m<sup>3</sup>; **Table 17**). Between 13 and 15 of September the concentrations of all PFRs but TDCP are substantially enhanced at Alnabru-T (**Figure 4**) probably due to a special meteorological situation called inversion (for explanation see chapter 2.1.1 Alnabru).

These results are in agreement with Marklund *et al.* (2005b) that concluded that traffic is an important source of TCPP and TPhP. The sources to these BFRs may be the interior of cars (TCPP in polyurethane foam) and from lubricants and engine oils (TPhP) in the vehicles. TBP and TIBP are also important constituents of the OP pattern in Alnabru-T (**Figure 4**) but may not be related to the traffic (Marklund *et al.* 2005b).

In the indoor air samples taken in an office and sports outfitters (Alnabru-S) dominated the OP TPhP 2300-47000 ng/m<sup>3</sup>). In these environments were also high concentrations of TCPP (21-49 ng/m<sup>3</sup>), TEBP (8-55 ng/m<sup>3</sup>) recorded (**Table 17**). Marklund *et al.* (2005c) reported that TCEP (0.4-720 ng/m<sup>3</sup>) and TCPP (10-570 ng/m<sup>3</sup>) were the most abundant OP in air albeit TBEP was the main OP used as flame retardant. The concentrations measured of TPhP and TBEP by Marklund *et al.* (2005c) were between (<0.3-23 ng/m<sup>3</sup>) and (<0.4-55 ng/m<sup>3</sup>) respectively. This may be explained by higher vapor pressure of TCEP and TCPP compared to TBEP. The detected concentrations of OPs in indoor air at Alnabru-S are high compared to these previously reported results (**Table 21**). Higher concentrations are often found in official environments such as hospital, prison, office, library, and bowling alley (570-950 ng/m<sup>3</sup>; Marklund *et al.* 2003; 2005c) because flooring, upholstered furniture, acoustic ceilings, floor police are strict flame protected with OPs. The pattern of OPs in air from these environments varies greatly according to the used flame retardant (Marklund *et al.* 2003; 2005c).

TIBP in municipal wastewater sludge has been previously quantified (*Table 18*).

*Table 18. Previous measurements of TIBP in the environment.*

Study area	Medium	Value	Unit	Reference
Sweden	sludge	27-2700	µg/kg dw	Marklund <i>et al.</i> 2005a

TBP in air, snow, and samples in connection with wastewater treatment facilities has been previously quantified through other investigations (*Table 19*).

*Table 19. Previous measurements of TBP in the environment.*

Study area	Medium	Value	Unit	Reference
Indoor, Japan	air	0.11-0.6	µg/m <sup>3</sup>	Otake <i>et al.</i> 2001
Indoor, dismantling facility	air	24	ng/m <sup>3</sup>	Staff <i>et al.</i> 2005
Lecture hall	air	5	ng/m <sup>3</sup>	Staff <i>et al.</i> 2005
Computer hall	air	<0.3	ng/m <sup>3</sup>	Staff <i>et al.</i> 2005
Sweden	Living room	14-120	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Sweden	Prison	20	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Sweden	Office	8.2	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Sweden	influent	3	µg/l	Paxeús 1996
Sweden	influent	6.6-52	µg/l	Marklund <i>et al.</i> 2005a
Sweden	effluent	0.36-6.1	µg/l	Marklund <i>et al.</i> 2005a
Sweden	sludge	39-850	µg/kg dw	Marklund <i>et al.</i> 2005a
Sweden	snow, road	11-19	ng/kg	Marklund <i>et al.</i> 2005b
Sweden	snow airport	2.1-25	µg/kg	Marklund <i>et al.</i> 2005b
Finland	air, background	280	pg/m <sup>3</sup>	Marklund <i>et al.</i> 2005b

TBEP in air, snow, and samples in connection with wastewater treatment facilities has been previously quantified through other investigations (*Table 20*).

*Table 20. Previous measurements of TBEP in the environment.*

Study area	Medium	Value	Unit	Reference
Indoor, Japan	air	<0.0004 to 0.03	µg/m <sup>3</sup>	Otake <i>et al.</i> 2001
Indoor, dismantling facility	air	130	ng/m <sup>3</sup>	Staff <i>et al.</i> 2005
Sweden	Living room	<0.4-0.6	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Sweden	Prison	55	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Sweden	Office	<0,2	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Sweden	influent	28	µg/l	Paxeús, (1996).
Sweden	influent	5.2-35	µg/l	Marklund <i>et al.</i> 2005a
Sweden	effluent	3.1-30	µg/l	Marklund <i>et al.</i> 2005a
Sweden	sludge	<5.1 to1900	µg/kg dw	Marklund <i>et al.</i> 2005a
Sweden	snow, road	2-12	ng/kg	Marklund <i>et al.</i> 2005b
Sweden	snow airport	7-94	µg/kg	Marklund <i>et al.</i> 2005b
Finland	air, background	<1.6	pg/m <sup>3</sup>	Marklund <i>et al.</i> 2005b

TPhP in air, snow, and samples in connection with wastewater treatment facilities has been previously quantified through other investigations (**Table 21**).

*Table 21. Previous measurements of TPhP in the environment.*

<b>Study area</b>	<b>Medium</b>	<b>Value</b>	<b>Unit</b>	<b>Reference</b>
Indoor, Japan	air	<1.2 to 10	ng/m <sup>3</sup>	Otake <i>et al.</i> 2001
Indoor, dismantling facility	air	17	ng/m <sup>3</sup>	Staff <i>et al.</i> 2005
Lecture hall	air	<0.3	ng/m <sup>3</sup>	Staff <i>et al.</i> 2005
Sweden	Living room	<0.3-8.8	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Sweden	Prison	<0.4	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Sweden	Office	7.1	ng/m <sup>3</sup>	Marklund <i>et al.</i> 2005c
Computer hall	air	1	ng/m <sup>3</sup>	Staff <i>et al.</i> 2005
Sweden	influent	3	µg/l	Paxeús, (1996).
Sweden	influent	0.076-0.290	µg/l	Marklund <i>et al.</i> 2005a
Sweden	effluent	0.041-0.13	µg/l	Marklund <i>et al.</i> 2005a
Sweden	sludge	52-220	µg/kg dw	Marklund <i>et al.</i> 2005a
Sweden	snow, road	4-68	ng/kg	Marklund <i>et al.</i> 2005b
Sweden	snow airport	120-830	µg/kg	Marklund <i>et al.</i> 2005b
Finland	air, background	12000	pg/m <sup>3</sup>	Marklund <i>et al.</i> 2005b

EHDPP in municipal wastewater sludge has been previously quantified (**Table 22**).

*Table 22. Previous measurements of EHDPP in the environment.*

<b>Study area</b>	<b>Medium</b>	<b>Value</b>	<b>Unit</b>	<b>Reference</b>
Sweden	sludge	320-3200	µg/kg dw	Marklund <i>et al.</i> 2005a

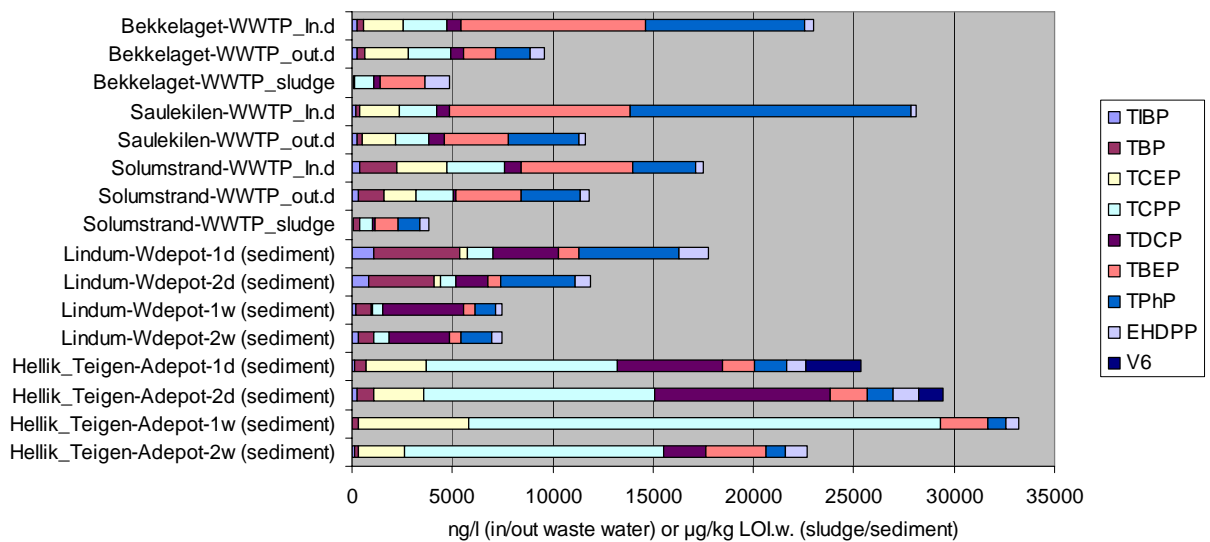
### 3.1.2 Wastewater treatment facilities

#### Results

There were 16 samples from three domestic wastewater treatment plants (WWTP) (three influent samples, three effluent and two sludge samples), one landfill site (four sediment samples) and one car demolishing site (four sediment samples) were analysed for nine different PFRs (**Table 23, Figure 5**). All samples contained PFRs, sum ranges were 9590-28110 ng/l in the water samples (highest at Solumstrand WWTP), 3873-4808 µg/kg loss of ignition weight (LOI.w.) in the sludge samples (highest at Bekkelaget WWTP) and 7483-33750 µg/kg LOI.w. in the sediment samples (highest at the car demolishing site Hellik Teigen AS).

*Table 23. Phosphorus Flame Retardants (PFRs) compounds in samples from wastewater treatment facilities (ng/l for in/out discharge water, µg/kg LOI weight for sludge and sediment). Concentrations over detection limit are shaded. Percent LOI is shown. (See Annex 2 for sample ID description.)*

Sample ID	LOI	TIBP	TBP	TCEP	TCP	TDCP	TBEP	TPhP	EHDPP	V6
Bekkelaget-WWTP_In.d		270	280	2000	2200	730	9200	7900	460	<500
Bekkelaget-WWTP_out.d		250	360	2200	2100	670	1600	1700	710	<500
Bekkelaget-WWTP_sludge	54	52	69	<9	944	330	2200	13	1200	<37
Saulekilen-WWTP_In.d		210	160	2000	1860	630	9000	14000	250	<500
Saulekilen-WWTP_out.d		270	270	1600	1700	740	3200	3500	320	<500
Solumstrand-WWTP_In.d		410	1800	2500	2900	820	5600	3100	390	<500
Solumstrand-WWTP_out.d		310	1300	1600	1900	86	3300	2900	490	<500
Solumstrand-WWTP_sludge	26	81	270	<19	650	110	1200	1100	462	<77
Lindum-Wdepot-1d (sediment)	40	1100	4300	380	1300	3300	1000	5000	1500	<50
Lindum-Wdepot-2d (sediment)	46	850	3300	280	800	1500	650	3700	760	<43
Lindum-Wdepot-1w (sediment)	37	195	760	78	490	4100	540	1000	320	<27
Lindum-Wdepot-2w (sediment)	37	300	780	27	760	3000	600	1500	490	<27
Hellik Teigen-Adepot-1d (sediment)	40	150	580	3000	9500	5300	1600	1600	930	2800
Hellik Teigen-Adepot-2d (sediment)	40	230	880	2500	12000	8800	1900	1300	1300	1200
Hellik Teigen-Adepot-1w (sediment)	2	<250	300	5500	24000	<250	2400	900	650	<500
Hellik Teigen-Adepot-2w (sediment)	17	100	210	2300	13000	2200	2900	1000	1100	<59





*Figure 5. Phosphorus Flame Retardents (PFRs) compounds in samples from the wastewater treatment facilities (ng/l for in/out discharge water, µg/kg LOI weight for sludge and sediment). (See Annex 2 for sample ID description.)*

#### *Wastewater treatment facilities - water samples*

All PFRs included in the analyses were found above the detection limit in all water and sludge samples from the three WWTPs, except for V6 that was not found in any of the samples and TCEP that was found in all but one sludge sample. Unfortunately, no analytical results were available from the Saulekilen WWTP sludge sample.

TBEP and TPhP were the dominating PFRs in the influent to all three WWTPs (5600-9200 ng/l and 3100-14000 ng/l, respectively) with the lowest concentrations in the influent to Solumstrand WWTP. The concentrations of TCEP and TCPP were within the same range in the influent to all plants (2000-2900 ng/l).

Comparing the influent concentrations with the effluent concentrations indicated an overall PFR removal ratio of ca. 60 % at Bekkelaget WWTP and Saulekilen WWTP, while a somewhat lower removal ratio was obtained at Solumstrand WWTP (ca. 30 %). Looking at the individual compounds; at Bekkelaget and Saulekilen WWTPs the two dominating PFRs compounds TBEP and TPhP were removed by ca. 70-80 %, while at Solumstrand WWTP the same compounds were only removed by ca. 40 % and ca. 6 %, respectively. The chlorinated PFRs TCEP, TCPP and TDCP went more or less right through the Bekkelaget and Saulekilen WWTPs, but removed by ca. 40 % at Solumstrand WWTP.

#### *Wastewater treatment facilities - sludge samples*

In the sludge sample from Bekkelaget WWTP with biological and chemical treatment and anaerobic sludge digestion TBEP, EHDPP and TCPP dominated the PFR content constituting ca. 90 % of the total 4856 µg/kg LOI weight; 2222, 1222 and 944 µg/kg LOI weight. It should be noted that the influent-effluent water samples indicated that neither EHDPP nor TCPP would be removed from the water, however, they were found at relatively high concentrations in the final sludge. In the sludge from Solumstrand WWTP with only chemical treatment TBEP, TPhP, TCPP and EHDPP dominated; 1154, 1115, 654 and 462 µg/kg loss of ignition weight, respectively, with a total PRF concentration of 3850 µg/kg loss of ignition weight.

#### *Landfill site and car demolishing site - sediment samples*

All sediment samples contained considerable amounts of PFRs. In samples taken at the Lindum landfill site and at the car demolishing site, Hellik Teigen, total PFR concentration values of 7460-17760 and 22580-33200 µg/kg LOI weight, respectively, were found. While TPhP, TBP and TDCP dominated the sediment samples from Lindum with concentrations of 1100-5000, 760-4300 and 1500-3300 µg/kg LOI weight, respectively, TCPP was the dominating PFRs in all sediment samples from Hellik Teigen (9500-23500 µg/kg LOI weight).

## **Discussion**

The influent levels to the three WWTPs were much the same independent of their sizes (person equivalents) and influences from industrial wastewaters indicating that PFRs are used on a broad scale in the society, as was also commented by the investigators in the Swedish screening report on organophosphates in the Swedish environment (Haglund & Marklund, undated). Results the Swedish screening project on PFRs in WWTPs and published by Marklund *et al.* (2005a) are presented in **Table 24** through **Table 31** together with other previously published data on PFRs in influent, effluent and sludge samples from WWTPs. As

for the present study, the alkyl PFR TBEP was a dominating PFR compound in all the studies, though, often at significantly higher levels than we found. However, in the present study we found somewhat higher levels of the chlorinated PFRs TCEP and TCPP (ca. 2 times higher) and particularly higher levels of the aryl-PFR TPhP (up to ca. 50 times higher) than found in the earlier reported studies. The available Norwegian data is too scarce to evaluate whether this apparent discrepancy in PFR composition in influent WWTP samples between the present study and the other reported studies is statistically significant or mere coincidental.

The chemical-physical properties of the different PFRs vary widely, hence they will partition differently through the treatment at each wastewater treatment plant. Some of the included PFRs have a high sludge sorption potentials ( $\log K_{ow} > 4$ ); TPhP ( $\log K_{ow}$  4.59) and EHDPP ( $\log K_{ow}$  5.73), but most of the others have a medium sludge sorption potential ( $\log K_{ow}$  2.5-4). The exception is TCEP with a  $\log K_{ow}$  of 1.44. Also, the water solubility of some of the included PFRs is relatively high, such as for TCPP (1.2 g/l), TBEP (1.1 g/l), TCEP (7.0 g/l) and TBP (0.28 g/l) (the chemical-physical properties were retrieved from <http://www.syrres.com/esc/physdemo.htm>). Furthermore, the chlorinated PFRs are known to be poorly biodegradable (WHO 1998), while the alkyl PFRs are expected to be more readily biodegradable than the aryl-PFRs. All this taken into account, the results in the present study seems to be fairly reasonable and similar to the results reported by Marklund *et al.* (2005a); compounds with a combination of high  $\log K_{ow}$  and low expected biodegradability accumulated in the sludge, in both studies dominated by EHDPP, TCPP and TBEP. In the present study we saw a distinct difference between Bekkelaget WWTP (biological-chemical treatment and thermal anaerobic sludge digestion) and Solumstrand WWTP (only chemical treatment) in that TPhP clearly accumulated in the sludge at Solumstrand WWTP, while it was almost absent in the sludge from Bekkelaget WWTP.

Table 24. Previous measurements of TIBP in wastewater treatment facilities.

Study area	Medium	Value	Unit	Reference
Sweden	sludge	27-2700	$\mu\text{g}/\text{kg dw}$	Marklund <i>et al.</i> 2005a

Table 25. Previous measurements of TBP in wastewater treatment facilities.

Study area	Medium	Value	Unit	Reference
Sweden	influent	3000	ng/l	Paxeús 1996
Sweden	influent	6600-52000	ng/l	Marklund <i>et al.</i> 2005a
Sweden	effluent	360-6100	ng/l	Marklund <i>et al.</i> 2005a
Sweden	sludge	39-850	$\mu\text{g}/\text{kg dw}$	Marklund <i>et al.</i> 2005a

Table 26. Previous measurements of TCEP in wastewater treatment facilities.

Study area	Medium	Value	Unit	Reference
Japan	influent	540-1200	ng/l	Ishikawa <i>et al.</i> 1985
Japan	effluent	500-1200	ng/l	Ishikawa <i>et al.</i> 1985

Table 27. Previous measurements of TCPP in wastewater treatment facilities.

Study area	Medium	Value	Unit	Reference
Japan	influent	980	ng/l	Ishikawa <i>et al.</i> 1985
Japan	effluent	320	ng/l	Ishikawa <i>et al.</i> 1985

Table 28. Previous measurements of TDCP in wastewater treatment facilities.

Study area	Medium	Value	Unit	Reference
Japan	influent	330-1600	ng/l	Ishikawa <i>et al.</i> 1985
Japan	effluent	280-1400	ng/l	Ishikawa <i>et al.</i> 1985
Sweden	effluent	<500-3000	ng/l	Paxeús 1996

Table 29. Previous measurements of TBEP in wastewater treatment facilities.

Study area	Medium	Value	Unit	Reference
Sweden	influent	28000	ng/l	Paxeús 1996
Sweden	influent	5200-35000	ng/l	Marklund <i>et al.</i> 2005a
Sweden	effluent	3100-30000	ng/l	Marklund <i>et al.</i> 2005a
Germany	effluent	800-34900	ng/l	Bohlen <i>et al.</i> 1989
Sweden	sludge	<5.1 to1900	µg/kg dw	Marklund <i>et al.</i> 2005a

Table 30. Previous measurements of TPhP in wastewater treatment facilities.

Study area	Medium	Value	Unit	Reference
Sweden	influent	3000	ng/l	Paxeús 1996
Sweden	influent	76-290	ng/l	Marklund <i>et al.</i> 2005a
Sweden	effluent	41-130	ng/l	Marklund <i>et al.</i> 2005a
Sweden	sludge	52-220	µg/kg dw	Marklund <i>et al.</i> 2005a

Table 31. Previous measurements of EHDPP in wastewater treatment facilities.

Study area	Medium	Value	Unit	Reference
Sweden	sludge	320-3200	µg/kg dw	Marklund <i>et al.</i> 2005a

### 3.1.3 Freshwater and marine recipients

#### Results

All PFRs except V6 were had levels above the detection limit in some of the recipient samples, primarily from sediments, but none were quantifiable in all samples (**Table 32**, **Figure 6**).

#### Recipient sediments

The following compounds were quantifiable in all 8 sediment samples: TIBP (62-470 µg/kg LOI.w.), TBP (66-480 µg/kg LOI.w.), TCPP (63-16000 µg/kg LOI.w.), TDCP (63-870 µg/kg LOI.w.), and EHDPP (140-680 µg/kg LOI.w.). The most common compound in most samples was TCPP, followed by TCEP and TIBP. TPhP was only quantifiable in 2 of the samples, Bekkelaget station 1 and Loselva station 3. The by far highest levels of PFRs was found at two Loselva stations. This station is closest to the Hellik Teigen car distruction site, and the dominance of TCPP TBEP and TCEP reflected the pattern found in the Hellik Teigen samples.

#### Blue mussel

PFRs in blue mussel is below the detection limits except for TBP and TCEP in the sample from Gressholmen, inner Oslofjord.

*Cod liver*

PFRs were below the detection limits in all the cod liver samples, with the exception of one high and questionable value from the inner Oslofjord “Bekkelaget\_1” (see qualifying footnote in **Table 32**).

*Table 32. Phosphorus Flame Retardents (PFRs) compounds in sediment ( $\mu\text{g}/\text{kg}$  LOI weight), blue mussel and cod liver ( $\mu\text{g}/\text{kg}$  wet weight) from recipient waters. Concentrations over detection limit are shaded. Percent LOI is shown. (See Annex 2 for sample ID description.)*

<b>Sample ID</b>	<b>LOI</b>	<b>TIBP</b>	<b>TBP</b>	<b>TCEP</b>	<b>TCPP</b>	<b>TDCP</b>	<b>TBEP</b>	<b>TPhP</b>	<b>EHDPP</b>	<b>V6</b>
Bekkelaget_1 (sediment)	12	92	183	180	560	230	83	330	300	<170
Drammen, Teigen (sediment)	5	62	66	1100	3800	200	600	<100	680	<400
Drammen, Lierterminalen (sediment)	6	73	67	770	400	270	170	<83	140	<330
Loselva_0_(st_3, sediment)	13	77	177	1600	16000	660	3100	370	520	<150
Loselva_down_(st_1 (sediment)	13	85	92	65	1200	170	120	<38	150	<150
Loselva_up_(st_2, sediment)	7	109	119	<71	130	100	<71	<71	190	<290
Arendal (sediment)	1	470	480	810	750	870	<500	<500	560	<2000
Lista_(reference, sediment)	8	100	110	<63	63	63	<63	<63	150	<250
Gressholmen (mussel)	<10	17	23	<10	<10	<10	<20	<10	<20	<20
Akershuskaia (mussel)	<10	<10	<10	<10	<10	<10	<20	<10	<20	<20
Arendal_(Ærøya)-1 (mussel)	<20	<20	<20	<20	<20	<20	<40	<20	<40	<20
Espevær (mussel)	<10	<10	<10	<10	<10	<10	<10	<10	<20	<20
Res_Q_recipient (mussel)	<30	<30	<30	<30	<30	<30	<30	<30	<40	<20
Haugesund (mussel)	<10	<10	<10	<10	<10	<10	<10	<10	<20	<20
Bekkelaget_1 (cod liver)	<5	<5	<5	<5	<5	<5	<10	<5	2900 <sup>1</sup>	<20
Bekkelaget_2 (cod liver)	<5	<5	<5	<5	<5	<5	<10	<5	<15	<20
Karihavet (cod liver)	<5	<5	<5	<5	<5	<5	<10	<5	<15	<20

1) The high concentration of EHDPP is uncertain and contamination of the sample during the analytical work can not be excluded. Result has been double-checked, however, not re-analyzed due to lack of spare material.

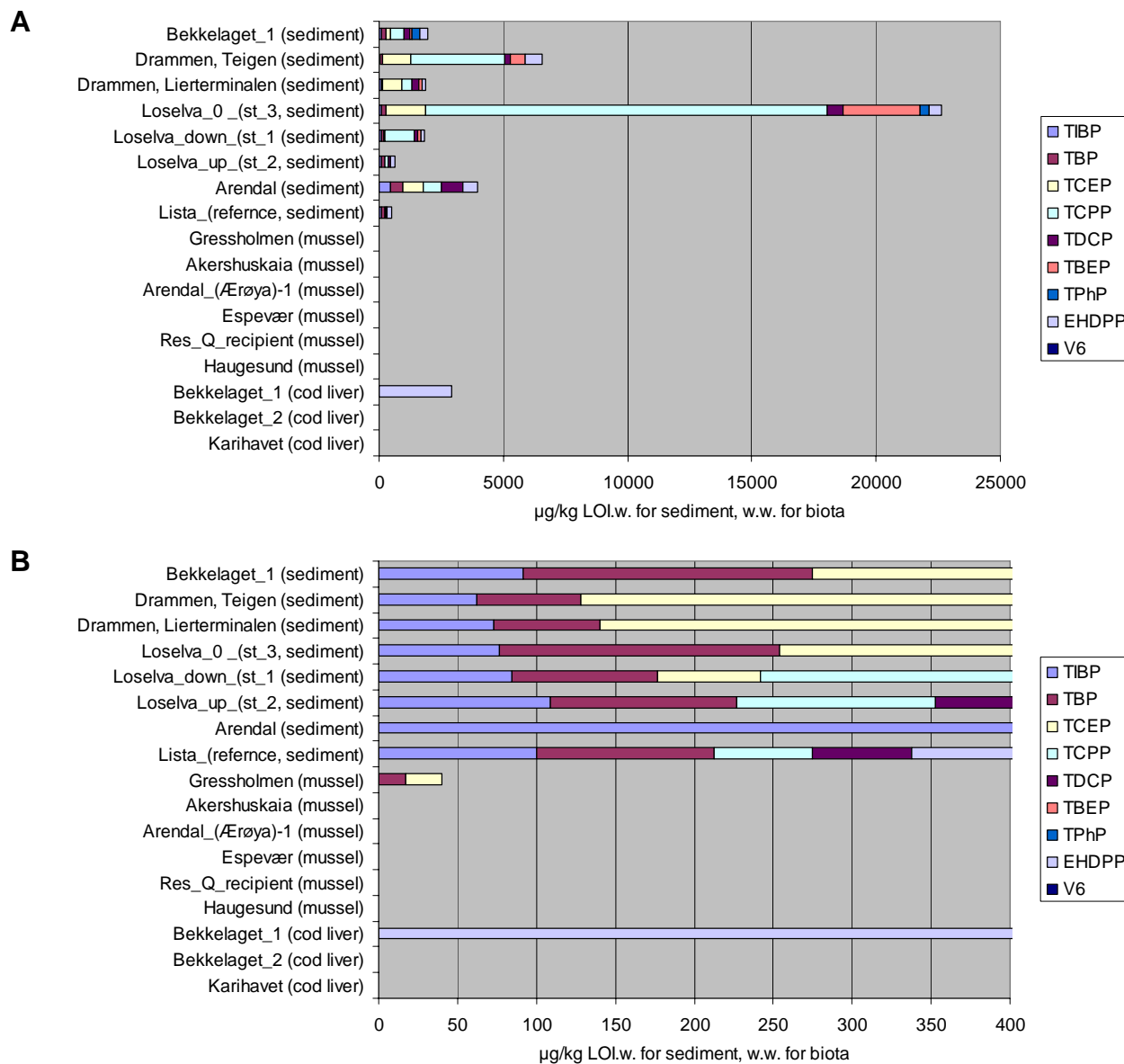


Figure 6. Phosphorus Flame Retardant-compounds in sediment ( $\mu\text{g}/\text{kg}$  LOI weight), blue mussel and cod liver ( $\mu\text{g}/\text{kg}$  wet weight) from recipient waters. Note two scales: overview (A) and detail of low concentrations (B). (See Annex 2 for sample ID description.)

## Discussion

The highest PFR values were found at two sediment stations close to the Hellik Teigen car destruction site. The highest (Loselva\_0) was located closest to destruction site. In addition to TCPP TBEP and TCEP, TDCP also dominated the sediment samples taken at the car destruction site (cf. **Table 23**).

The patterns of PFR in the discharge water from the wastewater treatment facilities at Bekkelaget, Solumstrand and Saulekilen were not similar to those found in sediment in the vicinity. Water circulation and dilution, biodegradability and distance to the point of discharge are likely important influencing factors for this discrepancy.

Some results for TCEP and TDCP in sediment (<63-1600 and 63-870 µg/kg dry weight, respectively) were somewhat higher than those found from other investigations (cf. **Table 33**, **Table 34**).

Quite high concentrations of chlorinated PFRs were detected in sediments indicating that the compounds are not readily degraded in the environment and they have a high affinity to particulate organic matter. This situation was not mirrored in biota samples that showed low or concentrations below the detection limit. This may be confusing but the bioavailabilities of the bound PFRs are unknown and may be a limiting factor in this context. Furthermore, TCPP and TDCPP have a short half life time ( $t_{1/2}$ ) in fish. For example is  $t_{1/2}$  for TCPP 31 h and 42 h in Killer fish and Goldfish, respectively. This fast clearance also explains the low bioaccumulation in Killer fish and Goldfish (BCF ~ 47-107). The elimination rate in these experiments was determined to 1.65 h (EHC 209, 1998). The PFRs with higher bioaccumulation potential ( $\log K_{ow} > 3$ ) have a longer elimination speed e.g. TPhP in Rainbow trout had a  $t_{1/2}$  of 79 h (Muir, Grift et al. 1980) and in lower organisms e.g. Chironomus 30-79 h (Muir and Grift 1981). These facts make it less likely to detect PFRs in biota collected from the environment, at least at high concentrations. However, PFRs have been detected in perch collected from lakes in Sweden and the dominating PFRs detected were TPhP and TCPP. The sum concentrations of the BFRs in the samples were mainly < 20 ng/g w.w.. The concentration of TCPP was between 2-15 ng/g w.w. and TPhP 3-25 ng/g w.w. (Marklund 2005d).

*Table 33. Previous measurements of TCEP in recipients.*

Study area	Medium	Value	Unit	Reference
Japan	sediment	13-28	ng/kg <sup>1</sup>	Ishikawa <i>et al.</i> 1985 <sup>1</sup>
Japan	sediment	10-70000	µg/kg	WHO 2000 <sup>2</sup>
Japan	fish and shellfish	<0.5-19	µg/kg	Kenmochi <i>et al.</i> 1981 <sup>2</sup>

1) Value and units, as quoted by WHO 1998; units seem questionable. This reference (Ishikawa *et al.* 1985) was not used in review by Haglund (undated – SFT pers.comm.) who also cited WHO 1998 in this context.

2) As cited by Haglund (undated – SFT pers.comm.)

*Table 34. Previous measurements of TDCP in recipients.*

Study area	Medium	Value	Unit	Reference
Japan	sediment	9-17	µg/kg	WHO 2000
Japan	fish	15-25	µg/kg	WHO 1998

### 3.2 Polyfluorinated organic compounds (PFCs)

For the group PFCs a total of 53 samples were analyzed, where only a few of the 9 volatile compounds were detected (10-17%) (**Table 35**) and even lower percentage of the 27 ionic compounds were above the detection limit (

**Table 36**). One volatile (FTOH) and eleven ionic PFCs (8:2 FTS, PFPS, PFDoS, PFTrS, PFTS, PFPeS, PFPA, PFHpA, PFOA, PFNA, and PFPeA) were not detected in any matrix. Most of the PFCs with longer carbon chain (C12- C15) are not industrial applied, and thus not expected in high concentrations in air, recipients and WWT-facility outlets. However, the limited findings of PFCA are surprising and can be partly explained by matrix effects and a reduced sensitivity of the used equipment.

*Table 35. Volatile polyfluorinated compounds (PFCs) analysed and number of samples above detection limit. Total indicates total number of samples and % indicates percent of total with concentration above the detection limit.*

Sample type	4:2 FTOH	6:2 FTOH	8:2 FTOH	10:2 FTOH	12:2 FTOH	N-Me-FOSA	N-Et-FOSA	N-Me-FOSE	N-Et-FOSE	Total	%
Air samples	0	4	8	2	0	0	0	0	0	16	10
WWT-facilities	0	2	7	9	2	2	1	1	3	18	17
Recipient	0	1	2	6	1	2	1	1	5	19	11

*Table 36. Ionic polyfluorinated compounds (PFCs) analysed and count over detection limit. Total indicates number of samples and % indicates average percent of total that is over detection limit.*

Sample type	6:2 FTS	8:2 FTS	PFOSA	PFBS	PFPS	PFHxS	PFHpS	PFOS	PFNS	PFDS
Air samples	1	0	6	1	0	4	1	16	0	8
WWT-facilities	1	0	3	1	0	7	2	18	3	10
Recipient	0	0	8	0	0	0	0	19	0	4

Sample type	PFUnS	PFDoS	PFTrS	PFTS	PFPeS	PFBA	PFPA	PFHxA	PFHpA	PFOA
Air samples	0	0	0	0	0	4	0	0	0	0
WWT-facilities	2	0	0	0	0	0	0	2	0	0
Recipient	1	0	0	0	0	0	0	0	0	0

Sample type	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTA	PFPeA	Total	%
Air samples	0	1	0	1	0	0	0	16	10
WWT-facilities	0	0	1	0	1	1	0	18	11
Recipient	0	1	0	0	0	0	0	19	6

### 3.2.1 Air samples

#### Results

##### Volatile PFCs

Air samples were collected assessing differences between urban and remote locations as well as between indoor and outdoor location in an urbanized area (Table 37, Figure 7). About 650 m<sup>3</sup> air were collected at the urbanized outdoor location on three days, 12 m<sup>3</sup> at the urban indoor location and about 1000 m<sup>3</sup> at the remote locations.

No volatile PFCs were detected in air collected at the remote locations Birkenes and New Ålesund. However, in 8 out of 10 samples from the urban location, volatile PFCs could be found. The 8:2 FTOH dominated the compound pattern in all these samples. The indoor samples were up to 100 times higher contaminated compared to the outdoor samples (up to 60 pg/m<sup>3</sup> outdoor and 9500 pg/m<sup>3</sup> 8:2 FTOH indoor). In comparison, minimum-maximum ΣFTOH concentrations of 64-311 pg/m<sup>3</sup> (remote) and up to 150546 pg/m<sup>3</sup> (urban) and minimum-maximum Σ(FOSA + FOSE) concentrations between 12 and 54 pg/m<sup>3</sup> (remote) and 29 and 151 pg/m<sup>3</sup> (urban) were determined by Jahnke *et al.* (2007) in 2007. Barber *et al.* (2007) reported 8:2 FTOH and 6:2 FTOH as the prevailing analytes found in the gas phase, at 5-243 pg/m<sup>3</sup> and 5-189 pg/m<sup>3</sup>, respectively.

Table 37. Volatile polyfluorinated compounds (PFCs) in air (pg/m<sup>3</sup>). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)

Sample ID	4:2 FTOH	6:2 FTOH	8:2 FTOH	10:2 FTOH	12:2 FTOH	N-Me- FOSA	N-Et- FOSA	N-Me- FOSE	N-Et- FOSE
Alnabru-T_Sep.24-25	<30	<10	60	<20	<40	<10	<10	<40	<20
Alnabru-T_Sep.25-26	<20	<10	40	<20	<30	<10	<10	<20	<10
Alnabru-T_Sep.26-27	<20	<10	40	<20	<30	<10	<10	<30	<10
Alnabru-T_Sep.27-28	<20	<10	10	<20	<30	<10	<10	<20	<10
Alnabru-T_Sep.28-29	<20	<10	<10	<10	<30	<10	<10	<20	<10
Alnabru-T_Sep.29-30	<20	<10	<20	<10	<20	<10	<10	<20	<10
Alnabru-O_Oct.12	<10	660	1100	<50	<50	<20	<20	<80	<40
Alnabru-O_Oct.15	<10	780	1140	<40	<40	<20	<10	<60	<30
Alnabru-S_Nov.02	<10	1720	9470	3460	<60	<30	<20	<90	<40
Alnabru-S_Nov.05	<10	1480	8010	2360	<60	<30	<20	<90	<40
LRT-Birkenes_Oct.31- Nov.02	<10	<10	<10	<10	<20	<10	<10	<10	<10
LRT-Birkenes_Nov.07- 09	<10	<10	<10	<10	<20	<10	<10	<10	<10
LRT-Birkenes_Nov.14- 16	<10	<10	<10	<10	<20	<10	<10	<10	<10
LRT-New- Ålesund_Nov.03-05	<10	<50	<70	<150	<150	<70	<50	<170	<90
LRT-New- Ålesund_Nov.05-07	<40	<120	<190	<390	<390	<170	<130	<450	<240
LRT-New- Ålesund_Nov.28-30	<10	<30	<60	<110	<220	<50	<40	<130	<70



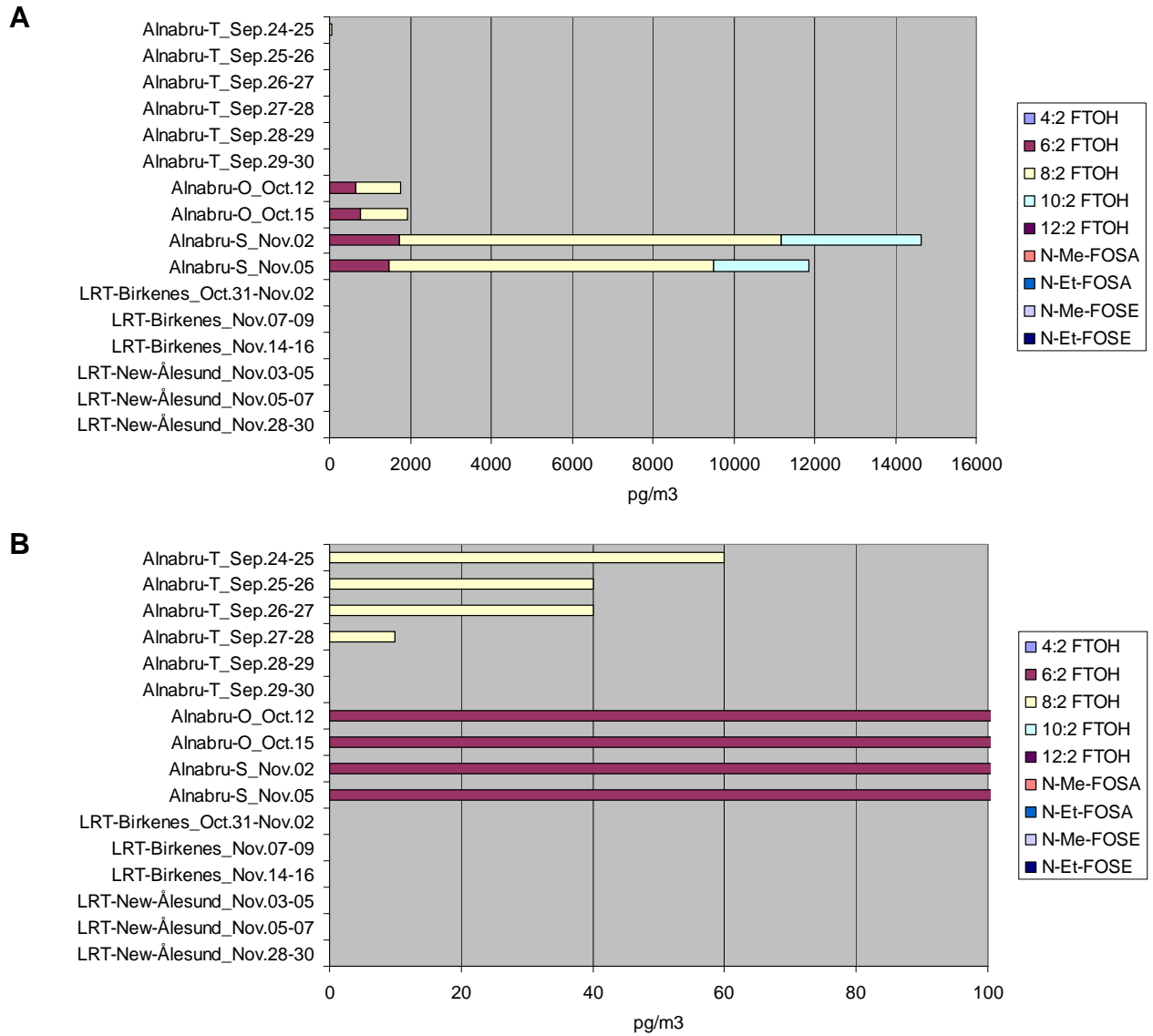


Figure 7. Volatile polyfluorinated organic compounds (PFCs) in air (pg/m<sup>3</sup>). Note two scales: overview (A) and detail of low concentrations (B). (See Annex 2 for sample ID description.)

### *Ionic PFCs*

A broad variety of compounds could be detected in all samples, but at very low concentrations close to the detection limit (**Table 38, Figure 8**). However, PFOS was ubiquitous in all samples analysed. Samples from the remote locations showed an average of 0.06 pg/ m<sup>3</sup>, urban outdoor air 0.9 pg/ m<sup>3</sup> and indoor air 2.6 pg/ m<sup>3</sup> of PFOS, respectively. This is in good agreement with the mean PFOS concentrations measured by Barber (2007) in Kjeller with 1.0 pg/m<sup>3</sup>.

However, besides PFBA, no PFCA could be detected in the air samples. In comparison, Barber *et al.* (2007) detected PFCA with a chain length between C6-C9 in samples from Kjeller, Norway. He found PFOA as the predominant analyte found in the particulate phase at concentrations ranging from 1-818 pg/ m<sup>3</sup>. The mean PFOA concentration measured in Kjeller, Norway, was 1.5 pg/m<sup>3</sup>.

In total, ionic PFCs show comparable levels at remote and urbanized locations (average 0.51 and 0.96 pg/m<sup>3</sup> respectively). Indoor air sampled in office environments was almost double as high contaminated with ionic PFCs than the sport shop (average 12.2 and 6.7 pg/ m<sup>3</sup>).

Table 38. Ionic polyfluorinated compounds (PFCs) (pg/m<sup>3</sup>) in air. Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)

Sample ID	6:2 FTS	8:2 FTS	PFOSA	PFBS	PFPS	PFHxS	PFHpS	PFOS	PFNS
Alnabru-T_Sep.24-25	<1.98	<3.14	<0.3	<0.18	<0.08	0.11	<0.09	1.72	<0.13
Alnabru-T_Sep.25-26	<0.93	<1.18	<0.13	<0.1	<0.05	<0.08	<0.08	0.73	<0.07
Alnabru-T_Sep.26-27	<1.22	<1.02	<0.15	<0.13	<0.08	<0.09	<0.08	0.56	<0.06
Alnabru-T_Sep.27-28	<1.02	<0.81	<0.12	<0.12	<0.1	<0.06	<0.06	0.83	<0.06
Alnabru-T_Sep.28-29	<1.4	<1.13	<0.19	<0.16	<0.08	0.06	<0.08	0.76	<0.08
Alnabru-T_Sep.29-30	<1.15	<0.64	<0.23	<0.08	<0.07	<0.05	<0.06	0.78	<0.06
Alnabru-O_Oct.12	<17.33	<25.43	6.36	<2.56	<2.9	<1.15	<1.53	2.60	<6.49
Alnabru-O_Oct.15	<14.52	<20.52	7.75	<2.42	<2.03	<1.6	<1.09	2.56	<1.68
Alnabru-S_Nov.02	<29.91	<25.89	<2.86	<2.71	<3.09	0.71	<2.17	3.32	<9.55
Alnabru-S_Nov.05	<20.89	<16.26	2.43	<3.53	<1.1	<0.96	<1.35	1.93	<1.02
LRT-Birkenes_Oct.31-Nov.02	<0.4	<0.36	<0.05	<0.04	<0.05	<0.02	<0.05	0.04	<0.03
LRT-Birkenes_Nov.07-09	<0.63	<0.44	<0.03	<0.04	<0.03	<0.03	<0.03	0.09	<0.03
LRT-Birkenes_Nov.14-16	<0.54	<0.38	<0.07	<0.04	<0.06	<0.03	<0.03	0.03	<0.04
LRT-New-Ålesund_Nov.03-05	0.11	<0.23	0.12	0.04	<0.04	0.01	0.01	0.10	<0.05
LRT-New-Ålesund_Nov.05-07	<0.36	<0.38	0.11	<0.02	<0.07	<0.03	<0.11	0.03	<0.02
LRT-New-Ålesund_Nov.28-30	<0.43	<0.4	0.08	<0.04	<0.03	<0.03	<0.03	0.15	<0.02
Sample ID	PFDS	PFUnS	PFDoS	PFTrS	PFTS	PFPeS	PFBA	PFPA	PFHxA
Alnabru-T_Sep.24-25	<0.07	<0.14	<0.24	<0.29	<0.3	<0.28	<0.53	<1.29	<2.13
Alnabru-T_Sep.25-26	0.04	<0.07	<0.07	<0.1	<0.09	<0.09	<0.24	<0.92	<1.37
Alnabru-T_Sep.26-27	0.10	<0.06	<0.11	<0.15	<0.18	<0.19	<0.19	<0.7	<1.53
Alnabru-T_Sep.27-28	<0.04	<0.06	<0.09	<0.1	<0.14	<0.14	<0.23	<0.58	<1.4
Alnabru-T_Sep.28-29	0.04	<0.08	<0.13	<0.16	<0.2	<0.22	<0.22	<0.92	<1.31
Alnabru-T_Sep.29-30	<0.04	<0.06	<0.09	<0.11	<0.12	<0.13	<0.28	<0.76	<1.1
Alnabru-O_Oct.12	5.13	<1.28	<1.93	<1.97	<4.56	<1.44	<10.34	<21.81	<17.67
Alnabru-O_Oct.15	<0.86	<1.18	<1.15	<2.04	<1.51	<2.25	<10.50	<22.24	<21.17
Alnabru-S_Nov.02	3.73	<1.63	<1.83	<2.94	<3.11	<3.28	<9.64	<22.74	<22.44
Alnabru-S_Nov.05	1.27	<0.87	<0.93	<1.03	<1.12	<1.46	<7.38	<17.84	<16.11
LRT-Birkenes_Oct.31-Nov.02	<0.02	<0.02	<0.03	<0.04	<0.04	<0.04	0.36	<0.4	<0.35
LRT-Birkenes_Nov.07-09	<0.02	<0.02	<0.02	<0.03	<0.03	<0.03	0.67	<0.34	<0.52
LRT-Birkenes_Nov.14-16	<0.02	<0.06	<0.05	<0.05	<0.05	<0.05	<0.17	<0.53	<0.63
LRT-New-Ålesund_Nov.03-05	0.03	<0.02	<0.02	<0.03	<0.02	<0.03	0.26	<0.11	<0.24
LRT-New-Ålesund_Nov.05-07	<0.01	<0.02	<0.02	<0.04	<0.02	<0.03	0.41	<0.09	<0.12
LRT-New-Ålesund_Nov.28-30	0.02	<0.03	<0.02	<0.03	<0.06	<0.3	<0.09	<0.16	<0.18
Sample ID	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTTrA	PFTA	PFPeA
Alnabru-T_Sep.24-25	<2.67	<2.76	<3.74	<3.49	<3.32	<2.9	<2.67	<3.96	<5.2
Alnabru-T_Sep.25-26	<1.08	<1.8	<2	<1.63	<1.71	<1.14	<1.63	<2.1	<2.44
Alnabru-T_Sep.26-27	<0.93	<1.73	<1.65	<1.4	<1.4	<1.41	<1.76	<1.96	<2.25
Alnabru-T_Sep.27-28	<1.29	<1.76	<1.88	<2	<2.02	<1.89	<1.71	<1.76	<1.95
Alnabru-T_Sep.28-29	<1.15	<2.21	<1.74	<1.95	<1.55	<1.42	<1.2	<1.8	<2.62
Alnabru-T_Sep.29-30	<0.65	<1.61	<1.23	<1.76	<1.62	<1.45	<1.47	<1.59	<2.17
Alnabru-O_Oct.12	<18.02	<174.34	<25.66	<25.54	<16.94	<21.48	<15.38	<16.91	<18.51
Alnabru-O_Oct.15	<15.89	<285.79	<33.92	<32.67	<15.47	<32.05	<14.57	<16.52	<18.74
Alnabru-S_Nov.02	<35.11	<155.45	<38.79	87.13	<20.03	<39.87	<30.59	<20.55	<24.71
Alnabru-S_Nov.05	<30.00	<183.24	<32.29	<29.02	<16.72	<28.52	<15.14	<16.04	<18.86
LRT-Birkenes_Oct.31-Nov.02	<0.41	<1.28	<0.57	<0.67	<0.72	<0.63	<0.55	<0.61	<0.72
LRT-Birkenes_Nov.07-09	<0.37	<1.6	<0.64	<0.98	<0.61	<0.49	<0.89	<0.76	<0.58
LRT-Birkenes_Nov.14-16	<0.54	<0.96	<1.18	<0.94	<0.96	<0.71	<0.85	<0.95	<1.21
LRT-New-Ålesund_Nov.03-05	<0.09	<0.23	<0.6	<0.25	<0.26	<0.36	<0.17	<0.23	<0.29
LRT-New-Ålesund_Nov.05-07	<0.17	<0.05	<0.24	<0.13	<0.27	0.36	<0.14	<0.17	<0.25
LRT-New-Ålesund_Nov.28-30	<0.19	<0.38	<0.86	<0.22	<0.41	<0.36	<0.33	<0.34	<0.47

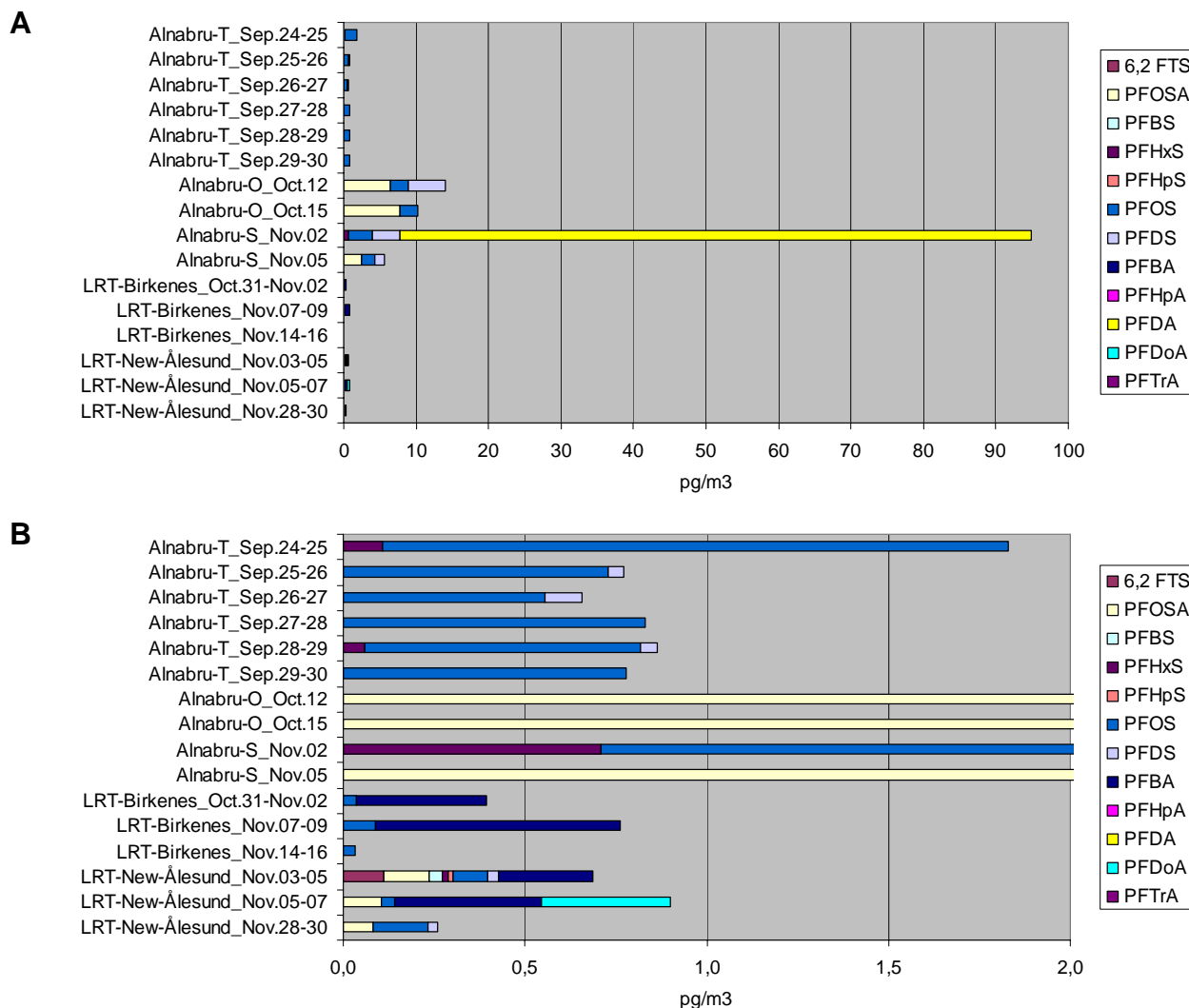


Figure 8. Ionic polyfluorinated compounds (PFCs) (pg/m<sup>3</sup>) in air. Note two scales: overview (A) and detail of low concentrations (B). (See Annex 2 for sample ID description.)

### Discussion

Air can carry and precipitation deposit gaseous and particle bound PFCs over considerable distances. The potential for airborne PFC emissions to undergo long-range transport or to be removed from the atmosphere is influenced by their physical-chemical properties. When PFCs enter the environment, their physical-chemical properties can vary significantly, depending on whether it exists as acid, salt, or dissociated ions. Ionic PFCs exist primarily in the particle phase in ambient air near direct sources of emissions, and they can get efficiently scavenged by rain droplets, making wet deposition an important removal mechanism for emissions followed by deposition onto soils and water bodies.

Volatile PFCs, like FTOH, will be distributed in the atmosphere available for long-range transport prior to degradation and deposition as the final product (in this case PFCAs). Both photodegradation, radical initiated oxidation as well as biotransformation of suitable precursor compounds can lead to the formation of ionic PFCs far away from the original emission.

Air mass trajectories are calculated using the Flextra model developed by Andreas Stohl (NILU) in cooperation with Gerhard Wotawa and Petra Seibert (Institute of Meteorology and Geophysics, Vienna) and using meteorological data provided from ECMWF (European Centre for Medium Range Weather Forecast).

Flextra trajectory plots are made four times a day for each location. Each trajectory spans 7 days in time. There are 3 trajectories in each plot with three different heights at arrival. Height above sea level at arrival is indicated by the legends in the upper right corner of each plot. Height along the trajectories is indicated by colour (colour/height scale in the lower left corner of the plot). Each 3-hour interval along the trajectory path is indicated by a small legend, each 24-hour interval by a big legend.

Publications using FLEXTRA results are requested to include an acknowledgement of, and citation to ECMWF, NILU and the model developers.

#### *Urban area - Oslo*

The urban air sampling location Alnabru in Oslo, experienced arriving airpackages from several different direction during the periods of sampling (**Figure 9A**). Air masses arrived from Canada and Greenland during the first sampling period, whilst the air masses came mainly from southeastern Europe during the second sampling. Effects of the shift of air flow direction can be seen in the 8:2 FTOH data. The change of direction was most prominent during the 29. and 30. of September, causing the arrival of 8:2 FTOH to stop. That would indicate, that volatile fluorotelomer alcohols are long-range transported from North America, but not from east-South Europe in the same magnitude. No difference in concentrations can be found for ionic PFCs.

#### *Remote area – Birkenes and New Ålesund*

Despite some changes of directions of air streams during the sampling period, no change in volatile and ionic PFCs can be seen in Birkenes (**Figure 9B**). However, when looking at New Ålesund, the picture changes. One main difference is the increased number of PFCs measured in samples collected in New Ålesund compared to Birkenes. Several PFS including PFOSA can be detected in the air sampled at New Ålesund. Secondly, the number of detected PFCs increases when air stream arrives mainly from USA/Canada compared to airstreams circling above Greenland (29. and 6. November, respectively) (**Figure 9C**). Arctic regions, here represented by New Ålesund, seem to be exposed to higher concentrations and a broader variety of PFCs, making them more vulnerable to these compounds.

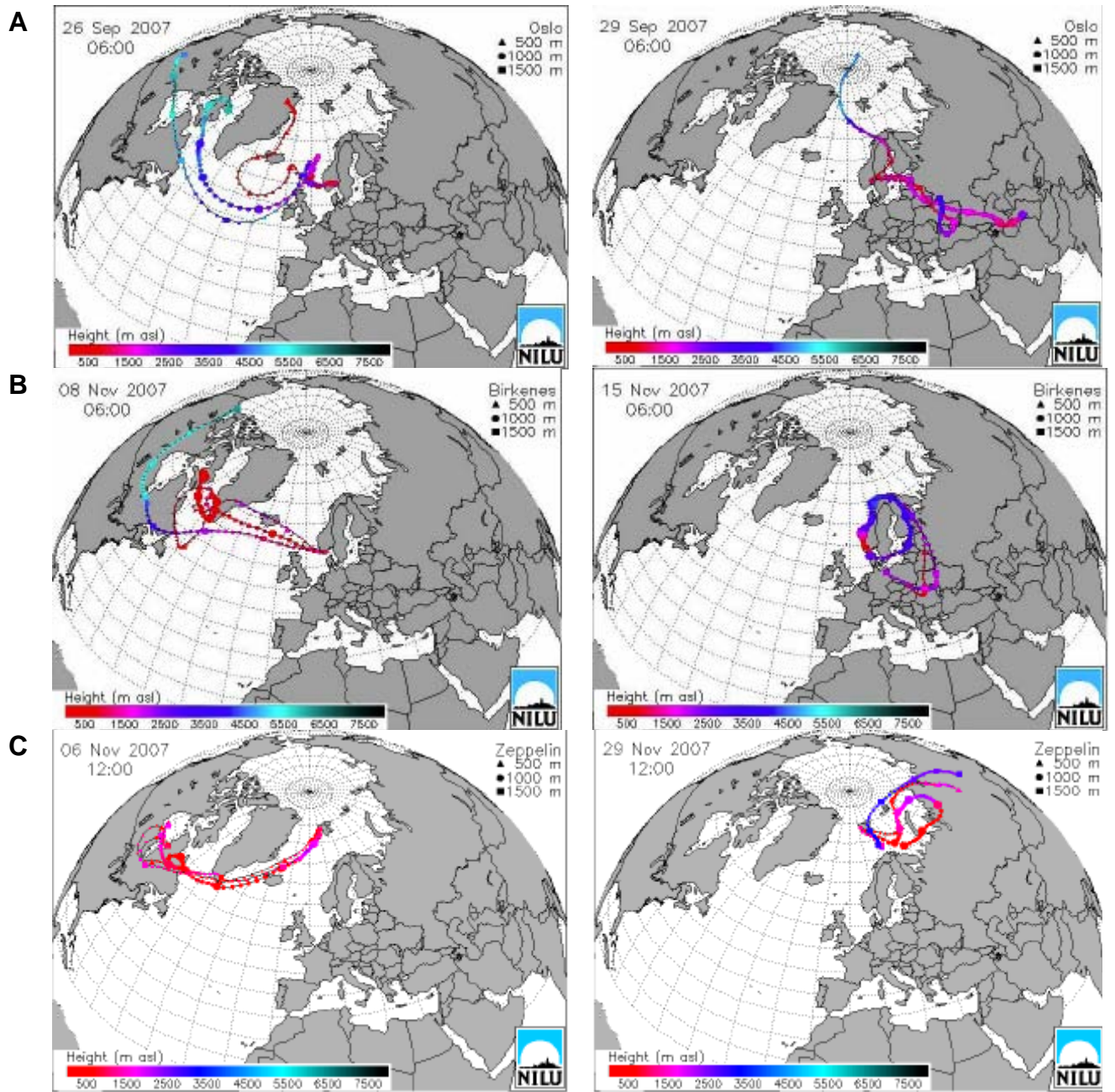


Figure 9. Representative trajectories of air transport to the Oslo (A) and long range transport monitoring stations Birkenes (B) and New Ålesund (C) for the two sampling times.

### 3.2.2 Wastewater treatment facilities

#### Results

##### *Volatile PFCs - general*

There were 18 samples from three domestic WWTP (influent, effluent and sludge samples), one fire drill site (five sediment samples) and one landfill site (four sediment samples) were analysed for nine different PFCs (**Table 39, Figure 10**). Only 5 of the 18 samples contained any appreciable concentrations of PFCs; the sludge sample from Solumstrand WWTP (0.07 ng/g dry weight), one sediment sample from the fire drill site Res-Q (0.19 ng/g dry weight) and three sediment samples from the landfill site *Lindum Ressurs og gjenvinning AS* (0.04-0.15 ng/g dry weight).

##### *Volatile PFCs –wastewater treatment facilities: Water and sludge samples*

Influent and effluent liquid samples and sludge samples were taken at the Bekkelaget, Saulekilen and Solumstrand WWTPs. Of all the collected samples only the sludge samples at Solumstrand WWTP contained appreciable concentrations of volatile PFCs: 6:2 FTOH, 8:2 FTOH, 10:2 FTOH and 12:2 FTOH summarised to 0.07 ng/g dry weight sludge.

##### *Volatile PFCs - Fire drill site and landfill site: Sediment samples*

The sediment sample with the highest total volatile PFC concentration was found at the fire drill site Res-Q (0.19 µg/kg dry weight) in the sample collected in the last manhole on the transfer line before discharge to the sea. 8:2 FTOH and 10:2 FTOH were the only volatile PFCs detected in the sample, in almost equal amounts. None of the other four sediment samples collected earlier in the treatment process contained any appreciable concentrations of volatile PFCs.

Three out of four sediment samples from the landfill site *Lindum Ressurs og Gjenvinning AS* contained PFCs above the detection limit. Also here only 8:2 FTOH and 10:2 FTOH were detected; up to 0.09 and 0.06 µg/kg dry weight.

Table 39. Volatile polyfluorinated organic compounds (PFCs) in samples from wastewater treatment facilities (ng/l for in/out discharge water, µg/kg dry weight for sludge and sediment). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)

Sample ID	4:2 FTOH	6:2 FTOH	8:2 FTOH	10:2 FTOH	12:2 FTOH	N-Me-FOSA	N-Et-FOSA	N-Me-FOSE	N-Et-FOSE
Bekkelaget-WWTP_In.d	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01
Bekkelaget-WWTP_out.d	<0.01	<0.01	<0.01	<0.02	<0.04	<0.01	<0.02	<0.01	<0.01
Bekkelaget-WWTP_sludge	<0.08	<0.08	<0.12	<0.21	<0.43	<0.09	<0.23	<0.28	<0.17
Saulekilen-WWTP_In.d	<0.01	<0.01	<0.02	<0.02	<0.05	<0.01	<0.03	<0.01	<0.02
Saulekilen-WWTP_out.d	<0.01	<0.01	<0.02	<0.02	<0.05	<0.01	<0.03	<0.01	<0.02
Saulekilen-WWTP_sludge	<0.08	<0.08	<0.12	<0.21	<0.41	<0.09	<0.22	<0.27	<0.16
Solumstrand-WWTP_In.d	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01
Solumstrand-WWTP_out.d	<0.01	<0.01	<0.02	<0.03	<0.05	<0.01	<0.03	<0.01	<0.02
Solumstrand-WWTP_sludge	<0.01	0.01	0.01	0.02	0.03	<0.01	<0.02	<0.01	<0.01
Res-Q_1-sediment-1	<0.03	<0.09	<0.13	<0.22	<0.22	<0.1	<0.07	<0.34	<0.16
Res-Q_2-sediment-2	<0.05	<0.15	<0.2	<0.34	<0.34	<0.15	<0.11	<0.53	<0.25
Res-Q_Firedrill-1 (sediment)	<0.03	<0.1	<0.13	<0.22	<0.22	<0.1	<0.08	<0.35	<0.17
Res-Q_Firedrill-2 (sediment)	<0.03	<0.09	<0.12	<0.2	<0.2	<0.09	<0.07	<0.31	<0.15
Res-Q_out-D (sediment)	<0.01	<0.01	0.09	0.1	<0.06	<0.01	<0.03	<0.02	<0.02
Lindum-Wdepot-1d (sediment)	<0.05	<0.05	<0.07	<0.13	<0.25	<0.05	<0.13	<0.16	<0.1
Lindum-Wdepot-2d (sediment)	<0.02	<0.02	<0.02	0.04	<0.08	<0.02	<0.05	<0.02	<0.03
Lindum-Wdepot-1w (sediment)	<0.01	<0.01	0.06	0.04	<0.02	<0.01	<0.01	<0.01	<0.01
Lindum-Wdepot-2w (sediment)	<0.01	<0.01	0.09	0.06	<0.03	<0.01	<0.02	<0.01	<0.01

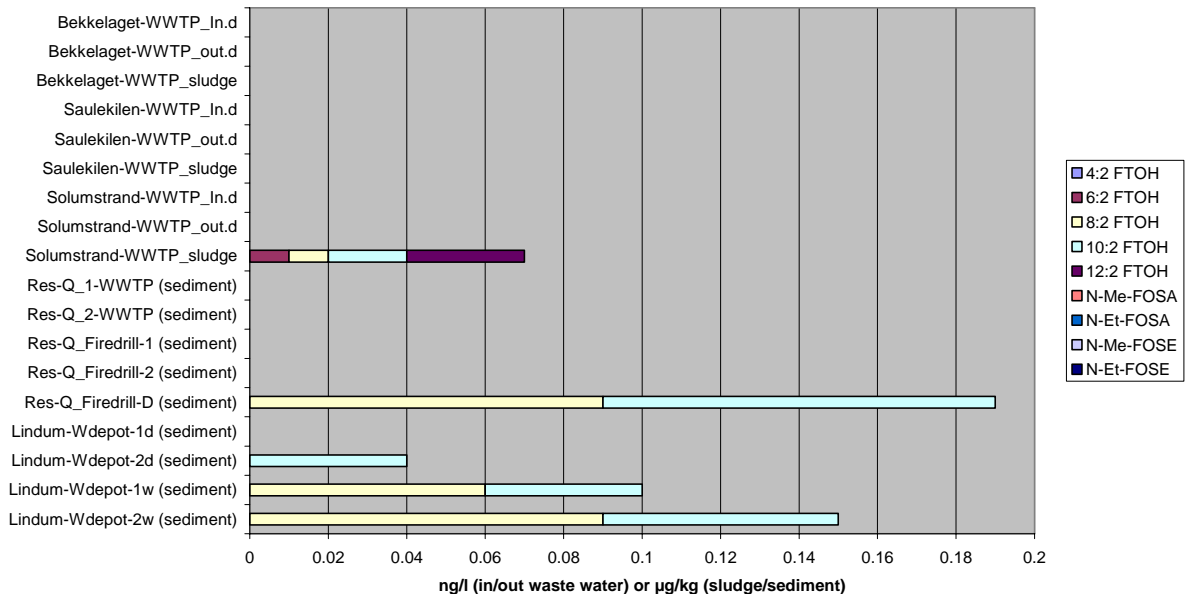


Figure 10. Volatile polyfluorinated compounds (PFCs) in samples from wastewater treatment facilities (ng/l in/out discharge water, µg/kg dry weight for sludge and sediment). Note two scales: overview (A) and detail of low concentrations (B). (See Annex 2 for sample ID description.)



### *Ionic PFCs - general*

There were 18 samples from three domestic WWTP (influent, effluent and sludge samples), one fire drill site (five sediment samples) and one landfill site (four sediment samples) were analysed for 27 different ionic PFCs (**Table 40, Figure 11**). All 18 samples contained appreciable concentrations of ionic PFCs amounting to a total of 0.74-2.17 ng/l in water samples, 1.55-12.1 µg/kg dry weight in sludge samples and 5.17-157 µg/kg dry weight in sediment samples. 14 out of the 27 selected PFCs were found in one or more of the collected samples, with PFOS being the only compound found in all samples: 0.67-1.47 ng/l in water samples, 1.20-5.16 µg/kg dry weight in sludge samples and 0.72-59 µg/kg dry weight in sediment samples. The highest sludge concentration was found at Bekkelaget WWTP, while the highest sediment concentration was found at the fire drill site Res-Q in the sample taken from the last manhole on the transfer line before discharge to the sea.

### *Ionic PFCs – WWTP*

In influent water samples taken from Bekkelaget and Saulekilen WWTPs we measured ionic PFCs concentrations of 1.28 ng/l and 0.74 ng/l, respectively, with PFOS and PFDS (only Bekkelaget WWTP) being the only ionic PFCs found at appreciable concentrations. The effluent ionic PFC concentrations from these WWTPs were at a similar level; 0.94 ng/l and 0.97 ng/l, respectively, but with PFOS being the only PCF compound detected at an appreciable concentration. These concentrations were more than one order of magnitude lower than what was found in the effluents from Bekkelaget and Saulekilen WWTPs in the 2004 screening (Fjeld *et al.*, 2005); 37.5 ng/l and 10.4 ng/l, respectively. However, the high quantification limits for the 2004-dominating ionic PFC PFOA in the 2007 screening – <33.4 ng/l and <40.6 ng/l, respectively – may mask similar PFOA levels in the 2007 samples. At Solumstrand WWTP PFTrA and PFTA dominated the influent water with concentrations of 25-26 ng/l, but also PFOS (1.47 ng/l), PFDS (0.37 ng/l) and PFNS (0.33 ng/l) were detected. In the effluent only PFOS was found at an appreciable concentration; 1.07 ng/l. Solumstrand WWTP was not included in the 2004 screening. The estimated discharge of ionic PFCs (i.e. PFOS) with effluent water from the three WWTPs within the respective sampling periods were 1.1 g from Bekkelaget WWTP (1.13 mill m<sup>3</sup> sewage), 0.13 g from Saulekilen WWTP (0.14 mill m<sup>3</sup> sewage) and 0.26 g from Solumstrand WWTP (0.25 mill m<sup>3</sup> sewage).

In the sludge samples from the WWTPs PFDS (0.35-6.8 µg/kg), PFOS (1.2-5.2 µg/kg) and PFUnS (0.15 µg/kg; only Bekkelaget WWTP) were the only ionic PFCs found at appreciable concentrations. The value of total ionic PFC concentrations in the Bekkelaget and Saulekilen WWTP sludge samples were 12.1 and 8.3 µg/kg sludge, respectively, which is about a magnitude higher than in the Solumstrand sample (1.55 µg/kg) and 4 times higher than the levels found in the respective sludge samples in the 2004 screening; 3.0 µg/kg and 2.2 µg/kg (Fjeld *et al.*, 2005). In the 2004 screening PFOS dominated in the WWTP sludge samples (1.2-2.0 µg/kg) with PFOA (0.34-0.49 µg/kg) and PFDS (0.43-0.46 µg/kg) making up most of the residual ionic PFC content.

### *Ionic PFCs - fire drill site: Sediment samples*

Somewhat high PFC concentrations were found in the sediment samples collected at the fire drill site Res-Q; 5.7-157 µg/kg. In the samples taken from settled materials in the ditch directly on the test site PFHxA (5.0-9.6 µg/kg) and PFDoA (14.0 µg/kg) completely dominated, though some PFOS was also detected (0.7-0.8 µg/kg). In the samples taken from the sedimentation basins, however, PFOS dominated (28.7-31.5 µg/kg) with also an elevated concentration of PFNS (11.3 µg/kg) in one of these samples. PFOSA, PFHxS, PFHpS and PFDS were also detected at appreciable concentrations, but the dominating compounds found

in the samples from the ditch on the test site (i.e. PFHxA and PFDoA) were not detected (<2.0-2.8 µg/kg and <5.5-5.8 µg/kg, respectively). However, the highest total PFC concentration (157 µg/kg) was found in the sample taken from the last manhole on the transfer line before discharge to the sea, hence, representing sediments that have travelled through the whole treatment process at Res-Q or coming from the mechanical WWTP Res-Q treating only household wastewater. In this sample PUnA (84 µg/kg) and PFOS (59 µg/kg) dominated, but elevated levels of PUnS (6.3 µg/kg), PFOSA (3.6 µg/kg) and PFDS (2.6 µg/kg) were also detected.

*Ionic PFCs – landfill site: Sediment samples*

In the sediment samples taken from the pump ditch at the landfill site *Lindum Ressurs og Gjenvinning AS*, pumping effluent leachate to the sewer leading to Solumstrand WWTP, the total PFCs concentrations summing compounds detected at appreciable levels were within the range 5.2-14.2 µg/kg with PFOS (3.8-7.5 µg/kg) and PFHxS (0.4-0.9 µg/kg) being found in all samples and PTrA (5.1 µg/kg), PFTA (5.0 µg/kg), 6:2 FTS (2.4 µg/kg), PFDS (0.15-0.17 µg/kg) and PFBS (0.13 µg/kg) being found at appreciable levels in two or fewer samples. Lindum was not included in the 2004 screening (Fjeld *et al.*, 2005), but the total PFC content in sediment samples from the seven different landfills included in that study was 1.3-23.5 µg/kg with PFOS, PFOA and PFHxA as dominating compounds. Hence, the overall concentrations of PFCs in the sediment samples from Lindum in this screening were within the concentration range found in the 2004 screening, but the PFC composition appeared to be somewhat different, though PFOS was the dominating compound in all samples with high PFC levels.

Table 40. Ionic polyfluorinated organic compounds (PFCs) in samples from wastewater treatment facilities (ng/l for in/out discharge water, µg/kg dry weight for sludge and sediment). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)

Sample ID	6:2 FTS	8:2 FTS	PFOSA	PFBS	PFPS	PFHxS	PFHpS	PFOS	PFNS
Bekkelaget-WWTP_In.d	<3.57	<6.32	<0.42	<0.35	<0.26	<0.26	<0.29	0.67	<0.27
Bekkelaget-WWTP_out.d	<3.77	<5.75	<0.37	<0.38	<0.27	<0.27	<0.27	0.94	<0.27
Bekkelaget-WWTP_sludge	<1.17	<2.21	<0.18	<0.13	<0.17	<0.09	<0.1	5.16	<0.1
Saulekilen-WWTP_In.d	<4.11	<7.2	<0.63	<0.53	<0.32	<0.35	<0.34	0.74	<0.4
Saulekilen-WWTP_out.d	<4.62	<6.58	<0.47	<0.36	<0.32	<0.37	<0.31	0.97	<0.37
Saulekilen-WWTP_sludge	<1.31	<2.3	<0.26	<0.36	<0.2	0.09	<0.09	4.49	<0.11
Solumstrand-WWTP_In.d	<4.08	<5.97	<0.47	<0.35	<0.3	<0.29	<0.29	1.47	0.33
Solumstrand-WWTP_out.d	<3.78	<5.36	<0.38	<0.29	<0.26	<0.29	<0.27	1.07	<0.26
Solumstrand-WWTP_sludge	<1.24	<2.18	<0.19	<0.18	<0.11	<0.11	<0.1	1.20	<0.12
Res-Q_1-sediment-1	<5.97	<5.52	2.02	<0.41	<0.29	<0.41	<0.37	28.69	11.32
Res-Q_2-sediment-2	<4.35	<4.43	1.57	<0.33	<0.23	0.65	0.41	31.45	<0.31
Res-Q_Firedrill-1 (sediment)	<4.7	<3.07	<0.29	<0.33	<0.19	<0.21	<0.15	0.81	<0.14
Res-Q_Firedrill-2 (sediment)	<5.64	<2.9	<0.29	<0.26	<0.21	<0.19	<0.16	0.72	<0.17
Res-Q_out-D (sediment)	<1.99	<2.53	3.55	<0.2	<0.15	1.00	0.20	58.85	0.67
Lindum-Wdepot-1d (sediment)	2.37	<1.75	<0.2	0.13	<0.1	0.40	<0.1	7.47	<0.1
Lindum-Wdepot-2d (sediment)	<1.77	<2.56	<0.23	<0.22	<0.15	0.35	<0.14	7.36	<0.13
Lindum-Wdepot-1w (sediment)	<1.3	<1.85	<0.19	<0.16	<0.94	0.94	<0.9	4.06	<0.09
Lindum-Wdepot-2w (sediment)	<1.41	<2.33	<0.21	<0.22	<0.11	0.09	<0.1	3.80	<0.11
Sample ID	PFDS	PFUnS	PFDoS	PFTTrS	PFTS	PFPeS	PFBA	PFPA	PFHxA
Bekkelaget-WWTP_In.d	0.61	<0.24	<0.3	<0.35	<0.39	<0.36	<2.7	<4.83	<4.21
Bekkelaget-WWTP_out.d	<0.21	<0.23	<0.25	<0.23	<0.23	<0.23	<3.07	<5.6	<4.91
Bekkelaget-WWTP_sludge	6.84	0.15	<0.11	<0.15	<0.16	<0.17	<0.7	<1.28	<1.02
Saulekilen-WWTP_In.d	<0.32	<1.01	<0.45	<0.76	<0.66	<0.82	<4	<8.14	<6.3
Saulekilen-WWTP_out.d	<0.25	<0.26	<0.33	<0.37	<0.32	<0.36	<3.72	<7.22	<6.31
Saulekilen-WWTP_sludge	3.72	<0.12	<0.15	<0.24	<0.27	<0.28	<0.77	<1.37	<1.09
Solumstrand-WWTP_In.d	0.37	<0.26	<0.29	<0.36	<0.42	<0.41	<3.68	<6.79	<5.16
Solumstrand-WWTP_out.d	<0.22	<0.24	<0.27	<0.29	<0.24	<0.36	<3.01	<5.18	<4.71
Solumstrand-WWTP_sludge	0.35	<0.09	<0.1	<0.12	<0.12	<0.12	<1	<1.89	<1.67
Res-Q_1-sediment-1	0.49	<0.24	<0.31	<0.45	<0.63	<0.99	<1.29	<2.82	<2.82
Res-Q_2-sediment-2	0.54	<0.37	<0.32	<0.61	<0.75	<1.03	<0.8	<1.7	<1.98
Res-Q_Firedrill-1 (sediment)	<0.13	<0.13	<0.14	<0.18	<0.23	<0.29	<1.31	<2.46	9.63
Res-Q_Firedrill-2 (sediment)	<0.15	<0.13	<0.15	<0.21	<0.22	<0.23	<0.73	<1.55	4.95
Res-Q_out-D (sediment)	2.61	6.30	<0.21	<0.2	<0.21	<0.23	<1.05	<1.89	<1.55
Lindum-Wdepot-1d (sediment)	<0.08	<0.1	<0.12	<0.12	<0.16	<0.19	<0.8	<2.01	<1.37
Lindum-Wdepot-2d (sediment)	<0.95	<0.12	<0.13	<0.15	<0.16	<0.22	<0.85	<1.55	<1.34
Lindum-Wdepot-1w (sediment)	0.17	<0.9	<0.91	<0.11	<0.13	<0.16	<0.57	<1.22	<0.98
Lindum-Wdepot-2w (sediment)	0.15	<0.99	<0.11	<0.14	<0.15	<0.19	<0.69	<1.37	<1.23
Sample ID	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTTrA	PFTA	PFPeA
Bekkelaget-WWTP_In.d	<3.74	<32.45	<10.96	<13	<13.81	<16.5	<16.02	<15.88	<17.23
Bekkelaget-WWTP_out.d	<3.99	<33.44	<4.84	<6.5	<13.54	<15.44	<15.97	<16.19	<15.99
Bekkelaget-WWTP_sludge	<1	<7.15	<1.05	<0.94	<8.2	<7.09	<12.43	<7.85	<9.36
Saulekilen-WWTP_In.d	<5.75	<46.5	<7.43	<7.31	<22.95	<23.32	<25.41	<25.33	<29.77
Saulekilen-WWTP_out.d	<6.22	<40.55	<11.7	<13.65	<31.35	<45.42	<36.82	<39.83	<39.38
Saulekilen-WWTP_sludge	<1.44	<8.07	<1.4	<1.48	<25.43	<25.9	<39.99	<33.68	<45.29
Solumstrand-WWTP_In.d	<5.52	<37.62	<6.85	<7.51	<20.3	<30.33	<25.56	<25.44	<26.08
Solumstrand-WWTP_out.d	<4.21	<31.6	<6.83	<8.56	<12.75	<14.2	<15.2	<15.95	<15.71
Solumstrand-WWTP_sludge	<1.45	<12.38	<1.17	<1.18	<4.46	<4.35	<4.8	<6.48	<4.77
Res-Q_1-sediment-1	<2.95	<12.8	<3.46	<2.64	<8.83	<5.79	<7.79	<8.24	<7.87
Res-Q_2-sediment-2	<1.7	<9.45	<2.41	<1.82	<6.44	<5.54	<17.73	<7.99	<13.83
Res-Q_Firedrill-1 (sediment)	<2.46	<11.29	<4.29	<2.26	<4.94	<14.01	<5.87	<5.76	<6.42
Res-Q_Firedrill-2 (sediment)	<1.53	<9.52	<3.54	<2.34	<5.95	<7.16	<6.96	<8.02	<6.76
Res-Q_out-D (sediment)	<1.47	<12.95	<2.85	<2.94	84.17	<13.2	<24.75	<15.26	<16.05
Lindum-Wdepot-1d (sediment)	<1.34	<10.81	<2.15	<1.47	<3.17	<2.95	<3.6	<3.57	<3.9
Lindum-Wdepot-2d (sediment)	<1.48	<11.82	<1.74	<2.49	<4.69	<4.35	<4.88	<5.13	<4.88
Lindum-Wdepot-1w (sediment)	<0.83	<7.96	<1.42	<1.58	<4.51	<4.6	<5.63	<5.63	<6.14
Lindum-Wdepot-2w (sediment)	<1.18	<9.04	<1.83	<2.38	<4.64	<4.06	5.08	4.95	<5.68

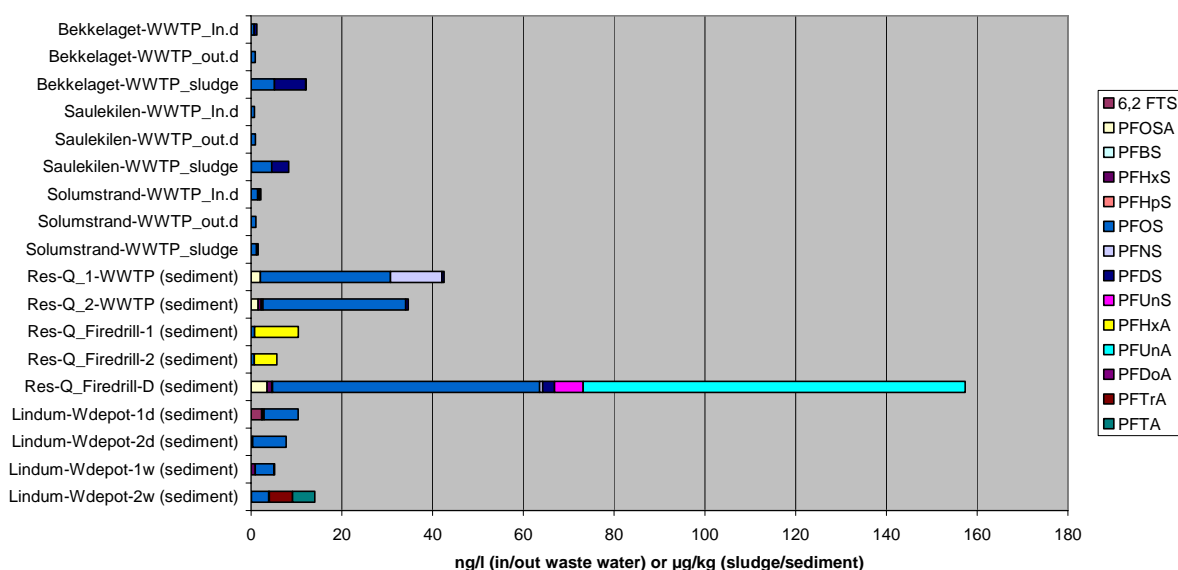


Figure 11. Ionic polyfluorinated organic compounds (PFCs) in samples from wastewater treatment facilities (ng/l for in/out discharge water, µg/kg dry weight for sludge and sediment). (See Annex 2 for sample ID description.)

## Discussion

### Volatile PFCs

There is increasing scientific interest to understand the environmental fate of fluorotelomer alcohols (FTOHs) and fluorotelomer-based products which may break down to FTOHs. Both are expected to enter aqueous waste streams, which would be processed in a wastewater treatment plant and therein subject to microbial biodegradation. A recent review on environmental risk of fluorotelomer alcohols by Källqvist (2008) confirm the relative scarcity of scientific literature on volatile PFCs degradation; Wang *et al.* (2005) studied the biodegradation of 8:2 FTOH in mixed bacterial culture and activated sludge and demonstrated that evaporation loss is minimal when in contact with activated sludge despite 8:2 FTOH being highly volatile and that the compound undergo partial mineralization by defluorination and carbon chain breakdown under conditions similar to those found in activate sludge treatment plants. A range of metabolites were detected, the most important being PFOA. The formation of PFHA and  $^{14}\text{CO}_2$  from the  $^{14}\text{C}$ -marked 8:2 FTOH showed that the degradation was enzymatic. Dinglasan *et al.* (2004) has suggested  $\beta$ -oxidation as the elimination pathway for 8:2 FTOH in a study using a mixed bacterial culture pre-acclimatized to degrade chlorinated organic compounds. They observed biodegradation from the initial concentration of 750 µg/l to ca. 110 µg/l after day 7 and to below the detection limit of 2 µg/l in 16 days. Also they identified PFOA to be the dominating final degradation product, with the first traces showing up after day 16.

The apparent non-presence of volatile PFCs in influent wastewater to the WWTPs in the present study may reflect the possible volatilisation of these compounds in the sewer network, being promoted by the often turbulent conditions in the typical Norwegian sewer, which is further influenced by hilly terrain and surface runoff in periods of heavy rain. Though, as a conclusion from the above discussion, partial biodegradation in the sewer and in the WWTPs themselves may have added to the elimination of volatile PFCs and the production of e.g.

PFOA. However, the high limit of detection for PFOA makes it impossible to assess this further.

#### *Ionic PFCs - wastewater treatment facilities*

The effluent concentrations at Bekkelaget and Saulekilen WWTPs (0.94 ng/l and 0.97 ng/l, respectively, and completely dominated by PFOS) were more than one order of magnitude lower than what was found in the effluents from the same WWTPs in the 2004 screening (Fjeld *et al.*, 2005); 37.5 ng/l and 10.4 ng/l, respectively. However, the high quantification limits for the 2004-dominating ionic PFC PFOA in the 2007 screening – <33.4 ng/l and <40.6 ng/l, respectively – may mask similar PFOA levels in the 2007 samples. Lien (2007) has summarized PFOS and PFAS concentrations in WWTP effluents in five cities (Yodo River area, Singapore, Ørebro, Shenzhen and Istanbul) and found concentrations in the range 2.5-467 ng/l for PFOS and 2.3-8007 ng/l for PFAS.

In a recent paper, Loganathana *et al.* (2007) reported on the biodegradation of ionic PFCs substances in WWTPs, and showed contamination profiles of perfluorinated compounds, including perfluoroalkyl sulfonates (PFASs; PFOS, PFOSA, PFHxS) and perfluoroalkyl carboxylates (PFACs; PFOA, PFNA, PFDA, PFDoDA, PFUnDA). The authors sampled a WWTP treating sewage in a rural area (Plant A) and a WWTP with urban influent wastewater (Plant B). PFOS was detected as the major contaminant in samples from Plant A (8.2–990 µg/kg in solid samples and 7.0–149 ng/L in aqueous samples), followed by PFOA (8.3–219 µg/kg in solid samples and 22–334 ng/L in aqueous samples). PFOA was shown to be predominant in samples from Plant B (7.0–130 µg/kg in solid samples and 1–227 ng/L in aqueous samples), followed by PFOS (<2.5–77 µg/kg in solid samples and 1.8–22 ng/L in aqueous samples). PFHxS, PFNA, PFDA, and PFOSA were detected in all samples. Loganathan *et al.* (2007) detected PFUnDA and PFDoA in very few samples, and concentration values of some of the ionic PFCs, particularly PFOA, were slightly higher in effluent than in influent samples. Hollingsworth *et al.* (2005) investigated the anaerobic biodegradability of wastewater effluents from the semiconductor industry, and found that PFOS was recalcitrant to biodegradation. Hence, the studies confirm the apparent limited biodegradation of both PFOA and PFOS, both being possible terminal biodegradation products. Unfortunately, the high limit of detection for PFAS in the present study makes it impossible to assess this further.

#### *Ionic PFCs - fire drill site*

Since 3M started facing out the production of PFOS, the main concern when using fire extinguishers with aqueous film-forming foam (AFFF) has been the potential formation of PFOA when using these AFFF extinguishers (Hoskins 2005). However, because it is predominantly C<sub>6</sub> fluorosurfactants that are used in these fire extinguishers, the C<sub>8</sub> PFOA are not likely to be formed (Swedish EPA 2004). The high detection limit (9.45-12.95 µg/kg dry weight) for PFOA in this study may mask levels of PFOA up to this level. Moody *et al.* (1999) reported levels of PFOA in groundwater in wells downstream fire drill sites in Nevada and Florida of 45-6570 µg/l, while PFOS was reported found in sediments downstream the fire drill site Rosersberg close to the Swedish lake Mälaren in concentrations of 80 µg/kg dry weight. Hence, the latter within the same range as found in this study.

#### *Ionic PFCs – landfill site*

Lindum was not included in the 2004 screening (Fjeld *et al.*, 2005), but the total PFAS content in sediment samples from the seven different landfills included in that study was 1.3-23.5 µg/kg with PFOS, PFOA and PFHxA as dominating compounds. Hence, the overall

concentrations of PFAS in the sediment samples from Lindum in this screening were within the concentration range found in the 2004 screening. But the ionic PFCs composition appeared to be somewhat different, though PFOS was the dominating compound in all samples with high ionic PFC levels.

### 3.2.3 Freshwater and marine recipients

#### Results

##### *Volatile PFCs - general*

Of the 19 recipient samples analysed only 8 had levels of one or more volatile PFCs above the detection limits (**Table 41**, **Figure 12**). One should also note that all of the quantifiable concentrations were within the range of the detection limits for other comparable samples.

##### *Volatile PFCs – sediments and biota*

The sediment from Bekkelaget station 1 had quantifiable levels of 6 of the 9 compounds analysed, whereas Bekkelaget station 2 had none. The freshwater samples from Loselva had none above detection limit, whereas 8:2FTOH and 10:2FTOH could be quantified in the reference sediment from Lista. The data set showed no systematic pattern.

Only 10:2 FTOH and N-Et-FOSE were detected in four blue mussel samples, however none of them had both compounds. None of the cod liver samples had volatile PFCs above the detection limit. The detection limit for these samples and compounds varied between 0.13 and 0.66 µg/kg wet weight.

*Table 41. Volatile polyfluorinated organic compounds (PFCs) in sediment (µg/kg dry weight), blue mussel and cod liver (µg/kg wet weight) from recipient waters. Concentrations above detection limit are shaded. (See Annex 2 for sample ID description.)*

Sample ID	4:2 FTOH	6:2 FTOH	8:2 FTOH	10:2 FTOH	12:2 FTOH	N-Me- FOSA	N-Et- FOSA	N-Me- FOSE	N-Et- FOSE
Bekkelaget_1 (sediment)	<0.01	<0.01	0.02	0.05	0.09	<0.03	0.02	0.09	0.25
Bekkelaget_2 (sediment)	<0.06	<0.06	<0.09	<0.17	<0.33	<0.07	<0.18	<0.22	<0.13
Drammen-1 (sediment)	<0.01	0.01	<0.02	0.03	<0.06	0.01	<0.01	<0.02	0.02
Drammen-2 (sediment)	<0.01	<0.01	<0.01	0.03	<0.03	0.01	<0.02	<0.01	0.07
Loselva_st_1 (sediment)	<0.19	<0.19	<0.28	<0.49	<0.99	<0.21	<0.53	<0.64	<0.39
Loselva_st_2 (sediment)	<0.06	<0.06	<0.09	<0.16	<0.33	<0.07	<0.17	<0.21	<0.13
Loselva_st_3 (sediment)	<0.01	<0.03	<0.04	<0.07	<0.07	<0.03	<0.02	<0.11	<0.05
Arendal (sediment)	<0.01	<0.01	<0.01	<0.02	<0.04	<0.02	<0.01	<0.01	<0.01
Lista_(reference, sediment)	<0.01	<0.01	0.02	0.04	<0.04	<0.02	<0.01	<0.01	<0.01
Gressholmen (mussel)	<0.02	<0.01	<0.02	<0.03	<0.06	<0.01	<0.04	<0.02	0.02
Akershuskaia (mussel)	<0.03	<0.02	<0.03	<0.06	<0.11	<0.03	<0.07	<0.03	<0.04
Arendal_(Ærøya)-1 (mus- sel)	<0.01	<0.01	<0.01	0.02	<0.04	<0.02	<0.01	<0.01	<0.01
Arendal_(Ærøya)-2 (mus- sel)	<0.08	<0.08	<0.12	<0.22	<0.43	<0.09	<0.23	<0.28	<0.17
Espevær (mussel)	<0.04	<0.04	<0.05	0.09	<0.18	<0.04	<0.1	<0.05	<0.06
Res_Q_recipient (mussel)	<0.03	<0.02	<0.03	<0.06	<0.11	<0.03	<0.06	<0.03	0.04
Haugesund (mussel)	<0.03	<0.02	<0.04	<0.06	<0.12	<0.03	<0.07	<0.03	<0.04
Bekkelaget_1 (cod liver)	<0.13	<0.13	<0.18	<0.31	<0.62	<0.13	<0.34	<0.2	<0.25
Bekkelaget_2 (cod liver)	<0.14	<0.13	<0.18	<0.32	<0.63	<0.14	<0.35	<0.2	<0.25
Karihavet (cod liver)	<0.14	<0.13	<0.19	<0.33	<0.66	<0.14	<0.37	<0.21	<0.26

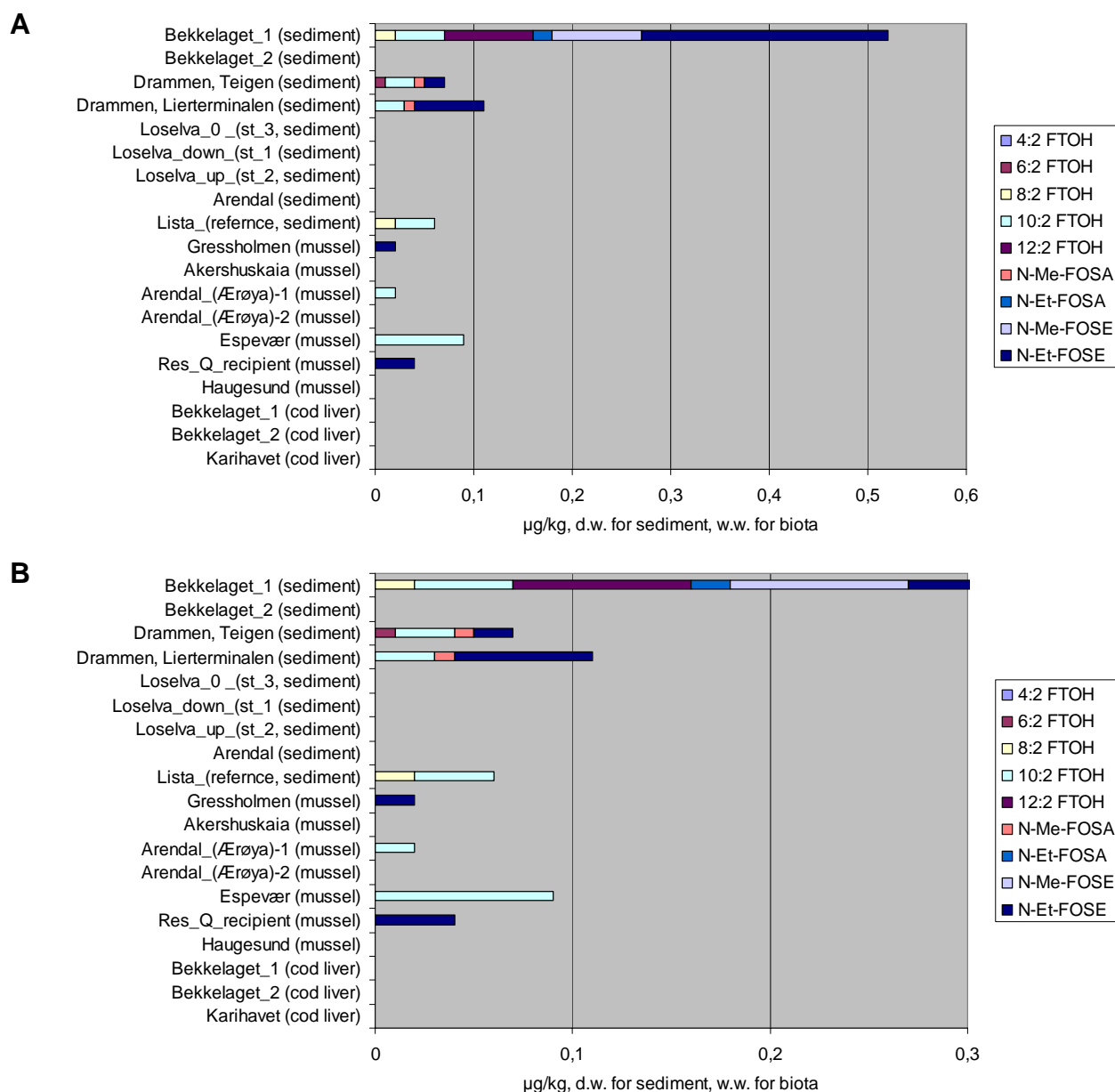


Figure 12. Volatile polyfluorinated organic compounds (PFCs) in sediment (ng/kg dry weight), blue mussel and cod liver (ng/kg wet weight) from recipient waters. Note two scales: overview (A) and detail of low concentrations (B). (See Annex 2 for sample ID description.)

### Ionic PFCs general

Among the 27 compounds analysed only PFOS had levels exceeding the detection limit in all sediment, mussel and cod liver samples (**Table 42, Figure 13**). Also, PFOSA, PFDS, PFUnS, and PFDA were found in concentrations above the detection limit in some samples, whereas the rest were below this limit in all recipient samples.

### Ionic PFCs - sediments and biota

Of the 27 ionic PFCs investigated only five were detected; PFOS being the most dominant these. Quantifiable concentrations of PFOS varied in the range 0.1-6.7 µg/kg dry weight among the 9 samples analysed. Sediments from Loselva, Drammensfjord and Bekkelaget all

show elevated values for PFOS relative to the reference sample from Lista. Highest level was found at Bekkelaget Station 1 (up to 20 times higher than at Lista).

The freshwater sediments from Loselva had PFOS in the range 0.8-2.3 µg/g dry weight.

Quantifiable PFDS and PFUnS were only found at Bekkelaget Station 2, whereas none of the sediment samples had PFOSA or PFDA above detection limit.

Quantifiable concentrations of PFOS in mussels varied in the range 0.2-1.9 µg/kg wet weight among the 7 samples analysed. Highest level was found outside the Res-Q fire fighting facility at Haugesund. All mussel samples except from Espevær had quantifiable levels of PFOSA in the range 0.4-2.9 µg/kg wet weight. PFDS was quantifiable only in mussels from Akershuskaia. PFDA was only quantifiable in mussels from Espevær, and in this sample it was the dominating PFC. One should note that the few quantifiable levels of PFDS and PFDA were just above the detection limits for the other mussel samples. PFUnS was below detection limits in all samples.

Levels of PFCs were higher in cod liver than in mussels and sediments. Highest levels of PFOS were found in the two samples from Bekkelaget (19.8 and 28.0 µg/kg wet weight), whereas the sample from Karihavet, facing the open North Sea, had only 4.4 µg/kg wet weight. Cod liver from Bekkelaget also had quantifiable levels of PFOSA (8.4 and 11.3 µg/kg wet weight) and PFDS (3.4 and 5.4 µg/kg wet weight).



Table 42. Ionic polyfluorinated organic compounds (PFCs) in sediment ( $\mu\text{g}/\text{kg}$  dry weight), blue mussel and cod liver ( $\mu\text{g}/\text{kg}$  wet weight) from recipient waters. Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)

Sample ID	6:2 FTS	8:2 FTS	PFOSA	PFBS	PFPS	PFHxS	PFHpS	PFOS	PFNS
Bekkelaøet 1 (sediment)	<1.37	<1.77	<0.13	<0.13	<0.11	<0.13	<0.1	6.66	<0.09
Bekkelaøet 2 (sediment)	<1.37	<1.92	<0.12	<0.11	<0.21	<0.15	<0.09	3.48	<0.1
Drammen-1 (sediment)	<1.53	<3.48	<0.19	<0.35	<0.15	<0.15	<0.14	2.38	<0.12
Drammen-2 (sediment)	<1.55	<2.28	<0.19	<0.13	<0.11	<0.09	<0.12	3.60	<0.1
Loselva st 1 (sediment)	<2.52	<5.22	<0.28	<0.24	<0.19	<0.2	<0.22	0.81	<0.2
Loselva st 2 (sediment)	<2.22	<3.42	<0.24	<0.29	<0.14	<0.21	<0.16	0.63	<0.15
Loselva st 3 (sediment)	<1.6	<2.51	<0.24	<0.12	<0.12	<0.1	<0.15	2.27	<0.13
Arendal (sediment)	<1.02	<2.12	<0.11	<0.1	<0.15	<0.11	<0.09	0.11	<0.08
Lista (reference, sediment)	<1.31	<2.44	<0.13	<0.12	<0.15	<0.1	<0.11	0.34	<0.1
Gressholmen (mussel)	<2.72	<4.66	1.75	<0.23	<0.21	<0.17	<0.18	0.24	<0.17
Akershuskaia (mussel)	<2.15	<4.41	2.56	<0.23	<0.18	<0.17	<0.17	0.62	<0.18
Arendal (Ærøya)-1 (mus-)	<2.52	<4.33	0.37	<0.25	<0.21	<0.19	<0.18	0.81	<0.18
Arendal (Ærøya)-2 (mus-)	<2.5	<4.34	0.69	<0.22	<0.21	<0.18	<0.19	0.48	<0.19
Espevær (mussel)	<2.95	<4.77	<0.36	<0.24	<0.22	<0.2	<0.23	0.17	<0.3
Res Q recipient (mussel)	<2.75	<4.93	2.86	<0.22	<0.22	<0.2	<0.2	1.89	<0.23
Haugesund (mussel)	<2.39	<4.38	1.27	<0.22	<0.19	<0.17	<0.18	0.26	<0.28
Bekkelaøet 1 (cod liver)	<4.98	<9.12	8.43	<1.28	<0.46	<0.4	<0.42	27.95	<0.49
Bekkelaøet 2 (cod liver)	<6.08	<7.21	11.25	<0.64	<0.43	<0.37	<0.41	19.80	<0.42
Karihavet (cod liver)	<7.27	<10.65	<1.56	<1.02	<0.68	<0.5	<0.56	4.41	<0.62
Sample ID	PFDS	PFUnS	PFDoS	PFTrS	PFTS	PFPeS	PFBA	PFFA	PFHxA
Bekkelaøet 1 (sediment)	<0.08	<0.09	<0.08	<0.1	<0.1	<0.09	<1.21	<2.05	<2.11
Bekkelaøet 2 (sediment)	0.46	0.17	<0.09	<0.07	<0.18	<0.08	<0.92	<1.85	<1.99
Drammen-1 (sediment)	<0.15	<0.13	<0.11	<0.11	<0.11	<0.11	<1.22	<3.13	<1.69
Drammen-2 (sediment)	<0.07	<0.11	<0.16	<0.12	<0.11	<0.1	<0.99	<1.62	<1.42
Loselva st 1 (sediment)	<0.23	<0.17	<0.24	<0.2	<0.21	<0.25	<2.35	<4.39	<3.42
Loselva st 2 (sediment)	<0.12	<0.12	<0.15	<0.14	<0.16	<0.16	<2.07	<3.92	<3.19
Loselva st 3 (sediment)	<0.08	<0.1	<0.13	<0.14	<0.12	<0.18	<1.07	<1.92	<1.77
Arendal (sediment)	<0.08	<0.07	<0.07	<0.07	<0.08	<0.01	<0.75	<1.72	<1.23
Lista (reference, sediment)	<0.07	<0.09	<0.11	<0.08	<0.08	<0.07	<1.33	<2.45	<2.04
Gressholmen (mussel)	<0.14	<0.22	<0.2	<0.2	<0.31	<0.28	<2.11	<3.44	<2.71
Akershuskaia (mussel)	0.20	<0.22	<0.15	<0.2	<0.22	<0.24	<2.27	<3.8	<3.16
Arendal (Ærøya)-1 (mus-)	<0.15	<0.26	<0.18	<0.23	<0.24	<0.23	<1.64	<2.89	<2.43
Arendal (Ærøya)-2 (mus-)	<0.15	<0.36	<0.19	<0.24	<0.24	<0.35	<1.95	<3.43	<3.16
Espevær (mussel)	<0.18	<0.37	<0.2	<0.23	<0.24	<0.39	<2.49	<4.18	<3.97
Res Q recipient (mussel)	<0.16	<0.18	<0.21	<0.28	<0.27	<0.31	<2.36	<4.15	<3.56
Haugesund (mussel)	<0.15	<0.2	<0.17	<0.21	<0.24	<0.4	<1.77	<3.32	<2.81
Bekkelaøet 1 (cod liver)	5.35	<0.61	<1.12	<2.33	<4.01	<4.37	<13.31	<22.03	<18.27
Bekkelaøet 2 (cod liver)	3.35	<0.58	<1	<1.93	<3.73	<3.87	<9.62	<15.87	<13.37
Karihavet (cod liver)	<0.56	<0.85	<1.86	<3.96	<4.87	<7.49	<7.39	<10.24	<11.87
Sample ID	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTra	PFTA	PFPeA
Bekkelaøet 1 (sediment)	<2.62	<12.45	<2.13	<3.08	<4.81	<5.29	<6.5	<5.95	<4.85
Bekkelaøet 2 (sediment)	<2.54	<3.48	<3.4	<4.69	<4.99	<5.15	<6.27	<5.66	<6.12
Drammen-1 (sediment)	<1.41	<11.04	<2.7	<3.01	<5.9	<6.05	<6.34	<7.67	<8.05
Drammen-2 (sediment)	<1.34	<8.91	<2.36	<2.87	<3.72	<3.35	<3.75	<3.68	<4.01
Loselva st 1 (sediment)	<3.12	<20.42	<4.42	<2.71	<12.25	<13.78	<12.81	<12.87	<15.03
Loselva st 2 (sediment)	<2.86	<23.45	<2.82	<3.59	<8.85	<9.42	<9.6	<9.45	<10.27
Loselva st 3 (sediment)	<1.77	<13.77	<1.21	<2.17	<3.83	<3.57	<4.53	<2.94	<3.38
Arendal (sediment)	<1.05	<15.54	<2.27	<2.64	<3.46	<3.76	<4.1	<3.99	<4.23
Lista (reference, sediment)	<2.05	<65	<2.11	<3.19	<7.48	<8.09	<11.71	<7.85	<9.02
Gressholmen (mussel)	<3.04	<64.37	<4.9	<6.26	<5.59	<5.88	<6.23	<8.71	<9.07
Akershuskaia (mussel)	<3	<65.65	<3.85	<3.55	<4.56	<5.48	<5	<7.37	<8.15
Arendal (Ærøya)-1 (mus-)	<2.34	<5.92	<3.83	<4.34	<8.85	<10.59	<10.22	<11.76	<17.06
Arendal (Ærøya)-2 (mus-)	<2.6	<5.75	<2.66	<3.73	<4.86	<5.95	<5.87	<7.08	<7.34
Espevær (mussel)	<3.19	<9.2	<3.47	6.38	<7.41	<8.62	<8.61	<10.46	<10.54
Res Q recipient (mussel)	<3.29	<7.78	<4.92	<5.58	<6.68	<10.01	<7.81	<8.31	<12.96
Haugesund (mussel)	<2.26	<62.44	<3.47	<3.6	<4.88	<5.34	<5.31	<6.32	<8.59
Bekkelaøet 1 (cod liver)	<21.45	<49.62	<4.67	<5.2	<7.25	<7.9	<8.12	<11.41	<23.14
Bekkelaøet 2 (cod liver)	<13.13	<30.38	<5.02	<5.85	<9.02	<8.98	<9.85	<14.84	<32.78
Karihavet (cod liver)	<8.41	<19.58	<7.51	<7.68	<8.31	<8.68	<10.73	<17.12	<30.86

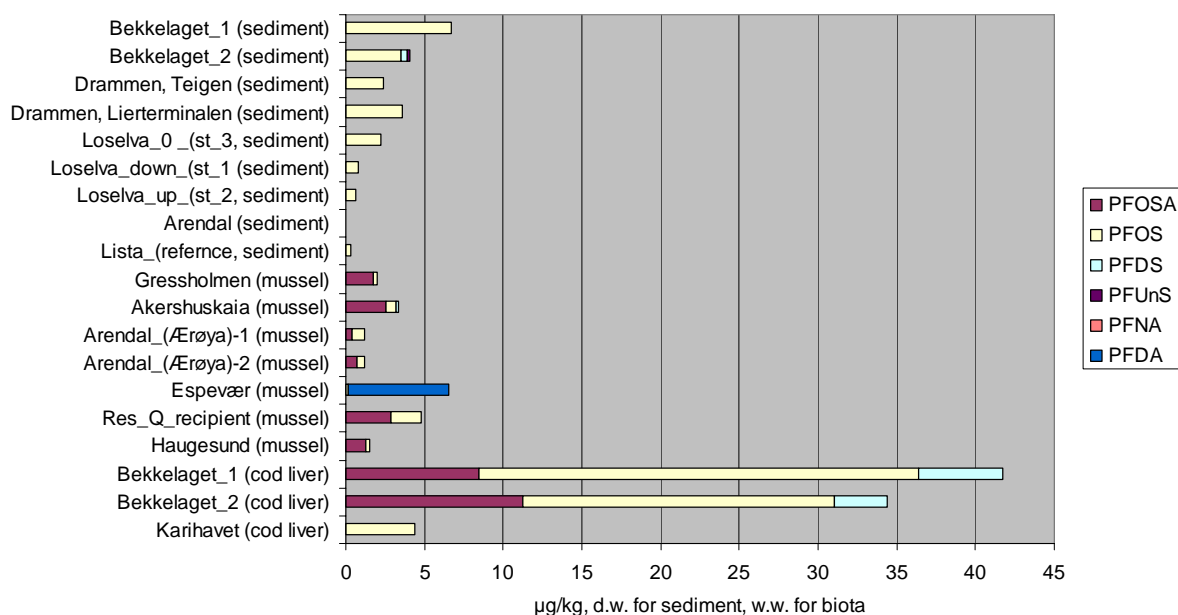


Figure 13. Ionic polyfluorinated organic compounds (PFCS) in sediment ( $\mu\text{g}/\text{kg}$  dry weight), blue mussel and cod liver ( $\mu\text{g}/\text{kg}$  wet weight) from recipient waters. (See Annex 2 for sample ID description.)

## Discussion

### Volatile PFCs

Some FTOHs may be expected to recipients, especially if there is little microbial degradation (cf. section 3.2.2). However, the results for sediment, blue mussel and cod liver show that concentrations were near or below the limit of detection (range: 0.01-1  $\mu\text{g}/\text{kg}$  dry weight for sediment and 0.01-0.7  $\mu\text{g}/\text{kg}$  wet weight for biota). No PNEC-data were found to given an indication of possible toxic affects these compounds might have on the environment at this level of detection.

### Ionic PFCs

The quantifiable range of PFAS concentrations for sediment is 0.1-6.7  $\mu\text{g}/\text{kg}$  dry weight. The corresponding ranges for PFOS in sediment in the 2004 and 2006 screening surveys were reasonably similar, 0.2-5.9  $\mu\text{g}/\text{kg}$  dry weight and 0.08-3.62  $\mu\text{g}/\text{kg}$  dry weight respectively (**Table 43**). Data for PFOS in marine sediments are also available from 6 offshore installations at Haltenbanken in 2006 and the range here was similar: 0.2-1.8  $\mu\text{g}/\text{kg}$  dry weight (**Table 43**). All concentrations in these study, include the investigation described in this report, are well below the potential no effect concentration (PNECs) of 220  $\mu\text{g}/\text{kg}$  for PFOS in marine sediments in the revised SFT risk assessment tool (SFT 2007) and should therefore pose no risk to the environment.

The freshwater sediments from Loselva had PFOS in the range 0.8-2.3  $\mu\text{g}/\text{g}$  dry weight. In comparison, the highest level found in freshwater sediments in 2006 was 3.6  $\mu\text{g}/\text{kg}$  wet weight (Vansjø). The sediments from Loselva do not deviate to any extent from the range seen in Norwegian freshwater sediments in 2004 (Fjeld *et al.* 2005) and 2006 (Bakke *et al.* 2007) and in a Nordic screening survey from 2004 (Kallenborn *et al.* 2004). Even accounting for possible differences in sensitivity between freshwater and marine ecosystems, the above

marine PNEC<sub>s</sub> for PFOS suggests that these concentrations also should represent no environmental risk.

The PFOS range found in blue mussel in the 2004 screening survey was 0.03-0.2 µg/kg wet weight, and in 2006: 0.1–0.6 µg/kg wet weight (**Table 43**). With a range of 0.2-1.9 µg/kg wet weight found in 2007, this suggests that the increase in PFOS in mussels from 2004 to 2006 continues into 2007. However, it should be noted that the samples differ from one year to another. Mussels from Espevær have been analysed all 3 years and the PFOS concentrations here are very stable (0.17 µg/kg wet weight in 2004, 0.14 µg/kg wet weight in 2006, and 0.17 µg/kg wet weight in 2007). The overall trend should still be an argument for continued monitoring of PFOS in blue mussel.

The range found for PFOSA in blue mussel was 0.4-2.9 µg/kg wet weight, which is at the same level with the 2006 range: 0.2-1.8 µg/kg wet weight (**Table 44**). The only quantifiable PFDS concentration found in mussels from Akershus was over three times higher than what has been found in previous screening exercises (**Table 45**)

Cod liver from inner Oslofjord was also analysed in 2004 and 2006 with the PFOS ranges 2.1-6.3 µg/kg wet weight and 37.1-62.2 µg/kg wet weight, respectively, suggesting an increase since 2004 (**Table 43**). The results for 2007 from the inner Oslofjord (range 20-28 µg/kg wet weight) indicate that relatively high concentrations are still prevalent. The relatively low concentration of 4.4 µg/kg wet weight found the sample of cod liver from the reference station on the West Coast was in the range found from more remote sites studied in the 2006 screening.

PFOSA and PFDS concentrations in cod liver from the inner Oslofjord and the remote site, were similar the corresponding concentrations found in the two previous screening exercises (**Table 44, Table 45**)

No PNEC-data were found for blue mussel and cod which would give an indication of possible toxic effects these compounds might have on the environment at this level of detection. This underlines the need for further research to establish useful environmental quality standards.

*Table 43. Previous measurements of PFOS in recipient; µg/kg dry weight for sediment and µg/kg wet weight for blue mussel and cod liver. Unless otherwise specified, the highest detection limit and highest concentration quantified is indicated.*

Study area	Medium	Value	Reference
Norway	sediment	0.17-1.04	Fjeld <i>et al.</i> 2005
Norway	sediment	<0.06-3.73	Bakke <i>et al.</i> 2007
Western Scheldt (NL)	sediment	0.002	de Voogt 2006 <sup>2</sup>
North Sea	sediment	0.22-1.78	DnV 2007
Norway	blue mussel	0.034-0.165	Fjeld <i>et al.</i> 2005
Norway	blue mussel	<0.06-0.56	Bakke <i>et al.</i> 2007
Barents Sea	polar cod liver	1.07–2.85	Haukås, <i>et al.</i> 2007
Sweden	cod liver	5-61 <sup>3</sup>	Berger <i>et al.</i> 2004
Norway	cod liver	0.45-6.26	Fjeld <i>et al.</i> 2005
Norway, inner Oslofjord	cod liver	37-63	Bakke <i>et al.</i> 2007
Norway, remote sites <sup>1</sup>	cod liver	2-10	Bakke <i>et al.</i> 2007

1) Ålesund, Gangstøvika, Lofoten, Tromsø, Varangerfjord; except for Ålesund assumed to be areas of low exposure

2) As cited by Bakke *et al.* 2007

3) Estimated from Figure 3 in Berger *et al.* 2004.

*Table 44. Previous measurements of PFOSA in recipient; µg/kg dry weight for sediment and µg/kg wet weight for blue mussel and cod liver. Unless otherwise specified, the heighest detection limit and heighest concentration quantified is indicated.*

<b>Study area</b>	<b>Medium</b>	<b>Value</b>	<b>Reference</b>
Norway	sediment	<0.010-237 <sup>2</sup>	Fjeld <i>et al.</i> 2005
Norway	sediment	<0.12	Bakke <i>et al.</i> 2007
North Sea	sediment	<0.04	DnV 2006
Norway	blue mussel	<0.008-0.16	Fjeld <i>et al.</i> 2005
Norway	blue mussel	<0.11-1.77	Bakke <i>et al.</i> 2007
Sweden	cod liver	1-5 <sup>3</sup>	Berger <i>et al.</i> 2004
Norway	cod liver	<0.004-0.056	Fjeld <i>et al.</i> 2005
Norway, inner Oslofjord	cod liver	20-22	Bakke <i>et al.</i> 2007
Norway, remote sites <sup>1</sup>	cod liver	<2	Bakke <i>et al.</i> 2007

1) Ålesund, Gangstøvika, Lofoten, Tromsø, Varangerfjord; except for Ålesund assumed to be areas of low exposure

2) Hvaler, near mouth of the Glomma river. Only value above the detection limit.

3) Estimated from Figure 3 in Berger *et al.* 2004.

*Table 45. Previous measurements of PFDS in recipient; µg/kg dry weight for sediment and µg/kg wet weight for blue mussel and cod liver. Unless otherwise specified, the heighest detection limit and heighest concentration quantified is indicated.*

<b>Study area</b>	<b>Medium</b>	<b>Value</b>	<b>Reference</b>
Norway	sediment	<0.008-0.094 <sup>2</sup>	Fjeld <i>et al.</i> 2005
Norway	sediment	<0.15-0.93	Bakke <i>et al.</i> 2007
North Sea	sediment	<0.13	DnV 2006
Norway	blue mussel	<0.007	Fjeld <i>et al.</i> 2005
Norway	blue mussel	<0.06-0.05	Bakke <i>et al.</i> 2007
Norway	cod liver	<0.005-0.005	Fjeld <i>et al.</i> 2005
Norway, inner Oslofjord	cod liver	4-7	Bakke <i>et al.</i> 2007
Norway, remote sites <sup>1</sup>	cod liver	<0.2	Bakke <i>et al.</i> 2007

1) Ålesund, Gangstøvika, Lofoten, Tromsø, Varangerfjord; except for Ålesund assumed to be areas of low exposure

2) Rubbestadneset, on the West Coast. Only concentrations in two samples above the detection limit.

### 3.3 Nitro-PAHs in air

#### Results

For this group of 8 compounds, 19 air samples were analyzed, where relatively few compounds were quantifiable, only 16% (**Table 46**).

*Table 46. Nitro-PAH compounds analysed and count over detection limit. Total indicates number of samples and % indicates average percent of total that is over detection limit. Count over detection limit is shaded.*

Sample type	3-NBA	9-NAA	7-NBAA	2+3-NFA	1-NPY	4-NPY	1,3-dNPY	1,6-dNPY	Total	%
Air samples	3	4	1	10	16	10	1	2	19	16

Of the nitro- and nitrooxy-PAHs 1-NPY is detected in 16 of 19 samples and shows with one exception the highest concentration of all measured nitro-PAHs. 4-NPY and 2-NFA+3-NFA could be found in 10 of 19 samples (**Table 47, Figure 14**). The other compounds are only found occasionally. 3-NBA was detected in two traffic related samples.

*Table 47. Nitro-PAH compounds in air (pg/m<sup>3</sup>). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)*

Sample ID	3-NBA	9-NAA	7-NBAA	2+3-NFA	1-NPY	4-NPY	1,3-dNPY	1,6-dNPY
Alnabru-T_Sep.01	<4.2	<1.6	<4.7	4.96	136.66	3.36	<4.68	<7.82
Alnabru-T_Sep.04-05	<1.35	25.40	<1.43	<0.61	44.80	<0.53	<1.66	<2.77
Alnabru-T_Sep.05-06	1.07	<2.06	<2.2	97.04	42.18	83.99	<2.44	<4.09
Alnabru-T_Sep.06-07	<1.89	<0.85	<1.47	<0.65	70.92	4.91	<1.4	<2.34
Alnabru-T_Sep.08	<4.62	<1.7	<8.3	<0.57	67.43	6.34	<8.57	<14.2
Alnabru-T_Sep.15	2.08	<1.29	<6.99	<0.48	45.66	3.76	<9.29	<15.39
Alnabru-O_Oct.10	<372.10	<75.36	<690.48	147.02	475.72	<52.22	<550.59	<964.15
Alnabru-O_Oct.11	<899.35	<179.92	<1627.75	98.05	376.59	<104.66	<1447.75	<2535.16
Alnabru-S_Oct.31	<713.55	<133.59	<1319.29	103.78	157.32	<88.99	<1151.27	<2015.99
Alnabru-S_Nov.01	<20.66	<3.50	<30.99	415.65	1415.11	<2.11	<24.02	<42.06
LRT-Birkenes_Sep.09-11	<0.83	1.06	<1.54	<0.06	0.70	<0.1	<1.51	<2.5
LRT-Birkenes_Sep.14-16	<0.72	<0.18	<1.44	0.24	1.97	0.68	<1.22	<2.02
LRT-Birkenes_Sep.16-18	<0.54	<0.19	<0.97	<0.06	4.68	<0.09	<1.63	<2.7
LRT-New-Ålesund_Nov.05-07	<1.13	<0.27	<2.24	<0.08	<0.2	<0.12	<3.01	<4.98
LRT-New-Ålesund_Nov.07-09	<1.54	<0.29	<2.59	<0.08	<0.22	<0.13	<2.12	<3.52
LRT-New-Ålesund_Nov.15-16	<1.69	<0.42	<3.18	<0.11	<0.28	<0.16	<3.02	5.01
LRT-New-Ålesund_Nov.21-23	<0.18	<0.08	<0.18	0.17	0.29	0.24	<0.16	<0.23
LRT-New-Ålesund_Nov.23-26	<0.3	<0.12	<0.27	0.58	1.08	0.10	<0.3	<0.44
LRT-New-Ålesund_Nov.26-28	<0.26	<0.13	<0.26	0.79	0.56	<0.05	<0.22	<0.32

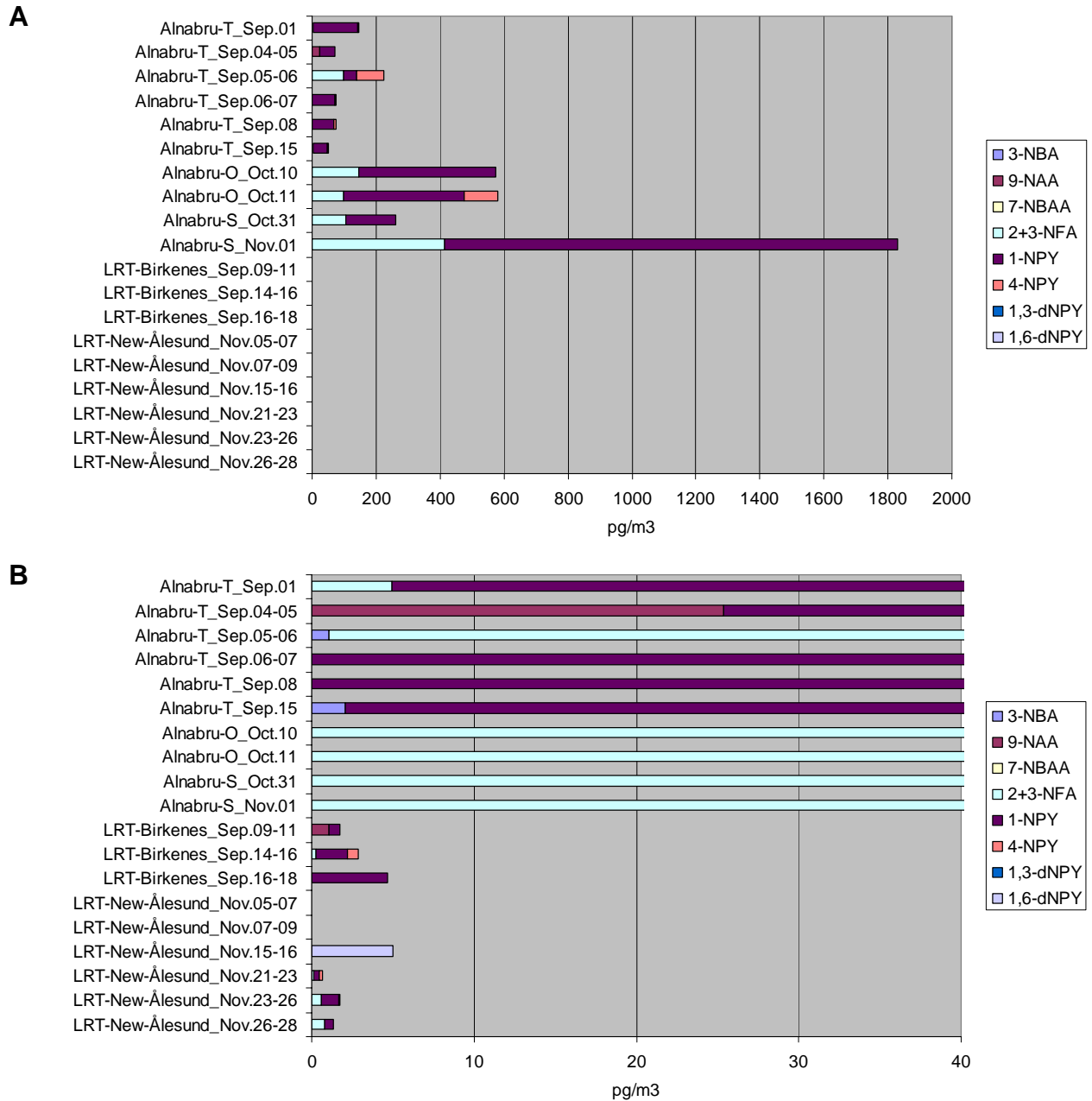


Figure 14. Nitro PAH compounds in air ( $\text{pg}/\text{m}^3$ ). Note two scales: overview (A) and detail of low concentrations (B). (See Annex 2 for sample ID description.)

### Discussion

The indoor air samples and the traffic related samples showed in general the highest concentration of the measured nitro-PAHs. There are several reasons why the indoor air samples are more contaminated compared to the outdoor air samples from the same site: as long as we know smoking as a source of indoor air pollution can be excluded. However, both indoor air sites are situated east to one of the major source namely Strømsveien, whereas the outdoor samplers are placed west to this main source. With prevailing winds from the southwest the car exhaust emissions are blown directly to these indoor sites and away from the outdoor site. An other issue is that the outdoor and indoor samples were not taken at the same

time. Air pollution concentrations can be very variable with both day-to-day variations and seasonal variations.

Nitro-PAHs are not part of a standard air monitoring programme and results from other Nordic countries are sparse. In **Table 48** some results from semi-rural and urban sites in Denmark and Maryland, USA are listed.

*Table 48. Previous measurements of nitro-PAH compounds in air (pg/m<sup>3</sup>).*

<b>Study area</b>	<b>3-NBA</b>	<b>9-NAA</b>	<b>7-NBAA</b>	<b>2+3-NFA</b>	<b>1-NPY</b>	<b>4-NPY</b>	<b>1,3-dNPY</b>	<b>1,6-dNPY</b>
Risø, Denmark 1998*	<3-70	<1-120		24-400	6-145			
Copenhagen, Denmark 1998*		10-225		10-500	<1-360			
Baltimore, USA Jan. 2001**		38-98	10-40	32-110	14-45	1-4	<1	<1
Baltimore, USA July 2001**		15-87	0,7-5	23-210	3-16	0.2-1	<1	<1
Fort Meade, USA Jan. 2001**		23-91	6-20	30-98	8-38	1-3	<1	<1
Fort Meade, USA July 2001**		7-25	0.8-1	11-55	0.5-2	.05-0.3	<1	<1

\*) Feilberg, 2001, 2002.

\*\*\*) Bamford, 2003.

In general, the results from this study are in the same order of magnitude or somewhat lower as these previous results. Several nitro- and nitro-oxy-PAHs are shown to be possible carcinogens (IARC 1989, WHO 2003). WHO, however, emphasize that this chemical should be attributed to increased attention and that proper data is missing to make certain conclusions about its potential as a carcinogen. To get a better overview over average concentrations and seasonal variations the measurement of nitro- and nitro-oxy PAHs could without a lot of extra sampling effort be included in the recently started urban PAH monitoring.

### 3.4 Silver and platinum

Silver and platinum were investigated in 40 samples, and for both dust and wastewater treatment facilities, relatively few compounds were quantifiable, only 16% (**Table 49**).

*Table 49. Silver and platinum analysed and count over detection limit. Total indicates number of samples and % indicates average percent of total that is over detection limit. Count over detection limit is shaded.*

Sample type	Ag	Pt	N	%
Dust and road dust	14	9	23	16
WWT-facilities	14	10	17	16

#### 3.4.1 Road dust and air

##### Results

In the present report, results from analysis of road dust from Alnabru are presented. Alnabru is an area with high traffic density caused by both light and heavy traffic. Levels above limit of detection were found for 3 out of a total of 11 samples (**Table 50, Figure 15**).

*Table 50. Silver (Ag) and platinum (Pt) road dust ( $\mu\text{g}/\text{kg}$  dry weight) and in air ( $\text{pg}/\text{m}^3$ ). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)*

Sample ID	Ag	Pt
Alnabru-P1_May.10.a	894	<143
Alnabru-P1_May.10.b	1839	<143
Alnabru-P1_May.10.c	963	<143
Alnabru-P1_May.10.d	1006	<143
Alnabru-P1_May.10.e	1547	225
Alnabru-P1_May.10.f	1296	<143
Alnabru-P2_Oct.10.a	393	<143
Alnabru-P2_Oct.10.b	1332	172
Alnabru-P2_Oct.10.c	1185	<143
Alnabru-P2_Oct.10.d	986	159
Alnabru-P2_Oct.10.e	720	<143
Alnabru-P2_Oct.10.f	937	<143
Alnabru F1_Aug.27-28	<400	5
Alnabru F2_Aug.28-29	<400	2
Alnabru F3_Aug.29-30	<400	3
Alnabru F4_Aug.30-31	<400	5
Alnabru F5_Sep.1	<400	4
Alnabru F6_Sep.4	<400	3
LRT-Birkenes F1_Aug.31-Sep.2	<400	<1
LRT-Birkenes F2_Sep.2-4	<400	<1
LRT-New-Ålesund_Jun.1-4	<4	<1
LRT-New-Ålesund_Aug.1-3	4	<1
LRT-New-Ålesund_Sep.28-Oct.1	20	<1



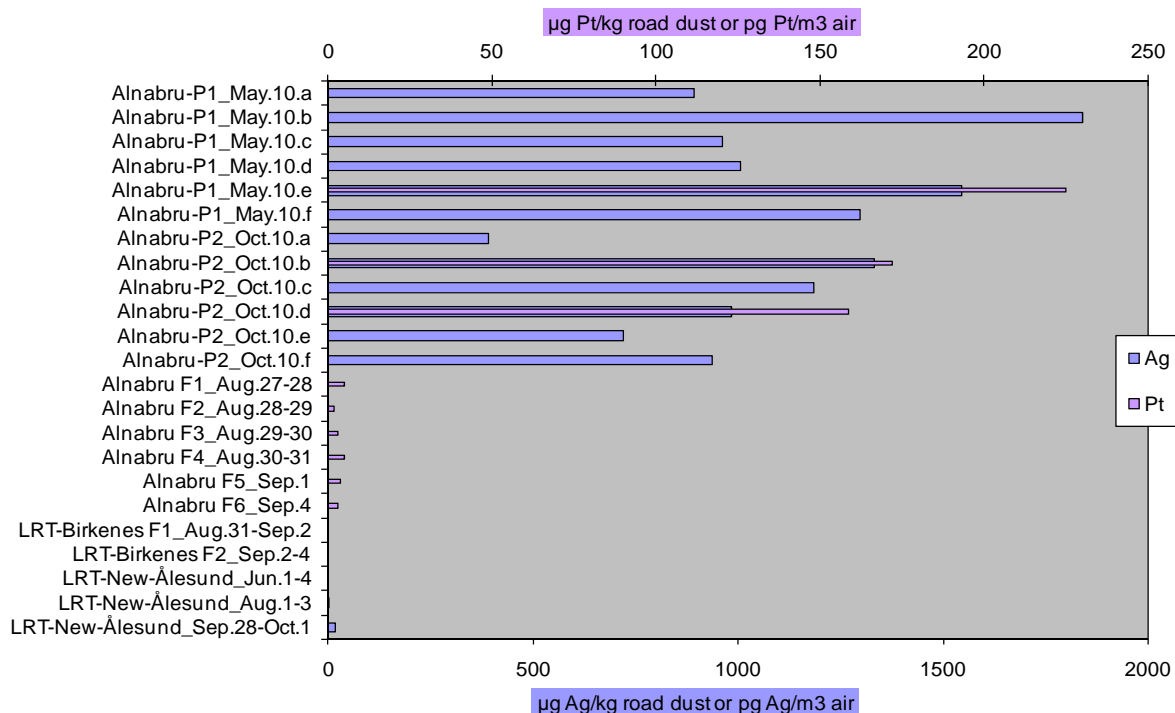


Figure 15 Silver (Ag) and platinum (Pt) in road dust ( $\mu\text{g}/\text{kg}$  dry weight) and air ( $\text{pg}/\text{m}^3$ ). (See Annex 2 for sample ID description.)

### Discussion

Since the introduction of catalytic converters in vehicles, investigations of platinum group elements (PGEs) in different environmental samples such as air, road dust, soil, plants and water has been undertaken and several studies from different countries are published. The data shows some discrepancy that may be due to different conditions affecting the PGEs content such as traffic density, weather conditions, sampling methods and period of use of catalytic converter.

The platinum content measured in these samples is comparable to levels found in road dust from other European major roads and cities with high traffic density (Gomez *et al.*, 2002; Kovacheva & Djingova, 2002).

New measurements of platinum are recommended in order to optimise the analytical method. More results above the limit of detection will give a better overview of the situation.

Data on silver content in road dust has not been found..

### 3.4.2 Wastewater treatment facilities

#### Results

##### General

There were 17 samples from three domestic WWTP (influent, effluent and sludge samples), one landfill site (four sediment samples) and one car demolishing site (four sediment samples) were analysed for platinum (Pt) and silver (Ag). All samples except the effluent samples from the WWTPs contained appreciable concentrations of silver; 180 – 530 ng/l in influent WWTP samples, 482-7640  $\mu\text{g}/\text{kg}$  dry weight in sludge samples and 319-7427  $\mu\text{g}/\text{kg}$  dry weight in sediment samples (Table 51, Figure 16). The platinum concentrations were much lower and

exceeded the detection limit in only one water sample (influent to Saulekilen WWTP; 5 ng/l), in all sludge samples (2-10 µg/kg dry weight) and in six out of eight sediment samples (5-262 µg/kg dry weight). The highest concentrations of both metals were for sludge found at Bekkelaget WWTP and for sediment found at the car demolishing site Hellik Teigen AS.

*Wastewater treatment facilities: Water and sludge samples*

All three influent water samples to the Bekkelaget, Saulekilen and Solumstrand WWTPs contained silver; 180-530 ng/l, but none of the effluent samples contained appreciable concentrations of silver. In sludge samples taken from the same WWTPs the measured silver concentrations were 7640, 4043 and 482 µg/kg dry sludge, respectively. Of all collected water samples to the WWTPs, only in the influent sample to the Saulekilen WWTP was there found appreciable concentration of platinum (5 ng/l), though all sludge samples contained some of the metal (2-10 µg/kg).

*Landfill site and car demolishing site: Sediment samples*

Concentrations of silver in sediment samples collected at the Lindum landfill site and at the car demolishing site (Hellik Teigen) contained 319-2399 µg/kg dry weight and 3397-7477 µg/kg dry weight, respectively. Only for two of the sludge samples from Lindum did we find quantifiable concentrations of platinum (5-11 µg/kg dry weight), whilst at Hellik Teigen we found significantly higher levels of the metal in all sediment samples; 145-262 µg/kg dry weight.

*Table 51. Silver (Ag) and platinum (Pt) in samples from wastewater treatment facilities (ng/l for in/out discharge water, µg/kg dry weight for sludge and sediment). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)*

<b>Sample ID</b>	<b>Ag</b>	<b>Pt</b>
Bekkelaget-WWTP_In.d	430	<2
Bekkelaget-WWTP_out.d	<10	<10
Bekkelaget-WWTP_sludge	7640	10
Saulekilen-WWTP_In.d	530	5
Saulekilen-WWTP_out.d	<10	<10
Saulekilen-WWTP_sludge	4043	5
Solumstrand-WWTP_In.d	180	<2
Solumstrand-WWTP_out.d	<10	<10
Solumstrand-WWTP_sludge	482	2
Lindum-Wdepot-1d (sediment)	1196	5
Lindum-Wdepot-2d (sediment)	319	<3,5
Lindum-Wdepot-1w (sediment)	448	<3,5
Lindum-Wdepot-2w (sediment)	2399	11
Hellik-Teigen-Adepot-1d (sediment)	7427	262
Hellik-Teigen-Adepot-2d (sediment)	6168	207
Hellik-Teigen-Adepot-1w (sediment)	4851	175
Hellik-Teigen-Adepot-2w (sediment)	3397	145

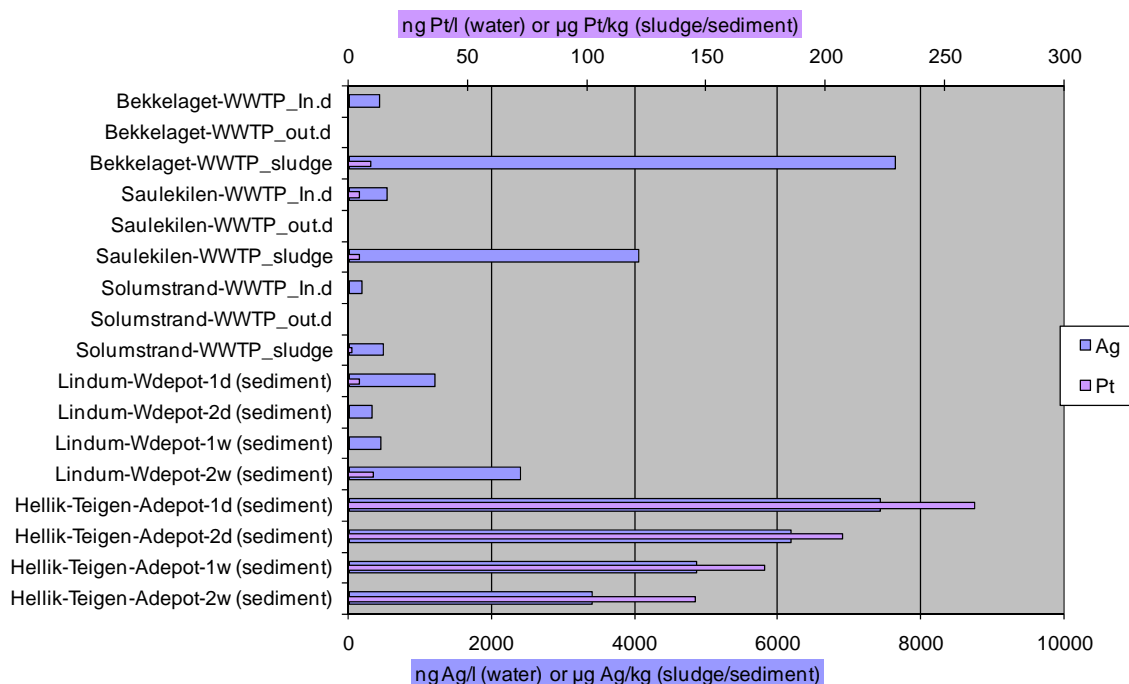


Figure 16. Silver (Ag) and platinum (Pt) in samples from wastewater treatment facilities (ng/l for in/out discharge water, µg/kg dry weight for sludge and sediment). (See Annex 2 for sample ID description.)

## Discussion

### Wastewater treatment facilities

Using the environmental classification criteria for marine sediments in lack of similar for freshwater sediments or sewage sludge the sludge samples from Bekkelaget, Saulekilen and Solumstrand WWTPs would be classified as strongly contaminated (SFT environmental Class IV: 5-10 mg Ag/kg), markedly contaminated (Class III: 1.5-5 mg Ag/kg) and moderately contaminated (Class II: 0.3-1.3 mg Ag/kg), respectively. The silver concentration in sewage sludge samples from Bekkelaget and Solumstrand are in the same concentration level as reported in Sweden. Henriksdal and Bromma, two wastewater plants in Stockholm, reports for 2006 average silver concentrations of 6600 µg/kg and 3800 µg/kg (dry weight), respectively (Stockholm Vatten AB, 2008). Swedish environmental protection agency reports concentrations of 61 trace elements in sewage sludge, inclusive silver and platinum. Silver is determined in samples from all 48 sewage works and the concentrations varies from 1.1-32.7 mg kg<sup>-1</sup>. However, 75% of the results are below 10 mg kg<sup>-1</sup> (Naturvårdverket, 2001). The Swedish Environmental Protection Agency recommends a limit value of 15 mg silver/kg (DW) in sludge for use in agriculture.

Platina is determined in samples from 6 out of 48 sewage works. 87.5 % of the results are below detection limit (0.04 mg/kg). The concentration levels reported are in the range of 0.04-0.20 mg/kg (Naturvårdverket, 2001). In comparison, the platinum concentration levels presented in this report are below this level.

Scientific literature is not conclusive on the inhibitory impacts of silver and platinum on mixed autotrophic and heterotrophic bacteria population typical to activated sludge, and it thus warrants further research. Determination of silver content in sewage sludge should be done and a limit value should be recommended

*Landfill site and car demolishing site*

Hence, using again the marine classification criteria for sediments, all sediment samples from Lindum would be characterised as moderately or markedly contaminated and all sediment samples from Hellik Teigen would be characterised as markedly or strongly contaminated.

### 3.5 Sucralose

#### 3.5.1 Wastewater treatments facilities

##### Results

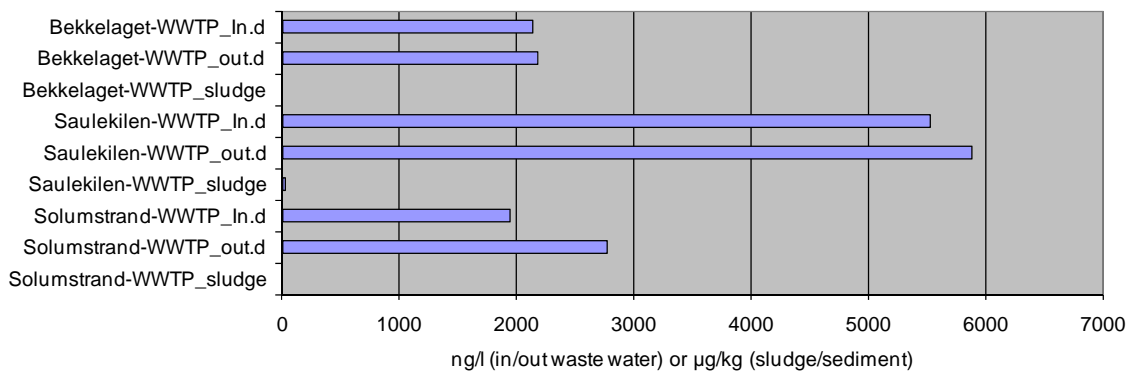
The 9 samples from three domestic WWTP (influent, effluent and sludge samples) were analysed for sucralose. Considerable concentrations were found in all water samples, while none or just trace levels were found in the three sludge samples. The highest effluent concentration was found at Saulekilen WWTP with 5876 µg/l (**Table 52, Figure 17**).

##### Water and sludge samples

Influent water samples from Bekkelaget, Solumstrand and Saulekilen WWTPs showed sucralose concentrations of 2131, 5520 and 1940 ng/l, respectively. In the effluent samples the sucralose concentration was either similar or somewhat higher than in the influent, and only the sludge from Saulekilen WWTP showed quantifiable traces of sucralose (22 µg/kg dry weight).

*Table 52. Sucralose in samples from wastewater treatment facilities (ng/L for in/out discharge water, µg/kg wet weight for sludge). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)*

Sample ID	Sucralose
Bekkelaget-WWTP_In.d	2131
Bekkelaget-WWTP_out.d	2176
Bekkelaget-WWTP_sludge	<5
Saulekilen-WWTP_In.d	5520
Saulekilen-WWTP_out.d	5876
Saulekilen-WWTP_sludge	22
Solumstrand-WWTP_In.d	1940
Solumstrand-WWTP_out.d	2771
Solumstrand-WWTP_sludge	<5



*Figure 17. Sucralose in samples from wastewater treatment facilities (ng/L for in/out discharge water, µg/kg wet weight for sludge). (See Annex 2 for sample ID description.)*

## Discussion

The results from this study are in the same concentration range as the results shown in a recent Swedish study (IVL 2008).

Concentrations measured in WWTP effluent are in the same range or even higher than in the influent and suggest that sucralose goes straight through all treatment steps in all plants in the study. The estimated discharge of sucralose with effluent water from the three WWTPs within the respective sampling periods were 2458 kg from Bekkelaget WWTP (1.13 mill m<sup>3</sup> sewage), 812 kg from Saulekilen WWTP (0.14 mill m<sup>3</sup> sewage) and 684 kg from Solumstrand WWTP (0.25 mill m<sup>3</sup> sewage).

The limited data available on the biodegradability of sucralose indicate that it is poorly biodegradable, as also indicated by the results in this study. Labare and Alexander (1994) studied the biodegradation of sucralose by bacteria prevailing in activated sludge, and concluded that mineralization is slow in sewage under aerobic conditions, and organic products are not produced during the process. Bacteria in culture did not use sucralose as a carbon source but did convert it to the presumed unsaturated aldehyde, 1,6-dichloro-1,6-dideoxy-D-fructose and possibly the uronic acid of sucralose. The chlorinated disaccharide is shown to be slowly metabolized by a galactose oxidase preparation, and it was hypothesised by the authors that the chlorinated sugar could be biodegraded via co-metabolism.

### 3.5.2 Sea water

#### Results

Levels of sucralose were above the detection limits in all but one sample (*Table 53, Figure 18*). The concentrations measured in the Bekkelaget basin were 3 to 4 times higher than in the samples from Arendal. This may be explained both by the higher total sewage water flow at Bekkelaget and by the fact the Bekkelaget basin is a much more enclosed recipient than outside Arendal. Outside Bekkelaget the concentration range was 18-30 ng/l and with no systematic change with distance from the Bekkelaget outlet. The concentration range outside Saulekilen in Arendal ranged from <6 to 8 ng/l, also here without any gradient with distance.

*Table 53. Sucralose in recipient seawater (ng/l). Concentrations over detection limit are shaded. (See Annex 2 for sample ID description.)*

Sample ID	Sucralose
Bekkelaget-0 m	27
Bekkelaget-99 m	24
Bekkelaget-206 m	30
Bekkelaget-347 m	18
Bekkelaget-500 m	27
Bekkelaget-667 m	19
Bekkelaget-853 m	25
Bekkelaget-1224 m	23
Bekkelaget-1503 m	26
Arendal_0 m	<6
Arendal_47 m	7
Arendal_196 m	8
Arendal_804 m	8
Arendal_1991 m	7

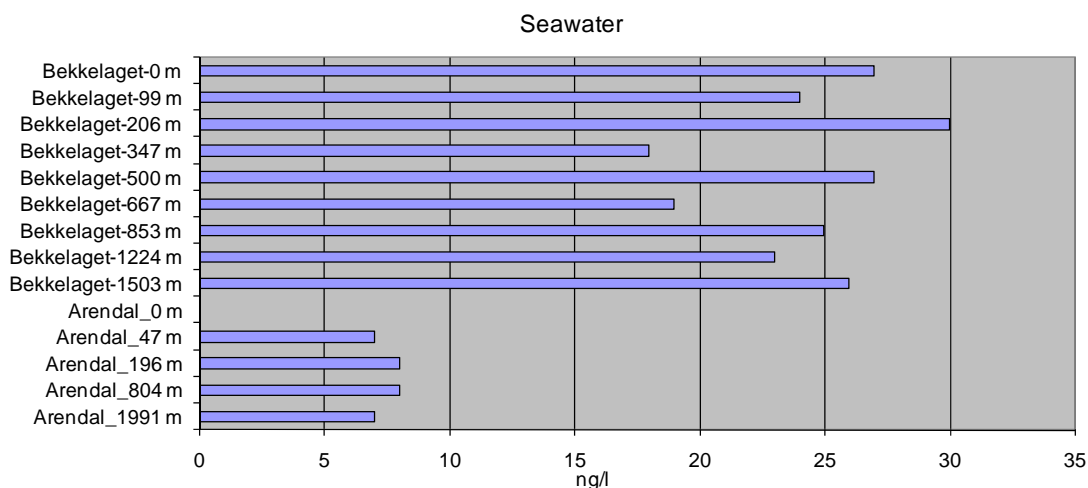


Figure 18. Sucralose in recipient seawater (ng/l). (See Annex 2 for sample ID description.)

### Discussion

There was no evident gradient found either at Bekkelaget nor at the Arendal stations perhaps due to a high background in each basin that made a gradient hard to detect. Rapid mixing of the surface waters would also make possible gradient difficult to register with these few samples.

Sucralose is neither acutely toxic nor does it bio accumulate (NICNAS, 2003 and Grice, 2000). However, it has been shown that sucralose can interact with the sucrose (“normal” sugar) transporting mechanisms in sugarcane (Reinders, 2006). This sugarcane study was not an environmental risk study, but clearly shows that physiological functions of sucrose can be disturbed by sucralose. Sucrose transport is fundamental for plants and even a small interference of sucrose transport in aquatic species may have consequences for the entire ecosystem.

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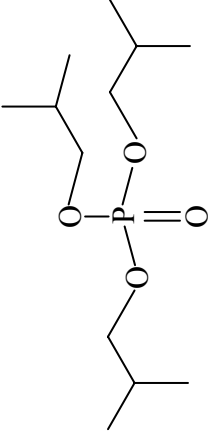
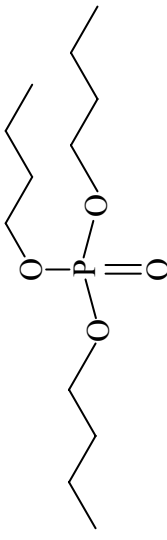
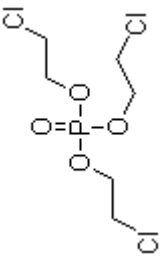
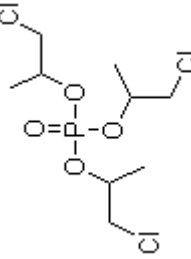


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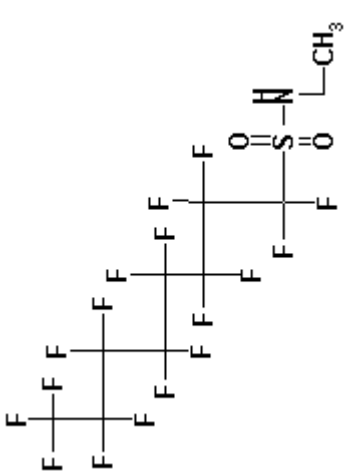
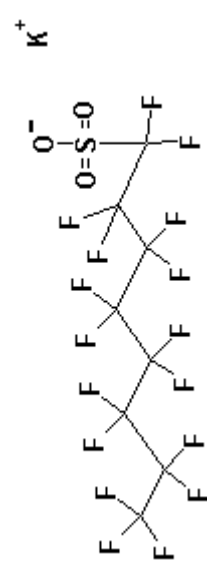
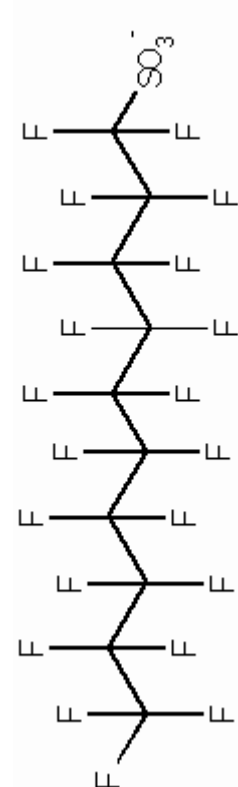
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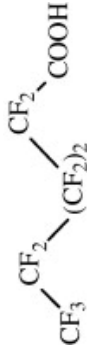




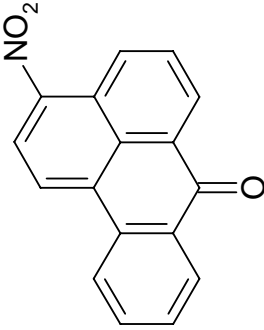
## 5. Annex 1 – Selected metals and compounds – technical information

Compound	Abbreviation	CAS-no,	Structure
<b>Phosphorus Flame Retardants (PFRs)</b> tri-iso-butylphosphate	TIBP	126-71-6	
tributylphosphate	TBP	126-73-8	
tri(2-chloroethyl)phosphate	TCEP	115-96-8	
tri(1-chloro-2-propyl)phosphate	TCPP	13674-84-5	

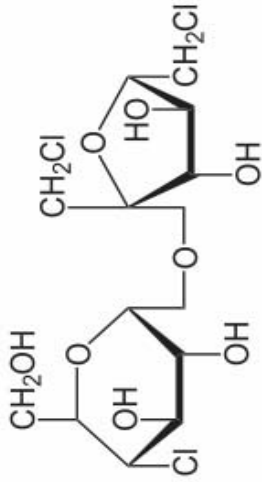
Compound	Abbreviation	CAS-no,	Structure
tri(1,3-dichloro-2-propyl)phosphate	TDCP	13674-87-8	
tri(2-butoxyethyl)phosphate	TBEP	78-51-3	
triphenylphosphate	TPhP	115-86-6	
2-ethylhexyl-di-phenylphosphate	EHDPP	1241-94-7	

Compound	Abbreviation	CAS-no,	Structure
tetrakis(2-chlorethyl)dichloroisopentylidiphosphate	V6	38051-10-4	
<b>Volatile PFCs</b>			
3,3,4,4,5,5,6,6,6-nonafluorohexan-1-ol	4:2 FTOH		
3,3,4,4,5,5,6,7,7,8,8-tridecafluorooctan-1-ol	6:2 FTOH	647-42-7	
3,3,4,4,5,5,6,7,7,8,9,9,10,10,10-pentadecafluorodecan-1-ol	8:2 FTOH	865-86-1	
3,3,4,4,5,5,6,7,7,8,9,9,10,10,11,12,12,12-hentacosafuorododecan-1-ol	10:2 FTOH	678-39-7	
3,3,4,4,5,5,6,7,7,8,9,9,10,10,11,11,12,12,13,13,14,14,14-pentacosafuorotetradecan-1-ol	12:2 FTOH	39239-77-5	
n-methyl perfluorooctane sulfonamide	N-Me-FOSA	31506-32-8	
n-ethyl perfluorooctane sulfonamide	N-Et-FOSA	4151-50-2	
n-methyl perfluorooctane sulfonamidoethanol	N-Me-FOSE	24448-09-7	
n-ethyl perfluorooctane sulfonamidoethanol	N-Et-FOSE	1691-99-2	
<b>Ionic PFCs</b>			

Compound	Abbreviation	CAS-no,	Structure
fluorotelomer sulfonate	6:2 FTS		
fluorotelomer sulfonate	8:2 FTS		
sulfuramid or N-ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-1-octanesulfonamide	PFOSA	4151-50-2 754-91-6	
perfluorobutane sulfonate	PFBS	2795-39-3	
perfluoropentane sulfonate	PFPS	29420-49-3	
perfluorohexanoic sulfonate	PFHxS	432-50-7	
perfluoroheptanoic sulfonate	PFHpS		
perfluorooctanoic sulfonate /perfluorooctane sulfonate	PFOS	2795-39-3	
perfluorononanoic sulfonate	PFNS		
perzfluorodecanoic sulfonate	PFDS	67906-42-7	
perfluoroundecanoic sulfonate	PFUnS		
perfluorododecanoic sulfonate	PFDoS		
perfluorotridecanoic sulfonate	PFTriS		
perfluorotetradecanoic sulfonate	PFTS		
perfluoropentadecanoic sulfonate	PFPeS		
perfluorobutanoic acid	PFBA		

Compound	Abbreviation	CAS-no,	Structure
perfluoropentanoic acid	PFPA	307-24-4	
perfluorohexanoic acid	PFHxA		
perfluoroheptanoic acid	PFHpA	375-85-9	
perfluorooctanoic acid	PFOA	335-67-1	
perfluorononanoic acid	PFNA	375-95-1	
perfluorodecanoic acid	PFDA	335-76-2	
perfluoroundecanoic acid	PFUnA	2058-94-8	
perfluorododecanoic acid	PFDoA		
perfluorotridecanoic acid	PFTiA		
perfluorotetradecanoic acid	PFTA		
perfluoropentadecanoic acid	PFPeA		
<b>Nitro-PAH</b> 3-nitrobenathrone, also known as C <sub>17</sub> H <sub>9</sub> NO <sub>3</sub> and 3-nitro-7H-benz[ <i>d,e</i> ]anthracen-7-one	3-NBA	17117-34-9	
9-nitroanthracene	9-NAA	602-60-8	
7-nitrobenz[ <i>a</i> ]anthracene	7-NBAA	20268-51-3	
2+3-nitrofluoranthene	2+3-NFA	13177-29-2, 892-21-7	
1-nitropyrene	1-NPY	5522-43-0	



Compound	Abbreviation	CAS-no,	Structure
4-nitropyrene	4-NPY	57835-92-4	
1,3-dinitropyrene	1,3-dNPY	75321-20-9	
1,6-dinitropyrene	1,6-dNPY	42397-64-8	
Metals			
silver	Ag	7440-22-4, 7783-90-6, 7785-23-1, 7761-88-8	
platinum	Pt	7440-06-4	
<b>Sucralose</b> 1,6-dichlor-1,6-dideoxy-β-D-fructofuranosyl-4-chlor-4-deoxy-α-D-glucopyranosid (C <sub>12</sub> H <sub>19</sub> Cl <sub>3</sub> O <sub>8</sub> )	Sukr	56038-13-2	
3-Nitrobenathrone	3-NBA		

## 6. Annex 2 – Samples collected

Where Category (C) has three groupings: air (A), effluent (E), and recipient (R); sample date/time indicated as dd/mm/yyyy and start-stop hhmm; bulked sample count (N) and number of replicated individuals in bulked sample (n); water depth (m); tissue (tiss).

Map station ID	Sample ID	Location	NILU sample ID	Latitude°	Longitude°	Sample type	C	Site description	date/time	N	n	m	Size/cut	Collection method	Comments
Alnabru-T/-F	Alnabru-T_Sep.24-25	Alnabru - metering station	07/1510	59°55.664	10°50.793	Air	A	Near main roads	24-25/09/2007 0629-0625	1	1				
Alnabru-T/-F	Alnabru-T_Sep.25-26	Alnabru - metering station	07/1511	59°55.664	10°50.793	Air	A	Near main roads	25-26/09/2007 0644-0632	1	1				
Alnabru-T/-F	Alnabru-T_Sep.26-27	Alnabru - metering station	07/1512	59°55.664	10°50.793	Air	A	Near main roads	26-27/09/2007 0653-0630	1	1				
Alnabru-T/-F	Alnabru-T_Sep.10-11	Alnabru - metering station	07/1387	59°55.664	10°50.793	Air	A	Near main roads	10-11/09/2007 0627-0628	1	1				
Alnabru-T/-F	Alnabru-T_Sep.07-08	Alnabru - metering station	07/1391	59°55.664	10°50.793	Air	A	Near main roads	07-08/09/2007 0635-0635	1	1				
Alnabru-T/-F	Alnabru-T_Sep.11-12	Alnabru - metering station	07/1392	59°55.664	10°50.793	Air	A	Near main roads	11-12/09/2007 0644-0615	1	1				
Alnabru-T/-F	Alnabru-T_Sep.01	Alnabru - metering station	07/1319	59°55.664	10°50.793	Air	A	Near main roads	01-01/09/2007 0847-1847	1	1				
Alnabru-T/-F	Alnabru-T_Sep.04-05	Alnabru - metering station	07/1347	59°55.664	10°50.793	Air	A	Near main roads	04-05/09/2007 0614-0614	1	1				
Alnabru-T/-F	Alnabru-T_Sep.05-06	Alnabru - metering station	07/1352	59°55.664	10°50.793	Air	A	Near main roads	05-06/09/2007 0628-0621	1	1				
Alnabru-T/-F	Alnabru-T_Sep.27-28	Alnabru - metering station	07/1518	59°55.664	10°50.793	Air	A	Near main roads	27-28/09/2007 0641-0636	1	1				
Alnabru-T/-F	Alnabru-T_Sep.28-29	Alnabru - metering station	07/1519	59°55.664	10°50.793	Air	A	Near main roads	28-29/09/2007 0646-0629	1	1				
Alnabru-T/-F	Alnabru-T_Sep.29-30	Alnabru - metering station	07/1520	59°55.664	10°50.793	Air	A	Near main roads	29-30/09/2007 0644-0644	1	1				
Alnabru-T/-F	Alnabru-T_Sep.12-13	Alnabru - metering station	07/1403	59°55.664	10°50.793	Air	A	Near main roads	12-13/09/2007 0630-0621	1	1				

Mapping selected metals and new organic contaminants 2007 (TA-2367/2008).

Map station ID	Sample ID	Location	NILU sample ID	Latitude ° e	Longitude	Sample type	C	Site description	date/time	N	n	m	Size/cut	Collection method	Comments
Alnabru-T/-F	Alnabru-T_Sep.13-14	Alnabru - metering station	07/1441	59°55.664	10°50.793	Air	A	Near main roads	13-14/09/2007 0631-0620	1	1				
Alnabru-T/-F	Alnabru-T_Sep.14-15	Alnabru - metering station	07/1449	59°55.664	10°50.793	Air	A	Near main roads	14-15/09/2007 0633-0633	1	1				
Alnabru-T/-F	Alnabru-T_Sep.06-07	Alnabru - metering station	07/1358	59°55.664	10°50.793	Air	A	Near main roads	06-07/09/2007 0629-0625	1	1				
Alnabru-T/-F	Alnabru-T_Sep.08	Alnabru - metering station	07/1386	59°55.664	10°50.793	Air	A	Near main roads	08-08/09/2007 0901-1801	1	1				
Alnabru-T/-F	Alnabru-T_Sep.15	Alnabru - metering station	07/1450	59°55.664	10°50.793	Air	A	Near main roads	15-15/09/2007 0909-1809	1	1				
Alnabru-O	Alnabru-O_Oct.12	Alnabru - office	07/1639	59°55.567	10°50.942	Air	A	Inside office building	12/10/2007 1000-1800	1	1				
Alnabru-O	Alnabru-O_Oct.15	Alnabru - office	07/1663	59°55.567	10°50.942	Air	A	Inside office building	15/10/2007 1000-1800	1	1				
Alnabru-O	Alnabru-O_Oct.08	Alnabru - office	07/1567	59°55.567	10°50.942	Air	A	Inside office building	08/10/2007 1300-2035	1	1				
Alnabru-O	Alnabru-O_Oct.09	Alnabru - office	07/1590	59°55.567	10°50.942	Air	A	Inside office building	09/10/2007 1116-1800	1	1				
Alnabru-O	Alnabru-O_Oct.10	Alnabru - office	07/1594	59°55.567	10°50.942	Air	A	Inside office building	10/10/2007 1000-1800	1	1				
Alnabru-O	Alnabru-O_Oct.11	Alnabru - office	07/1607	59°55.567	10°50.942	Air	A	Inside office building	11/10/2007 1000-1800	1	1				
Alnabru-S	Alnabru-S_Nov.02	Alnabru - sports store	07/1854	59°55.638	10°50.829	Air	A	sporting-goods store inside	02/11/2007 1000-1800	1	1				
Alnabru-S	Alnabru-S_Nov.05	Alnabru - sports store	07/1856	59°55.638	10°50.829	Air	A	sporting-goods store inside	05/11/2007 1000-1800	1	1				
Alnabru-S	Alnabru-S_Oct.30	Alnabru - sports store	07/1844	59°55.638	10°50.829	Air	A	sporting-goods store inside	30/10/2007 1000-1800	1	1				
Alnabru-S	Alnabru-S_Oct.29	Alnabru - sports store	07/1822	59°55.638	10°50.829	Air	A	sporting-goods store inside	29/10/2007 1205-1800	1	1				
Alnabru-S	Alnabru-S_Oct.31	Alnabru - sports store	07/1850	59°55.638	10°50.829	Air	A	sporting-goods store inside	31/10/2007 1000-1800	1	1				
Alnabru-S	Alnabru-S_Nov.01	Alnabru - sports store	07/1852	59°55.638	10°50.829	Air	A	sporting-goods store inside	01/11/2007 1000-1800	1	1				

Mapping selected metals and new organic contaminants 2007 (TA-2367/2008).

Map station ID	Sample ID	Location	NILU sample ID	Latitude ° e	Longitude ° e	Sample type	C	Site description	date/time	N	n	m	Size/cut	Collection method	Comments
Alnabru-T/-F	Alnabru F1_Aug.27-28	Alnabru - metering station	07/1295	59°55.664	10°50.793	Air dust	A	Near main roads	27-28/08/2007	1	1				
Alnabru-T/-F	Alnabru F2_Aug.28-29	Alnabru - metering station	07/1296	59°55.664	10°50.793	Air dust	A	Near main roads	28-29/08/2007	1	1				
Alnabru-T/-F	Alnabru F3_Aug.29-30	Alnabru - metering station	07/1308	59°55.664	10°50.793	Air dust	A	Near main roads	29-30/08/2007	1	1				
Alnabru-T/-F	Alnabru F4_Aug.30-31	Alnabru - metering station	07/1310	59°55.664	10°50.793	Air dust	A	Near main roads	30-31/08/2007	1	1				
Alnabru-T/-F	Alnabru F5_Sep.1	Alnabru - metering station	07/1346	59°55.664	10°50.793	Air dust	A	Near main roads	01/09/2007	1	1				
Alnabru-T/-F	Alnabru F6_Sep.4	Alnabru - metering station	07/1353	59°55.664	10°50.793	Air dust	A	Near main roads	04/09/2007	1	1				
Alnabru-T/-F	Alnabru-P1_May.10.a	Alnabru - metering station	07/263-1	59°55.664	10°50.793	Road dust	A	from a main road	10/05/2007	1	1				
Alnabru-T/-F	Alnabru-P1_May.10.b	Alnabru - metering station	07/263-2	59°55.664	10°50.793	Road dust	A	from a main road	10/05/2007	1	1				
Alnabru-T/-F	Alnabru-P1_May.10.c	Alnabru - metering station	07/263-3	59°55.664	10°50.793	Road dust	A	from a main road	10/05/2007	1	1				
Alnabru-T/-F	Alnabru-P1_May.10.d	Alnabru - metering station	07/263-4	59°55.664	10°50.793	Road dust	A	from a main road	10/05/2007	1	1				
Alnabru-T/-F	Alnabru-P1_May.10.e	Alnabru - metering station	07/263-5	59°55.664	10°50.793	Road dust	A	from a main road	10/05/2007	1	1				
Alnabru-T/-F	Alnabru-P1_May.10.f	Alnabru - metering station	07/263-6	59°55.664	10°50.793	Road dust	A	from a main road	10/05/2007	1	1				
Alnabru-T/-F	Alnabru-P2_Oct.10.a	Alnabru - metering station	07/264-1	59°55.664	10°50.793	Road dust	A	from a main road	10/10/2007	1	1				
Alnabru-T/-F	Alnabru-P2_Oct.10.b	Alnabru - metering station	07/264-2	59°55.664	10°50.793	Road dusts	A	from a main road	10/10/2007	1	1				
Alnabru-T/-F	Alnabru-P2_Oct.10.c	Alnabru - metering station	07/264-3	59°55.664	10°50.793	Road dust	A	from a main road	10/10/2007	1	1				

Mapping selected metals and new organic contaminants 2007 (TA-2367/2008).

Map station ID	Sample ID	Location	NILU sample ID	Latitude ° e	Longitude ° e	Sample type	C	Site description	date/time	N	n	m	Size/cut	Collection method	Comments
Alnabru-T/-F	Alnabru-P2_Oct.10.d	Alnabru - metering station	07/264-4	59°55.664	10°50.793	Road dust	A	from a main road	10/10/2007	1	1				
Alnabru-T/-F	Alnabru-P2_Oct.10.e	Alnabru - metering station	07/264-5	59°55.664	10°50.793	Road dust	A	from a main road	10/10/2007	1	1				
Alnabru-T/-F	Alnabru-P2_Oct.10.f	Alnabru - metering station	07/264-6	59°55.664	10°50.793	Road dust	A	from a main road	10/10/2007 31/08-	1	1				
Birkenes	LRT-Birkenes F1_Aug.31-Sep.2	Birkenes	07/1393	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	02/09/2007	1	1				
Birkenes	LRT-Birkenes F2_Sep.2-4	Birkenes	07/1394	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	02-04/09/2007	1	1				
Birkenes	LRT-Birkenes F3_Sep.7-9	Birkenes	07/1451	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	07-09/09/2007	1	1				
Birkenes	LRT-Birkenes_Nov.07-09	Birkenes	07/1983	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	07-09/11/2007	1	1				
Birkenes	LRT-Birkenes_Nov.14-16	Birkenes	07/1984	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	14-16/11/2007 31/10-	1	1				
Birkenes	LRT-Birkenes_Oct.31-Nov.02	Birkenes	07/1985	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	02/11/2007	1	1				
Birkenes	LRT-Birkenes_Sep.23-25	Birkenes	07/1525	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	23-25/09/2007	1	1				
Birkenes	LRT-Birkenes_Sep.21-23	Birkenes	07/1524	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	21-23/09/2007 30/09-	1	1				
Birkenes	LRT-Birkenes_Sep.30-Oct.02	Birkenes	07/1604	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	02/10/2007	1	1				
Birkenes	LRT-Birkenes_Sep.28-30	Birkenes	07/1603	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	28-30/09/2007	1	1				
Birkenes	LRT-Birkenes_Sep.09-11	Birkenes	07/1452	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	09-11/09/2007	1	1				
Birkenes	LRT-Birkenes_Sep.14-16	Birkenes	07/1485	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	14-16/09/2007	1	1				
Birkenes	LRT-Birkenes_Sep.16-18	Birkenes	07/1486	58°23.407	8°15.175	Air	A	LRT <sup>1)</sup>	16-18/09/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.21-23	Svalbard	07/2189	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	21-23/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.23-26	Svalbard	07/2190	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	23-26/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.26-28	Svalbard	07/2191	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	26-28/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Oct.26-29	Svalbard	07/2021	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	26-29/10/2007 31/10-	1	1				
New Ålesund	LRT-New-Ålesund_Oct.31-Nov.02	Svalbard	07/2022	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	02/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.02-05	Svalbard	07/2023	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	02-05/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.07-09	Svalbard	07/2019	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	07-09/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.15-16	Svalbard	07/2020	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	15-16/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.05-07	Svalbard	07/2024	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	05-07/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.28-30	Svalbard	07/2192	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	28-30/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.03-05	Svalbard	07/2193	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	03-05/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Nov.05-07	Svalbard	07/2194	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	05-07/11/2007	1	1				
New Ålesund	LRT-New-Ålesund_Jun.1-4	Svalbard	07/3081	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	01-04/06/2007	1	1				
New Ålesund	LRT-New-Ålesund_Aug.1-3	Svalbard	07/3082	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	01-03/08/2007 28/09-	1	1				
New Ålesund	LRT-New-Ålesund_Sep.28-Oct.1	Svalbard	07/3083	78°54.383	11°53.276	Air	A	LRT <sup>1)</sup>	01/10/2007	1	1				
Bekkelaget	Bekkelaget-WWTP_In.d	Oslo	7-257-1	59°53.100	10°45.960	Influent	E	influent	18-25/06/2007	1	2				7-day <sup>3)</sup> rain <sup>5)</sup>
Bekkelaget	Bekkelaget-WWTP_out.d	Oslo	07/3052/0	59°53.100	10°45.960	Effluent	E	effluent	18-25/06/2007	1	2				7-day <sup>3)</sup> rain <sup>5)</sup>

Mapping selected metals and new organic contaminants 2007 (TA-2367/2008).

Map station ID	Sample ID	Location	NILU sample ID	Latitude ° e	Longitude ° e	Sample type	C	Site description	date/time	N	n	m	Size/cut	Collection method	Comments
			7-257-2			ent									
Bekkelaget	Bekkelaget-WWTP_sludge	Oslo	07/3053/0	59°53.100	10°45.960	Sludge	E	final centrifuged sludge	25/06/2007	1	2			grab sample	rain <sup>5)</sup>
Sauekilen	Sauekilen-WWTP_In.d	Arendal	07/3054/0	58°25.440	008°44.58	Influent	E	influent	25/06-25/06-02/07/2007	1	2			7-day <sup>3)</sup>	rain <sup>5)</sup>
Sauekilen	Sauekilen-WWTP_out.d	Arendal	07/3055/0	58°25.440	8°44.580	Efluent	E	effluent	25/06-02/07/2007	1	2			7-day <sup>3)</sup>	rain <sup>5)</sup>
Sauekilen	Sauekilen-WWTP_sludge	Arendal	07/3056/0	58°25.440	8°44.580	Sludge	E	final centrifuged sludge	02/07/2007	1	2			grab sample	rain <sup>5)</sup>
Solumstrand	Solumstrand-WWTP_In.d	Drammen	07/3057/0	59°42.394	10°16.089	Influent	E	influent	22-29/06/2007	1	2			7-day <sup>3)</sup>	rain <sup>5)</sup>
Solumstrand	Solumstrand-WWTP_out.d	Drammen	07/3058/0	59°42.394	10°16.089	Efluent	E	effluent	22-29/06/2007	1	2			7-day <sup>3)</sup>	rain <sup>5)</sup>
Solumstrand	Solumstrand-WWTP_sludge	Drammen	07/3059/0	59°42.394	10°16.089	Sludge	E	final centrifuged sludge	22-29/06/2007	1	2			7-day grab <sup>3)</sup>	rain <sup>5)</sup>
Res-Q	Res-Q_1-sediment-1	Haugesund	07/3060	59°28.190	5°14.543	Sediment	E	last basin <sup>13)</sup>	02/07/2007	1	2			grab <sup>6)</sup>	
Res-Q	Res-Q_2-sediment-2	Haugesund	07/3061	59°28.190	5°14.543	Sediment	E	last basin <sup>13)</sup>	02/07/2007	1	2			grab <sup>6)</sup>	
Res-Q	Res-Q_Firedrill-1 (sediment)	Haugesund	07/3062	59°28.196	5°15.036	Sediment	E	ditch <sup>14)</sup>	02/07/2007	1	2			grab <sup>6)</sup>	
Res-Q	Res-Q_Firedrill-2 (sediment)	Haugesund	07/3063	59°28.196	5°15.036	Sediment	E	ditch <sup>14)</sup>	02/07/2007	1	2			grab <sup>6)</sup>	
Res-Q	Res-Q_out-D (sediment)	Haugesund	07/3064	59°28.177	5°14.114	Sediment	E	Manhole, WWTP in Sveio <sup>2)</sup>	02/07/2007	1	2			grab <sup>6)</sup>	
Lindum	Lindum-Wdepot-1d (sediment)	Drammen	07/3065/0	59°40.540	10°15.509	Sediment	E	pump pit <sup>15)</sup>	21/06/2007	1	2			grab <sup>6)</sup>	low flow <sup>7)</sup>
Lindum	Lindum-Wdepot-2d (sediment)	Drammen	07/3066/0	59°40.540	10°15.509	Sediment	E	pump pit <sup>15)</sup>	21/06/2007	1	2			grab <sup>6)</sup>	low flow <sup>7)</sup>
Lindum	Lindum-Wdepot-1w (sediment)	Drammen	07/3067/0	59°40.540	10°15.509	Sediment	E	pump pit <sup>15)</sup>	21/06/2007	1	2			grab <sup>6)</sup>	rain period <sup>8)</sup>
Lindum	Lindum-Wdepot-2w (sediment)	Drammen	5/MR6697	59°40.540	10°15.509	Sediment	E	pump pit <sup>15)</sup>	29/08/2007	1	2			grab <sup>6)</sup>	rain period <sup>6)</sup>
Helik Teigen	Helik Teigen-Adepot-1d (sediment)	Hokksund	07-315-1/MR6699	59°45.351	9°56.332	Sediment	E	Inside pipeline <sup>11)</sup>	25/10/2007	1	2			grab <sup>6)</sup>	missed dry period <sup>9)</sup>
Helik Teigen	Helik Teigen-Adepot-2d (sediment)	Hokksund	07-315-2/MR6700	59°45.351	9°56.332	Sediment	E	Inside pipeline <sup>11)</sup>	25/10/2007	1	2			grab <sup>6)</sup>	missed dry period <sup>9)</sup>

Mapping selected metals and new organic contaminants 2007 (TA-2367/2008).

Map station ID	Sample ID	Location	NILU sample ID	Longitude ° e	Latitude ° e	Longitud type	Sample C	Site description	date/time	N	n	m	Size/cut	Collectio n method	Comme nts
Hellik Teigen	Hellik Teigen-Adepot-1w (sediment)	Hokksund	07-315-3/MR6701	59°45.351	9°56.332	Sed-iment	E	outside pipeline <sup>12)</sup>	01/11/2007	1	2			grab <sup>6)</sup>	rain period <sup>8)</sup>
Hellik Teigen	Hellik Teigen-Adepot-2w (sediment)	Hokksund	07-315-4/MR6702	59°45.351	9°56.332	Sed-iment	E	outside pipeline <sup>12)</sup>	01/11/2007	1	2			grab <sup>6)</sup>	rain period <sup>8)</sup>
Bekkelaget_1S	Bekkelaget_1 (sediment)	Bekkelaget	07/3001	59°52.969	10°45.418	iment	R	80 m vest of diffuser	15/08/2007	1	2	52	0-2 cm	grab	
Drammen-1S	Drammen, Teigen (sediment)	Drammen	07/3002	59°44.70	10°14.520	iment	R		25/09/2003	1	5			grab	
Drammen-2S	Drammen, Lierterminalen (sediment)	Drammen	07/3003	59°44.76	10°14.820	iment	R		25/09/2003	1	5			grab	
Loselva-Down	Loselva_down_(st_1 (sediment)	Hokksund	07/3004	59°45.469	9°56.496	iment,	R	ca.40 m downstream	25/06/2007	1	5	0.5		coret <sup>6)</sup>	high water <sup>9)</sup>
Loselva-Up	Loselva_up_(st_2, sediment)	Hokksund	07/3005	59°45.454	9°56.542	Sed-iment	R	ca.400 m upstream	25/06/2007	1	5	0.5		coret <sup>6)</sup>	high water <sup>9)</sup>
Loselva-0	Loselva_0_(st_3, sediment)	Hokksund	07/3006	59°45.442	9°55.691	Sed-iment	R	drain	25/06/2007	1	5	0.2		coret <sup>6)</sup>	high water <sup>9)</sup>
Arendal-S	Arendal (sediment)	S. Norway, Arendal	07/3007	58°24.663	8°45.796	iment	R	discharge	06/06/2007	1	2			grab	
Lista-S	Lista_(reference, sediment)	S. Norway, reference (Lista)	07/3008	58°00.10	6°34.30	Sed-iment	R		06/06/2007	1	2	41	0-2 cm	grab	
Bekkelaget_2S	Bekkelaget_2 (sediment)	Bekkelaget	07/3009	59°52.969	10°45.418	iment	R		05/06/2007	1	2	386	0-2 cm	grab	
Gressholmen-B	Gressholmen (mussel)	Inner Oslofjord, Bekkelaget area	07/3010/M R6505	59°53.014	10°42.659	Blue mus. <sup>16)</sup>	R	JAMP St.30A	22/08/2007	1	20		3-5 cm	rake	
Akershuskaia-B	Akershuskaia (mussel)	Bekkelaget area	07/3011	59°54.320	10°44.202	Blue mus. <sup>16)</sup>	R	JAMP St. I301	15/08/2007	1	20		3-5 cm	rake	
Arendal-B	Arendal_(Ærøya)-1 (mussel)	S. Norway, Arendal	07/3012/M R6521A/B	58°24.888	8°45.818	Blue mus. <sup>16)</sup>	R		12/10/2007	1	20		3-5 cm	rake	one of two, <sup>17)</sup>
Arendal-B	Arendal_(Ærøya)-2 (mussel)	S. Norway, Arendal	07/3013	58°24.888	8°45.818	Blue mus. <sup>16)</sup>	R		12/10/2007	1	20		3-5 cm	rake	one of two, <sup>17)</sup>
Espevær-B	Espevær (mussel)	reference, St.22A	07/3014/M R6522	59°35.021	5°08.749	Blue mus. <sup>16)</sup>	R		21/09/2007	1	20		3-6 cm	rake	
Res-Q-B	Res_Q_resipient (mussel)	Haugesund Res-Q	07/3015/M R6523	59°29.326	5°14.197	Blue mus. <sup>16)</sup>	R		22/09/2007	1	20		2-5 cm	rake	
Haugesund-B	Haugesund (mussel)	Haugesund I. Oslofjord, Bekkelaget area	07/3016/M R6524	59°19.341	5°19.127	Blue mus. <sup>16)</sup>	R		22/09/2007	1	20		2-6 cm	rake	
Bekkelaget_1C	Bekkelaget_1 (cod liver)	Bekkelaget area	07/3017/M R6507	59°49.509	10°34.237	Cod <sup>18)</sup>	R	JAMP st.30B	24/10/2006	1	5		1 bulk	trawl	
Bekkelaget_2C	Bekkelaget_2 (cod liver)	I. Oslofjord,	07/3018/M R6507	59°49.509	10°34.237	Cod <sup>18)</sup>	R	JAMP st.30B	24/10/2006	1	5		1 bulk	trawl	

Mapping selected metals and new organic contaminants 2007 (TA-2367/2008).

Map station ID	Sample ID	Location	NILU sample ID	Latitude °	Longitude °	Sample type	C	Site description	date/time	N	n	m	Size/cut	Collection method	Comments
Karihavet_C	Karihavet (cod liver)	Bekkelaget area West Coast, reference JAMP St.23B	07/3019/M R6509	59°54	5°08	Cod <sup>(18)</sup>	R	JAMP st.23B "0 m" ca. 80 m west of diffuser	16/09/2006	1	5		1 bulk	water can	
Bekkelaget-0	Bekkelaget-0 m	I. Oslofjord, Bekkelaget	07/3020 - 07/3021	59°52.967	10°45.402	Sea-water	R	ca. 99 m seaward from "0 m" ca. 206 m seaward from "0 m" ca. 347 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	mix <sup>19)</sup>
Bekkelaget-99	Bekkelaget-99 m	I. Oslofjord, Bekkelaget	07/3022	59°52.950	10°45.318	Sea-water	R	ca. 500 m seaward from "0 m" ca. 667 m seaward from "0 m" ca. 853 m seaward from "0 m" ca. 1224 m seaward from "0 m" ca. 1503 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	
Bekkelaget-206	Bekkelaget-206 m	I. Oslofjord, Bekkelaget	07/3023	59°52.960	10°45.197	Sea-water	R	ca. 500 m seaward from "0 m" ca. 667 m seaward from "0 m" ca. 853 m seaward from "0 m" ca. 1224 m seaward from "0 m" ca. 1503 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	
Bekkelaget-347	Bekkelaget-347 m	I. Oslofjord, Bekkelaget	07/3024	59°52.960	10°45.044	Sea-water	R	ca. 500 m seaward from "0 m" ca. 667 m seaward from "0 m" ca. 853 m seaward from "0 m" ca. 1224 m seaward from "0 m" ca. 1503 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	
Bekkelaget-500	Bekkelaget-500 m	I. Oslofjord, Bekkelaget	07/3025	59°52.960	10°44.88	Sea-water	R	ca. 500 m seaward from "0 m" ca. 667 m seaward from "0 m" ca. 853 m seaward from "0 m" ca. 1224 m seaward from "0 m" ca. 1503 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	
Bekkelaget-667	Bekkelaget-667 m	I. Oslofjord, Bekkelaget	07/3026	59°52.959	10°44.7	Sea-water	R	ca. 500 m seaward from "0 m" ca. 667 m seaward from "0 m" ca. 853 m seaward from "0 m" ca. 1224 m seaward from "0 m" ca. 1503 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	
Bekkelaget-853	Bekkelaget-853 m	I. Oslofjord, Bekkelaget	07/3027	59°52.960	10°44.5	Sea-water	R	ca. 500 m seaward from "0 m" ca. 667 m seaward from "0 m" ca. 853 m seaward from "0 m" ca. 1224 m seaward from "0 m" ca. 1503 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	
Bekkelaget-1224	Bekkelaget-1224 m	I. Oslofjord, Bekkelaget	07/3028	59°52.958	10°44.1	Sea-water	R	ca. 500 m seaward from "0 m" ca. 667 m seaward from "0 m" ca. 853 m seaward from "0 m" ca. 1224 m seaward from "0 m" ca. 1503 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	
Bekkelaget-1503	Bekkelaget-1503 m	I. Oslofjord, Bekkelaget	07/3029	59°52.958	10°43.8	Sea-water	R	ca. 500 m seaward from "0 m" ca. 667 m seaward from "0 m" ca. 853 m seaward from "0 m" ca. 1224 m seaward from "0 m" ca. 1503 m seaward from "0 m"	15/08/2007	1	1	0	surface water	water can	
Arendal_0	Arendal_0 m	S. Norway, Arendal	07/3030	58°24.905	8°45.224	Sea-water	R	At diffuser ca. 47 from diffuser ca. 196 from diffuser ca. 804 from diffuser ca. 1991 from diffuser	06/06/2007	1	1	0	surface water	water can	
Arendal_47	Arendal_47 m	S. Norway, Arendal	07/3031	58°24.883	8°45.249	Sea-water	R	At diffuser ca. 47 from diffuser ca. 196 from diffuser ca. 804 from diffuser ca. 1991 from diffuser	06/06/2007	1	1	0	surface water	water can	
Arendal_196	Arendal_196 m	S. Norway, Arendal	07/3032	58°24.825	8°45.357	Sea-water	R	At diffuser ca. 47 from diffuser ca. 196 from diffuser ca. 804 from diffuser ca. 1991 from diffuser	06/06/2007	1	1	0	surface water	water can	
Arendal_804	Arendal_804 m	S. Norway, Arendal	07/3033	58°24.619	8°45.848	Sea-water	R	At diffuser ca. 47 from diffuser ca. 196 from diffuser ca. 804 from diffuser ca. 1991 from diffuser	06/06/2007	1	1	0	surface water	water can	
Arendal_1991	Arendal_1991 m	S. Norway, Arendal	07/3034	58°23.89	8°45.90	Sea-water	R	At diffuser ca. 47 from diffuser ca. 196 from diffuser ca. 804 from diffuser ca. 1991 from diffuser	06/06/2007	1	1	0	surface water	water can	



**Annex 2 (cont.) – Footnotes:**

- 1) Remote area, monitoring long range atmospheric transport
- 2) In last manhole on discharge pipeline before sea downstream discharge from WWTP in Sveio
- 3) Flow-proportional 7-days sample
- 4) Composite daily grab sample over 7 days
- 5) Much rainfall during sampling period
- 6) Stainless steel
- 7) Relatively low flow rate
- 8) In the middle of rainy period
- 9) Much rain before sampling; high groundwater level
- 10) Samples not taken in what is usually considered the dry period of the year
- 11) Inside discharge pipeline from automobile destruction site to the Loselva stream
- 12) From bank sediment outside discharge pipeline from automobile destruction site the Loselva stream
- 13) Last of the primary sedimentation basins
- 14) Primary run-off ditch at test site for FTS foam use
- 15) In pump pit at landfill and before discharge to Solumstrand
- 16) Blue mussel (bulk sample 20 ind. ca. 40g)
- 17) One of the chucked samples divided into two samples at laboratory
- 18) Cod liver, bulked sample from 5 individuals
- 19) A mixture of two samples collected within about 80 m west of diffuser


**Statlig program for forurensningsovervåking**


Statens forurensningstilsyn (SFT)

Postboks 8100 Dep, 0032 Oslo - Besøksadresse: Strømsveien 96

Telefon: 22 57 34 00 - Telefaks: 22 67 67 06

E-post: postmottak@sft.no - Internett: www.sft.no

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Oppdragstakers prosjektansvarlig Norman Green, NIVA.	Kontaktperson SFT Bård Nordbø	TA-nummer 2367/2008
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Forfatter(e)		
Norman Green (NIVA)	Christian Dye (NILU)	Mikael Remberger (IVL)
Martin Schlabach (NILU)	Dorte Herzke (NILU)	Merete Schøyen (NIVA)
Torgeir Bakke (NIVA)	Sandra Huber (NILU)	Hilde Thelle Uggerud (NILU)
Einar M. Brevik (NIVA)	Benedek Plosz (NIVA)	Christian Vogelsang (NIVA)

**Tittel -**  
Screening of selected metals and new organic contaminants 2007. Phosphorus flame retardants, polyfluorinated organic compounds, nitro-PAHs, silver, platinum and sucralose in air, wastewater treatment facilities, and freshwater and marine recipients

**Sammendrag – summary**  
This investigation take account of phosphorus flame retardants (PFRs), polyfluorinated organic compounds (PFCs), nitro-PAHs, silver, platinum, and sucralose in air, samples from wastewater treatment facilities, seawater, marine and freshwater sediment, blue mussel and cod liver taken in 2007 (with the exception of 2 sediment samples from 2003). The survey covers 54 individual compounds and 2 metals from 59 sites, of which 5 are for air sampling, 22 for wastewater treatment facilities, 3 for freshwater sediment and 29 for the marine environment. Samples of air also included dust and road dust. Waste treatment facilities included domestic wastewater treatments plants, a landfill, a car demolishing site and a fire fighting test site. The report should be a guideline in the planning of environmental monitoring where these substances are concerned.

4 emneord Nasjonal screeningundersøkelse PFR PFC Nitro-PAH	4 subject words National screening PFR PFC Nitro-PAH
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0032 Oslo

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[www.sft.no](http://www.sft.no)

Statlig program for forurensningsovervåking omfatter overvåking av forurensningsforholdene i luft og nedbør, skog, vassdrag, fjorder og havområder.

Overvåkningsprogrammet dekker langsiktige undersøkelser av:

- overgjødsling
- forsuring (sur nedbør)
- ozon (ved bakken og i stratosfæren)
- klimagasser
- miljøgifter

Overvåkningsprogrammet skal gi informasjon om tilstanden og utviklingen av forurensningssituasjonen, og påvise eventuell uheldig utvikling på et tidlig tidspunkt. Programmet skal dekke myndighetenes informasjonsbehov om forurensningsforholdene, registrere virkningen av iverksatte tiltak for å redusere forurensningen, og danne grunnlag for vurdering av nye tiltak. SFT er ansvarlig for gjennomføringen av overvåkningsprogrammet

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